Handbook of Vegetable Preservation and Processing

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Preface

Vegetables, fresh or frozen, are always part of a balanced meal, especially in a family setting. Think of all the processed vegetables we have been eating all these years: canned beans, frozen corn, pickled cucumbers and peppers, tomato paste, mushrooms, vegetable soups, cold salads, and many more. Of course, don't forget those frozen French fries. This book is about processing and preserving vegetables and vegetable products. It uses several approaches:

The science of vegetables: botany, nutritive values, and postharvest technology.
The principles of traditional processing of vegetables: canning, drying, freezing, fermenting, and chemical preservation.
The manufacturing procedure for vegetable products, such as canned tomatoes, canned water chestnuts, frozen peas, frozen French fries, mushrooms, herbs, jalapeño peppers, kimchi, and sourkraut.
The safety of processing vegetables: pH, pathogens, vegetable juices, modified atmosphere packaging, acidified foods, action levels, macroanalytical methods, and new technology in microbial inactivation.

Apart from the above, this book introduces additional topics that are related to vegetable processing:

Minimally processed products: cook–chill and sous vide, salads, and cold soups.
The use of vegetables and vegetable products in dietary supplement and functional foods.
Fermented soy products. These are made from soybeans including soy sauce, miso, tempeh. Although they are favorites among Asians, Americans and Europeans are consuming them in increasing numbers. Although soybeans are legumes, soy products are usually consumed as vegetables or seasonings.

This book is unique in several aspects. It is an updated and comprehensive reference source, and contains many topics not covered in similar books. An appendix that reproduces major enforcement tools used in the United States to safeguard the wholesomeness of fresh and processed vegetables is included. This information does not appear in similar books. Contributors to this volume include experts from the government, industry, and academia of 12 countries. In sum, this book is an essential reference for professionals in vegetable products processing.

The editorial team thanks all the contributors for sharing their experience in their fields of expertise. They are the people who made this book possible. We hope you enjoy and benefit from the fruits of their labor.

We know how hard it is to develop the contents of a book. However, we believe that the production of a professional book of this nature is even more difficult. We thank the production team at Marcel Dekker, Inc., and express our appreciation to Ms. Theresa Stockton, coordinator of the entire project.

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1
Vegetables: Types and Biology

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I. DEFINITION OF A VEGETABLE

A vegetable is defined as "an edible, usually succulent plant or a portion of it eaten with staples as main course or as supplementary food in cooked or raw form" (1).

II. IMPORTANCE OF VEGETABLES

More than 10,000 plant species are eaten as vegetables worldwide. Among these species, only fifty or so are commercially important (2). Vegetables contribute to humans with essential minerals, vitamins, dietary fibers, proteins, fats, starches, and energy. Vegetables are major sources of vitamin C. The amounts of carotenes in pumpkins, capsicum peppers, and tomato are useful to mankind. Dietary fibers in vegetables include cellulose, hemicellulose, pectic substances, and lignin, which are important in preventing several human diseases. Vegetables also neutralize the acid substances produced by other high-energy foods (3). While organic acids and volatile compounds are responsible for flavor and aroma, chlorophyll, carotene, and anthocyanin make up the colors. Vegetables not only form an essential part of a well-balanced diet, but the flavor, aroma, and color also make them important in human diet and appetite (4).

III. DOMESTICATION OF VEGETABLES

All modern crops had their earliest beginnings as wild plants. These wild plants with specific characteristics attracted humans to harvest them for medicinal (5), herbal, or food purposes. Then the seeds and other plant parts were dispersed. This was the beginning step during plant domestication. Vegetables were brought into cultivation 10,000 years ago; thus humans produced sufficient vegetables of their own. Artificial selection created gene combinations for higher yield and better quality (6). The evolution of consumption, production techniques, socioeconomic interest, general political climate, production policy, international competition and trade agreements made the structure of today's vegetable exploitation heterogeneous (7).

IV. CLASSIFICATION OF VEGETABLES

Vegetables are commonly grouped according to botany, edible parts, life cycle, sensitivity to temperature, family grouping, or accepted use (2). Other classification schemes include sensitivity to soil pH and chilling damage, tolerance to nutrient levels and salt, and depth of rooting (2–4,8–10).

A. Botanical Classification

Botanical classification is based on morphology, anatomy, embryology, physiology, biochemistry, etc. The successive groupings of plants are kingdom, division, subdivision, phylum, subphylum, class, subclass, order, family, genus, and species (2,8). All vegetables belong to the class Angiospermae, which is divided into the subclasses Monocotyledoneae and Dicotyledoneae. Most vegetables belong to the Dicotyledoneae. There are fewer monocot vegetables, i.e. sweet corn, asparagus, yam, and onion. The genus and species make up the scientific name that is accepted worldwide. The climate requirements, the use for economic purposes, and the disease and insect controls of a particular family or genus are often similar. Well-known families of vegetables are Solanaceae, Brassicaceae, Fabaceae, Alliaceae, and Apiaceae (10).

B. Classification Based on Edible Part

Classification of vegetables by edible part informs a grower or handler with specific cultural or handling techniques. Common groupings include root, stem, leaf, immature flower bud, fruit, and sprout. Root crops include carrot, radish, beet, turnip, and sweet potato. Stem vegetables are asparagus and potato. The yield and quality of root and stem vegetables are affected by soil texture, fertility, and irrigation. Leafy crops include lettuce, cabbage, celery, spinach, kale, and mustard, which are very perishable. The edible parts of cauliflower, broccoli, and artichoke are immature flower buds. Immature fruits are harvested from pea, snap bean, lima bean, summer squash, cucumber, okra, sweet corn, and eggplant. But actually we eat the immature seeds of lima beans and sweet corn. Edible parts of cucurbits (pumpkin, white gourd, squash, muskmelon, and watermelon), tomato, and pepper are mature fruits (1–3,8–10).

C. Classification Based on Temperature

Vegetables are separated into warm-season and cool-season vegetables based on temperature requirement for optimum growth and development. Warm-season crops are adapted to 18–29°C, intolerant to frost, and mostly grown for edible fruits. Exceptions are sweet potato for storage root and New Zealand spinach for leaves. Cool-season vegetables have optimum growth at cooler temperature and are shallower rooted and smaller sized. Cool-season crops are grown for edible stems, leaves, roots, and immature flower parts. Asparagus, brussels sprouts, broccoli, cabbage, celery, garlic, onion, pea, radish, artichoke, and spinach are cool-season vegetables. Exception is garden pea grown for seeds. Harvested parts are usually stored near 0°C except potato (2,8–10).

The subgrouping of cool-season crops into hardy and half-hardy vegetables, and warm-season crops into tender and very tender vegetables, is based on the ability of young plants to withstand frost, and the ability of seeds to germinate at low temperatures. Hardy vegetables generally tolerate moderate frost without injury. Tender vegetables are susceptible to damage during cold weather. The very tender vegetables are easily damaged by light frost (10).

D. Classification Based on Life Cycle

Vegetables are also classified based on their life span. Most vegetables are annuals that complete life cycles within one growing season. Biennial vegetables require two seasons for completing their life cycle. Many cole crops such as broccoli, cauliflower, cabbage, and root crops such as carrot are biennials but grown as annuals. Perennial vegetables complete their life cycle in more than two years. Rhubarb, globe artichoke, and asparagus are grown commercially as true perennials. Tomato, pepper, eggplant, potato, and sweet potato are perennials in their native environments but are grown as annuals for production in temperate regions (2,3,8–10).

V. TYPES OF VEGETABLE GROWING

There are several types of vegetable growing such as home gardening, commercial production, and processing production. The commercial vegetable production includes at least three categories: fresh market, processing, and controlled environment production (5,11).

A. Home Gardening

People grow vegetables in their own gardens for money saving, outdoor leisure, fresher tasting and better quality vegetables, and better nutrition and improved health (2).

B. Commercial Production

The goal of commercial production of vegetables is only economic profits.

1. Fresh Market

The harvested vegetables are sold for fresh use (2,5,11).

1. **Market Garden.** Market gardens are located near but on the outskirts of population centers. A wide variety of small-scale high-profit crops are grown intensively and year-round. The harvested vegetables are for local consumption (2,5,11).
2. **Truck Farm.** Truck farms are often located in inexpensive rural areas and near transportation systems. One or two crops are grown on a large acreage for distant markets. Transport over large distances permits specialization and the delocalization of production (2,11).
3. **Controlled Environment Production.** Vegetables are grown in the modified environment for optimal plant growth. Light, temperature, humidity, nutrients, and even the composition of the atmosphere may be controlled. Investment and production costs including heating and cooling are expensive (5).

2. Processing Production

Vegetables are highly perishable. Postharvest decay is estimated to be more than 20–50% in the tropics and subtropics. Processing is one of the various feasible technological measures to reduce high postharvest losses of vegetables (3). Now in processing production, vegetables are grown in the field as raw materials for processing, usually on large acreage, harvested by machines and through contracts. The contract specifies production techniques, the price at a given quality, and standards for the acceptance of the harvest. Growers usually have a low margin of profit (11).

VI. CONSUMPTION OF VEGETABLES

The per capita consumption of vegetables varies among countries and regions, according to people's eating habits and the supply. The average world consumption of vegetables is around 85 kilograms per person per year; in industrialized countries it is around 120 kg per capita (12). It is around 30 kg per capita in sub-Saharan Africa and around 150 kg per capita in China (7).

VII. COMMERCIALLY IMPORTANT VEGETABLE CROPS

A. Root Crops

Several root crops are grown especially for their edible storage roots and tuber portions. They belong to different botanical families. Only one enlarged (fleshy) underground root is produced per plant for carrot (Apiaceae), table beet (Chenopodiaceae), radish, turnip, and rutabaga (Brassicaceae). Several fleshy roots are produced from one plant for sweet potato (Convolvulaceae). They are consumed either fresh or in processed forms. Most root crops have long storage life and extend the market supply over a long period. There are other minor root crops produced more on a regional basis, such as salsify (*Tragopogon porrifolius*) and black salsify (*Scorzonera hispanica*) of the Compositae, parsnip (*Pastinaca sativa*) and celeriac (*A. graveolens* var. *rapaceurm*) of the Apiaceae, yam bean (*Pachyrrhizus erosus*) of the Fabaceae, and horseradish (*Armoracia rusticana*) of the Brassicaceae (12,14).

The carrots, table beet, radish, turnip, and rutabaga are all direct-seeded to well-prepared seedbeds. After emergence, plants are thinned to desired population density. The crops are established more easily under cool and moist conditions (14).

1. Carrots [*Daucus carota* L. spp. *sativus* (Htoffm.) Arcang]

Cultivated carrots, which originated in Afghanistan and central Asia, became popular in Europe around the 13th century. European settlers brought carrots to the U.S. in the 17th century (15,16). Carrots are now mainly grown in Asia and Europe. The Eastern/Asiatic carrots have reddish purple (anthocyanin-containing) or yellow roots, pubescent leaves, and a tendency for early flowering. Western carrots have orange, yellow, red, or white roots, fewer pubescent leaves, and also a tendency to bolt. The Western orange type, as selections from yellow ones for high carotenoid content, developed into modern cultivars. In the U.S., carrots are mainly grown for the fresh market, California being the leading state in acreage. For processing, Washington state leads the production (14).

Carrot is a cool-season crop with optimal mean growing temperatures ranging between 16 and 21°C. At these temperatures, root color and shape are also optimized. At a mean temperature of 12–13°C, roots tend to grow relatively long and slender, whereas at a constant 24°C, roots are shorter and thicker. Alternating low night and moderate day temperature also tends to produce roots long and slender. Temperature greater than 30°C, particularly in the later stage of development, induces undesirable strong flavor and coarseness in the roots (16).

Carrot cultivars are classified by root shape and date of maturity (14):

1. Danvers: roots medium to long with broad shoulders, tapering toward the tip (tapered tips).
2. Imperator: roots slender, slightly longer and smoothly tapered, late maturing, good for storing, grown for winter market consumption.
3. Nantes: roots nearly cylindrical shaped, medium to long, early maturing, eaten fresh in summer.

4. Chatenay: medium to short and tapered with blunt end, maturing by midsummer.

Carrots are usually mechanically harvested 90–120 days after planting. Large-scale carrots are eaten raw, cooked, or processed into juice. The harvest stage is judged by suitability, before the carrots achieve their full potential size or weight. Fresh carrots are marketed either topped or bunched with attached tops. Fresh cut-and-peel baby carrots are also available; they may also be cut into short pieces from mature carrots. Carrots are good plant sources of provitamin A, containing about 5–8 mg/100 g of β-carotene (14).

2. Radish (*Raphanus sativus* L.)

Radish is unknown in the wild state. Its origin may be in the eastern Mediterranean or in China, with a long history of cultivation. Now radishes are grown worldwide but consumed mostly by Chinese, Koreans, and Japanese. Large variations exist in the shape, size, and color of the roots. Radishes were among the first European crops introduced into America by the Spaniards and grown by the early colonists (14,16).

Radish is a cool-season vegetable crop with optimum growing temperature ranging between 15 and 20°C. At higher temperatures, the enlargement of the roots is retarded, which results in coarseness and pungency (14).

Radishes are commonly grouped into four types (16):

1. Western or small radishes, usually consumed raw as relishes
2. Oriental radishes, with mild-flavored large roots, usually cooked or pickled in the East
3. Leaf radishes, consumed as greens by Chinese, also cultivated for fodder
4. Rattailed radishes, cultivated in Asia with young pods consumed raw, cooked, or pickled

In the U.S. garden radishes are very popular in home gardens because of their short growth cycle and because they are easy to grow. The white, long-rooted types are also popular in many regions.

3. Table Beets (*Beta vulgaris* L. Crassa group)

Originating in Europe and Western Asia, the garden beet or table beet is one of the various forms of *Beta vulgaris* of Chenopodiaceae family (17). It is closely related to Swiss chard, sugar beet, and fodder beet. The leaf beets were developed before the root beets. Red root beets were cultivated by the Romans. The root beet is grown throughout Europe and America. The red pigment, betanin (a nitrogen-containing anthocyanin) can be used for food coloring. The table beet, being introduced in 1800, is one of the most popular home garden crops in the U.S.

Table beets prefer a cool climate and sunny days. Temperatures for optimum growth range between 16 and 19°C. During hot weather, the roots may become tough. They are very sensitive to soil acidity and require a pH of 6.2 to 6.8 (17).

Beet roots may vary in color and shape. The oblate- or globe-shaped red-rooted types are most popular, and most of the commercial production is for processing (14).

4. Turnip [*Brassica rapa* L. var. *rapa* (DC) Metzz.] and Rutabaga [*B. napus* L. var. *napobrassica* (L.) Reichb.]

Both turnip and rutabaga are members of the Brassicaceae family. They are similar in plant size and general characteristics. Turnip is an ancient crop, its exact origin unknown, while rutabaga is of European origin and known as Swede in Europe (13,14). The turnip roots have little or no neck and a distinct taproot, while the rutabaga roots have a thick neck bearing a number of leaf-base scars, and roots containing the taproot and those originating from the underside of the edible root.

Turnips and rutabagas are both cool-season crops, requiring 15–18°C for best root growth. Turnips are easy to grow and require two months of growth. Rutabagas grow less rapidly and require an additional four weeks.

Both turnip and rutabaga have swollen roots in different colors or shapes. However, most turnip cultivars are round, and white-fleshed and rutabaga cultivars are globe-shaped with yellow flesh. There are also turnip cultivars grown for green foliage (14).

5. Sweet Potato [*Ipomoea batatas* (L.) Lam]

Sweet potato, a member of Convolvulaceae family, originated from tropical America. It was grown for its storage roots in the New World long before Columbus arrived. Storage root of sweet potato is a major carbohydrate source in developing nations. It contains about 27% carbohydrate, provitamin A, vitamin C, calcium, and iron. Tender leaves and shoot tips are also used as vegetables in Southeast Asia. Besides as food, sweet potato has industrial applications as a source of starch, glucose, syrup, and alcohol. It is also used as livestock feed. Older vines are fodder for cattle, swine, and fish. Some vining cultivars can be used as ground cover or ornamental (18).

Sweet potato is a tender, warm-season crop. The best growing temperatures are 29°C days and 21°C nights, with an optimum mean of 24°C (14,18). It is a perennial herb but is commonly grown as an annual. Adventitious buds arise from fleshy storage roots and develop into branching vines that quickly cover the ground (18).

Sweet potato is propagated by slips or vine cuttings. The thin skin of the storage root is easily broken. Four to 7 days of 26.6–29.4°C and 85–90% RH curing promotes the formation of cork layers on wounded surfaces, which prevents decay (18).

Storage roots of sweet potato as food are of two types: soft-fleshed and firm-fleshed (18):

1. Soft-fleshed (wet): sweeter, softer, medium to deep orange flesh, commonly used for baking
2. Firm-fleshed (dry): yellow skin with white, yellow, or light orange flesh, mostly used for boiling and frying

B. Stem and Tuber Crops

Stem vegetables are those grown for their succulent tender shoots (asparagus, bamboo shoots), fleshy stems (kohlrabi, celtuce, strumous mustard), starchy underground tubers (potato), corms (taro), and succulent rhizomes (ginger). Among them, kohlrabi, celtuce, strumous mustard, and asparagus are seed propagated, and the others are asexually propagated. The latter have low multiplication rates and need reliable sources for healthy growing materials. In the United States, asparagus and potatoes are of greater commercial importance.

1. Potato (*Solanum tuberosum* L.)

The potato, native to the Andean regions of Peru and Bolivia, has been cultivated since early civilization (19). It is one of the most important food crops in the world. The Spaniards introduced it to Europe, and Irish immigrants brought it to New England in 1718. The potato is referred to as the Irish potato because of its association with the potato famine in Ireland in 1845–1846. Idaho and Washington states are the largest producers of potatoes in the United States (20).

Potatoes are grown for its tubers, the enlarged underground storage stems. In addition to their starch content, the tubers serve as a good source of vitamin C. It is also a source of moderate levels of proteins and minerals. The protein of potato is richer in lysine than that of cereal, and its

biological value is high. Potatoes can be cooked in a great variety of ways. They can also be processed into chips, French fries, flakes, and dehydrated products. French fries and potato chips are popular food items worldwide (19).

Potatoes are asexually propagated by healthy tubers, which are obtained from certified disease-free stocks grown in favorable cool areas. The young shoots develop from the buds or "eyes" of the seed tubers. Potato is a cool-season crop. The interaction of photoperiod and temperature are the most important factors affecting plant and tuber development. Long days delay the start of tuberization, and temperatures above 30°C prevent tuber initiation. Tubers are usually initiated about 45 days after planting. Following tuberization, tuber enlargement is ideal at mean temperatures of 17°C (19).

Based on skin color and texture, potato cultivars are classified as white, red, or russet. Russet tubers tend to be oblong and relatively dark colored and thick skinned at maturity. There are early, midseason, and late cultivars according to maturity time. Based on starch content or specific gravity, potatoes are grouped into baking, boiling, and processing types. Russet Burbank is the leading cultivar grown in the U.S., being excellent for frying and baking. Kennebec is an excellent all-purpose potato (20).

2. Asparagus (*Asparagus officinalis* L.)

Asparagus, a dioecious perennial monocot, is a member of the Liliaceae family (21). The region between the eastern Mediterranean and eastward to the Caucasus Mountain is the center of origin of asparagus (22). It has been cultivated for medicinal and food use for more than 2,000 years. In the 1600s it was introduced into America. Commercial production is centered in California, Washington, and Michigan states (23).

Priced as a gourmet item, asparagus produces tender spears, the unexpanded shoots, each year. Nutritionally, asparagus is a source of vitamins A and C (22). The plant is composed of ferns, a crown, and the root system. The fern is a photosynthetically active modified stem called a cladophyll. The crown is a series of rhizomes (underground rootlike stems) attached to the plant base. Upper portions of the horizontal rhizome contain the buds from which spears arise. Fleshy and fibrous roots develop from the lower portion of the rhizome. The fleshy roots act as storage organs. The carbohydrates stored in crown and roots support spear growth in the spring.

Asparagus grows best under conditions of high light intensity, warm days, cool nights, low relative humidity, and adequate soil moisture. Optimum productivity occurs at 25–29°C in the day and 13–19°C at night (22).

Female plants generally produce larger spears than males, but the males produce more and smaller diameter spears. All male lines are developed for superior productivity with reduced seed production (23).

C. Bulb Crops

Bulb crops are all herbaceous monocot species of Allium and are members of Alliaceae family. The genus Allium contains about 500 species, mostly wild. The few species cultivated as vegetables are grown for their fleshly leaf bases and/or tender leaves. Only onions and garlic have prominent bulbs; all others have pseudostems instead. All bulb crops contain the thioallyl compound alliin, which breaks down to give a number of volatile sulfur-containing compounds, which give the characteristic odor and pungency of the crop. The chemical substances in onion and garlic especially are believed to be associated with reduced risks of cardiovascular diseases and certain cancers (21,24).

The bulb crops are propagated by seeds (onion, Welsh onion, and Chinese chives), cloves (garlic), or division (Welsh onion and Chinese chive).

1. Onion (*Allium cepa* L. Cepa group)

Originating in Central Asia, the common onion has been cultivated for more than 4,000 years (24,25). As an important flavoring, onion is a very popular crop worldwide. Asia is the largest producer, with Japan and China taking a share of 27%. Columbus introduced onion to America and it soon spread to all parts of the Americas. The onion has many culinary uses. It can also be processed into dry products such as rings, flakes, and powder for the food processing industry. Its quercetin, a flavonoid, provides the protective effect against cancer. Onions can be planted using sets (small bulbs produced in the previous season), transplants, and seeds.

The onion is a cool-season crop, optimum growth temperature ranging between 13 and 24°C. Onion bulbing is usually favored by long days. However, the lengths of time required for specific cultivars are different. Under favorable day length, temperatures of 21–27°C are favorable for bulb development. Low relative humidity extending into the harvest and curing periods is desirable (24,25).

Onions are usually grouped by their day length requirement for bulbing. Within the group, there are early and late maturing cultivars. Onions can also be grouped into mild or pungent (26):

1. Short-day type (European onion): bulbing in response to 10–11 h day length, mild, soft-fleshed bulbs for fresh use
2. Intermediate-day type: bulbing in response to 12–13 h day length, pungent, soft-fleshed for fresh use
3. Long-day type (Spanish onion): bulbing in response to 14 or more hours of day length, pungent, hard, good for storage

Bulbs vary in skin color, shape, and size. There are more yellow or brown onion cultivars than red or white cultivars.

2. Garlic (*Allium sativum* L.)

Originating in Central Asia, garlic has been cultivated from at least 2000 B.C. Being widely grown in Asia, garlic is eaten not only for the bulbs but also for the foliage and the flower stalks. Each plant develops the bulb underground, and 8–20 cloves together form a cluster covered by a white or purplish papery sheath.

Garlic has long been believed to have medical advantages in addition to its flavoring use. Garlic is dehydrated to produce garlic powder, and garlic oil capsules are made of garlic extracts as a diet supplement. In the U.S., most garlic is produced in California for the bulbs. The planting is carried out in late summer and fall from clean and healthy cloves. Overwintered in the field, the plants resume rapid top growth after spring. Large cloves produce greater yields than small cloves.

Garlic is a cool-season crop with cloves germinating best in temperatures of 20–25°C. The optimum temperatures for plant growth and bulb development are 18–20°C and 20–25°C, respectively. Bulbing is initiated as temperatures and day length increase (24,25).

Garlic cultivars can be grouped by their day length requirement for bulbing (26). They are classed as late and early. They can also be classed as the hardneck type and the softneck type. In the Orient, the softneck type is preferred for foliage production (27).

D. Cole and Related Crops

Cole crops from the east Mediterranean and Asia Minor are members of the species *Brassica oleracea* of the family Brassicaceae. During domestication, many cultivated types with distinct edible parts have formed, including cabbage and brussels sprouts (head), kohlrabi (thickened stem), cauliflower and broccoli (inflorescence), kale and Chinese kale (foliage) (28–31).

1. Cabbage (*Brassica oleracea* L. *Capitata* group)

Cabbage has been used as food for more than 3,000 years. The ancient Greeks held cabbage in high esteem. Cabbage was probably introduced by the Romans or by Celts from the coastal regions of the Mediterranean Sea to the chalky coasts of England and northwestern France. Present-day cultivars most likely originated from wild nonheading types. Cabbage is very popular worldwide and is grown extensively in Eastern Europe and the Far East (30).

Cabbage is a herbaceous biennial but is grown as an annual. During vegetative development, the plant produces a succession of outspreading leaves on a stem with very short internodes. New leaves, around twenty, incurve, overlap, and form a compact head. Leaves are broad, thick, fleshy, heavily veined, and covered with wax. Cabbage is durable for storing and shipping. It ranks higher than tomato but lower than spinach in mineral content (30).

Cabbage is grown for three types of markets: fresh market, late or stored market, and the sauerkraut market. There are several types of cabbage head (31):

1. Wakefield: pointed, small, pointed head, early-maturing
2. Copenhagen market: round, medium-large head, early maturing
3. Flat Dutch: large, flat, very solid head
4. Danish Ballhead: round-oval, medium-sized head, relatively late maturing, storable
5. Savoy: medium-large, flat-globe-shaped head, crinkly leaves, good quality for the fresh market
6. Red: round, medium-sized heads, reddish-purple leaves

2. Cauliflower (*Brassica oleracea* L. var. *botrytis* L.)

Both cauliflower and broccoli are of the cabbage family with cauliflower being more exact in environmental and cultural requirements. Cauliflower is grown for the curd (head), which is the shortened shoot with bracts and undifferentiated flower parts at the terminal end of the plant axis. The curd may be white, creamy, yellowish green, purple, or orange. However, pure white curds are preferred. It was first mentioned in the United States in 1806. California has been leading in commercial production (30).

Optimum temperatures for growth are 15–20°C with an average maximum of 25°C and a minimum of 8°C. But many tropical cultivars are early maturing and require higher temperature and long days to have good vegetative growth before forming the curd. After the white head has developed to 5–7.5 cm, it is protected from sunburn and turning green by tying the outer leaves together over the head center or just bending a few outer leaves to cover it. In Asia, blanching is achieved by covering the developing head with a piece of spun-bonded material which can be reused (28,29).

Cauliflowers are generally grouped into three major types by maturity (30):

1. Super Snowball (early): dwarf with medium sized leaves and somewhat flattened, maturing in 50–55 days after transplanting
2. Snowball (mid-season): larger and later, large rounded and very dense curd, maturing in 70–80 days after transplanting

3. Winter (later): grown where winters are mild, maturing 150 or more days after transplanting

The later the maturity, the larger the curd. In California, they may also be grouped by curd size and density.

3. Broccoli (*Brassica oleracea* L. var. *italica* Plenck)

Broccoli was evolved from wild cabbage earlier than cauliflower and was cultivated by the ancient Romans (28). However, it was relatively unknown in England until the 18th century and was grown in the United States in the early 1800s (28–30). But its popularity was much later.

Broccoli is similar to cauliflower in the structure of its flower head. Unlike cauliflower, the edible plant portion is the inflorescence consisting of fully differentiated immature flower buds and the tender portion of the upper stem. These flower buds form a compact head. If the terminal inflorescence is removed, secondary inflorescences may develop in the axils of lower leaves.

Broccoli is the most nutritious of the cole crops in vitamin content, calcium, and iron. Recently its anticancer advantage has been often reported. Per capita consumption continues to increase. California is the largest producer in the United States (30).

Broccoli is adapted to a range of soil types and can tolerate heat to a greater degree than cauliflower. The optimum temperatures for plant growth are 20–22°C, for head development 18°C. It is sensitive to boron deficiency (28,29).

There is no major subgroup for broccoli. The cultivars Calabrease, Green Comet, Green Duke, and Premium Crop are popular (30).

E. Other Leafy Vegetables

Greens are grown for leafy portions both for cooking and for salads. They are high in mineral and vitamin contents. All greens are specialty crops except spinach, which is produced on a large commercial scale. All greens in North America are cool-season crops except New Zealand spinach, a warm-season crop (32).

Lettuce, endive-escarole, and chicory are leafy salad vegetables. Their tender leaf blades with a little petiole and stem are used fresh or raw in salads. They are excellent dietary sources of bulk and fiber. Only lettuce is grown on a large scale (34).

1. Chinese cabbage, pe-tsai (*Brassica rapa* L. Pekinensis group)

Chinese cabbage is native to China and eastern Asia (32). Its recent popularity has resulted in a considerable increase in Europe and the United States. It produces an elongated head. Moderate day and cool night temperatures are essential for productivity and quality. Temperatures ranging between 13 and 21°C and suitable for its growth (28).

A high temperature during head formation causes a loose head and increased incidence of topburn. There are several types of head: elongated, shorter, tall, and short and compact (28,32).

2. Spinach (*Spinacia oleracea* L.)

Spinach is thought to be native to Central Asia. It ranks second only to broccoli in total nutrient concentration. Spinach is used fresh and for canning, freezing, and pureed baby food. Owing to its short growth period of 30–50 days, annual spinach is cultivated between plantings of other vegetable crops (33).

Spinach is usually dioecious, and rarely monoecious. Dioecious types produce extreme male and vegetative male. The extreme male plant is small. While the vegetative male and female plants produce more foliage and flower more lately, they are the preferred types for commercial production (33).

Spinach is a hardy, cool-season vegetable. It prefers 15–20°C for growth and 15°C for seed germination. Spinach is direct-seeded. Now, sized seed and specialized belt seeders are used to reduce the seeding rate (33).

Cultivars of spinach are classified into (33)

1. Savoy type: large, fresh market use, suitable to longdistance shipment for less anaerobic respiration
2. Smooth-leaved: mostly for processing, for easy washing of leaves
3. Semi-savoyed type: for both fresh market and processing into frozen packs

3. Lettuce (*Lactuca sativa* L. var. *capitata*)

Lettuce is native to the Mediterranean area and inner Asia Minor. From the 18th century, lettuce has been widely used in the Americas. Now the U.S. leads in the production and consumption of lettuce in the world. Lettuce cannot be processed. It is a leafy salad vegetable (34).

Lettuce prefers 24°C for seed germination and 18–23/7–11°C of day/night temperatures for growth. Lettuce is direct-seeded or transplanted. Coated or pelleted seeds are direct-seeded by the seeder. Osmoconditioning of seeds and fluid drilling are also used (34).

There are four distinct types of lettuce (34):

1. Crisphead type (Iceberg): large and solid head, usually over 0.9 kg and 15.2 cm in diameter, brittle and crisp leaves with prominent veins and midribs, very large outer leaves in medium to dark green, inner leaves tightly folded in light color, most endurable for shipping and handling
2. Butterhead type (Boston, Bibb, or semiheading): smooth, soft, pliable leaves forming a loose head, better table quality and more delicate flavor than crisphead type, leaves easily torn and bruised, mainly for local markets, often for greenhouse production
3. Cos type (Romaine): long and narrow leaves, upright plant, long and somewhat loose heads, more tolerant to stress, best for local markets
4. Loose-leaf type (bunching): not heading, early, easy to grow, popular in home gardens, not suitable for long-distance shipment because of its short market life, produced primarily in greenhouses in winter

Stem lettuce or celtuce (*L. sativa* var. *asparagina* Bailey) is grown for its thick, succulent stem. It is usually cooked in stews and other dishes, or pickled. Stem lettuce is popular in the Far East, but it is not widely grown in the U.S.

4. Celery (*Apium graveolens* L. var. *dulce*)

Celery came from Sweden. It was initially used for medicinal purpose. Now the long, fleshy, but low-nutritive-content petiole is harvested for its flavor and texture, mostly for the fresh market. It is used mainly as a salad crop, some in soups, and a little dehydrated. The seeds are also a condiment for flavor (35).

Celery is biennial but is grown as an annual. Outer ribs along the petiole's abaxial length are composed mainly of thick-walled collenchyma cells responsible for mechanical strength and stringiness. Celery is dependent on climates. It prefers 15.6–18°C for growth. The production costs per acre are the highest among all vegetable crops (35).

Celery cultivars are classified into two types (2):

1. Golden (yellow or self-blanching) type: golden foliage, earlier, less vigorous, thinner petioles, more sharply ribbed, stringy, inferior in eating and keeping quality, primarily for specialty markets
2. Green type: green foliages
   a. Utah type: predominate, many attractive and well-overlapped petioles, a well-developed heart
   b. Summer Pascal type: excellent eating quality, generally lacking compactness, few petioles, poor heart development, less affected by cold, less likely to bolt in early planting
   c. Slow Bolting type: less affected by cold, less likely to bolt in early planting

Celeriac or knob, root celery (*Apium graveolens* var. *rapaceum*) is grown for its enlarged root. Smallage (*A. graveolens* var. *secalinum*), occurring long before, celery is most popular in Asian and Mediterranean regions. It produces rosettes of long, thin petioled leaves (16,36).

F. Fruit Vegetables

Fruit vegetables are grown for their fruits for consumption. They are mainly grouped into Cucurbits, legumes, and Solanum fruits. Within the same botanical family, different crop species have similar cultural requirements and pest problems. Other fruit vegetables include okra and sweet corn.

1. Cucurbitaceae

The Cucurbitaceae, a very important food crop family, have been consumed and utilized by human beings for more than 10,000 years. The gourd family consists of 118 genera, of which only nine are used as vegetables. Among them, three genera, *Cucumis*, *Citrullus*, and *Cucurbita*, are of commercial importance in the world as a whole; however others are of more importance in Asia or other regions. These include genera of *Benincasa*, *Lagenaria*, *Luffa*, *Momordica*, *Sechium*, and *Trichosanthes*. Genera *Cucurbita* (pumpkin and squash) and *Sechium* (chayote) were domesticated in the Americas, while the others were of Old World origin (Asia and Africa). All are warm-season crops and much susceptible to cold injury. However, some types adapt to cool and dry climates. They are herbaceous annuals except chayote, which can be grown as a perennial. These cultivated species of the Cucurbitaceae have similar plant habits and cultural methods. They are also known as cucurbits or vine crops. The plant is either a climbing or trailing vine or a bush type. The bush type is of determinate growth and usually bears earlier than the vine type. The root system consists of a deep taproot and highly branched short laterals with horizontal distribution similar to the range of plant canopy. They are grown mainly for their fruits. Other parts of the plant may also be consumed as food such as seeds of watermelon and squash, flowers of squash and luffa, and shoots of chayote. Indeterminate vines continue to grow until the plant dies. Side shoots emerge from the leaf axils. Large leaves are born singly and alternately (38–41).

Most cucurbits are monoecious, producing female and male flower at separate nodes in the same plant. Usually female flowers are borne singly and male flowers either singly or in clusters in the leaf axils. Melons are of the andromonoecious type, producing perfect flowers and male flowers in the same plant. The gynoecious types, producing only female flowers, are also available in cucumber. The sex expression, a genetic trait, can be modified by environmental factors and growth regulators. High temperature and long day length favor male blooms, while low temperature and short days favor female flowers. The use of ethephon induces female flowering, while gibberellic acid and silver nitrate promote male flowers. The plants can be manipulated for the purpose of seed production (38–41).

Most Cucurbits can be grown from direct seeding or by transplanting, but special care is required for the latter practice (43). The seedlings are grown in individual containers to the 3–4 true leaf stage to be transplanted. Most crops are direct-seeded in the field in the U.S. The plant spacing varies according to the plant types, with closer in-row spacing for small vined and bush types than that for large vined ones. Plastic mulch can be used in the field to raise the temperature for early plantings. A critical period for water occurs during blooming and early fruit set. For sufficient pollination of the plants, the beehives may be brought into the field after female flowers bloom. Cultivation, weed control, irrigation, and pest control are managed similarly to all vine crops (39,42).

a. Bitter Melon (Momordica charantica L.) Bitter melon, indigenous to the tropics of India and Southeast Asia, is very popular in tropical areas. It is distinct from other vegetable cucurbits by its delicate foliage, slender stems, and simple tendrils. The fruit surface is studded with protuberances. The bitterness of the fruit is due to momordicosides, glycosides of tetracyclic triterpenoids. Immature fruits are less bitter and can be eaten raw or cooked. It may also be picked or dried for later use. At maturity the fruits turn orange and split open at the blossom end, to expose the bright red fleshy arils surrounding the seeds. The sweet arils can be eaten. Young shoots, leaves, and flowers are eaten as potherbs in India and southeast Asia. All parts of the whole plant are employed as folk medicine. The fruit of bitter melon is a good source of vitamin C and has been also investigated as an agent inhibiting the growth of the HIV virus.

Bitter melon requires warm, sunny areas with fertile, high water-retaining soils of pH 5.5–6.5. The optimum temperatures for seed germination are 30–35°C, for vine growth and fruiting, 25°C. Commercial crops are produced either on the ground or on support in an arch shape or in a triangle shape. The fruits are usually protected from light and fruit flies with paper bags or crude fibers (42,44).

The cultivated forms of bitter melon are grouped by fruit color into white, light green, and green, by fruit shape into spindle, pear-shapped, and elongated, by fruit size and shape into regular (up to 30 cm long and 10 cm in diameter) and wild (up to 8 cm long and 4 cm in diameter), and by the shape of the protuberence.

b. Pumpkins and Squashes (Cucurbita spp.) Pumpkins and squashes make up four of the five cultivated species of the genus *Cucurbita*. They come from tropical and subtropical America and have been cultivated for thousands of years. However, different types of pumpkins and squashes are not easily distinguished by botanical names or by morphological characteristics. The intercrossability among different types and among species makes clear classification difficult. The classification is largely based on culinary use and stage of maturity. *C. moschata* is believed to have originated in Central America or northern South America, *C. maxima* in the Andes mountains of South America, and both *C. pepo* and *C. argyrosperma* in northern Mexico and the southwestern U.S. After pumpkins were introduced to China and Japan, they became important vegetable crops there and many oriental types were derived. All this give much diversity in fruit shape, color, and size to the crop (42,44).

The crop requires a warm season with temperatures between 18 and 30°C for optimum growth. Optimum temperatures for seed germination are 25–30°C, and for fruit development, 25–27°C. Growth periods from planting to harvest range from 40–60 days for summer squash up to 80 to 140 days for pumpkins and winter squash. For early production, a light loamy soil is desired. Sunny, dry weather is important for successful pollination by honeybees and good fruit development (39,42,43).

C. maxima, in general, has better fruit quality in flavor and texture than *C. moschata.* But *C. moschata* has disease resistance and stands high temperature better than *C. maxima.*

In the U.S., *Cucurbita* species that have round and orange fruits are called pumpkins, while those that have fruits of other colors and shapes are called squashes (39,43):

1. Summer squash: commonly *C. pepo*, grown for their immature fruits with soft skin, including yellow crookneck and straight neck, scallop squash, cocozelle, and zucchini
2. Winter squash: including all four *Cucurbita* species, grown for mature fruits usually with hard rind, such as acorn, hubbard, butternut, banana, and orange marrow
3. Pumpkins: mostly *C. pepo* and *C. moschata*, grown for their ripe fruits used as an ingredient in pies

The naked-seeded pumpkins are grown for their seeds to be roasted for snacks. *C. maxima* can grow to jumbo size (22–45 kg) for exhibition purposes.

c. Cucumber (Cucumis sativa L.) Both cucumber and melon are members of genus *Cucumis*, though each belongs to a different subgenus. Cucumber is indigenous to India and has been cultivated for more than 3,000 years. It also has a long history in China where it is considered a secondary center of genetic diversification. Early travelers brought cucumber to Mediterranean countries (42). In the early 14th century, cucumber was cultivated in the U.K. It was introduced to the U.S. by 1539. Now cucumber is widely used as fresh and processed products. The leading states in the U.S. for fresh market cucumbers are Georgia and Florida, while Michigan, North Carolina, and Texas lead in processing type production (43).

Cucumber requires temperature of 30°C in the day and 20°C at night for optimum plant growth. The seeds germinate best at 25–30°C, and in this range fruits develop rapidly. The crop growth rate increases steadily as the temperature increases to 32°C (42,43). Glasshouse cultivation is also common for the cucumber in northern Europe, Asia, and the Middle East.

Cucumbers are divided by use into slicing type and pickling type, by culture into outdoor type and greenhouse type (39,43):

1. Pickling cucumber: fruits cylindrical in shape with blocky ends and a medium green color
2. Slicing cucumber: smooth, symmetrical, and white-spine, fruits longer than pickling type, with glossy, dark-green skin
3. Greenhouse cucumber: mostly parthenocarpic (set fruit without pollination)

d. Wax Gourd (Benincasa hispida (Thunb.) Cogn) Wax gourd is the only species of the genus *Benincasa*, which is named for Italian botanist Count Benincasa. The species name refers to the pubescence on the foliage and immature fruit. Of Indo-Malayan origin, the wax gourd is an important vegetable in India, China, the Philippines, and elsewhere in Asia. Both mature and immature fruits are consumed, either cooked or picked. The mature fruits harvested in summer can be stored at 13–15°C and 70–75% RH for over 6 months. The name winter melon refers to its long storage life. The fruits are especially valued for their high water content, bland taste, and cooling properties. The sliced pulp is dried for later use and sometimes candied in sugar syrup. The candied fruits are boiled to make the popular summer drink wax gourd tea, and it serves as a seasonal and festival specialty. The Chinese steam the entire mature fruit for soup with various ingredients. The wax gourd is also important in traditional medical practices. The rinds and seeds enter into various medications throughout southern Asia. The fruit wax is sometimes collected to make candles. Mo-kwa (*B. hispida* var. *Chieh-qua* How.), a botanical form of wax gourd, is usually grown for its immature fruit, which is about 0.4–0.7 kg and 18–25 cm long. It is high yielding and greatly heat tolerant.

Wax gourd grows best in sunny, moderately dry areas. It requires fertile, well-drained soils of pH 5.5–6.4. The optimum temperatures for seed germination are 30–32°C and for plant growth and fruiting 24–27°C (42,44). The cultivated forms of wax gourd can be divided by fruit

shape into long cyclindrical and short cylindrical, by fruit size into small (1.5–5 kg) and large (7–20 kg), by skin color and the presence of waxy white bloom on fruits into dark green, light green, and waxy.

e. Other Cucurbits As many Asian immigrants moved to the U.S., other cucurbits of Asian or African origin become common in areas with large Asian populations. These crops include immature fruits of smooth luffah (*Luffa aegyptaca* Miller), angled loofah [*L. acutangula* (L.) Roxb.], bottle gourd [*Lagenaria siceraria* (Mol.) Standl.], wax gourd or Mo-kwa, and the immature fruits of *Benincasa hispida* (42,44).

2. Legumes

Vegetable legumes, all dicotyledonous annuals, are members of the Leguminosae (Fabaceae) family. The immature fruits are important vegetables, and the dry seeds are an important staple food. In some, the leaves, the tender shoots, or the roots are harvested and used as vegetables (47). Legumes may be classified according to the position of the cotyledons in the germinated seedlings. The epigeal is the type whose cotyledons are above the ground; the hypogeal is the type whose cotyledons remain underground. Many legumes can assimilate their own source of nitrogen as a result of the symbiotic relationship with bacteria of *Rhizobium* in their root nodules. However, before a successful symbiotic relationship is established, the crop needs an adequate supply of nitrogen in the soil for growth (46,47).

Peas and broad beans are cool-season crops, while beans are warm-season crops, intolerant of frost. Each legume species has strains or varieties adapted to a particular range of conditions. All vegetable legumes are direct-seeded to the field. The pole type or the tall cultivars are usually supported or trained on poles. Generally bush types require less time for flowering than the pole cultivars (48).

a. Common Bean, Snap Bean (Phaseolus vulgaris L.) The common bean is the most widely cultivated bean in the genus *Phaseolus.* Dated over 7,000 years ago, the common bean originated in Central and South America. It was introduced into Europe in the 16th century and soon spread to other parts of the Old World (47). Beans are marketed fresh, canned, or frozen. Wisconsin is the largest bean-producing state for processing, and Florida leads in fresh market production (48,49).

The optimum soil temperatures for germination are 25 to 30°C. The optimum temperature range for growth is 16 to 30°C. Temperatures above 30°C at flowering can cause flowers to abort. Vine types are adapted to cooler temperatures than bush types. The desirable maturity characteristics are undersized seed development and low sidewall fibers (47–49).

Common beans are divided into bush and vining types according to growth habits, fresh market and processing cultivars according to uses. Based on pod color, common beans are either green-podded or yellow-podded, and sometimes even purple-podded. Beans may also be classified by the shape of the pod or the color of the seeds (48).

b. Lima Bean (Phaseolus lunatus L.) These are two types of lima beans, the large-seeded and the small-seeded. They originated in both Central and South America before 5000 B.C. (47). Native Americans spread the crop and it became an important vegetable crop in the U.S. It can be consumed fresh, frozen, or canned. The lima bean growth habit is similar to that of the common bean. California is the only state to harvest dry lima beans, both baby lima beans and large-seeded ones (48,49).

Lima beans require a slightly warmer climate than do common beans (47). They germinate at 15–30°C with an optimum soil temperature of 25°C. Mean monthly temperatures of 15–24°C are necessary to grow the crop. The small-seeded type, being less restrictive, can tolerate hotter and drier conditions than the large-seeded one (47).

The U.S. cultivars have seed coats of white, creamy, buff, or light green. The large-seeded type is narrowly adapted but is of better quality. The small-seeded type is grown widely (48):

1. Bush type: productive with small seeds, ex. Henderson, Early Thorogreen
2. Pole type: largely for home gardens (Pierce), producing small seeds

c. Peas (Pisum sativum L. spp. sativum) As one of the most ancient crops, peas originated in the eastern Mediterranean region and the Near East. They can be dated to 7,000–9,000 years ago (47,48). Dry peas were used for food in Europe from very early days, though green peas were not used until the 16th century (46). The edible podded types evolved in more recent times. In the Orient, the tender shoots of peas are used as greens (50). The term English pea reflects the many cultivars of peas developed and grown in England. Columbus brought the pea to North America where it quickly spread to all parts. Commercial production in the U.S. is primarily for processing, including canning and freezing. Seeds are either smooth or wrinkled, the former being starchy and the latter sweeter (48,49).

Peas thrive in cool and moist weather. The crops grow best at mean temperatures of 13–18°C. Long days and cool temperatures accelerate flowering. The smooth-seeded types are more adapted to cool weather conditions than the wrinkle-seeded types. The edible podded types are more adapted to warm conditions than the green pea types. Heat units are commonly used to predict harvest dates for the processing industry (47).

There are several types of peas, including shelled peas, edible podded peas, and dry peas. Pea cultivars are classified by seed color, growth habit, seed quality, and pod appearance (48,49):

1. Dry peas: light green seed color, starchy
2. Canning peas: most determinate, light green and sugary seeds
3. Freeze peas: most determinate, dark green and sugary seeds
4. Edible podded peas: pods lacking the stiff, papery inner parchment, the whole pods consumed
   a. Snow peas: sugary seeds slightly enlarged
   b. Snap peas: sugary seeds more developed and pod wall thickened

d. Southern Pea [Vigna unguiculata (L.) Walp. spp. unguiculata (L.) Walp.] The origin of the southern pea is rather obscure. It is possibly of tropical African origin (47) or a native of India (47,48). There are three distinct cultivar groups in *Vigna unguiculata*, characterized by growth habit and pod character (48). The immature pods of all three are used as vegetables. The yard-long bean is popular with Southeast Asians with pods ranging from 30 to 75 cm in length. Catjang cowpea has erect small pods 7–12 cm long with seeds small and cylindrical. It is more common in India. Southern peas, also known as black-eyed peas, mostly confined to the south in the United Sates, are grown primarily for the green shelled seeds, of which large amounts are processed and canned or frozen (48).

The southern pea grows best in hot, dry climates. Optimum temperatures for growth are 27–30°C in the day and 17–22°C at night. It tolerates heat better than common beans or lima beans. Fresh market peas may be harvested 16 to 17 days after blooming (47).

Cultivars of the southern pea differ in maturity, in pod color, and in the crowding of seeds in the pods. Black-eyed peas are those having a dark outline or eye around the hilum. Other major types include purple hulled and creamy yellow. The large cultivars are well suited for pick-your-own and local sale (49).

3. Solanum Fruits

Solanum fruit crops, all of tropical origin, are members of the Solanaceae family. They include tomato, peppers (both bell and chili peppers), and eggplant, all grown as annuals for commercial production. Tremendous phenotype variations are available in fruit shape, size, and color. They are warm-season crops, eggplant being more heat tolerant than pepper or tomato. Chili peppers can grow in higher temperatures than bell peppers. The potato, in same genus as the eggplant, is discussed under stem and tuber crops (20,52).

These crops share similar disease problems. In some countries, grafting of tomato and eggplant on resistant stocks are done to combat soil-borne diseases. Early production can be forced by planting transplants to fields mulched by plastics. Direct seeding can be successfully used for later, especially processing, production. Transplants are usually greenhouse grown in plugs. Tomato and bell pepper are grown in glasshouses or other protective structures in some regions where climate limits field production (20).

a. Tomato [Lycopersicon esculentum (L.) Mill] The tomato originated in the Andes of South America and evolved from the cherry tomato (*L. esculentum* var. *cerasiforme*). It was introduced from Mexico into Europe early in the 16th century (37,52). Early use of the tomato was hampered by the belief that it was poisonous, because many of the Solanum species contain alkaloids. The tomato was introduced into the United States in 1710 and was produced in New Orleans in 1779 (51,52).

Worldwide, the tomato is one of the most important vegetables or salad plants (37). The acidic sweet taste and unique flavor account for its popularity and diverse usage. Although not among the most valuable crops in nutrient contents, the tomato is an important contributor of vitamins A and C because of the substantial per capita consumption. The U.S. leads in total tomato production and processing of the tomato. California and Florida lead the nation in fresh market and processing tomatos, respectively (20).

The tomato requires temperatures of 25–30°C for optimum germination. Day temperatures of 25–30°C and night temperatures of 16–20°C are optimal for growth and flowering (20,51,52). Fruit set is best between 18 and 24°C, night temperatures being more critical than day temperatures. Cultural practices of pruning, staking, and caging are used to increase light interception and aeration for production enhancement.

Tomatoes are classified as determinate and indeterminate in growth. Higher planting densities are given to the former type to compensate for their lower yield potential. Tomatoes are grouped as fresh market, processing, and home garden types according to use. Processing cultivars are usually determinate and ready for harvest in 75 days after field setting. Greenhouse tomatoes are indeterminate, and the home garden types may be either determinate or indeterminate. Variation in shapes (globe to pear), fruit color (yellow, pink, and red), and size (cherry, beef) exist in different cultivars (20).

b. Pepper (Capsicum annuum L.) With a long history of cultivation for more than 7,000 years, peppers are native to tropical and subtropical America (52). Among the five domesticated species in the genus *Capsicum*, *C. annuum* is the most widely cultivated and economically important species and includes both bell pepper and chili pepper. *C. frutescens* has small fruits. Tabasco is the best known cultivar, grown commercially for making Tabasco sauce (20,54).

Columbus introduced peppers into Europe and subsequently into Africa and into Asia. Peppers were soon integrated into people's cuisine owing to the characteristic flavor and pungency. Peppers are also used in pharmaceutical products such as pepper plaster. They are even an indispensable food in many countries. Asia is the largest producer with China leading in world production (53). In the United States, New Mexico leads in chili pepper production, while California leads in bell pepper production (55). Peppers are good sources of vitamins C and A.

Peppers are a warm-season crop. The optimum temperature for pepper growth and development is higher than that for tomato. The seeds germinate rapidly at 25–30°C. The base growing temperature is 18°C. The average temperature for optimum growth is 21–30°C, for fruit set 20–25°C, and for color development 18–24°C. The plants are not photoperiod sensitive for flowering. The small fruit cultivars are more tolerant to high temperature (51–53).

Peppers are classified into two main types, the sweet fleshed fruit and pungent fleshed fruit. They can also be grouped by the fruit appearance and use. Classified by pod type, there are bell, pimiento, cheese, ancho, cayenne, Cuban, jalapens, serran, wax, and cherry, etc. Important commercial types are listed as follows (20,54):

1. Bell type: large blocky fruit with three to four lobes and thick flesh, mature green fruits harvested for fresh market, mature colored fruits in red, orange, or gold, also in commercial markets
2. Cherry peppers: round or slightly flattened fruits, orange to deep red when harvested, sweet or hot, small or large
3. Chili type: pungent and thin-flesh fruit, from cherry size to slender fruit up to 20 cm long
4. Pimento peppers: fruit sweet with thick wall, conical or heart-shaped, turning red at maturity
5. Tabasco peppers: fruits 2.5–7.5 cm long, slim, tapered, and highly pungent

Peppers can be fresh, canned, brined/pickled, frozen, fermented, dehydrated, and extracted for oleoresin (53).

c. Eggplant (Solanum melongena L.) A native of India, the eggplant is not as popular as tomato or pepper as a vegetable. However, it is widely used in China, India, Japan, and many Mediterranean countries. The name egg-plant is believed to reflect the early forms with small, white fruits resembling eggs. There are in general three forms of eggplant: round egg-shaped fruits, long slender fruits, and dwarf plant forms (20,51,52). Fruit tissues contain high levels of phenolics; upon cutting they are quickly oxidized by enzymes resulting a brown discoloration of the flesh (51).

Introduced into American gardens in 1806, it was primarily an ornamental curiosity until the 20th century. Commercial eggplant acreage is primarily located in Florida and New Jersey (20).

Eggplant is very sensitive to low temperatures, and it requires a relatively long, warm growing season. Optimum temperatures for seed germination are 24–32°C and for growth and development, day temperatures of 22–30°C and night temperatures of 18–24°C. The elongated fruit type tends to be more resistant to high temperature than the small fruit type. To have high yield, plants require high light intensity (51,52).

There are two basic types of eggplants based on fruit shape (52):

1. Standard oval-shaped type: large, smooth, glossy purplish-black fruit
2. Oriental type: long slender purple-black fruit

There are also types with white, yellow, or apple-green fruits.

4. Sweet corn (*Zea mays* L.)

Sweet corn is a monocot of the Poaceae (Gramineae) family. Being an ancient crop from about 5,000 B.C., corn originated in the highlands of Central and South America. Sweet corn originated from a mutation of grain corn (56). It was not favored in early cultures because of the difficulty of

store it. Commercial sweet corn production began about 200 years ago in the United States, which leads world sweet corn production. In addition to fresh use, a considerable volume is processed by canning and freezing of kernels after removal from the cob (57).

Corn plants are monoecious with male flowers borne as the terminal inflorescence on the main stem and female flowers borne as lateral ear shoots. The basal nodes of an ear shoot are concentrated, so there is little internode space. They form a tight husk around the developing ear. Each individual kernel is a single-seeded fruit composed of a small embryo and a large endosperm. Sweet corn kernels contain less starch and more sugar and water-soluble polysaccharides, which are responsible for the creamy texture (56).

The optimum temperature range for corn growth is 24–30°C. In general, the warmer the air temperatures, the faster the corn will grow to maturity (57). However, moderate temperatures are optimum for carbohydrate accumulation. Cool nights are particularly important at harvest time. Plants flower sooner under short days. The crop is sensitive to soil acidity, requiring a soil pH of 6.0–6.8. It demands much water, but not waterlogging, and high fertilization.

Sweet corn cultivars are classified by kernel color (yellow, white, and bicolor), by maturity date (early and late), and by use (market, freezing, canning, or shipping). By the difference in kernel sweetness, there are (57):

1. Standard sweet corn: containing recessive *su 1*, traditional sweet corn flavor and texture
2. Modified sugary sweet corn: containing sugary enhancer gene *se*, high sugar, thin pericarp
3. Supersweet corn: containing recessive *sh* 2 gene, higher in sugar, lower in starch, tougher skinned

G. Bean Sprouts

Bean sprouts are produced mostly from germinated seeds of mung bean [V*igna radiata* (L.) Wilcz] and soybean [*Glycine max* (L.) Merr]. The use of bean sprouts has a long history in China. The seeds are soaked for 24 h, sprouted, and allowed to grow in the dark for several days before harvesting for consumption. The etiolated hypocotyls and young cotyledonary leaves are eaten with other vegetable dishes (58). The sprouts are a good source of vitamins B1 and B2 and dietary fiber. More than 20 kinds of sprouts have been developed. Among them, pea sprouts and alfalfa sprouts are popular vegetable sprouts grown from legume seeds. Light is given a few days before harvest to produce pea sprouts green in color. Sprouts are grown under light to harvest green sprouts. Daily watering is necessary. The growth of sprouts does not require supplemental nutrients but depends on the storage reserve of the seeds. Given optimum temperature for seed germination, water for sprouts to grow, and proper aeration, bean sprouts can be produced year round in controlled environments (58).

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2
Nutritional Value of Vegetables

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I. INTRODUCTION

Vegetables are considered a significant part of all major dietary guidance systems. Their many chemical elements and compounds are known to affect thousands of physiological functions and to promote health (1). This chapter provides an overview of nutrients and non-nutrient phytochemicals commonly found in vegetables, along with a description of the basic nutrient profile for vegetables in general. Factors affecting nutrient variations, both naturally occurring and due to processing, are summarized. Lastly this chapter reviews many of the purported health benefits derived from various vegetable phytochemicals.

II. NUTRIENTS

A. Nutrients

About a century ago, researchers observed that the growth and survival of animals were directly affected by various individual components in foods. These components were termed nutrients and came to be considered required for normal growth and health. In the early 1900s, researchers began to focus on the disease-preventing properties of vegetables. McCollum and colleagues realized that the addition of vegetables to a seed diet was necessary to prevent deficiency conditions in omnivore species (2). Researchers then realized that a diet deficient in even a single essential nutrient (required from food) could result in a dietary deficiency disease or even death (3).

Strictly speaking, nutrients are compounds that cannot be synthesized by the human body from other chemicals or cannot be synthesized rapidly enough to meet the needs of the body. Thus, by the classical definition of nutrient, the term essential nutrient is redundant. However, the terms nonessential nutrient and dispensable nutrient are sometimes used to describe chemical compounds that are contained in foods and have a function in the body but are typically synthesized by the body in adequate amounts.

As nutrition science evolved, a third category of nutrients has been identified as conditionally essential. This terminology is used to describe substances that may become essential under specific conditions that reduce the body's capability of synthesizing adequate amounts of

the compound. This may be caused by changes in physiological demands due to a genetic defect, a disease condition, the stress of surgery, or the use of certain drugs as with statins and coenzyme Q10 (4,5).

Presently, there are approximately 50 individual food elements and chemical compounds identified as essential nutrients. These nutrients are classified into six broad chemical categories based on chemical structure and functions: water, proteins, fats, carbohydrates, vitamins, and minerals. Table 1 lists nutrients by essentiality category and the basic physiological functions of providing energy, structure, or regulation of the body's thousands of chemical reactions.

Nutrients frequently act in concert to regulate specific physiological functions. For example, calcium, magnesium, and potassium regulate muscle contraction and relaxation (7,8). Vitamins B-6, B-12, and folate function in concert to prevent the excessive accumulation of homocysteine, which in turn reduces the risk of coronary artery disease (9).

The proper proportion of specific nutrients is also important in maintaining health. For example, the ratio of omega-3 fatty acids (primarily from fish oils and some vegetable oils) to omega-6 fatty acids (primarily derived from many vegetable oils) is an example of the essentiality of correct nutrient proportions. Both types of fatty acid are essential for regulating eicosanoid synthesis, which in turn affects physiological functions such as blood pressure, inflammation, and blood clotting. The appropriate proportion of omega-3 to omega-6 fatty acids is 1 to 4 up to 1 to 10. An imbalance of these fatty acids appears to be related to various chronic health problems (10).

Nutrients, even essential nutrients, are known to be harmful in excessive amounts. The Institute of Medicine has published both the recommended levels of intake and the tolerable upper intake levels for many nutrients. These recommendations provide guidelines on what constitutes generally safe ranges of intake and what levels of a nutrient may be excessive and even harmful to humans (11–14).

The use of certain drugs may require nutrient intake to be maintained within a more narrow range. For example, excess vitamin K intake, even from naturally occurring plant sources, can interfere with the function of common blood anticoagulant drugs (15).

B. Nutrient Profiles

Foods from various common food groups (meat and poultry, milk products, fruits, vegetables, grains, and beans) have classic nutrient profiles or distinctive nutrient fingerprints. Typically, these nutrient profiles are expressed as the amount of various key nutrients typically contained in 100 grams of an edible portion.

Compared to other food group nutrient profiles, vegetables provide the nutrient characteristics that most consumers perceive as health promoting (Table 2). Vegetables contain no cholesterol, very little fat, sugar, and sodium, yet provide concentrated sources of many vitamins and minerals. There are literally hundreds of vegetables, with the majority of these cultivated in Asia (17). Table 3 presents representative nutrient ranges and means for 38 of the more commonly consumed vegetables in the United States (18).

C. Factors Affecting Nutrient Composition of Vegetables

Biological, chemical, and physical factors all affect the nutrient composition of vegetables. For these reasons, nutrient values for any particular vegetable may differ significantly from published values commonly used in databases. Table 4 presents a partial list of factors that can significantly

Table 1 Human Essentiality and Physiological Function of Nutrients Found in Plants

Nutrient	Essentiality	Physiological function			Examples of key specific functions
		Energy	Structure	Regulation	
WATER	Essential		x	x	Provides fluid structure for every cell
PROTEIN–AMINO ACIDS					Source of kilocalories; protein structure of all cells; regulate chemical reactions through enzymes; necessary for DNA
Histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, valine	Essential	x	x	x	
Alanine, arginine, asparagine, aspartic acid, glutamic acid, glycine, proline, serine	Dispensable	x	x	x	
Cysteine, glutamine, tyrosine	Conditional	x	x	x	
LIPID–FATTY ACIDS					Source of calories; cell membrane, structure; eicosanoid synthesis
Linoleic–omega-6, alpha-Linolenic: omega-3	Essential	x	x	x	
Other fatty acids	Dispensable	x	x		
CARBOHYDRATES					Energy source especially essential, for red blood cells and brain
Glucose	Dispensable	x			
MINERAL ELEMENTS					
Calcium, fluoride, magnesium	Essential		x	x	Bone and tooth structure

(*Table continued*)

Table 1 Continued

Nutrient	Essentiality	Physiological function			Examples of key specific functions
		Energy	Structure	Regulation	
Phosphorus	Essential		x	x	Miscellaneous physiological and regulatory functions including energy metabolism; synthesis and transport of red blood cells and hormones, water balance, and immune system functions
Chloride, chromium, copper, iodine, iron, manganese, molybdenum, potassium, selenium, sodium, zinc	Essential			x	
Arsenic, boron, nickel, silicon	Essential			x	Functions unclear
VITAMINS					
Biotin, choline, folate, niacin (B-3), pantothenic acid, riboflavin (B-2), pyridoxine (B-6), hiamin (B-1), vitamin A (carotenoids), vitamin C (ascorbic acid),vitamin E (tocopherol), vitamin K	Essential			x	Miscellaneous regulatory functions including preventing oxidation; energy metabolism; blood clotting; and eye health

Essential nutrients not present in vegetables include vitamin D and vitamin B12. Dietary fiber is commonly classified as a nondigestible form of carbohydrate. However, it is not a nutrient and has been included in Table 5 as a phytochemical.
Source: Ref. 6.

Table 2 Nutrient Profile of "Classic" Food Groups Based on 100 g of Edible Material as Raw or Minimally Prepared for Consumption[a]

	Water (g)	Calories (kcal)	Total fat (g)	Saturated fat (g)	Cholesterol (mg)	Sodium (mg)	Carbohydrate (g)	Fiber (g)	Sugar (g)	Protein (g)	Vitamin A (IU)	Vitamin C (mg)	Calcium (mg)	Iron (mg)
Vegetables	64–96	5–145	0.04–0.7	0.0–0.17	0	2–201	2–24	0–5	0–6	0–5	0–19000	3–93	0–119	0.1–3.3
	90	35	0.25	0	0	35	7	2	1.5	2	1770	24	50	0.9
Fruits (not including avocado)	70–95	27–92	0.09–0.96	0–0.22	0	0–20	6–23	0–4	1–18	0–1	10–3800	4–98	4–40	0.1–0.6
	85	50	0.25	0	0	2	12	1.8	10	1	550	28	15	0.3
Grains, cooked	65–90	43–135	0.16–1.08	0.2–2.0	0	1–35	9–30	0–7	0–1	1–4	0–98	0	1–13	0.2–1.5
	76	96	0.5	1	0	15	20	2.2	0.5	2.5	10	0	8	0.8
Beans, cooked	61–70	118–173	0.38–8.98	0.05–1.32	0	1–13	10–28	2–9	0–3	7–17	0–9	0–2	14–142	1.1–5.2
	65	139	2.2	0.5	0	3	21	6	2	10	3	1	62	2.8
Nuts	2–47	224–718	1.12–76.5	0.16–29.7	0	0–38	12–73	0–11	0–13	3–26	0–1091	0–36	1–234	0.9–9.2
	12	533	45	7	0	9	28	5	4	13	130	8	74	3.2
Meat	47–76	110–274	1.25–21	0.33–8.54	41–440	39–102	0–6	0	0	17–32	0–35350	0–34	4–11	0.7–8.6
	66	173	8.5	3	100	68	0	0	0	22	2165	3	11	2.2
Eggs	70–75	149–185	10.0–13.8	3.1–3.7	425–933	125–150	0–1	0	0–1	13–14	300–1328	0	50–100	1.4–4.1
	73	170	12	3.5	790	140	1	0	1	13	820	0	67	3.3
Milk	81–91	35–108	0.18–7.01	0.12–4.6	2–27	44–52	4–5	0	4–5	3–6	126–205	1–4	119–193	0.0–0.1
	87	64	3	2	11	50	5	0	5	4	180	2	138	0.1

[a]Information is based on USDA Nutrient Database Series 14 and presented as unrounded range and rounded mean for each food group.
Source: Ref. 16.

Table 3 Vegetable Composition Based on 100 grams (g) of Edible Material as Raw or Minimally Prepared for Consumption[a]

Vegetable	Water (g)	Kilocalories	Fat (g)	Protein (g)	Total carbohydrates[b] (g)	Sugar (g)	Fiber (g)
Artichoke (globe)	80–86	17–70	0.3–0.4	0.5–4.5	13	2	0.8–5.4
Asparagus	92–93	9–27	0.2	2.2–3.9	4.6	1.3–2.3	0.07–2.1
Beetroot	83–89	44–58	Tr-0.7	1.3–1.8	10	6–7.3	0.6–3.1
Broccoli	89–91	28	Tr-0.3	3.1–4.0	5.3	0.4–2	1.3–3
Brussels sprouts	84–89	16–58	Tr-0.5	2.4–4.4	8.7	3.6–4	1.3–4.6
Cabbage	86–93	8–36	Tr-0.7	1.4–3.3	5.4	2.7–3.8	0.6–3.4
Carrot	84–95	19–47	Tr-0.7	0.6–2.0	10.1	5.4–7.5	0.6–2.9
Cassava	50–74	120–153	Tr-0.7	0.7	27	1–1.2	0.6–1.7
Cauliflower	84–92	11–34	Tr-0.3	1.8–3.4	5.2	2.4–2.6	0.8–2.4
Celery	89–96	5–22	Tr-0.5	0.7–2.0	3.7	1–1.2	0.7–2.7
Chard	91–94	16–19	0.2–0.4	1.5–2.6	3.8	0.8–1.1	0.6–1.6
Chayote	74–95	24–29	0.1	0.8	5.1	—	0.4–0.6
Cucumber	91–97	9–16	Tr-0.2	0.6–1.4	2.8	1.8–2.6	0.3–0.7
Eggplant	89–94	15–38	Tr-0.7	0.7–2.4	6.7	2.1–4.2	0.9–2.5
Endive	93–94	11–24	Tr-0.2	1.6–1.8	3.4	0.3–1.0	0.8–2.2
Leek	71–92	25–52	Tr-0.4	1.3–2.5	7.6	1–4	1.0–3.3
Lettuce	92–97	11–27	Tr-0.5	0.8–1.6	2.2	1.1–2.2	0.3–1.4
Mustard	68–89	10–28	Tr-0.3	1.6–2.4	2.1	0.4–0.9	1.8–3.7
Onion	81–93	13–49	Tr-0.35	0.9–2.2	8.6	5.2–6.7	0.5–1.7

Parsley	68–89	21–60	Tr-1.0	3.7–5.2	6.9	Tr	0.9–9.1
Parsnip	79–83	56–83	Tr-0.5	1.5–1.7	19.5	5.5–9.5	2.2–4.4
Pea	65–81	49–138	Tr-0.8	4.6–8.2	15.6	2.3–7.4	1.8–5.5
Peppers	70–93	27–37	0.1–0.7	1.2–2.0	6.4	1.7–13.9	0.5–2.7
Plantain	58–74	116–128	0.05–0.8	1	31.2	5.6	0.3–2.3
Pumpkin	80–96	15–36	Tr-0.2	0.6–1.8	4.9	2.5–3.2	0.5–1.3
Potato	71–85	75–109	Tr-0.1	1.6–2.3	25.2	0.3–1.6	0.3–2.4
Radish	92–95	15–22	Tr-1.1	0.7–1.2	3.6	2.0–3.4	0.5–1.0
Spinach	91–93	16–35	0.3	2.3–5.1	3.5	0.3–0.4	0.6–2.7
Summer squash	86–95	19–44	0.03–0.3	0.6–1.5	4.4	1.0–3.9	0.3–1.9
Sweet corn	57–80	86–142	0.8–2.1	2.9–4.5	19	3.2–5.2	0.6–3.2
Sweet potato	60–80	98–125	0.04–0.7	0.5–2.8	24.3	5.4–11.6	0.5–2.3
Taro	54–83	111–142	0.1–0.5	0.5–2.9	34.6	1	0.4–5.1
Tomato	90–96	14–23	Tr-1.26	0.7–1.2	4.7	1.2–3.4	0.4–1.8
Turnip	87–93	11–35	Tr-0.2	0.6–1.1	6.5	3.8–4.6	0.7–2.8
Watercress	90–94	11–29	Tr-0.6	1.7–3.1	1.3	0.2–0.6	0.5–3.3
Yam	54–84	104–116	0.03–4	1.5–2.4	27.6	0.5	0.4–3.9
Zucchini	95–98	7–16	Tr	0.4	4	1.3–2.2	0.6–1.4

[a]Range information based on various including USDA nutrient database series 14 and others.
[b]USDA database values only—expressed as total carbohydrate by difference; includes sugar, starch, and dietary fiber.
Sources: Refs. 16, 18.

Table 4 Factors that Can Affect Nutrient Content of Foods or Reported Nutrient Values

General references relating to multiple factors (19–22)	
Agriculture production Genetics: species and plant variety	Environmental Geography, altitude, climate, pest control, season, sunlight, soil composition/fertilization, water
Harvesting, shipping, and storage Plant maturity, harvesting time and method; ripeness of plant, harvesting time and temperature, time before, during, and after processing	Added food ingredients and/or supplemented with nutrients
Level and type of processing Fresh, canned, frozen, concentrated, dehydrated, dried, fermented, salted, smoked, with/without sweeteners, salt, fat, added liquid	Preparation methods Whole or cut, cut/grind size, mixed/whipped/blended, hot/cold preparation, dry or moist heat, frying, cooled/frozen
Heat processing Pasturization, irradiation, ultra-high temperature, high-temperature short term, microwave, pressure	Laboratory analysis (23) Sampling scheme, chemical analysis methods, laboratory procedures, use of calibration standards, intralaboratory variation, interlaboratory variation, data transcription

Source: Refs. 18–22.

affect the variability of nutrient content in foods. Comprehensive texts and research papers (as well as references cited within) are referenced in this table for those interested in a deeper understanding of any single production factor.

Because of the virtually endless possibilities of factor combinations, there is no definite set of rules dictating how the exact nutrient composition of any single plant may vary from the usual. Vitamins and minerals, rather than protein, fat, and carbohydrates, are the nutrients likely to have the greatest variation even within a single plant species.

Vitamins, functioning as cell regulating cofactors, will continue to be utilized by the plant even after being harvested (24). Other factors such as heating, acid or alkaline exposure, and processing techniques that cause oxidation can decrease the vitamin concentration to a fraction of the initial value (25).

The content of some minerals in plants is dependent upon the amount of a particular element available in the soil for the growing plant. For example, depending upon the selenium content in the soil, plants may have very low levels of selenium or contain toxic amounts (26).

D. Bioavailability

Even though vegetables may contain ample quantities of nutrients and phytochemicals, some vegetables also contain chemicals that bind with nutrients and phytochemicals, making the beneficial compounds unavailable for absorption. An understanding of these bioavailability considerations is essential to avoid using nutrient data of vegetables in a misleading way (27,28).

Nutrient antagonists can significantly decrease the bioavailability of nutrients from foods. High levels of one mineral may competitively reduce the absorption of another mineral element. For example, magnesium interferes with calcium absorption (29). Zinc also is known to interfere with magnesium absorption (30). And phytochemicals, like dietary fiber and phytic acid, can reduce the bioavailability of minerals such as iron or calcium.

Minerals are the nutrient class most commonly affected by decreased bioavailability. Most commonly, the low availability of the mineral to the body is due to the mineral's chemical form or to other components in the diet. Bioavailability for each mineral can vary extensively. For example, on the average, a human absorbs from the diet about 1 to 10% of the iron and manganese, 1 to 20% of the zinc, and 15 to 40% of the magnesium and calcium. These percentages will vary based on the quantity of food components such as dietary fiber and oxalic acid which bind with minerals, making them unavailable for absorption. Spinach is a good example of a vegetable with relatively high levels of calcium that is virtually unavailable to the body owing to the high oxalate concentration in the spinach. Consequently, listing spinach as a food that is high in calcium is technically correct, but it is misleading because spinach is not a good source of calcium for humans (31).

Another factor that can affect the bioavailability of minerals is the physiological status of a person. For some minerals, the efficiency of absorption is increased (within certain limits) during times of dietary deficiency, and the absorption efficiency is decreased during times of high intake (32).

III. NON-NUTRITIVE PHYTOCHEMICALS

A. Phytochemicals

Many components of foods are not strictly required by the body for growth and daily maintenance, yet some of these components may promote health and help to prevent disease. It has become common to call these compounds by the general term phytochemicals when present in plant foods or zoochemicals when present in animal foods. Some phytochemicals are conspicuous by their colors (carotenoids) or flavors (tannins), but the presence of many other phytochemicals is not as evident.

In 1919, E. V. McCollum wrote in his *Newer Knowledge of Nutrition*,

> A plant structure, or an animal body is an exceedingly complex mixture of chemical substances many of which are themselves individually as complicated in their structure as the most complex machine. The first step in the direction of reaching an understanding of the chemistry in the living mass, must involve the separation and the study of the structural units of which the tissues are composed (2, p. 2).

Although McCollum was likely writing about nutrients, his statement is as true today as it was nearly a century ago. Presently the field of nutrition is identifying and quantifying thousands of nonnutritive phytochemicals. Many of these plant chemicals have been identified as having health-promoting qualities. A partial list of vegetable phytochemicals linked to beneficial biological activities is presented in Table 5. Other phytochemicals have negative effects upon health either by inhibiting specific nutrient utilization or by being toxic (57).

B. Phytochemical Profiles

The development of chemical profiles for vegetable phytochemicals is in its infancy, and owing to the enormity of the task, it will likely be decades before good phytochemical profiles exist.

C. Factors Affecting Phytochemical Composition of Vegetables

Many of the factors that affect nutrient composition (i.e. genetics, environmental factors, and processing) likely also affect the phytochemical composition of vegetables. This is especially true for the phytochemicals functioning as antioxidants. However, information on this topic is extremely limited.

Table 5 List of Important Non-Nutrient Phytochemicals in Vegetables

Phytochemical	Anticancer	Antioxidant	Anti-inflamatory	Blood clotting	Detoxification	Eye health	GI tract health	Heart health	Immune system	Osteoporosis	Examples of food sources	Ref. #
Capsaicin	+/−			+							Hot chile peppers	33
Carotenoids alpha-carotene, beta-carotene, beta cryptoxanthin, lutein, lycopene, zeaxanthin	+/−	+				+		+			Orange, yellow, and green vegetables	34,35,36
Curcumin (phenolic)	+	+	+						+		Turmeric, mustard	37
Coumarins				+							Vegetables, tonka bean, sweet clove	38,39
Dietary fiber	+						+	+			Wide variety of vegetable sources	33,40,41, 42,43
Glucosinolates (glucobrassicin) isothiocyanates (sulphorophane) indoles (indole-3-carbinol)	+	+									Cruciferous vegetables, broccoli, sprouts	36,37,40, 44,45,46
Inositol phosphates (phytate)	+	+									Whole grains, beans	47
Monoterpene (limonene)	+										Citrus fruit peel	36,37,40
Organousulfur compounds diallyl sulfide, allyl methyl disuflide, allyl methyl trisulfide, S-allyl cysteine, allyl trisulfide, and others allyl isothiocyanate	+/−										Garlic, onions and other allium vegetables, mustard and horseradish	33,48,49
Protease inhibitors	+/−										Legumes, cereals, vegetables	36,50
Tannins	+/−	+							+		Grapes, tea, lentils, wine	51,52
Flavonoids apigenin, catechins, chrysin, kaempferol, myricetin, quercetin	+	+	+		+			a		+	Green vegetables, onions, garlic, tea	40,47,48, 53
Isoflavonoids, biochanin A, daidzein, formononetin, genistein, glycitein	+/−							+		+	Soybeans, clover sprouts, alfalfa sprouts	54,55
Ligans	+										Flaxseed, berries, whole grains	54,56
Coumestans	+										Soybeans, clover sprouts, alfalfa, beans	54,56

IV. HEALTH BENEFITS DERIVED FROM VEGETABLES

Modern society has dramatically affected how we eat. Since the introduction of TV dinners, it appears that convenience greatly influences people's food choices. Researchers have found that monkeys or apes foraging in the wild appear to get far higher levels of many essential nutrients and beneficial phytochemicals relative to their body weight than the average American (58).

Without a doubt, vegetables can be considered more nutrient-dense (nutrient content per kilocalorie of food) than foods from other food groups. However, the phytochemicals in vegetables may provide equally important benefits for the prevention of chronic diseases like cancer and heart disease (59).

Research on the purported health benefits of vegetables focuses on two main areas of study: maintenance of gastrointestinal tract health and reduction of chronic disease risk.

A. Gastrointestinal Tract Health

The gastrointestinal tract (GI tract) is the gateway through which the body transports nutrients and phytochemicals into the circulation for delivery to body cells. A complex network of internal organs and tissues is responsible for the digestion or breakdown of food components into compounds and elements that can be absorbed into the body. In addition, the GI tract serves as a protective barrier to prevent some substances from entering the body (60).

Due to the extremely active and chemically hostile internal environment necessary to accomplish the digestive process within the GI tract, cells along the 25–30 feet of intestine are exposed to a great deal of chemical and physical damage. Consequently, many of these cells have only a 3 to 5 day life span. This constant turnover of GI tract cells results in continuous cellular replacement and repair of damage.

There is a significant amount of nutrient recycling from injured GI tract cells, which allows many nutrients to be digested and absorbed along with new food components. This combination of recycled and dietary nutrients is utilized to support adequate replacement of the cell lining of the GI tract.

Over the last decade there has been an increase in the number of reported cases of various gastrointestinal diseases. Two of the most common GI tract diseases are diverticulitis (inflammation of small pouches formed along the gastrointestinal tract) and gastroesophageal reflux disease (GERD), the common cause of indigestion, which causes the pain popularly called heartburn (61). In fact, GERD is so common and chronic in the United States that Prilosec® was one of the world's top selling drugs in the year 2000.

Diverticulitis and GERD have one significant dietary factor in common. Both of these conditions appear to be related to years of inadequate dietary fiber intake (61,62). Ironically, fiber is the most abundant phytochemical in vegetables.

Vegetables contain both soluble and insoluble forms of dietary fiber. The physiological effects of these two dietary fiber types have both similarities and some significant differences.

Both soluble and insoluble fiber types hold water and create bulk inside the GI tract. Soluble fibers slow the rate of stomach emptying into the small intestine. It is thought that the stomach distension caused by fiber bulk and the slower stomach emptying produces an extended feeling of satiety after a meal (63,64). Intake of high soluble fiber also tends to decrease the overall nutrient absorption rate and may also reduce the amount of nutrients and phytochemicals absorbed. This can benefit those with problems in the management of blood glucose and may reduce the absorption of cholesterol (65). Excessively high intake of dietary fiber can interfere with the absorption of minerals.

B. Immune System Health

The immune system is part of the body's natural defense system against disease and disease-producing conditions. Approximately 80 percent of the immune system is located directly adjacent to the gastrointestinal tract. Ordinarily, undigested food molecules, microorganisms, and many toxins cannot readily cross through the intestinal lining and do not enter the circulatory system. However, disruptions to the integrity of the GI tract can challenge the immune system beyond its capacity to maintain health (60).

C. Chronic Disease

Many phytochemicals have been associated with preventing or decreasing the incidence of disease. Disease conditions and related mechanisms that are purported to be affected by various phytochemicals are summarized in Table 5.

No doubt there are numerous triggers in the initiation of cancer and heart disease. Although there may be many varied mechanisms of phytochemicals with anticancer and heart-promoting properties, one mechanism may be related to the antioxidant property shared by many of these compounds. The process of normal cellular metabolism produces chemicals that are reactive oxygen species like hydrogen peroxide and the superoxide anion free radical. It is thought that free radical production causes a secondary oxidative stress whenever there is an imbalance of antioxidants to oxidants. This can occur with an excess of oxidation stress or an inadequate amount of antioxidants in the diet.

Research has shown that antioxidants are involved in delaying many diseases and conditions that are associated with aging, such as cancer, heart disease, decreased immune functioning, and visual and cognitive impairment (66). A number of vitamins, minerals, and phytochemicals provide antioxidant protection in the body. On a per gram or per kilocalorie basis, vegetables contain significant amounts of antioxidants.

Dietary phytoestrogens may help reduce the risk of developing certain hormone-stimulated cancers such as breast and prostate cancers. However, much more research on this relationship is needed, since some studies indicate that phytoestrogen compounds may stimulate the progression of some types of cancer (67).

Flavonoids such as those found in onions, tea, and red wine also are under study for potential cancer prevention. The possible mechanisms of action may vary from one flavonoid to another. They may prevent cancer cell proliferation through specific enzyme inhibition (68).

V. SUMMARY

As a major category of foods, vegetables have a variety of qualities and characteristics that supports common recommendations to include them as a significant part of a balanced and varied diet. They serve as important sources of a wide variety of vitamins and minerals essential for normal human nutrition.

Vegetables supply these nutrients in forms that are generally low in energy and fat, making them more nutrient-dense than most other foods. The nutrient content of a particular vegetable can vary, with the extent dependent on the nutrient, and a variety of factors including plant genetics, agricultural factors, storage and handling, processing, packaging, and preparation. Nutrient content values in databases generally reflect averages.

The extent to which a vegetable food is a good source of a nutrient also depends on the type of processing and the bioavailability of the nutrient. In some cases, a vegetable can contain high

levels of a mineral such as calcium or iron, but the form of the mineral or interfering compounds in the vegetable allow very little of the mineral to be absorbed into the body. Some nutrients are not found in vegetables, including vitamins D and B-12 and the long-chain omega-3 fatty acids commonly found in fish oils and some species of algae.

In addition to nutrients, vegetables provide a great variety of nonnutrient chemical compounds commonly called phytochemicals. The potential benefits and risks of various phytochemicals found in vegetables represents an increasingly active area of nutrition research. The body of scientific research to date supports the inclusion of a wide variety of vegetables in the human diet for reducing the risk of developing a number of disease conditions that tend to develop with age. Additional research is needed to clarify more specific risks and benefits of various types of chemical compounds found in vegetables.

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3
Postharvest Preservation and Storage

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I. INTRODUCTION

A diverse range of tissues, cell types, and structures give vegetables, as a class of perishable products, a correspondingly diverse range of responses after harvest, creating a wide range of storage potential. For example, compare the highly perishable nature of leafy vegetables to the much longer storage life of storage organs such as potatoes (*Solanum tuberosum* L.).

While growing, vegetables are connected to a parent plant and obtain all the resources needed for growth and maintenance of biological structures. However, once harvested, the only resources available are those within the plant part harvested. As the living cells and tissues of the harvest vegetable continue living and responding to the environment, the cellular and physiological processes occurring deplete these resources, leading to an irreversible decline in quality.

Furthermore, harvested vegetables still undergo developmental processes, e.g., growth, maturation, and ripening, which may accelerate the decline in quality. The corollary of these processes is that the quality of harvested vegetables is the greatest at harvest.

This chapter briefly describes the major physiological processes that lead to a decline in quality of harvested vegetables. Vegetables can be grouped based on the major physiological processes that occur after harvest (Fig. 1). The importance of these processes is different for each vegetable. We discuss the current understanding of the influence of developmental changes on the quality and physiological behavior and the ways that various factors of the environment influence harvested vegetables. Finally we show how typical postharvest handling practices for vegetables take these factors into account.

II. PHYSIOLOGICAL PROCESSESS AFTER HARVEST

A. Respiration

Respiration is an essential process in all living cells. Respiration releases energy, carbon dioxide, and water through the breakdown of stored reserves of carbon compounds (1,2). Two forms of respiration, aerobic and anaerobic, occur in harvested vegetables.

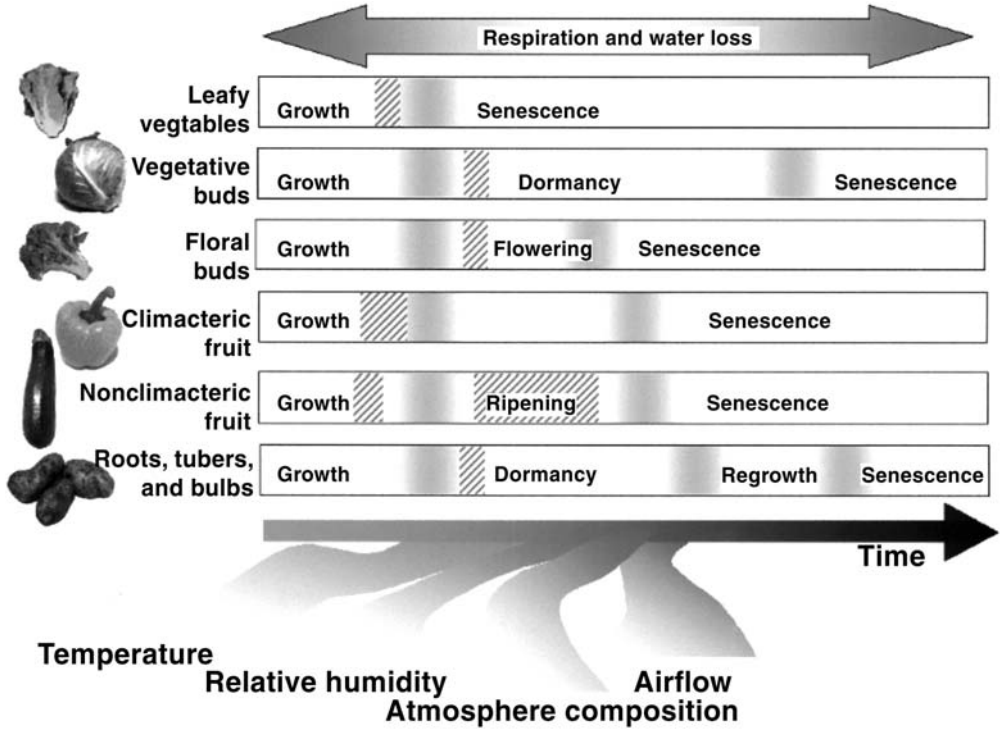

Figure 1 Outline of major physiological and developmental processes of harvested vegetables. Vegetables are classed into five major groups that experience similar processes after harvest. Shelf life for the vegetables within each group will differ as determined by the species, cultivar, and environmental conditions used during handling after harvest. The hatched areas indicate commercial harvest periods, which will differ depending on the vegetable.

A generalized equation, Eq. (1), for the complete oxidation of glucose during aerobic respiration is

$$\underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6O_2} \rightarrow \underset{\substack{\text{carbon}\\\text{dioxide}}}{6CO_2} + \underset{\text{water}}{6H_2O} + \underset{\text{energy}}{686\ \text{kcal}} \quad (1)$$

Glucose from starch or sucrose is broken down in a sequence of enzymatically controlled steps within the cell. The chemical energy released from these sugars is made available to the cell in the form of ATP (adenosine triphosphate), the universal carrier of energy for plant and animal cells.

If oxygen is limited, cells begin a process termed anaerobic respiration. A product of anaerobic respiration is acetaldehyde that is converted to ethanol in vegetables. This can lead to the development of alcoholic flavors often termed off-flavors in vegetables.

The primary functions of respiration are the release of energy from the stored chemicals and the formation of carbon skeletons used in other maintenance reactions in the cell. Respiration requires the presence of a carbohydrate substrate such as starch or lipids. These molecules are broken down into simple sugars for respiration. Therefore respiration results in a depletion of energy reserves, reducing the subsequent shelf life of the product and the total nutritional value

through the reduced energy content. Often, when normal energy reserves of tissues are exhausted, organic acids or proteins are utilized for respiration; accelerating senescence (3), particularly in plant parts that do not have large carbon resources [e.g., leaves and flower parts (1)].

During respiration there is a net loss of carbon (Eq. 1). This net loss of carbon represents a loss of saleable weight from the product (4). In those fresh product sales that are predominately based on weight, this net loss of carbon represents a decreased value.

As oxygen is the other substrate in respiration (Eq. 1), the rate of respiration depends on the oxygen concentration. A reduction of environmental O_2 levels (controlled atmosphere storage or modified atmosphere packaging) is used in postharvest handling to reduce the respiration rate and lengthen preservation, as is discussed later in this chapter. On the other hand, if oxygen levels around vegetables are reduced excessively, anaerobic respiration may occur with the possible development of off-flavors or injury to vegetables (5).

Carbon dioxide is produced during respiration, so in an enclosed environment, respiration also results in elevated CO_2 levels. While increased levels of carbon dioxide can be effective at slowing the rate of respiration, excessive levels (greater than 2–5%) can lead to injury in many stored vegetables (6).

Respiration is an inefficient process, and most of the energy generated by respiration is lost as heat (about 60%), while the remaining energy is retained in chemical forms by the cell (1). This addition of heat from respiration influences the temperature balance of fruit and is often referred to the heat of respiration.

B. Water Loss

Fresh vegetables continuously release water vapor through transpiration into the surrounding atmosphere. Transpiration is the diffusion of water vapor from the plant part into the surrounding environment. Diffusion is a spontaneous process leading to the net movement of a material from one region to an adjacent one, from high concentration to low concentration (7).

This diffusive water loss can be represented by a steady-state solution of Fick's first law of diffusion (7):

$$r'_{H_2O} = AP'_{H_2O}\Delta p_{H_2O} \tag{2}$$

where

r'_{H_2O} = rate of water loss from product ($mol \cdot s^{-1}$)
A = surface area of fruit (m^2)
P'_{H_2O} = effective permeance of the fruit surface to movement of water vapor under prevailing conditions ($mol \cdot s^{-1} \cdot m^{-2} \cdot Pa^{-1}$)
$\Delta p'_{H_2O}$ = difference in partial pressure of water vapor between the environment and inside the fruit (Pa)

Equation (2) illustrates that the rate of water loss depends on barrier properties of the vegetable surface (water vapor permeance), surface area of the vegetable, and the driving force for water vapor transfer (difference in partial pressures between fruit and environment). Any difference in rate of water loss of vegetables relates to change in one or more of these factors.

Like the net loss in carbon during respiration, the continuous loss of water vapor from the vegetables represents a saleable net loss in mass or weight over time that, in weight based product sales, represents a loss in value.

However, in addition to the loss in saleable weight, a loss of a small amount of water (3–10%) can have a serious effect on other quality parameters (8). For example, transpiration leads to a reduction of the tissue's moisture content; initially the cells within the vegetable lose turgor

pressure (pressure exerted against the cell wall by contents of the cell), leading to a loss in crispness and the development of a rubbery texture. Ongoing water loss leads to the development of other symptoms such as discoloration or the loss of greenness or loss of flavor and aroma (8). During water stress, vitamins are often lost, reducing the nutritional value (9–11). In addition, water stressed vegetables are more susceptible to chilling injury (12) and pathological infection (13). In avocado (*Persea Americana* Mill.), water loss has been shown to encourage ripening (16), and in other vegetables, senescence (see Sec. II.D) is accelerated (9,11,15). Finally, excessive water loss results in a wilted or shriveled appearance (16), when the reductions in volume of the product exceed the elasticity of the skin.

Water loss is a major cause of postharvest losses in leafy vegetables such as lettuce (*Lactuca sativa* L.) and spinach (*Spinacea oleracea* L.), and is important in immature fruits such as cucumbers (*Cucumis sativus* L.), eggplant (*Solanum melongena* L.), and snap beans (*Phaseolus vulgaris* L.) (9). Water loss is less important in mature fruits such as tomatoes (*Lycopersicon esculentum* Mill) and root vegetables such as potatoes (*Solanum tuberosum* L.) and sweet potatoes (*Ipomoea batatas* L. Lam.).

Permeance to water vapor characterizes the ease with which water vapor can escape from vegetables, and it is a characteristic of vegetable surface structures. The cuticle is the outermost layer of some vegetables and acts as a barrier to prevent excessive loss of water by evaporation from the plant to its environment (18). Below the cuticle is the epidermis, a tightly packed layer of regular cells. The cuticles are found on leaves, primary stems, flowers, petioles, fruits, hairs, and even glands (19) and contain cutin and crystalline waxes, which provide substantial barriers to gas movement (O_2, CO_2, and water vapor).

Instead of epidermis and cuticle, some vegetables have a periderm. A periderm consists of a layer of phellogen or cork cambium from which phellem or corked cells arise. The phellem cells are dead when mature and the cell walls are suberized. Suberin is a fatty acid substance like a wax in the cell walls (1) that provides some barrier to water movement and pathogen invasion. Periderm is formed in response to the wounding of any part of the plant in most species. In some vegetables, e.g., parsnips (*Pastinaca sativa*, L.) and carrots (*Daucus carota* L.) the periderm consists of only a few living phellem cells, while the potato (*Solanum tuberosum* L.) has 5–15 layers of mature phellem cells (20). Sometimes the periderm is not fully developed at harvest: a curing period is required to encourage periderm development.

While the outer layers of vegetables present considerable barriers to gas movement, they have to be sufficiently permeable to exchange oxygen and carbon dioxide for normal aerobic respiration to occur (19). Stomata, lenticels, and stem scars provide gas exchange pores for oxygen and carbon dioxide, but these structures are also permeable to water vapor.

The numbers of stomata and lenticels per unit of surface area differ for each type of plant part. This influences both the amount and location of transpiration. In leafy vegetables most of the water is lost through the many stomata (92% in brussel sprouts, *Brassica oleracea* L., Gemmifera group, and kale, *Brassica oleracea* L., Acephala group) (21). In comparison, for those vegetables that are botanically fruit or root structures, the majority of water is lost through the cuticle or periderm (3% through lenticels in potatoes, *Solanum tuberosum* L.) (20).

Many factors are known to influence the permeance to water vapor or susceptibility to water loss in a given environment of vegetables, including species (8), cultivar (20), maturity (20), ripening and senescence (22–24), mechanical damage during handling (25), application of artificial waxes (8), and presence of surface structures such as hair (26).

Surface area will influence the rate of water loss in direct proportion when water loss is expressed as represented in Eq. (2). However, as water loss is commonly expressed on a per unit weight basis (% weight loss), the surface area to volume ratio must also be considered.

Large vegetables will have a large surface area, but a smaller surface area to volume ratio than smaller vegetables. This leads to a greater rate of water loss per vegetable [from Eq. (2)] but less weight loss when water loss is expressed on a per unit weight basis. In general, smaller vegetables will develop wilting or shriveling symptoms of excessive water loss sooner than larger vegetables because of their large surface area to volume ratio.

The driving force for transpiration from vegetables is the difference in moisture content between the intercellular spaces and the surrounding air, expressed as partial pressures. The amount of water vapor in the air can be described in different ways. Relative humidity (RH) is probably the best known term for quantifying the amount of water vapor in air. RH is a ratio, usually expressed as a percentage, of partial pressure of water vapor actually in the air to the saturation partial pressure at the environmental temperature. However, it should be noted that the saturation partial pressure is dependent on the temperature, i.e., the amount of moisture in the air at 100% RH and 20°C is considerably more than that in air at 100% RH and 5°C (Fig. 2). Therefore an RH at one temperature represents a different amount of moisture than that RH at another temperature.

The partial pressure of water vapor in the intercellular spaces can be assumed to be very close to saturation at fruit temperature (20). The amount of water vapor of air in typical storage environments is generally less than the partial pressure of water vapor in the intercellular spaces. The magnitude of this difference depends upon temperature and relative humidity of the air, so the main factors influencing driving force for water loss are fruit temperature, relative humidity, and temperature of the environment.

C. Ripening

Ripening is a series of irreversible qualitative and quantitative transformations that occur toward the end of the growth phase for fruits. There are two general classes of fruit that some vegetables fall into: fleshy fruits (parenchymatic) such as tomato (*Lycopersicom esculentum* Mill.) and bell peppers (*Capsicum annuum* L.); and dry fruits (sclerenchymatic) such as peas (*Pisum sativum* L.) or corn (*Zea mays* L.). Ripening in fleshy fruits is distinct and dramatic, whereas it is less defined

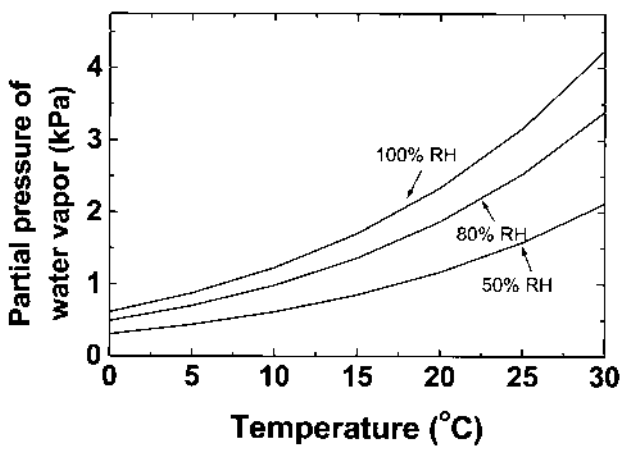

Figure 2 Effect of temperature and relative humidity (RH) on partial pressure of water vapor in air.

for dry fruit (1). Ripening in these fleshy fruits will be discussed briefly here. For information on ripening in dry fruits see Kays (1).

There is considerable variation in the ripening behavior among fleshy fruits. Fruits can differ in the time required to ripen, the ability to ripen once detached from the parent plant, and the time after initiation of ripening before senescence (1). Within fleshy fruits, there is a distinction between climacteric and nonclimacteric fruits. Climacteric fruits can be harvested unripe and will undergo normal ripening when detached from the plant, whereas nonclimacteric fruit will not ripen further once detached and tend to enter senescence after being harvested. Climacteric and nonclimacteric fruits also exhibit different behavior during ripening when considering changes in respiration rate and production of the plant hormone ethylene.

It is important to note that some vegetables that are fruit, e.g., cucumbers (*Cucumis sativas* L.) and squash (*Cucurbita pepo* L.), are marketed and utilized in their unripe state. Changes occurring during ripening therefore have undesirable effects on the quality attributes for these vegetables. Thus inhibiting the ripening process may be of interest during postharvest handling of these vegetables.

There are many biochemical processes that may occur during the process of ripening (Table 1). These processes can be grouped by the influence they have on the three main quality attributes: texture, appearance, and flavour.

1. Textural Changes

The texture of fleshy fruits is influenced by the composition of the cell walls, cellular constituents, and turgor. During ripening, the pectin-rich middle lamella region becomes more soluble, and the structural components of cell walls are enzymatically broken down (1,27). These changes

Table 1 Chemical and Physical Changes That Occur During the Ripening of Fleshy Fruits

Attribute		Specifics
Color	Pigmentation	Loss of chlorophyll Synthesis of carotenoids Synthesis of anthocyanins
Texture	Softening	Changes in pectin composition Alteration in structural components of cell walls Hydrolysis of storage materials
Flavor	Carbohydrate composition	Starch conversion to sugar Sugar introversions
	Organic acids	Decrease in organic acids
	Aroma volatiles	Increase in synthesis of volatiles Qualitative changes in volatile compounds
Energy	Respiration rate	Sudden peak in respiration for climacteric fruit Gradual decline for nonclimacteric fruit
Ethylene metabolism	Ethylene production	Sudden peak in production for climacteric fruit Constant production for nonclimacteric fruit
	Tissue sensitivity to ethylene	Increase in tissue sensitivity to ethylene

Source: Ref. 1.

influence adhesion between cells and strength of cell walls leading to softening. The biochemistries of these changes are not clearly understood, but the changes are likely to be mediated by complex interactions of enzymes (27).

2. Appearance

The most visible change during ripening is that of color. Color changes are often used as an index for the degree of ripening or to indicate suitable harvest time for some fleshy fruits (1). Generally, the alteration in pigments consists of the loss of chlorophyll to unmask pigments formed earlier in the development and/or the further synthesis of carotenoids and anthocyanins (27).

3. Flavor

Sugars, acids, and volatile compounds determine flavor, taste, and aroma of vegetables. During ripening there is often an increase in sugars (28) via translocation from the parent plant while fruit are attached or from hydrolysis of starch reserves in harvested fruit. In many fruits, there is also a decrease in organic acids during ripening as these acids are utilized for respiration (29).

In addition, the characteristic aromas of many fruits change during ripening. Many volatiles contribute to the characteristic aroma of fruit. During ripening the synthesis of these volatiles increases, but the selection of volatiles also changes (1).

4. Respiration Rate

Respiration is essential for ripening as it provides the energy required to drive many of the reactions and changes described briefly here. Indeed, if respiration is inhibited, ripening is also inhibited (30,31).

Based on their respiration characteristics, vegetables that are fruit can be divided into climacteric or nonclimacteric fruit. In nonclimacteric fruits the relatively low, consistent rate of respiration is maintained during ripening (Fig. 3). These fruit often do not have large carbohydrate reserves, and ripening occurs while attached to the plant. Cucumber (*Cucumis salivus* L.) (32) and olive (*Olea europaea* L.) (33) are vegetables that are nonclimacteric.

In contrast, in climacteric fruits the respiration rate declines during the final stages of maturation (preclimacteric minimum) (Fig. 3). As ripening proceeds, the respiration rate increases, rapidly reaching a peak (often referred to as the climacteric peak), after which there is a subsequent decline in respiration (Fig. 3). Tomato (*Lycopersicum escalentum* Mil.) and bitter melon (*Momordica charantia* L.) exhibit climacteric ripening (1). The timing of the climacteric in relation to optimal eating quality, the speed of ripening, and the maximum respiration rate differs for each species of fruit.

5. Ethylene Production and Its Role in Regulating Ripening

Ethylene is a plant hormone with many roles in plant developmental processes (34). Ethylene is synthesized and evolves from cells of all fruits during their growth and development. Both nonclimacteric and climacteric fruit produce a background level of ethylene.

In nonclimacteric fruit, exposure to an external ethylene source leads to increased respiration rate. Ethylene also stimulates anthocyanin synthesis and loss of chlorophyll in fruit (35). The magnitude of responses depends on the concentration of ethylene. Respiration rate, anthocyanin synthesis, and loss of chlorophyll will return to normal when exposure to ethylene is discontinued (1).

In contrast, climacteric fruit respond more dramatically. During ripening there is a substantial increase in ethylene production during the respiratory climacteric period (36).

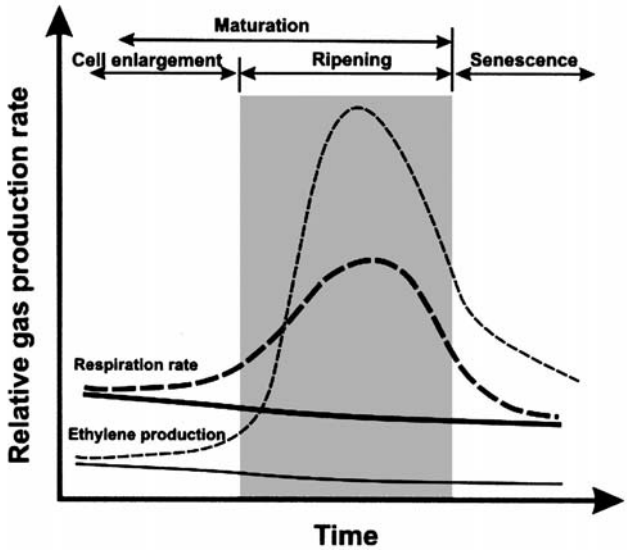

Figure 3 Relative respiration and ethylene production for climacteric and nonclimacteric fruits after harvest.

Climacteric fruits can be stimulated into ripening by exposure to an external source of ethylene. The fruit are particularly sensitive to ethylene just before the climacteric rise in respiration. Additional application of ethylene or removal of ethylene around fruit (particularly bulky organs) has little effect once ripening has been initiated (35), as ripening is irreversible. Higher concentrations of ethylene will stimulate ripening faster until a threshold is reached, above which there is no further effect.

D. Senescence

Senescence is the degradative changes that occur as all plants and harvested plant parts eventually die. Many of the changes occurring during senescence cause detrimental changes in product quality. Senescence is a genetically programmed sequence (37) occurring as a natural part of plant development.

In harvested vegetables, senescence is a premature process induced by detaching the vegetable from the parent plant (3). Senescence in harvested vegetables is most likely triggered by the inability of tissue to maintain homeostasis (38) or in other words maintain its internal stability through coordinated responses to disruptions of normal function (1).

Repair reactions are necessary to maintain homeostasis; these require the energy and carbon skeletons produced by respiration. In harvested vegetables there may be a lack of substrate for respiration (1). This situation may lead to the dismantling of nonessential cell components to obtain substrate to maintain homeostasis, eventually leading to the dismantling of essential cell components (mitochondria, nucleus, plasma membrane), which leads to death.

The degradation of chlorophyll is the most evident symptom of senescence in harvested vegetables.

Storage conditions can damage cell components and processes, placing the harvested vegetable under stress, which further accelerates senescence. Stresses known to accelerate senescence are high or low temperature (12,39), gas atmospheres (40), water deficit (8), pathogens, mechanical damage, and mineral imbalances (1).

Exposure to ethylene promotes chlorophyll loss in leaves (35). The delays in senescence by treating with 1-methylcyclopropene (1-MCP, 41) and nitric oxide and nitrous oxide (42,43), both inhibitors of ethylene activity (44), indicate that ethylene plays an integral role in senescence. However, starvation for substrate for respiration may initiate senescence in vegetables that are rapidly growing and respiring prior to harvest (3).

E. Dormancy and Regrowth

Dormancy is a period of suspended growth that allows for regrowth and sprouting to occur when environmental conditions are favorable (1). During dormancy, the rates of respiration and other physiological changes are very low compared to other harvested vegetables. This makes dormant vegetables particularly suitable for long-term storage. Storage life of dormant vegetables is generally limited by the break in dormancy resulting in regrowth and sprouting (3).

Dormancy in some vegetables can be induced by environmental conditions, i.e., extended cold or dry periods (1). This type of dormancy is exhibited by carrots (*Daucus carota* L.) and beetroot (*Beta vulgaris* L.). Sprouting and regrowth from these dormant vegetables can be avoided by maintaining the appropriate temperature and moisture levels during storage.

In some cases, a form of dormancy is entered when the internal balance of plant hormones prevents growth (1). Onions (*Allium cepa* L.) and cabbage (*Brassica oleracea* L., Capatita group) exhibit this type of dormancy. These vegetables will eventually start regrowth and sprouting regardless of the storage conditions. In these vegetables, breeding and antisprouting compounds are used to extend storage (3).

III. ENVIRONMENTAL INFLUENCES

A. Temperature

Temperature is the most important environmental factor that influences the preservation of harvested vegetables. Deterioration is mediated through the effect of temperature on the physiological and biochemical processes that occur in harvested vegetables.

Lowering the temperature influences all metabolic processes governed by enzymes. Temperature will influence the activity of the enzymes catalyzing the biochemical reactions maintaining homeostasis in cells. However, these enzyme systems can be affected differentially by temperature. This can lead to imbalances in metabolism; an often-quoted example of this is low temperature sweetening in potatoes (*Solanum tuberosum* L.) (3,45).

As respiration is a series of biochemical reactions catalyzed and controlled by enzymes, it will be influenced by temperature. As temperature increases, respiration increases dramatically (Fig. 4), although the extent of this increase varies for each species and cultivar (20). The rate of the increase in respiration slows, and then respiration rate declines, as temperatures are raised above 25–35°C. This high temperature effect may be due to a denaturing of respiratory enzymes or from lack of oxygen because of a limited rate of diffusion.

The rate of deterioration in harvested vegetables generally increases with increasing temperature (Fig. 5) (46). As temperature is reduced, the relative shelf life of vegetables generally increases (Fig. 5) (46).

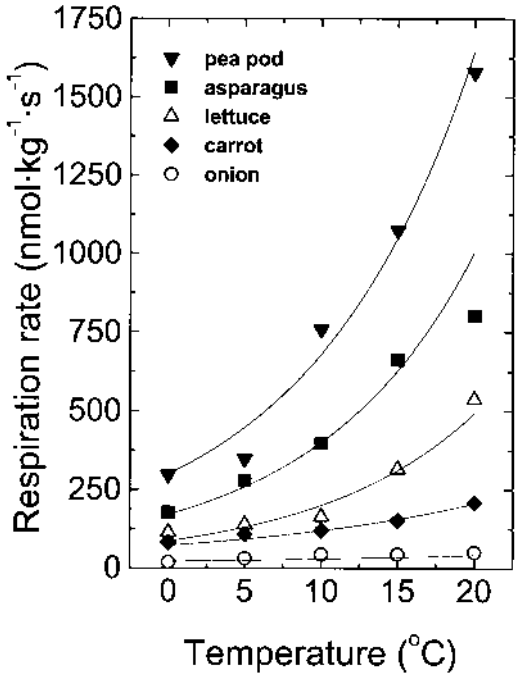

Figure 4 Effect of temperature on respiration rate of peas (*Pisum sativum* L.), asparagus (*Asparagus officinalis* L.), lettuce (*Lactuca sativa* L.), carrots (*Daucus carota* L.), and onions (*Allium cepa* L.). (Data calculated from Ref. 20.)

However, all harvested vegetables suffer tissue damage if frozen (Table 2). Some vegetable species, mainly of tropical or subtropical origin, are injured by nonfreezing temperatures less than 20°C (Table 2) (47). These vegetables when stored below their optimum temperature develop symptoms of injury that include discoloration, surface pitting, internal breakdown, loss of ripening ability, wilting, and decay (1). Injury from chilling is caused by initial physical changes in membrane lipids (48), which lead to secondary responses including an increase in respiration

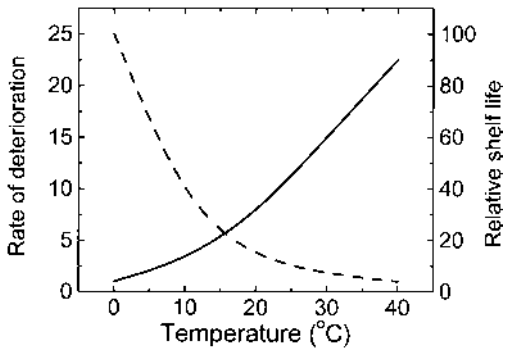

Figure 5 Effect of temperature on shelf life and decline in quality of fresh vegetables (developed from data from Ref. 55) not susceptible to damage from chilling.

Table 2 Optimum Transport Conditions and Predicted Storage Life for Some Vegetables

Vegetable	Transport temperature[a] (°C)	Freezing temperature[b] (°C)	Ventilation[c]	RH[d] (%)	Predicted storage life[e]
Artichoke (*Cynara scolymus* L.)	−0.5–4	−1	L	95–98	2–16 w
Asparagus (*Asparagus officinalis* L.)	0–4	−0.5	M	95–98	2–5 w
Beans (*Phaseolus vulgaris* L.)	0–8	−0.5	M/H	98	10–20 d
Beetroot (*Beta vulgaris* L.)	0	−0.5	L	92–95	2–12 w
Broccoli (*Brassica oleracea* L. Italica group)	0–5	−0.5	H	95–98	10–30 d
Brussels sprouts (*Brassica oleracea* L., Gemmifera group)	−1–5	−0.5	H	95–100	1–4 m
Cabbage (*Brassica oleracea* L., Capatita group)	−2–0	−0.5	H	98–100	3 w–6 m
Carrots (*Daucus carota* L.)	0–1	−1.4	L	98–100	10 d–8 m
Cauliflower (*Brassica oleracea* L., Botrytis group)	0	−0.5	H	95–100	3–12 w
Celery (*Apium graveolens* (Mill.) Pers.	0	−0.3	H	98–100	2–3 m
Chicory (*Chircorium intyvus* L.)	−1–0	−0.5	H	98–100	2–12 w
Cucumber (*Cucumis sativus*, L.)	7–13	−0.3	H	95	1–3 w
Eggplant (*Solanum melongena* L.)	7–12	−0.5	L	90–95	7–14 d
Garlic (*Allium sativum* L.)	−1–0	−0.5	L	65–70	3–7 m
Ginger (*Zingiber officinale*, Roscoe)	12–13	—	L	65	3–6 m
Leek (*Allium ampeloprasum* L., Porrum group)	0	−0.5	M	=95	2–5 m
Lettuce (*Lactuca sativa* L.)	0–1	−0.2	H	98	2–6 w
Marrow (*Cucurbita* spp.)	7–12	−0.3	L/M	60–90	1–12 w
Onion (*Allium cepa* L.)	0	−0.5	M	65–95	0.5–8 m
Pea (*Pisum sativum* L.)	−1–0	−0.5	M	98	1–3 w
Pepper (sweet) (*Capsicum annuum* L.)	7–13	−0.5	M	90–95	2–5 w
Potato (*Solanum tuberosum* L)	4–10	−0.5	M	90–95	3 w–9 m
Pumpkin (*Cucurbita* spp.)	10–13	−0.5	L	50–70	2–3 m
Rhubarb (*Rheum rhaponticum* L)	0	−0.5	L	95–100	2–4 w
Salsify (*Tragopogon porrifolius* L.)	0	−1	L	95–98	2–4 m
Sweet potato (*Ipomoea batatas* (L.) Lam.)	13–16	−0.8	L	85–90	4–7 m
Tomato (*Lycopersicom esculentum*, Mill)	4–16	−0.5	H	85–95	1–6 w

[a]Transport temperature depends on many factors, including variety, country of origin, and maturity. [b]The most conservative value from the literature was used. [c]Ventilation = changes/h: L = 1/h, M = 2–3/h, H = 4/h. [d]Depends on variety, country of origin, maturity, etc. [e]Determined by storage conditions and factors in noted.

rate and ethylene production as cells attempt to maintain homeostasis. Vegetables that have been injured by low temperature show an accelerated rate of senescence (39), associated poorer quality, and reduced shelf life.

Heat treatments have been used with varying success on harvested vegetables for insect disinfestations and disease control (49). For some vegetables, exposure to high temperatures has led to reduced senescence (50), most likely via the inhibition of ethylene biosynthesis (51) and reducing the susceptibility to and severity of injury from chilling when subsequently placed at low temperatures.

For vegetables that are fruit and are harvested, mature or optimal eating quality occurs when they are ripe; quality is dependent on the timing and balance of the various enzymatically controlled processes involved in ripening (Sec. II. C). As each enzyme system is influenced differentially by temperature, fruit temperatures during ripening will influence the final ripe quality. The optimum ripening temperatures are between 15 and 25°C (52); below these temperatures ripening is slowed, and aspects of texture, color, and flavor changes required for optimal quality may not occur. Above 30°C ripening may also be inhibited (52).

Ethylene production, a series of enzymatically catalyzed reactions (35), is influenced by temperature. Lowering temperature reduces the production of ethylene and hence delays ripening and senescence to some extent. In addition, reducing temperature also influences the sensitivity of plant tissue to ethylene (46), i.e., greater amounts of ethylene are required to induce the same magnitude of response obtained at a warmer temperature. However, lowering temperature below the low-temperature threshold for products susceptible to injury from chilling may induce a wound response, increased respiration rate, and ethylene production, leading to reduced shelf life.

Senescence in harvested vegetables has been linked to starvation for respiratory substrate (3), consequently reducing temperature, and the subsequent demand for respiratory substrate is essential for maintaining postharvest quality. The effects of temperature on rates of senescence through its effects on ethylene metabolism indicate that temperature is the most important environmental factor to preserve the quality of vegetables after harvest.

Temperature also influences preservation through its effects on water loss. The saturated partial pressure of water vapor in the air is highly dependent on temperature (Fig. 2). This influences the driving force for water loss, the difference between the amount of water with the fruit and that in the air. Reducing the driving force for water loss is the most manipulable of the factors governing water loss (see Sec. II. B). Reducing the temperature of harvested vegetables is effective in reducing the driving force and hence water loss (Fig. 6).

B. Relative Humidity

Relative humidity is the most common way of expressing the amount of moisture in air. The difference in the amount of moisture between the air in the vegetable and around the vegetable determines the driving force for water loss from harvested vegetables. When at a given temperature, the relative humidity of the air around the vegetable increases, the driving force is reduced rapidly (Fig. 6). However, even at 100% RH (saturated conditions), there may be some water loss, because the vegetable temperature is unlikely to equal the air temperature owing to heat of respiration.

The amount of moisture in air at a specified RH at one temperature is not the same as in air of the same RH at another temperature (Fig. 2). In addition, the maximum amount of moisture held in air is dependent on the temperature. This causes condensation when cold vegetables are placed in warm environments. When warm air comes in contact with the cold vegetable, it cools rapidly and can no longer hold as much moisture. Consequently the air deposits the excess water as condensation on the vegetable surface.

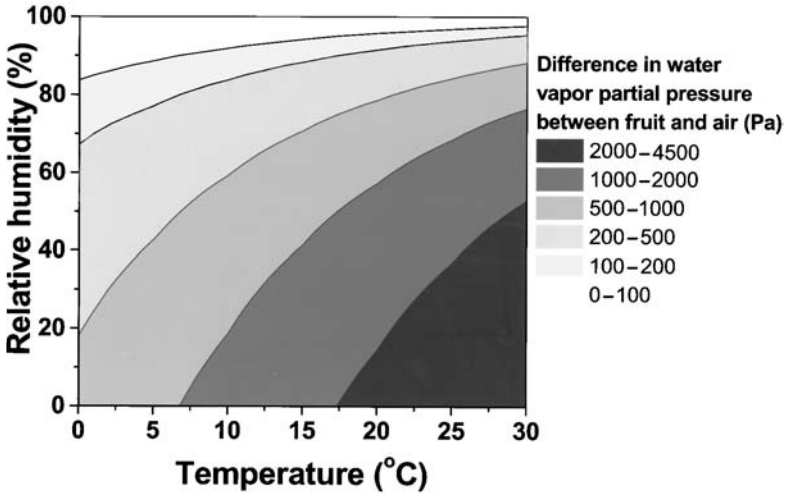

Figure 6 Effect of temperature and RH on difference in partial pressure of water vapor between fruit and environment, or driving force water loss from vegetables.

As temperature is reduced, it is easier to generate air with high humidity, as less moisture is required to humidify the air. However, at lower temperatures, fluctuations in temperature rapidly result in condensation on vegetable and packaging surfaces. Free water on the surface of vegetables encourages pathogens when temperatures are favorable (13). Condensation on paperboard-based packaging can lead to loss of strength and packaging collapse, causing further mechanical damage to products (53).

Enclosing harvested vegetables in packaging can generate high relative humidities by the reduction in airflow past the vegetables. Some packaging materials also act as barriers to water vapor movement, e.g., plastic films allowing an even higher relative humidity to be generated within packages.

Higher humidities reduce water loss (Fig. 6) and hence avoid losses in turgor, texture, appearance, and saleable weight. Once such high-humidity environments are generated, temperature fluctuations should be prevented to avoid condensation. For most vegetables, the relative humidity should be about 90 to 95 percent, except as noted under individual vegetables (Table 2).

C. Airflow

Airflow around vegetables affects relative humidity, temperature, and gas composition. Uneven or inadequate airflow will result in a wide spread of product temperatures throughout unit loads (i.e., packages or pallets of product), inducing spatial variation in product quality and subsequent shelf life. Sufficient air movement is necessary to remove heat of respiration and to minimize temperature gradients; but the higher the flow rates, the higher the rates of water loss from the produce (by reduced RH). The optimum airflow will be a compromise between removing heat from and maintaining water in harvested vegetables.

D. Atmosphere Composition

Air is normally composed of 78% N_2, 21% O_2, and 0.03% CO_2. Holding vegetables at altered atmospheres (decreased O_2 and increased CO_2 concentrations) as in controlled atmosphere (CA)

storage and modified atmosphere packaging (MAP), can be used to maintain quality for longer periods. Modified atmosphere storage is only a supplement to optimal temperature and relative humidity conditions (46). Atmosphere composition can be changed by utilizing the natural depletion of O_2 and production of CO_2 by respiring vegetables during MAP or by active modification and control of gas concentrations during CA storage. Adjusting the concentration of O_2 and CO_2 in the storage atmosphere will result in diverse reactions of the stored plant organ, depending on the actual gas composition inside the tissue. We will refer to the concentrations of O_2 and CO_2 in the atmosphere surrounding the vegetable, rather than the resulting atmosphere within the product. Manipulation of gases in the storage atmosphere has been the subject of an enormous number of studies (e.g., 5,6,54–65).

As oxygen is a substrate required for respiration, the rate of respiration depends on the concentration of O_2 within harvested vegetables (Fig. 7). The major reductions in respiration due to oxygen concentration often do not occur until oxygen is less than 10% (Fig. 7) (55). Depending on the product, anaerobic respiration begins around 2% O_2 as oxygen becomes limiting within the product (Fig. 7); energy to maintain and drive metabolism is sourced via the much less efficient anaerobic respiration (Fig. 7) (5). Anaerobic respiration produces an excessive amount of CO_2 and off-flavors from the further metabolism of acetaldehyde.

The effect of CO_2 on the respiration of vegetables is not as clear as for O_2. High CO_2 has been found to inhibit, have no effect on, or to stimulate respiration (6,69). The inhibition of respiration by high CO_2 is proposed to be via inhibition of an enzyme in the Krebs cycle (70) and decreasing pH of the cell sap (3). The stimulation of respiration is likely due to a stress response to injury (6,71).

Reduced O_2 or increased CO_2 reduces sensitivity to the action of ethylene (55,61,65) and inhibits enzymes in the biosynthetic pathway of ethylene, reducing production (35,61,72). The effect of reduced O_2 on ethylene production and the sensitivity of tissue is often considered the most useful application of modified atmospheres (67).

Modified atmospheres influence changes in pigment metabolism. Reduced O_2 and increased CO_2 can lead to a reduced chlorophyll loss (5,68,71), which is associated with senescence in leafy vegetables and unwanted ripening in vegetables that are immature fruits. However, for vegetables that are eaten as mature fruit, reduced chlorophyll loss during ripening may be unacceptable leading to a masking of other pigments. Overall, the effect of reduced O_2 and increased CO_2 on the physiology of vegetables can lead to an inhibition of ripening and a delay in senescence.

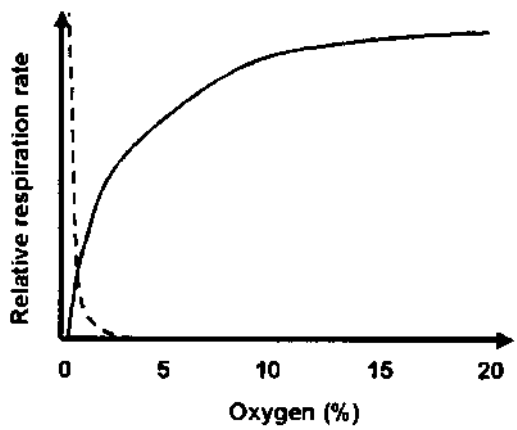

Figure 7 Effect of concentration of O_2 on respiration rate of vegetables.

Low O_2 inhibits the browning reaction catalyzed by polyphenol oxidase (PPO) (66). The suppression of PPO activity is particularly useful for applications with minimally processed vegetables (cut, sliced, diced, or shredded vegetables) that have exposed cut surfaces.

Reduced O_2 and increased CO_2 has some effect on volatile production of vegetables (73). When atmospheres are outside the tolerance limits of the vegetables and anaerobic respiration increases, accumulation of acetaldehyde and ethanol will influence the flavor and aroma of vegetables. The production of other volatiles is suppressed by low O_2, and elevated CO_2 either has no effect or appears to reduce synthesis (5). All changes are dependent on the volatiles of interest, the cultivar, and the storage conditions.

Modified atmospheres have an effect on texture via the effect on ethylene production and sensitivity of tissue to ethylene but also through changes in cell wall metabolism. Low O_2 and high CO_2 both decrease the action of enzymes associated with cell wall degradation (5,66,64,71) and hence reduce the loss of texture in storage.

Tolerance of commodities to low O_2 and high CO_2 varies greatly among vegetables. Broccoli (*Brassica oleracea* L., Italica group) and onion (*Allium cepa* L.) will tolerate about 1% O_2 compared to pea (*Pisum sativum* L.) and asparagus (*Asparagus officinalis* L.), which can only tolerate 5% O_2, or lettuce (*Lactuca sativa* L.) and celery [*Apium graveolens* (Mill.) Pers.], which can tolerate 2% CO_2, compared to sweet corn (*Zea mays* Bonaf.) and spinach (*Spinacea oleracea* L.), which can tolerate up to 15% CO_2. For a more comprehensive list see Kader (55), Herner (71), or Salveit (74). The tolerances for each gas are dependent on temperature, time of exposure, and concentration of each other (55,71,6).

When O_2 is reduced below or CO_2 is enhanced above the tolerance levels for that product, detrimental effects may occur. Induction of anaerobic respiration can lead to the production of off-flavors, but it can lead to a build up of CO_2, which can cause CO_2 injury. Various symptoms characterize CO_2 injury: internal browning disorders, pitting of surface, brown staining of surface, and a subsequent increase in susceptibility to decay (71,6). Care must be taken to avoid exposing vegetables to injurious CO_2 levels, as these symptoms will reduce the quality and the shelf life of vegetables.

Altered atmospheres have been shown to have insecticidal and fungicidal effects (71,5,55,75). High levels of CO_2 (10–15%) have been used to control fungal pathogens on some fruit (55) and, depending on tolerances to CO_2, could be expanded to some vegetables.

IV. POSTHARVEST HANDLING

A. Packaging

The choice of packaging for vegetable products is influenced by a wide range of factors including containment of the product, protection from damage, preservation of product quality, and presentation. Packaging must include ventilation both to enable cooling and to prevent the buildup of undesirable gases, while retaining strength in the storage environment, so a number of design factors must be balanced. The basic functions of packaging are outlined below, but it must be recognized that the environmental and purchase costs are still major criteria in the selection of packaging for vegetable products.

1. Containment

The basic function of packaging is to *contain* the product. This function is often ignored or its importance not appreciated (71). The package, whether it is a bottle of processed carrot juice (*Daucus carota* L.) or a bulk export bin of potatoes (*Solanum tuberosum* L.), must contain the product to function successfully.

2. Protection and Preservation

Protection is often regarded as the primary function of packaging. The package is expected to protect its contents from outside environmental effects such as dust, microorganisms, changes in temperature and humidity, gases (oxygen, carbon dioxide, and ethylene), shocks, vibrations, and compression forces that can bruise and mark harvested vegetables (72).

The package must have sufficient barrier properties to protect vegetables from microbial, chemical, and physical contamination, thus minimizing quality loss from the product. The primary packaging must meet such requirements as a low water vapor transmission rate, to reduce water loss, maintenance of strength, and performance at the storage temperature, properties that encourage the removal of field heat (if the vegetable is packed warm) and freedom from taint and odor. A further essential requirement of the package is that it does not interact with the product negatively.

3. Presentation

The package, if used at point of sale, presents the vegetables to the consumer. The appearance of retail packs (the consumer appeal) can have considerable influence on the sale of a product. High quality printing and graphics are required in many countries.

B. Packaging Materials Requirement

An example of a wide variety of materials, such as plastic bins and corrugated cardboard cartons, are used in primary (in direct contact with the product) and secondary (also termed outer or transport) packaging systems for vegetables. Primary packaging of fresh vegetables in plastic films has been a common practice to extend their shelf life. Packaging in plastic films enables changes in relative humidity and atmosphere compositions that all influence the basic physiology of harvested vegetables.

1. Perforated Packaging

Excessive in-package humidity levels may stimulate microbial growth, while low levels of humidity within the package would enhance weight loss of the fresh vegetables. Packaging should be designed to provide optimal water vapor levels in the package. Regulation of the exchanges of gases in the package, particularly water vapor, can be achieved by the use of perforation. An example of such studies by Tanner and coworkers (73–75) utilized a generalized mathematical simulation model for the development of an appropriately perforated package for kumara (a native sweet potato from New Zealand, *Ipomoea batatas* (L.) Lam). The optimal perforation area will be a compromise, balancing enhanced quality (reduced weight loss) with reduced risk of condensation (Fig. 8).

A number of studies have been carried out to look at the effects of perforations to the exchange of particularly CO_2 and O_2 (66,67,69,70) and in lesser extent to water vapor movement (68,74,76).

2. Modified Atmosphere Packaging

Modified atmosphere packaging (MAP) involves the modification of the gaseous conditions within the product's package, with the aim of reducing metabolic activity. This modification is realized by fine-tuning the permeability characteristics of the polymer film used in the MAP package, to the ambient environment and the physiology of the packed product.

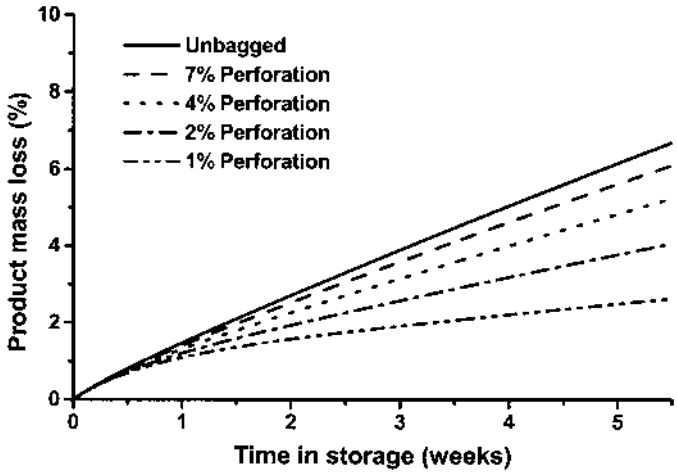

Figure 8 Conceptual assessment of product mass loss as a function of perforation area for New Zealand kumara (a native sweet potato, *Ipomoea batatas* (L.), Lam).

MAP is particularly useful when marketing minimally processed products (cut, sliced, diced, or shredded vegetables). With the generation of an acceptable modified atmosphere, MAP can reduce respiration, microbial spoilage, physiological disorders, enzymatic browning, and chlorophyll loss.

V. METHODS OF COOLING

All vegetables are perishable foodstuffs, and maintaining the freshness of vegetables for as long as possible is a major challenge. High product temperatures increase the rate of deterioration (Fig. 4). Rapid cooling of vegetables immediately after harvest to reduce their temperature to the recommended level, together with good temperature maintenance during subsequent storage and transport, is essentially important to maximize the shelf life of harvested vegetables.

There are a number of techniques available for cooling fresh produce. Most of these techniques can be used for vegetables, depending upon the market requirements. The selection between methods is based on capital cost, operating cost, cooling time required, volume of vegetables to be cooled, and the characteristics of the vegetable.

A. Icing

This method is commonly applied to boxes of vegetables by placing a layer of crushed ice on top of the vegetables or directly mixing it with the vegetables. Cooling is achieved as the ice melts and the cold water runs down through the vegetables. Ice slurry can also be applied, which is typically made from 60% fine crushed ice, 40% water, and usually 0.1% sodium chloride to lower the melting point of ice (80). This results in much quicker cooling than top icing because of the greater contact between the vegetables and the ice. The icing method is mainly used for road transport and can also be applied in the field immediately after harvest. However, packages used must be able to withstand exposure to free water. Ice also needs to be readily available at various points, for replenishment during long-distance transport (Fig. 9).

Figure 9 Broccoli cooled by icing.

B. Hydrocooling

Hydrocooling is used for root and stem vegetables. Most leafy vegetables can be hydrocooled but are usually vacuum cooled, as this method does not require a water-resistant box (78). In hydrocooling, the vegetables are rapidly cooled by contact with cold water. Water can be a very effective heat exchange medium when it is properly dispersed and flows rapidly over the vegetables. Efficient hydrocooling thus requires water moving over the surface in direct contact with the vegetables. Hydrocooling causes less or no water loss from vegetables and may even revive slightly wilted vegetables. Cooling can be achieved either by spraying cold water over the vegetables or by immersing them in cold water. In the first method, the vegetables move slowly and continuously through the shower. Immersion of the vegetables in cold water brings it in contact with all surfaces. For fast cooling, water must be actively circulated past each individual vegetable. Because the movement of the vegetables in the tank is slow, pumps or propellers are usually installed to circulate the water. Submersion in cold water is best suited for vegetables that are denser than water; this allows them to stay completely submerged. In general, submerging the vegetables in cold water tends to be less efficient because it is quite difficult to keep water moving fast through submerged vegetables (Fig. 10).

C. Vacuum Cooling

Vacuum cooling is most effective for cooling vegetables with high surface-area-to-volume ratios, such as leafy vegetables. It is based on the principle that the boiling point of water decreases as the

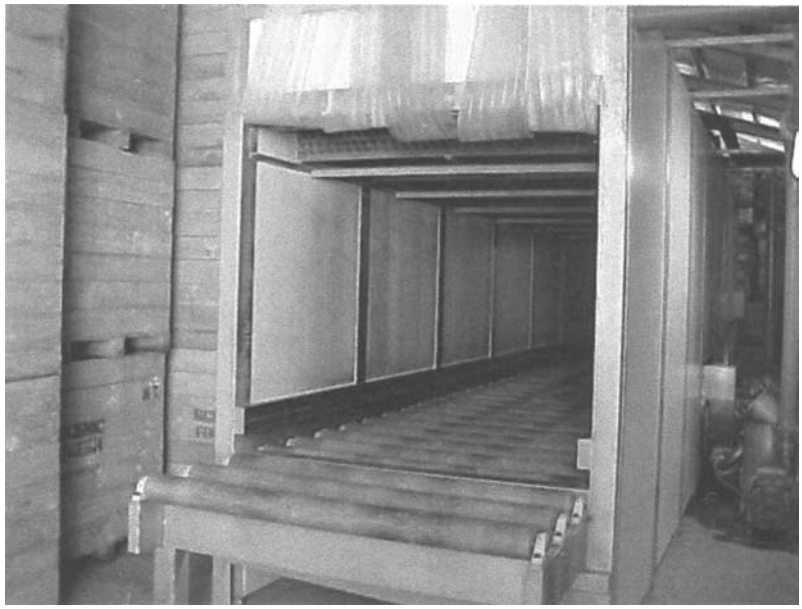

Figure 10 Hydrocooler used for cooling of harvested vegetables. (Photo courtesy of GROPAK, Palmerston North, NZ.)

pressure is reduced. The vegetables are placed into a sealed chamber and the pressure reduced using a vacuum pump. Water on the surface of the vegetable boils and turns to water vapor. As the pressure falls, water evaporates from the vegetables. The evaporation of water from the surface causes the vegetables to cool. The rate of cooling is largely influenced by the ease with which the vegetables lose water. Weight loss may be minimized by spraying vegetables with water before enclosing them in the vacuum chamber or toward the end of operation (77). However, this process requires a large amount of energy, and the high cost of the vacuum cooling equipment limits its suitability to a wider application (Fig. 11).

D. Forced-Air Cooling

Forced-air cooling is used for rapidly cooling packed containers of vegetables. Cooling is achieved by forcing cold air through containers and past individual items of vegetables (78). This method operates by a fan drawing refrigerated air through the packed vegetables, allowing close contact between the warm vegetable items and the cool air. The differential in air pressure forces air through the containers and carries product heat away by flow around the individual vegetables. The speed of cooling can be adjusted by regulating the rate of airflow. The method has the advantage of rapid cooling of pallet stacks of vegetables compared to room cooling, although usually it is slower than the other methods (i.e., hydrocooling, vacuum cooling). It has the drawback of causing excessive water loss in some vegetables. Effective forced-air cooling thus requires packaging with moisture barrier properties designed to prevent excessive moisture loss (Fig. 12).

Figure 11 Vacuum cooler used for cooling of harvested vegetables. (Photo courtesy of Intercoast Express Pty. Ltd., Werribee South, Victoria, Australia.)

E. Room Cooling

This method is the most commonly used cooling technique. Cooling is achieved by exposing vegetables to cold air in refrigerated storage. Cold air is horizontally discharged into a cold room, just below the ceiling. The air sweeps past the outside of the bins, pallets or individually spaced containers stacked on the floor. The air-handling system must be designed to distribute air uniformly throughout the storage room. This requires spaced stacking of palletized product to allow air to flow through the gaps. Room cooling has several advantages including simplicity in facility design and operation and less rehandling, as the vegetables may be cooled or stored in the same place. The major limitation of this method is that cooling is slow and may be inadequate for more sensitive vegetables.

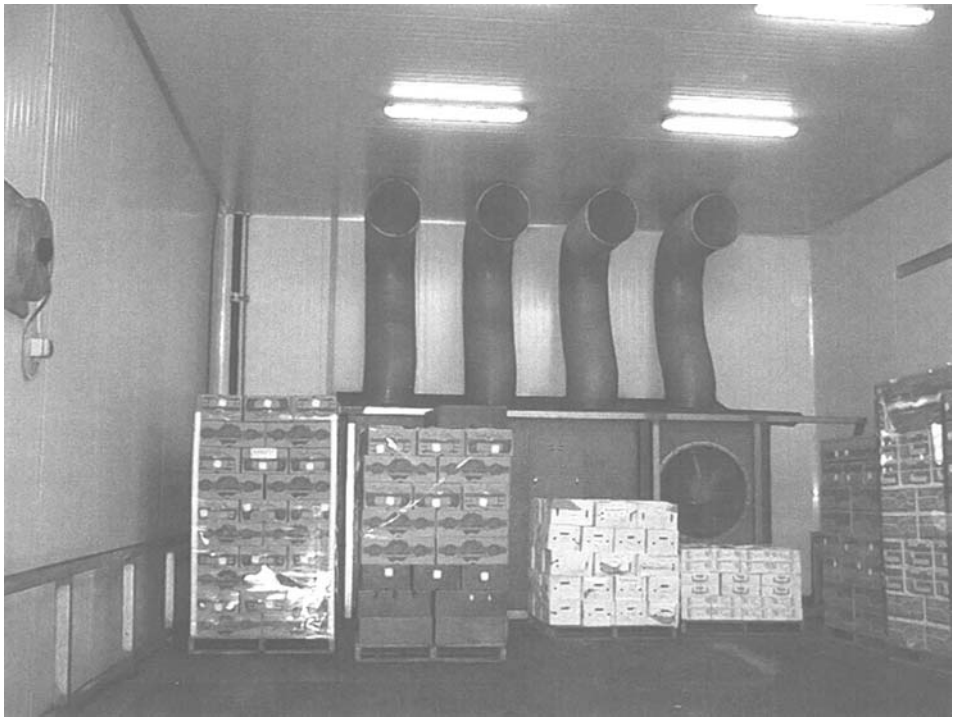

Figure 12 Forced draft cooling of harvested vegetables in ventilated packaging.

VI. STORAGE TECHNOLOGIES

To balance fluctuations in product supply and market demand, fresh vegetables often require short- or long-term storage. In some cases, long-term storage is necessary to extend the supply of these vegetables beyond the end of the harvest season. The storage potential of vegetables is very much dependent on their physiology as well on the storage conditions. Understanding the interaction between the vegetables and the environment is crucial in obtaining the most suitable conditions for extending shelf life. Good management of storage conditions is essential to slow down and delay the loss of quality.

A. Precooling Systems

The design of a cooling system depends largely on the specific requirements for each particular situation. In order to design efficient and effective cooling systems, one should be aware of the many factors that affect the cooling rate and cooling cost. The vegetable's physical properties (i.e., shape and size), thermal properties, configuration (i.e., bulk, cartons, unpackaged), initial temperature, and the desired final temperature influence the rate of cooling. A number of additional factors need to be considered when designing a cost-effective cooling system. These include the costs for cooling space, refrigeration equipment, labor, and electricity. A number of possible tradeoffs can occur when selecting design variables for a cooling system (81). For instance, while rapid cooling in forced-air cooling systems can be achieved by applying higher air velocities, the fan power requirement is also increased. Furthermore, lowering the temperature

accelerates the cooling process with the added expense of higher energy consumption. The selection of the cooling system should therefore be tailored on several considerations, such as the vegetable's limitations and temperature requirements, and the costs of operation.

B. Storage Facilities

Close control of the storage conditions is essential to optimize the storage life of vegetables. The maintenance of optimal storage conditions within the prescribed range depends on several design factors. The refrigeration system should be designed to handle maximum heat load. The air temperature leaving the refrigeration coils should be as close as possible to the desired temperature to prevent large fluctuations as the refrigeration system cycles on and off (79). Air circulation as well as adequate wall and ceiling insulations should also be provided to minimize temperature variation. The refrigeration equipment should also be designed to allow control of high humidity conditions. The advancement of computer technology and improvement of electronic and sensing components enable continuous monitoring and precise control of storage conditions of large refrigeration systems.

VII. TRANSPORT

It is important that the required conditions for storage of vegetables are maintained throughout transport. The most crucial factors (temperature, relative humidity, airflow, and atmospheric composition) have already been mentioned. Different commodities require different transport conditions and should be transported separately (e.g., respiring product, nonrespiring product, product producing high levels of ethylene, products requiring different temperatures). Optimal storage conditions for various vegetables are shown in Table 2.

Modern transportation systems provide avenues for a wide distribution of fresh vegetables to areas where they cannot be grown. There are number of important factors that need to be considered to ensure a high level of quality maintenance in the distribution chain. These include minimization of mechanical damage, maintenance of proper temperatures, and ensuring compatibility of the produce. These considerations are influenced by the type of transport system employed (e.g., air, road, or sea). The choice of a particular type of transportation is usually not quite simple, as the transport requirements between vegetables and the cost of transportation vary in postharvest systems.

A. Air

For air transport, vegetables are usually packed into cartons and placed in closed containers or net covered pallets specifically designed to fit into the aircraft (80). This mode of transport is used for quickly moving highly perishable vegetables over long distances. Airfreight cargo is usually exposed to pressurized compartments with facilities to provide control of temperature and other gases. Normally, airfreight charges are much higher than other transport systems (e.g., sea freight), hence the transport cost is a major issue to consider. Special care is also necessary for perishable vegetables transported by air, as no power is available during flights. Good insulation is essential, as is adequate precooling of product. In-transit cooling can be provided by water ice or dry ice where necessary.

B. Road

Transportation by road is appropriate for quickly moving fresh vegetables over short distances, for example from the field to the market or directly to the consumer. This mode of transport appears to be simple and relatively cheap, but it may result in losses due to physical damage if appropriate measures are not taken.

Extra hazards to be avoided during road transport include

Physical damage due to vibration of the vegetables. Suitable packaging should be used to prevent this by providing adequate cushioning.

Interruption to refrigeration. Truck refrigeration units should remain on power continuously until delivery of the vegetables.

Mixed loads.

Loading vegetables that are inadequately precooled. Truck refrigeration systems are unable to cool warm product efficiently.

C. Sea

This mode of transport is not generally used for vegetables owing to their relatively short storage life and their need for rapid transit to discerning markets. In cases where this is utilized (where the distance between markets is short or the product has a longer storage life, e.g., onions, *Allium cepa* L., and potatoes, *Solanum tuberosum* L.), care must be taken. Refrigeration and ventilation (where required) must be uninterrupted. Most important is that vegetables be adequately precooled prior to loading, as refrigerated containers are not designed to remove field heat. Palletized vegetables should be tightly stowed to ensure both even distribution of cool air throughout the stow and reduced movement of the vegetables, since movement can cause physical damage. Dunnage should be used where necessary to prevent the short-circuiting of airflow through the stow and maintain a "tight" stow.

VIII. CONCLUSION

Postharvest handling and storage systems influence the quality of harvested vegetables by affecting the physiology of harvested vegetables. Changes in the physiology of harvested vegetables are mediated through the influence of the environmental conditions created by the handling and storage system. The physiology of the harvested vegetables, environmental conditions, and handling and storage systems all interact and therefore cannot be considered in isolation when successfully preserving and storing high quality harvested vegetables.

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4
Canning Principles

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I. INTRODUCTION

Since ancient times, several techniques have been used to preserve vegetables and their products: drying, concentration, freezing, fermentation, and chemical preservation. Thermal processing, sterilization or canning, used for food preservation, is a more recent technology but has proven to be one of the most effective methods. Although several advanced processing techniques such as microwave heating, ohmic heating, and aseptic processing have been developed in recent years, the traditional canning processing is still dominant in the food industry. In North America alone, billions of cans of processed foods are produced each year.

The canning process was invented by the Frenchman Nicholas Appert in 1809, for which he received an award from the French government. In recognition, the canned food sterilization process is also referred to as "appertization". Nicholas Appert described the process very well but could not explain why the process achieved stability of the food and its extended shelf life. It was not until 1860 that Louis Pasteur, another Frenchman, explained that the heating process killed (or inactivated) the microorganisms that limited the shelf life of foods. This laid the foundations for advances in canning methods that eventually revolutionized the industry. In the 1890s, several scientists including Prescott, Underwood, Russell, and Barlow discovered the relationship between thermophilic bacteria and the spoilage of canned corn and peas. In the beginning of the 20th century, the basic biological and toxicological characteristics of *Clostridium botulinum* were investigated by several U.S. scientists, which became the theoretical foundation for understanding the importance of controlling *C. botulinum* in canned foods and establishing its control process.

Another important discovery, for canned foods was the relationship between the pH of foods and the heat resistance of bacterial spores, which was developed by Bigelow and Esty in the early 1920s. Their work laid the foundation for the classification of canned foods into acid foods and low-acid foods on the basis of their pH.

Bigelow et al. (1) developed the first scientific method for the calculation of minimum safe sterilization processes for canned food sterilization. It became known as the graphic or general method. Ball (2) subsequently developed theoretical methods, to be later recognized as formula methods, for the determination of thermal processes. Most subsequent developments on the subject have been based on these early concepts. Notably, Stumbo (3) developed procedures for the calculation of sterilization processes based on integrating lethality values over the entire volume of the contents of a container with mixed microflora. Since then, more advanced mathematical methods that eliminated certain relatively small errors inherent in some of the

previous mathematical procedures were developed. Teixeira et al. (4) led to the use of computers for more accurate, rapid, and routine heat process calculations and for monitoring and controlling thermal processes by on-line measurement of accomplished lethality. Today canning technology, with perhaps the most advanced scientific and technological background available, has become the backbone of the food processing industry.

II. BASIC CANNING OPERATIONS

Figure 1 illustrates the basic canning operations involved in the processing of vegetables: preparation of the food, container filling, exhausting the container, sealing, and thermal processing (sterilization).

A. Preparation of the food

Preparation of the food involves a number of processes such as washing, grading, peeling, and blanching. Washing usually involves agitating or tumbling the vegetables on moving belts or revolving screens while they are immersed in water or subjected to water sprays. Washing by means of high-pressure water sprays is the most satisfactory method. Sprays are effective only if the water reaches all parts of the product. This can be achieved if the sprays are directed from above and below a traveling woven wire-cloth conveyor, or by designing the washer so that the product is induced to roll over during the spraying process. Grading/sorting ensures the removal of inferior and/or damaged produce. An inspection belt may be used, in addition to trained personnel who detect poor quality produce unsuitable for canning. Several noninvasive technologies have been developed for the quality detecting, such as magnetic resonance imaging, ultrasound, and infrared. Application of these new technologies can improve the detecting efficiency and save labor costs for sorting. Acceptable vegetables are then size-graded by passing them over screens with holes of different diameters. Some vegetables are passed over a series of parallel bars with varying distances between the bars. In either case the screens may revolve or vibrate. Peeling is another important preliminary operation since, in conjunction with washing, it removes surface soiling and associated microbial contamination. Methods used include steam, mechanical, flame, abrasive, and lye peeling.

Blanching of vegetables is carried out prior to the canning process for the following reasons: (1) to remove respiratory gases that would reduce the ultimate vacuum in the can if they

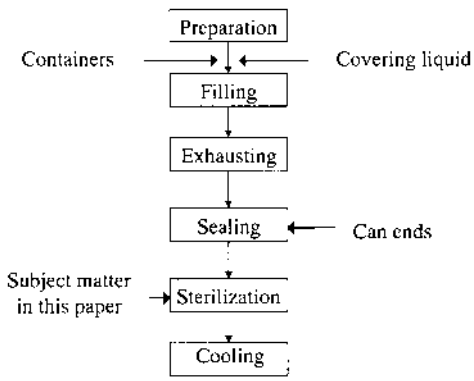

Figure 1 Flow diagram of the canning process.

were released during processing; (2) to inhibit enzymic reactions that might occur prior to the heat-processing stage; (3) to promote shrinkage of the product, thus permitting an adequate fill of the container: (4) to hydrate certain dry products that are not fully rehydrated prior to the blanching operation, and (5) to preheat the product in order to assist the vacuum formation in the can.

Different methods of blanching have been proposed. The most common is to immerse the vegetables in hot water at 85–95°C. The rotary immersion blancher, in which the product is conveyed by a screw on the inside of a rotating reel, the bottom part of which is immersed in the hot water, is widely used for this purpose. Chain conveyors are also used for transporting products through the hot water. In hydraulic-type pipe blanchers, the product is pumped with hot water through a continuous length of pipe; steam jets along its length are used to heat the water and assist the flow.

Because hot-water blanching causes loss of some nutrients and gives rise to large volumes of waste water, other methods have been proposed. The individual quick blanching (IQB) technique (5), based on a two-stage heat-hold principle, was shown to improve significantly the nutrient retention. The vegetable is heated in single layers to a temperature sufficiently high to inactivate the enzymes; in the second stage they are held in a deep bed sufficiently long to cause enzyme inactivation. Research and engineering efforts in the 1980s have led to the development of improved blanching equipment that makes use of steam (saturated or superheated) and recirculating hot water to improve nutrient retention, reduce leaching losses, and improve energy efficiency (6). Other nonconventional blanching procedures use moisturized hot gas, microwave, or ohmic heating techniques generally together with air cooling to minimize leaching.

B. Filling

Filling into glass or metal containers is accomplished mechanically or by hand. Apart from the economic aspects, careful control of the filling weight is important for technical reasons. The volume of the headspace may affect the efficiency of the exhausting procedure, and if an agitating process is used, the rate of heat penetration into the container. The ratio of solid to liquid material also influences the rate of heat penetration, thus affecting the extent of the heat processing treatment.

C. Exhausting the Container

The basic objective for the exhausting operation is to create an anaerobic environment (vacuum) in the can, which would inhibit microbial spoilage and minimize the strain on the can seams or pouch seals during processing. The creation of a vacuum after cooling ensures that the ends remain flat or slightly concave throughout moderate changes of storage temperature or barometric pressure, thus providing assurance to the consumer of the integrity of the container (7).

There are three methods used for achieving a vacuum in the container: a heat-exhaust, mechanical means, and steam injected into the headspace just prior to sealing. The heat-exhaust method, a conventional technique, involves the passage of the filled containers through a steam chamber or exhaust box prior to sealing. A vacuum is created in the can following condensation of the steam. The mechanical method includes sealing cans in a vacuum closing machine, sometimes preceded by vacuum syruping. In this method, cans filled cold with vegetable and syrup/brine are passed into a clincher, which clinches the cans but does not form an airtight seal. The cans are then subjected to a vacuum for only a short period of time. This practice will remove only the free headspace air, but not all dissolved gases within the product. In the headspace injection method, steam is flushed through ports around the seaming head of can closing machines in order to sweep

out air from the headspace. Steam flow is generally used during sealing of glass containers. The method is effective if a covering syrup or brine is present but may not be suitable for uncovered solids containing occluded air. Pouches may be sealed in a partial vacuum, although the use of a pressure plate that squeezes the pouch during sealing is often adequate.

D. Sealing

Can containers should be closed immediately after filling to prevent excessive cooling of the surface of the product. Modern can seaming machines operate at speeds as high as 300 cans per minute. Liquid products may be sealed in cans at speeds of up to 1600 per minute (8). The double seaming operation is critical for the assurance of a hermetic seal and good keeping quality of the final product during storage. Faulty seaming can result in deformations in the can during processing and eventual recontamination. Glass jars are closed with a screw cap. The sealing of flexible pouches, which relies on the fusion of two thermoplastic materials, is a slow operation, and the high speeds obtainable for cans and glass containers are not yet possible.

E. Thermal Processing

The objective of thermal processing is to effect sterilization of the contents in the sealed container. This is usually achieved by heating for a predetermined time and temperature under the given heating medium. The often used heating medium for food thermal processing can be saturated steam, heated water, or a steam–air mixture, which is largely determined by the type of package. Those requiring excess overpressure, such as glass and pouch packs, are processed in water with air overpressure, or in a steam–air mixture. The most widely used heating medium is saturated steam, since it transfers heat to the product by a high heat transfer coefficient and high latent heat of condensation. This is an ideal medium for the processing of cans. Water may be a more suitable medium for glass jars where care must be exercised to prevent thermal shocks to prevent breakage of containers. Some overpressure is desirable for these containers, especially during cooling, to prevent seal collapse. For flexible containers, overpressure processing is necessary during both heating and cooling. Steam/air mixtures or water with air overpressure media are employed for these products. Several types of thermal processing have been applied for vegetable cans, such as retort thermal processing. Some are detailed below. Following the retort operations, the containers are adequately cooled to slightly above the room temperature (which helps in efficient surface drying), labeled, and stored.

1. Retort Thermal Processing

Batch retorts. Retorts are specially designed pressure vessels in which the cans are loaded, usually stacked or jumbled into crates or cars. They can be classified into different types such as still vs. rotary or vertical vs. horizontal retorts. In general, these retorts are equipped to operate with pressurized steam or steam-heated water with or without added air overpressure. Conventional retorts have adequate control for steam pressure or temperature (since only steam is present in these retorts, a given pressure will have a specific temperature). In these retorts, venting is an essential step to remove the air from the retort so that a pure steam environment prevails in the retort. However, those operating on the overpressure principle will have both temperature and pressure controllers in order to maintain the desired temperature and overpressure processing conditions. Several types of industrial-scale batch retorts are commercially available. Rotary retorts are those in which the cans held in carts may be agitated through axial or end-over-end rotation process. The Rotamat can provide end-over-end or axial agitation depending upon the can

alignment in the rotating can, while the Orbitort rotates cans around their vertical axes after locking them in a helix. The heat penetration into the canned product is vastly improved by agitation, thus reducing process times and enabling higher temperatures to be used.

Continuous retorts. These can be of the rotary type, in which cans enter and leave the pressure zone through self-sealing rotary valves, or of the hydrostatic type, in which the mechanical valves are replaced by columns of water that balance the internal pressure.

Several types of continuous retorts are available in the food industry. The most widely used rotary type is the FMC Sterilmatic cooker–cooler, in which cans are carried in compartments at the circumference of a rotating reel. The reel pushes the cans through a spiral track attached to the inside of the shell, the lead of the spiral advancing the cans through the chamber. In the Hydrolock continuous cooker–cooler, agitation is achieved by cans rolling on a fixed perforated stainless steel plate as they are pushed through the equipment by carriers. The containers enter via a rotary paddle wheel with spring-loaded sealing bars. Hydrostatic cooker–coolers comprise "bring-up" and "come-down" legs, which balance the internal pressure of the steam chamber. The containers, which are conveyed through the machine by means of carriers connected to heavy duty chains, are subjected to gradual pressure and temperature changes as they enter and leave the sterilizing zone. Additionally, because only gentle rotation is applied, hydrostatic cookers are particularly gentle in their treatment of product and container alike.

2. Aseptic Processing

Aseptic processing has become a success story for liquid or liquid-containing small particulate foods. In this process, the food and the package are sterilized separately, and then they are assembled under sterile conditions. The product is first subjected to heat by passing the liquid product through a heat exchanger and held for a sufficient time in holding tubes to complete the required heat treatment. Following the required treatment, the product is then passed through another heat exchanger where it is cooled. The filling and sealing operations are then performed under aseptic conditions. There are two main reasons for its use: (a) to permit the use of containers that are unsuitable for in-package sterilization and (b) to take advantage of high-temperature short-time (HTST) processes, which are thermally efficient and generally give rise to food that is superior in quality to that produced by processing at lower temperatures for longer times.

3. Flame Sterilization

This technique is high-temperature (1370–1605°C) sterilization procedure for continuous, high-speed processing of liquid-filled cans containing vegetable pieces under axial agitation. Thin liquids, or solids packed in thin liquids, are suitable products for flame sterilization. The cans roll over the flames for a short time interval. Because of the direct contact with flame and the large temperature difference, heat is rapidly transferred to the contents of the can, creating the HTST processing conditions. A preheating section, which uses steam at atmospheric pressure to bring the contents to a uniform minimum temperature, is an essential step in this process.

III. PACKAGING MATERIALS

A. Cans

There are usually two types of metal cans: three piece and two piece. The three-piece can remains the most economical, reliable, and widely accepted form of tinplate container. Modern tinplate is made by electrolytically depositing tin onto a thin steel base plate, which may vary in thickness from 0.166 mm (double reduced) to 0.25 mm. Base plate specification is critical. Low phosphorus

and trace metal content is necessary if good corrosion resistance is required, as is the case for some fruits. Tin coating weight is expressed in grams per meter squared (g/m^2) and varies from 1.4 to 11.2, the actual amount depending upon the condition applying, and whether a protective lacquer is applied. The tin coating weight may need to be different for the internal and external surfaces of the can. To satisfy this requirement, differentially coated plate is available as follows (8):

Type L: Used for strongly corrosive products, so this steel carries the most rigorous restrictions on composition.

Type MR: To furnish benefits of low phosphorus steel for uses where small amounts of nonferrous metals are of no consequence. Used for mildly corrosive foods.

Types MC: Containing added P for strength. Used for applications in which neither this nor other residual elements matters. Used for foods producing little corrosion.

The three-piece can is made from a cylindrical body and two ends. To form the body, sheet cut from the coil is formed into blanks which are notched at the corners, so that when the side seam is formed the ends of the seam comprise only two thicknesses of metal. The side seam is formed by hooking the edges and locking these together to form the cylinder. Solder flowed into the seam completes the seal, after which the edges are flanged ready to receive the can ends. The can ends are stamped from tinplate and sealing compound is deposited in the curl at the edge. Once the end is positioned on the flange of the can body it can be formed into a seam by a two stage operation consisting of (a) rolling the curl of the end under the flange of the body and (b) ironing these together in a precise manner.

Two-piece cans, made from either tinplate or aluminum, are popular for some applications, for example, in the beverage industry. These are made by drawing a can complete with base from a single disc of metal. Developments in the methods of producing drawn cans enable full height cans to be made by this process. Two-piece drawn-redrawn cans, unlike their three-piece counterparts, nest top-to-bottom in stacks, giving greater stack stability and lower shelf profiles for an equal number of cans.

B. Glass Containers

Glass containers are suitable for a wide variety of heat-processed foods. When provided with a suitable closure, the jar or bottle provides an inert, hermetic, durable, and transparent package that is well suited for processed vegetables. Transparency of glass makes it the ideal choice for many products displayed for the consumer on the retail shelf. In addition, the resealability and storage characteristics of glass containers give them added consumer appeal.

Containers used for sterilized low-acid products such as vegetables are sealed by vacuum hermetic closures, the three types in general use being the pry-off (side seal), the lug type (twist-off), and the PT (press-on twist-off). These caps are applied and sealed in steam-flow cappers, and retained in place during the sterilization process by the vacuum so formed and an applied overpressure.

C. Flexible Pouches

Development of the retort pouch concept began in the U.S. in the early 1950s. Japanese and European firms obtained U.S. methods and technology through licensing arrangements that allowed them to start production of foods packed in retort pouches in the late 1960s. In 1968 the

U.S. Army Natick Development Center undertook a reliability study of the pouch. In comparing seal integrity, sterility, and overall defects, it was found that retort pouches could be produced that were equal to metal cans.

The structure of the pouch in general use is a three-ply laminate of polyester/aluminum foil/polypropylene in which the polypropylene forms the inner seal and the aluminum an oxygen and light barrier. Pouches of this makeup withstand sterilization temperatures of up to 130°C, which enables an HTST process to be applied, thus taking advantage of the thin cross section.

Many commodity foods such as corn, green beans, sliced or diced carrots, as well as special packs, such as potato salad, are candidates for this method of packaging.

IV. PRINCIPLES OF THERMAL PROCESSING

Foods subjected to thermal processing are not sterile, and the processes are not designed to make them sterile. The success of thermal processing depends on the destruction of all pathogenic and most spoilage-causing microorganisms in a hermetically sealed container, and creating an environment inside the package that is not conducive to the growth of spoilage-type microorganisms and their spores. Indeed, together with the nature of the food (pH), the environment (vacuum), its hermetic packaging, and the storage temperature, the given heat process prevents the growth of microorganisms of spoilage and public health concern.

In foods that are packaged under vacuum in hermetically sealed containers, low oxygen levels are intentionally achieved. Therefore the prevailing conditions do not support the growth of microorganisms that require oxygen (obligate aerobes) to result in food spoilage or public health problems. Furthermore, the spores of obligate aerobes are less heat-resistant than the microbial spores that grow under anaerobic conditions (facultative or obligate anaerobes). The growth and activity of these anaerobic microorganisms are largely pH dependent. From a thermal processing standpoint, foods are divided into three pH groups: (a) high-acid foods ($pH < 3.5$), (b) medium-acid foods ($pH < 4.5$), and (c) low-acid foods ($pH \geq 4.5$). Vegetables and most of their products belong to the low acid group. The most important distinction in the pH classification, especially with reference to thermal processing, is the dividing line between acid and low-acid foods. Most laboratories concerned with thermal processing have devoted attention to *Clostridium botulinum*. It has been generally recognized that C. *botulinum* does not grow and produce toxin below a pH of 4.6. Hence the dividing pH between the low-acid and acid groups is set at 4.5. In the low-acid foods ($pH > 4.5$), the destruction of C. *botulinum* spores is the primary concern and is the basis for establishing the process. However, there may be other microorganisms, for example, *Bacillus stearothermophilus, B. thermoacidurans*, and *C. thermosaccolyaticum*, more heat resistant than C. *botulinum*. These are generally thermophilic in nature (optimal growth temperature ca. 50–55°C) and hence are of little concern if the processed cans are stored at temperatures below 30°C.

In order to determine the extent of heat treatment, several factors must be known (9): the type and the heat resistance of the target microorganism, spore, or enzyme present in the food; the pH of the food; the storage conditions following the process; the heating and heat transfer conditions; and the thermophysical properties of the food and container shape and size. Some of these are reviewed below.

A. Heat Transfer

The mechanism of heat transfer is one of the key basic theories for the successful establishment of thermal processes, since it is used for determining the time–temperature profiles at specific positions in the container. The process of retort thermal processing (or canning) belongs to

unsteady-state heat transfer as the temperature of foods in the container continuously changes during processing. From an overall heat transfer process of view, there are three stages in the processing of canned foods. The first stage is heat transfer to the container from the heating or cooling medium; the main modes of heat transfer in this stage to be considered for the various heating media are detailed in Holdsworth (10). When the heating media is steam, the heat is transferred by condensation, which results in extremely rapid heat transfer across the container surface; thus the surface resistance to heat transfer can practically be neglected. In the case of other media (air, water, steam/air, or water/air), the main mode of heat transfer is convection, and it is necessary to take the convective heat transfer coefficient into account.

The second stage is through the container wall, in which the main transfer mode is conduction. For metallic containers of normal thickness, the thickness and the thermal conductivity of the material are such that there may be no appreciable resistance to heat transfer. However, for glass bottles and plastic containers there is a significant resistance, and this should be considered in determining the overall heat transfer resistance. The third stage is heat transfer into the product from the container wall; the types of heat transfer modes in this stage will be conduction, convection, or a combination depending on the types of food materials to be heated. Usually vegetable foods can be divided into four types: solid and liquid, which have corresponding heat transfer modes, conduction and convection.

1. Conduction

Governing equations. Heat penetration by conduction is based on Fourier's equation, established by the French physicist Jean Baptiste Joseph Fourier (1768–1830) and written as

$$\rho c \frac{\partial T}{\partial t} = k \nabla^2 T \tag{1}$$

or

$$\frac{\partial T}{\partial t} = \alpha \nabla^2 T \tag{2}$$

where ρ is the density (kg/m^3), c the specific heat or heat capacity (J/kg°C), k the thermal conductivity (W/m°C), α the thermal diffusivity (m^2/s), and ∇^2 the Laplace operator, given by

$$\nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2} \tag{3}$$

Equation (3) can be expressed in a variety of forms depending upon the coordinate system being used (Carslaw and Jaeger, 1959), such as

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} = \frac{1}{\alpha}\frac{\partial T}{\partial t} \tag{4}$$

$$\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r} + \frac{\partial^2 T}{\partial z^2} = \frac{1}{\alpha}\frac{\partial T}{\partial t} \tag{5}$$

$$\frac{\partial^2 T}{\partial r^2} + \frac{2}{r}\frac{\partial T}{\partial r} = \frac{1}{\alpha}\frac{\partial T}{\partial t} \tag{6}$$

where Eqs. (4), (5), and (6) usually represent the governing differential equations (no heat flow in angular) with different can or particulate shapes: rectangle, cylinder, and sphere, respectively. x, y, z are the coordinates of a rectangle can or food particulate, r is the coordinate in the radius, and z is the coordinate in the height.

Initial and boundary conditions. The solution of a partial differential equation is dependent on the initial and boundary conditions. For the retort thermal processing of foods in cylinder cans, there are two types of initial conditions: a uniform temperature T_0 or temperature function T_0 (r, z, 0) in space. Usually the former is used at the beginning of the heating period, while the latter is used at the beginning of the cooling for canned foods which have not achieved a uniform temperature distribution at the end of the heating period, especially with large can sizes. These initial conditions can be expressed as

$$T(r, z, t) = T_0 \qquad \text{at} \qquad t = 0 \tag{7}$$

$$T(r, z, t) = T_0(r, z, t) \qquad \text{at} \qquad t = 0 \tag{8}$$

Boundary conditions specify the temperature as a function of time at the two boundaries of the object. There are usually three categories of boundary conditions: Dirichlet, Neumann, and Robbins, which are expressed as

$$T(r, z, t) = T_R \qquad \text{at } r = a \text{ or } z = L \tag{9}$$

$$\begin{aligned} \frac{\partial T}{\partial r} &= 0 \quad \text{at } r = 0 \\ \frac{\partial T}{\partial z} &= 0 \quad \text{at } z = 0 \end{aligned} \tag{10}$$

$$\begin{aligned} k\frac{\partial T}{\partial r} &= h[T_R - T(r, z, t)] \quad \text{at} \quad r = a \\ k\frac{\partial T}{\partial r} &= h[T_R - T(r, z, t)] \quad \text{at} \quad z = L \end{aligned} \tag{11}$$

where T_R is the retort temperature constant or varying with time at come up time or VRT processing, h is the over-heat transfer coefficient, a is the radius of the can, and L is half of the can height. Eq. (9), the Dirichlet condition, is used at the can surface for the heating medium, pure steam; Eqs. (10), the Neumann conditions, is used at the can center axes of radius and height; Eqs. (11), the Robbins conditions, are used at the can surface but for the heating medium not pure steam.

Solutions of the governing partial differential equations. There are two ways to solve the governing partial differential equations: analytical and numerical. Taking Eq. (5) (a cylindrical can) as an example, solutions are described as

1. *Analytical method*. This, called classical method, was first used for solving the differential equations of heat conduction. The solutions for temperature ratios (U) under transient conditions in an infinite slab and infinite cylinder with uniform initial temperature and finite convective surface heat transfer, when plunged into a constant-temperature medium, were obtained by Carslaw and Jaeger (11). Equations were for an infinite slab or plate,

$$U = \frac{T_R - T}{T_R - T_0} = \sum_{n=1}^{\infty} \frac{2 \sin \beta_n}{\beta_n + \sin \beta_n \cos \beta_n} \cos\left(\frac{\beta_n x}{L}\right) \exp\left(-{\beta_n}^2 \frac{\alpha t}{L^2}\right) \tag{12}$$

where β_n is the nth positive root of

$$\beta \tan \beta = Bi \tag{13}$$

where Bi is the Biot number, and for an infinite cylinder,

$$U = 2Bi \sum_{n=1}^{\infty} \frac{J_0(\gamma_n r/a)}{(Bi^2 + {\gamma_n}^2) J_0(\gamma_n)} \exp\left(-\gamma_n \frac{\alpha t}{a^2}\right) \tag{14}$$

Where γ_n is the nth positive root of

$$\gamma J_0(\gamma) = Bi\ J_0(\gamma) \tag{15}$$

For sufficiently large values of t ($\alpha t/L^2$ or $\alpha t/a^2 > 0.2$), all terms in (12) and (14) except the first will vanish. Further, at the center of a cylinder or slab, $x = r = 0$. Imposing these conditions, Eqs. (12) and (14) are then simplified for an infinite slab or plate to

$$U_{\text{op}} = R_{\text{p}} \exp\left(-S_{\text{p}} \frac{\alpha t}{L^2}\right) \tag{16}$$

and for an infinite cylinder,

$$U_{\text{oc}} = R_{\text{c}} \exp\left(-S_{\text{c}} \frac{\alpha t}{a^2}\right) \tag{17}$$

where R_{p}, R_{c}, S_{p}, and S_{c} are characteristic functions of Biot number as given below:

$$R_{\text{p}} = \frac{2 \sin \beta_1}{\beta + \sin \beta_1 \cos \beta_1} \tag{18}$$

$$S_{\text{p}} = {\beta_1}^2 \tag{19}$$

$$R_{\text{c}} = \frac{2Bi}{(Bi^2 + \gamma_1^2) J_0(\gamma_1)} \tag{20}$$

$$S_{\text{c}} = \gamma_1^2 \tag{21}$$

Ramaswamy et al. (12) developed simple equations to predict R and S values from the Biot number for an infinite slab or plate,

$$R_{\text{p}} = 0.1138 \arctan(Bi) + 0.1111 \arctan\left(\frac{Bi}{3}\right) - 0.05142 \arctan\left(\frac{Bi}{7}\right) + 1.0016 \tag{22}$$

$$S_{\text{p}} = 2.0738 \frac{Bi}{(Bi + 2)} + 0.2795 \arctan\left(\frac{Bi}{3}\right) - 0.02915 \arctan(5Bi) + 0.001171 \tag{23}$$

and for an infinite cylinder,

$$R_{\text{c}} = 0.4411 \arctan\left(\frac{Bi}{2}\right) + 0.007242 \arctan(11Bi) - 0.1021Bi(Bi + 11) + 0.9984 \tag{24}$$

$$S_{\text{c}} = 4.1093 \frac{Bi}{(Bi + 2)} + 1.2365 \arctan\left(\frac{Bi}{3}\right) - 0.1641 \arctan(2Bi) - 0.007762 \tag{25}$$

Some values of characteristic R and S functions at low and high Biot numbers are listed in Table 1.

The temperature at any other location can be conveniently obtained from the center temperature. The unsteady temperature ratio at any given location for an infinite slab (U_{xp}) and infinite cylinder (U_{rc}) can be obtained from

$$U_{\text{xp}} = U_{\text{op}} \cos\left({S_{\text{p}}}^{1/2} \frac{x}{L}\right) \tag{26}$$

$$U_{\text{rc}} = U_{\text{oc}} J_0\left({S_{\text{c}}}^{1/2} \frac{r}{a}\right) \tag{27}$$

Table 1 Some Properties of R and S Functions at Low and High Biot Numbers

	Infinite slab		Infinite cylinder	
Biot number	R_p	S_p	R_c	S_c
0.02	1.003	0.020	1.005	0.040
50.0	1.273	2.372	1.600	5.557
Infinite	1.273	2.467	1.602	5.783

where the Bessel functions of zero order (J_0) can be calculated by

$$J_0(z) = 1 + \sum_{n=1}^{\infty} \frac{(-1)^n z^{2n}}{2^{2n}(n!)^2} \tag{28}$$

Some finite objects may be considered to be formed as the intersections of two or more infinite objects. A finite cylinder, for example, may be thought of as being formed from the intersection of a finite slab with an infinite cylinder. Temperature ratios at the centers of a finite cylinder can be obtained from

$$U_{ofc} = U_{op} U_{oc} \tag{29}$$

and at any given location other than the center

$$U_{rx} = U_{xp} U_{rc} \tag{30}$$

In most thermal processing applications, the heating behavior is characterized by a heating rate index, f, and a lag factor, j. Representing f and j by the following expressions, the equation for the temperature distribution in the cylinder can be written as

$$U = j \exp\left(-\frac{2.303}{f} t\right) \tag{31}$$

$$f = \frac{2.303}{(S_p/L^2 + S_c/a^2)\alpha} \tag{32}$$

$$j = R_p R_c \tag{33}$$

2. *Numerical solutions*. Many of the mathematical models for heat transfer into cylindrical containers have complex boundary conditions that do not permit simple analytical solutions to be obtained in a form that can easily be manipulated. Consequently, numerical methods have been developed, and they are now extensively used because of their suitability for modern computing (10). Numerical techniques used for solving partial differential equations include the finite difference method and the finite element method. The former is suitable for the case of regular shape and constant thermophysical properties and the latter for more complex cases. For the present case, the finite difference method was chosen to solve the differential equations for obtaining the temperature distribution, on the assumption that the can shapes are regular such as cylindrical or rectangular and the food thermal properties remain constant during heating.

The finite difference method consists of four steps. The first step is to take a section from a can or a particulate and divide it into a number of nodes dependent on the size and time interval. The second step is to replace the derivatives with the difference quotients. The third step is to give the initial and boundary conditions. The final step is to use an iteration method to calculate the

temperature at different times and locations. Taking the cylindrical can for example, one fourth of a vertical cross section is divided into $n*n$ elements as shown in Fig. 2. There are two methods, explicit and implicit, for solving the partial differential equations. Using the explicit method, Eq. (5) can be written in finite difference form as

$$\begin{aligned} T_{(i,j,k+1)} = T_{(i,j,k)} &+ \frac{\alpha\Delta t}{\Delta r^2}[T_{(i-1,j,k)} - 2T_{(i,j,k)} + T_{(i+1,j,k)}] \\ &+ \frac{\alpha\Delta t}{2r\Delta r}[T_{(i-1,j,k)} - T_{(i+1,j,k)}] \\ &+ \frac{\alpha\Delta t}{\Delta z^2}[T_{(i,j-1,k)} - 2T_{(i,j,k)} + T_{(i,j+1,k)}] \end{aligned} \tag{34}$$

where subscripts i, j, k represent the step in radius, height, and time, respectively.

Two important aspects of this solution method are the convergence and the stability criteria. Convergence implies that the finite difference solution will reduce to the exact solution when the size increments are infinitesimally small. Stability implies that the errors associated with the use of increments of finite size, round-off errors, and numerical mistakes will not increase as the calculations proceed. The convergence condition for the explicit method is

$$\Delta t \leq \frac{1}{2\alpha}\left(\frac{\Delta r^2 \Delta z^2}{\Delta r^2 + \Delta x^2}\right) \tag{35}$$

Comparatively, using the implicit method, the basic equation is given by

$$\begin{aligned} T_{(i,j,k+1)} = T_{(i,j,k)} &+ \frac{\alpha\Delta t}{\Delta r^2}[T_{(i-1,j,k+1)} - 2T_{(i,j,k+1)} + T_{(i+1,j),k+1)}] \\ &+ \frac{\alpha\Delta t}{2r\Delta r}[T_{(i-1,J,k+1)} - T_{(i+1,j,k+1)}] \\ &+ \frac{\alpha\Delta t}{\Delta z^2}[T_{(i,j-1,k+1)} - 2T_{(i,j,k+1)} + T_{(i,j+1,k+1)}] \end{aligned} \tag{36}$$

Theoretically, the solution of the implicit method is unconditionally stable, but this method results in three unknown temperatures, as shown in Eq. (36), and $m*n$ equations, where m and n

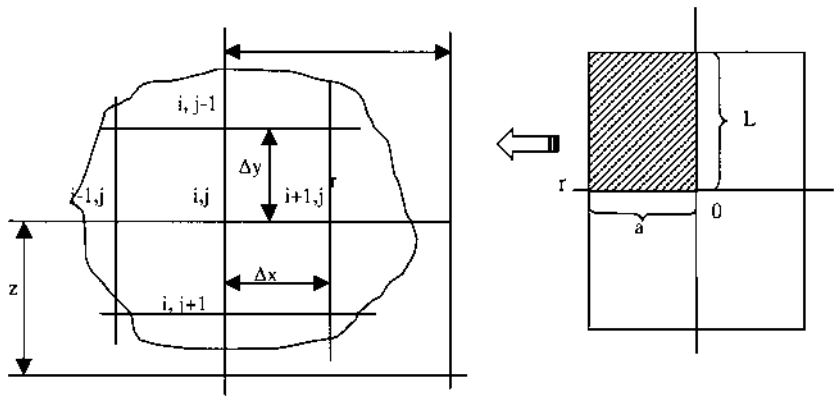

Figure 2 Labeling of grid nodes on a vertical plane of the can.

are the number of nodes for the radius and half of the height of the can. The nodal temperatures are obtained by simultaneous solution of the equations. Thus the implicit method will take much more computing time than the explicit method.

Both the explicit and the implicit method have been used to model the heat penetration for the canned thermal processing (4,13).

2. Convection

Convection heat transfer inside containers results either from the natural effects of changes in density in the liquid induced by changes in temperature at the container walls (free or natural convection) or by creating motion in the container contents by axial or end-over-end rotation (forced convection). There are three approaches developed for the prediction of temperatures in the heating of canned foods by convection: the energy balance model, the effective thermal diffusivity model, and the transportation equation model. The energy model is the simplest of the models, in which a bulk mean temperature (T_s) of the fluid and the overall heat transfer (h) were used. The basic equation for the temperature in the fluid core is

$$\frac{T_R - T_s}{T_R - T_i} = 10^{-\frac{hA}{2.303\rho cV}t} \tag{37}$$

where h is the overall transfer coefficient, A is the area of the can surface, c is the specific heat, V is the volume of can, and ρ is the density of the foods.

Comparing Eq. (37) with the heat penetration equation in the same form, we have

$$\frac{T_R - T}{T_R - T_i} = j * 10^{-\frac{1}{f}t} \tag{38}$$

Therefore

$$f = \frac{2.303\rho cV}{hA} \qquad \text{and} \qquad j = 1 \tag{39}$$

It should be noted that this equation was derived assuming that the system complies with Newton's law of heating/cooling. Convection heating under these ideal conditions implies that at time zero a step change in the heating medium temperature occurs with an instantaneous surface response to the new temperature. Under ideal conditions, there will be no temperature gradients inside the body. These conditions occur only in a unit of infinitely small volume. The associated Biot number will be very small ($Bi < 0.1$).

B. Kinetics and Thermal Processing

1. Basic Equations

The kinetics changes in thermal processing, including microbial inactivation, enzyme inactivation, and the degradation of quality factors, is mostly widely described by the general equation

$$\frac{dC}{dt} = -k(C)^n \tag{40}$$

where k is the rate constant; c is the concentration of a reacting species at any time t; n is the order of reaction. For the majority of foods, the time dependence relationships appear to be described by

zero- or first-order models (14). By integrating Eq. (40), we can have zero-order (Eq. 41), first-order (Eq. 42) and fractional conversion (Eq. 43) kinetic models as follows:

$$C = C_0 + kt \tag{41}$$

$$C = C_0 \exp(-kt) \tag{42}$$

$$\frac{C - C_f}{C_0 - C_f} = \exp(-kt) \tag{43}$$

where C_0 and C_f represent the initial and final equilibrium value of the quality factor C. In addition, the logistic model is one of the important kinetic models. As a special case of logistic model, we can write

$$C = U_0 + \frac{U}{1 + \exp(-k(t - t_0))} \tag{44}$$

where U_0 is a constant value related to the initial C value, U is a constant value related to the final C equilibrium value, and t_0 is the time constant value when the C value increases (decreases) to half of U.

2. Decimal Destruction Time (*D* value)

Numerous evidences suggest that the thermal destruction of microorganisms and quality factors follow a first-order reaction indicating a logarithmic order of death. In other words, the logarithm of the surviving number of microorganisms following a heat treatment at a particular temperature plotted against heating time will give a straight line curve (Fig. 3). These curves are commonly called survivor curves. The destruction rate is defined as a decimal reduction time (D value), which is the heating time in minutes at a given temperature required to result in one decimal reduction in the surviving microbial population or the concentration of quality factors. In other words, the D value represents a heating time that results in 90% destruction of the reactant concentration. Graphically, this represents the time range between which the survival curve passes

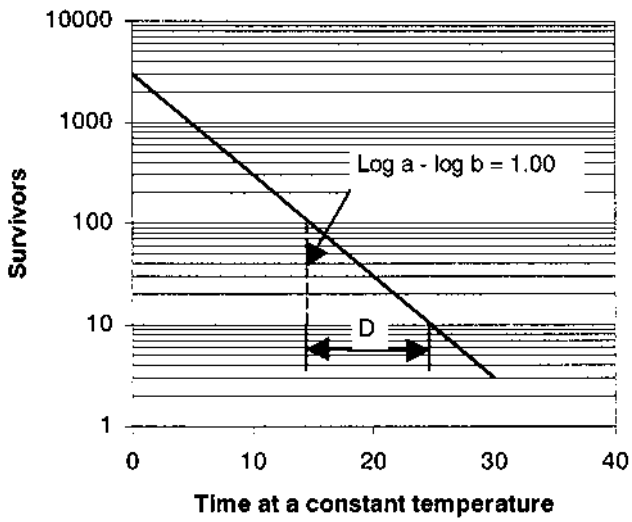

Figure 3 A typical survivor curve.

through one logarithmic cycle (Fig. 3). Mathematically,

$$D = \frac{(t_2 - t_1)}{\log(a) - \log(b)} \tag{45}$$

where a and b represent the survivors following heating for t_1 and t_2 min, respectively.

The logarithmic nature of the survivor or destruction curve indicates that complete destruction of microbial population is not a theoretical possibility, because a decimal fraction of the population should remain even after an infinite number of D values. In practice, calculated fractional survivors are treated by a probability approach; for example, a surviving population of 10^{-8}/unit would indicate one survivor in 10^8 units.

In food microbiology, another term is often employed: thermal death time (TDT), which is the heating time required to cause microbial death or destruction. TDT data are obtained by subjecting a microbial population to a series of heat treatments at a given temperature and testing for survivors. The TDT represents a time between the shortest destruction and the longest survival times. The death in this instance generally indicates the failure of a given microbial population, after the heat treatment, to show a positive growth in the subculture media. If TDT is measured with reference to a standard initial load or load reduction, it represents a multiple of the D value. For example, if TDT represented the time to reduce the population from 10^{12} to 10^0, then TDT is a measure of 12 D values.

It should be noted that there are several causes for deviation in the logarithmic behavior of the survivor curve. The first deviation is observed as a lag during the start of the heating period, whereas the second is represented by the tailing of the survivor curve at the end of the holding period and the commencement of the cooling process. The presence of a shoulder on the survivor curve of a spore-forming microorganism is attributed to the nature of the spore germination. A detailed discussion of several factors causing apparent deviations of the logarithmic order of microbial death has been provided (15), showing typical survivor curves for each situation: (a) heat activation for spore germination, (b) mixed flora, (c) clumped cells, (d) flocculation during heating, (e) the nature of the subculture medium, and (f) anaerobiosis. The various factors that influence the thermal resistance of bacteria are also summarized (15): conditions present during sporulation (temperature, ionic environment, organic compounds, lipids, age, or phase of growth) and conditions present during heat treatment (pH and buffer components, ionic environment, water activity, and composition of the medium).

3. Temperature Dependence (z value)

The D value depends strongly on the temperature employed. Higher temperatures obviously result in smaller D values. There are two types representing the relationship between the D value and the temperature: (a) the thermal death time method and (b) the Arrhenius kinetic method.

Thermal death time method (D–z model). The temperature sensitivity of D values at various temperatures is normally expressed as a thermal resistance curve with log D values plotted against temperature (Fig. 4). The temperature sensitivity indicator is defined as a z value, which represents a temperature range that results in a 10-fold change in D values, or graphically it represents the temperature range through which the D value curve passes through one logarithmic cycle. Mathematically,

$$z = \frac{(T_2 - T_1)}{\log(D_1) - \log(D_2)} \tag{46}$$

where D_1 and D_2 are the D values at T_1 and T_2, respectively. The D value at any given temperature can be obtained from a modified form of the above equation using a reference D value (D_0 at a

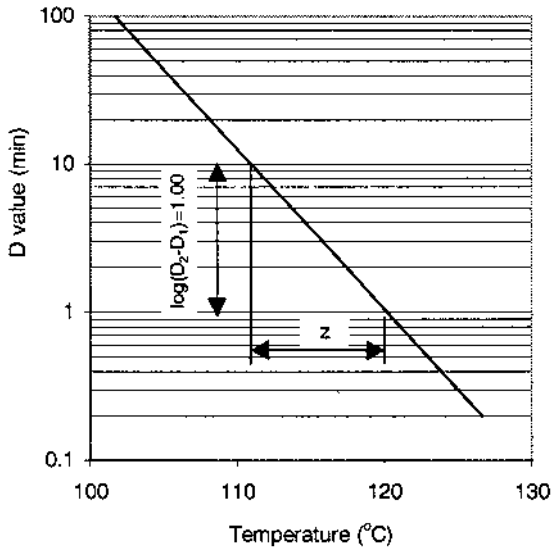

Figure 4 A typical thermal resistance curve.

reference temperature, T_r, usually 121°C for thermal sterilization):

$$D = D_0\, 10^{(T_r - T)/z} \tag{47}$$

Arrhenius kinetic method (k–E model). One of the most important approaches to modeling the effect of temperature T (in kelvins) on the specific reaction rate k (s^{-1}) was produced by Arrhenius (1889) as

$$k = A \exp\left(\frac{-Ea}{RT}\right) \tag{48}$$

or

$$k = \exp\left(\frac{-Ea}{R}\right)\left(\frac{1}{T_{\text{ref}}} - \frac{1}{T}\right) \tag{49}$$

where A is a frequency factor (s^{-1}), Ea is the activation energy ($kJ\,mol^{-1}$), and R is the molar gas constant ($8.135\,J\,mol^{-1}K^{-1}$). T and T_{ref} are the temperature and reference temperature (K), respectively.

The following relationship between Ea and z is useful and works well within the range of temperatures used for kinetic data gathering, but it can lead to large errors if used outside the range (16):

$$Ea = 2.303RT_{\text{ref}}\frac{T}{z} \tag{50}$$

C. Lethality Concept

Lethality (F value) is a measure of the heat treatment or sterilization processes. To compare the relative sterilizing capacities of heat processes, a unit of lethality needs to be established. For convenience, this is defined as an equivalent heating of 1 min at a reference temperature, which is usually taken to be 121°C for the sterilization processes. Thus the F value would represent a

certain multiple or fraction of the D value, depending on the type of the microorganism; therefore a relationship like Eq. (4) also holds good with reference to the F value:

$$F = F_0 10^{(T_r - T)/z} \tag{51}$$

The F_0 in this case will be the F value at the reference temperature (T_r). A reference (or phantom) TDT curve is defined as a curve parallel to the real TDT or thermal resistance curve (i.e., having the same z value) and having a TDT (F value) of 1 min at 121°C. With a phantom TDT curve so defined, it will be possible to express the lethal effects of any time–temperature combination in terms of equivalent minutes at 121°C or lethality or

$$F_0 = F 10^{(T - T_r)/z} \tag{52}$$

Thus an F value of 10 min at 115°C is equivalent to an F_0 of 2.78 min while the same F value at 125°C is equivalent to an F_0 of 27.8 min when $z = 10$°C. In these situations, it is assumed that heating to the appropriate temperature and the subsequent cooling are instantaneous. For real processes, where the food passes through a time–temperature profile, it should be possible to use this concept to integrate the lethal effects through the various time–temperature combinations. The combined lethality so obtained for a process is called process lethality and is also represented by the symbol F_0. Furthermore, with reference to the processing situation, the lethality can be expressed as related to a specific location (normally thermal center) or any other arbitrarily chosen location or the integrated over the container. From the microbiological safety point of view, the assurance of a minimal lethality at the thermal center is of utmost importance, while from a quality standpoint it is desirable to minimize the overall destruction throughout the container.

The criteria for the adequacy of a process must be based on two microbiological considerations: (a) destruction of the microbial population of public health significance and (b) reduction in the number of spoilage-causing bacteria. For low-acid foods, the microorganism of public health significance is *C. botulinum*, and hence destruction of the spores of this organism is used as the minimal criterion for processing. Once again, it has been arbitrarily established that the minimum process should be severe enough to reduce the population of *C. botulinum* through 12 decimal reductions. Based on published information, a decimal reduction time of 0.21 min at 121°C (15) is normally assumed for *C. botulinum*. A 12-decimal reduction would thus be equivalent to an F_0 value of $12 - 0.21 = 2.52$ min. The minimal process lethality (F_0) required is therefore 2.52 min. Several low-acid foods are processed beyond the minimum value. An F_0 value of 5 min is perhaps more common for these foods. The reason for this is the occurrence of more heat-resistant spoilage-type microorganisms that are not of public health concern. The average D_0 for these spoilage microorganisms is about 1 min. An F_0 value of 5 min would only be adequate to achieve a *5D* process with reference to these spoilage microorganisms. It is therefore essential to control the raw material quality to keep the initial count of these organisms below 100 per container on an average, if the spoilage rate were to be kept below one can in a thousand (10^2 to $10^{-3} = 5D$).

D. Process Calculations

1. General Method

The general method devised by Bigelow et al. (1) is the simplest and most accurate of all methods, involving graphical or numerical integration of the Eq. (53):

$$F = \int_0^t 10^{\frac{T - T_r}{z}} dt \tag{53}$$

The lethal effects at the different time–temperature combinations in a thermal process are integrated so as to account for the total accumulated lethality, since each temperature is considered to have a sterilizing value. Thermal destruction curves are obtained by plotting the time required to destroy the microbial population against the heating temperature. From the thermal destruction curve it is possible to obtain a lethal rate value for any temperature during the entire process. Process time calculation is based on the formula

$$\frac{F_T}{F_{T_r}} = 10^{(T_r - T)/z} = TDT \tag{54}$$

The term $10^{(T_r - T)/z}$ or TDT is equivalent to the thermal death time of 1 min at the reference temperature T_r. However, to determine the lethal effect at any temperature T the reciprocal of Eq. (54) is used:

$$\frac{1}{TDT} = \frac{1}{10^{(T_r - T)/z}} = 10^{(T_r - T)/z} \tag{55}$$

The lethality rate ($1/TDT$) is then used in a graphical integration procedure to compute thermal process times (17). The precision of this method is mainly dependent on how accurate the temperature measurements are as well as the time intervals for these measurements. This method is known as the improved general method since it is accurate and does not rely on assumptions about the heat penetration, but it is laborious (9,15,17).

2. Some Formula Methods

In order to estimate the process time or accumulated lethality under a given processing condition easily and faster, several formula methods (Ball, Stumbo, Pham, etc.) have been developed since the 1920s.

The Ball method is the simplest and most widely used technique for process calculations. It is based on the following equations derived from the heat penetration curve to estimate the process time, B (min):

$$\begin{aligned} B &= f_h \log\left(j_h \frac{I_h}{g_c}\right) \\ I_h &= T_R - T_i \\ g_c &= T_R - T \\ j_h &= \frac{T_R - T_{pih}}{T_R - T_{ih}} \end{aligned} \tag{56}$$

where T_R is the retort temperature, T_{ih} is the initial product temperature, T_{pih} is the pseudo-initial product temperature, f_h is the heating index, j_h is the heating lag factor, and I_h and g_c are the initial and final temperature differences (at the end of cooking), respectively. The determination of g_c is the key to estimate the process time using Eq. (56). Ball found and developed the relationship between f_h/U and g in the form of a table as well as in figure format, which greatly increases their

usefulness and ease of application; U is numerically equivalent to

$$U = F_0 F_i \tag{57}$$

$$F_i = 10^{(121.1 - T_R)/z}$$

where F_0 is the desired process lethality and F_i is the number of minutes at the retort temperature equivalent to 1 minute at 121.1°C.

In deriving the above relationship between g and f_h/U, Ball gave some assumptions as follows: $f_h = f_c$, $j_c = 1.41$, $z = 10$°C, and the cooling curve is initially hyperbolic followed by logarithmic. These assumptions became limitations to the use of Ball method.

In order to overcome these limitations of Ball method, Stumbo and Longley (18) published limited tables (z of 12 to 22) of $f_h/U : g$ that accounted for variations in the j value of cooling curves. Relationships for these tables were arrived at manually using the general method of integration. Later, Jen et al. (19) presented representative tables of $f_h/U : g$, the values which were

Table 2 Process Calculation by the General Method

Time (min)	Temperature (°C)	$L = 10(T - T_r)/z$	$L^*\Delta t$	$\sum L^*\Delta t$
0	16.4	0.000	0.000	0.000
2	17.5	0.000	0.000	0.000
4	21.4	0.000	0.000	0.000
6	29.2	0.000	0.000	0.000
8	36.9	0.000	0.000	0.000
10	46.4	0.000	0.000	0.000
12	56.4	0.000	0.000	0.000
14	68.1	0.000	0.000	0.000
16	76.9	0.000	0.000	0.000
18	86.4	0.000	0.001	0.001
20	94.2	0.002	0.004	0.005
22	103.6	0.018	0.036	0.040
24	110.0	0.077	0.155	0.195
26	113.6	0.178	0.356	0.551
28	116.1	0.316	0.632	1.183
30	118.1	0.495	0.990	2.173
32	119.2	0.639	1.278	3.451
34	119.7	0.726	1.453	4.904
36	120.0	0.774	1.549	6.452
38	120.3	0.825	1.651	8.103
40	120.8	0.938	1.876	9.979
42	121.1	1.000	2.000	11.979
44	121.1	1.000	2.000	13.979
46	118.6	0.562	1.125	15.104
48	110.3	0.083	0.165	15.269
50	96.4	0.003	0.007	15.276
52	82.5	0.000	0.000	15.276
54	69.2	0.000	0.000	15.276
56	58.1	0.000	0.000	15.276
58	46.9	0.000	0.000	15.276

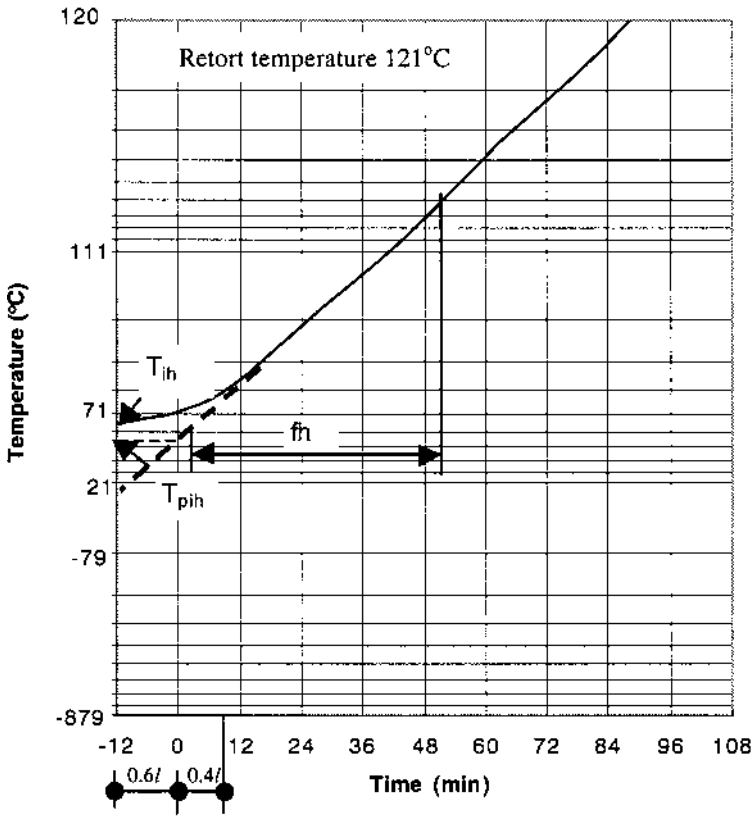

Figure 5 Semilogarithmic plot of a heating curve.

obtained by the computerized finite difference method of Teixeira et al. (4). Purohit and Stumbo (20) refined the method of Jen et al. (19) and developed separate tables (57) covering the z values from 8°F to 200°F, which make it possible for the Stumbo method to be used for the destruction of different microorganisms such as bacterial spores, vegetative cells, and nutrients.

Pham (21) developed two sets of simple algebraic equations and simplified tables for thermal process calculations, one for $U/f_h > 1$ and the other for $U/f_h < 1$. Pham (1987) claimed that his method provides values at least as accurate as Stumbo's and is more versatile because his one table substitutes for the 57 tables published by Stumbo. Pham (22) amended his equations to cover situations in which the heating and cooling rates differ, i.e. $f_h \neq f_c$.

3. Methodology of Process Calculation for Sterilization of Vegetables

Canned vegetables belong to the low-acid foods (pH value > 5.0), for which the minimum process required is $F_0 = 2.52$ min, which is often referred to as a "botulinum cook". Frequently, based on the presence of other heat-resistant micro-organisms, a process lethality of 5–10 min is usually adapted. The process calculation can be performed using either the general or the formula method as discussed above. A typical calculation using numerical integration techniques is shown in Table 2.

The formula method may also be employed using one of two approaches. The first approach is based on the criterion of achieving a certain minimal center point temperature in the product, for

Table 3 Process Time Calculation Using Ball Method

1	f_h	30 min
2	j_{ch}	1.2
3	Retort temperature (T_r)	121°C
4	Initial temperature (T_i)	21°C
5	$I_h = T_r - T_i$	100°C
6	$j_{ch}I_h$	120°C
7	log ($j_{ch}I_h$)	2.33
8	Target temperature (T_c)	111°C
9	$g = T_r - T_c$	10°C
10	log(g)	1.0
11	$B = f_h$*log($j_{ch}I_h$) − log(g)	68.9 min

example, 111°C. Using the heat penetration parameters and the above criterion, the process time can easily be calculated using Ball's formula:

$$B = f_h(\log j_{ch}I_h - \log g_c) \tag{58}$$

The parameters f_h and j_{ch} are obtained from the heat penetration data (Fig. 5), and T_{ih} and T_r are known. The value for g_c is also known because $g_c = T_r - 111$ (using the above criterion). A sample calculation is shown in Table 3.

The other approach in using the formula method is based on Ball or Stumbo tables with a reference temperature of 250°F and a z value of 18°F. Typical examples of process calculations using Stumbo's formula method (1) for calculating process times when the required process lethality is known and (2) for calculating process lethality when the process time is known are shown in Tables 4 and 5.

Table 4 Calculation of Process Time Using Stumbo Method

1	j_{ch}	1.30
2	f_h	12.9 min
3	Process lethality (F_0)	5 min
4	Retort temperature (T_r)	121°C
5	Initial temperature (T_i)	60°C
6	$I_h = T_r - T_i$	61°C
7	j_{ch}*I_h	79.3
8	log (j_{ch}*I_h)	1.9
9	z	10°C
10	$F_i = 10^{(121-T-)/z}$	1.0
11	$f_h/U = f_h/(F_0$*$F_i)$	2.58
12	j_{cc}	1.6
	From Stumbo's table for z = 10°C (j_{cc} = 1.8)	
	Obtain g value by interpolation	
	f_h/U g value	
	2.0 2.34	
	3.0 3.89	
	Interpolate	
	2.58 3.23	
13	$B = f_h$ [log (j_{ch} I_h/g)]	17.9 min

Table 5 Calculation of Process Lethality Using Stumbo Method

1	j_{ch}	1.30
2	f_h	12.9 min
3	Process time B	17.9 min
4	Retort temperature (T_r)	121°C
5	Initial temperature (T_i)	60°C
6	$I_h = T_r - Ti$	61°C
7	$j_{ch}{}^*I_h$	79.3
8	log ($j_{ch}{}^*I_h$)	1.9
9	z	10°C
10	$F_i = 10^{(180-T_r)}/z$	1.0
11	B/f_h	1.39
12	log (g) = log ($j_{ch}{}^*I_h$) − B/f_h	0.51
13	g	3.23
14	j_{cc}	1.6
	From Stumbo's table for $z = 18$°F ($j_{cc} = 1.8$)	
	Obtain f_h/U value by interpolation	
	f_h/U g value	
	2 2.34	
	3 3.89	
	Interpolate	
	2.58 3.23	
15	$F_0 = f_h/[(f_h/U)^*F]$	5.0 min

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5

Canned Chinese Bamboo Shoots, Water Chestnuts, Mushrooms, and Imitation Vegetarian Products

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I. CANNED CHINESE BAMBOO SHOOTS

A. Raw Materials

Young stems of bambusa, a perennial Gramineae, are called bamboo shoots. *Bambusa oldhamii, Phyllostachys makinoi, Phyllostachys pubescens, Phyllostachys pubescens* (in winter), *Bambusa edulis*, and *Dendrocalamus latiflorus* (Fig. 1) are the six principal species used in our diet (1). As a food material, bamboo shoots have many merits: they are abundant in vitamins A, B_1, B_2, and C (2), are low in calories, contain crude fiber valuable for digestion, have crisp texture, are covered with several layers of hulls to prevent pesticide contamination, and retain a good taste after processing. Bamboo shoots can be processed to obtain canned, refrigerated, dried, salted, or cured products. Canned products may be in tinplate cans or retort pouches. Tinplate cans contain processed fresh materials; retort pouches contain processed salted or cured materials. Most tinplate can products are used for cooking, and the pouch products are ready to eat.

It is necessary to choose the right materials for suitable products. This means paying attention to bamboo shoot quality, which in turn depends on soil, climate, and culturing techniques. Quality aspects for canned-product raw materials to be considered include size, freshness, tenderness, and shape (3). Excellent shoot materials are generally thick in the fleshy portion and short between knobs, have almost no crook, and look similar to a cannonball or hanging bell in shape. Length is also important: with regard to *Dendrocalamus latifloxus*, 2.5 times the length from base to tip of the base diameter is required for manufacturing good products. Bamboo shoots with stale fiber, worm disease, scratch marks, or knife injury, whether from harvesting or from tip cut (see dehulling below), should be rejected as canning materials, though they may be acceptable for salting or curing.

B. Processing Procedures

Canned bamboo shoots are usually processed as shown in Fig. 2. Described below are crucial steps and key points to be heeded to obtain good quality products (3,4).

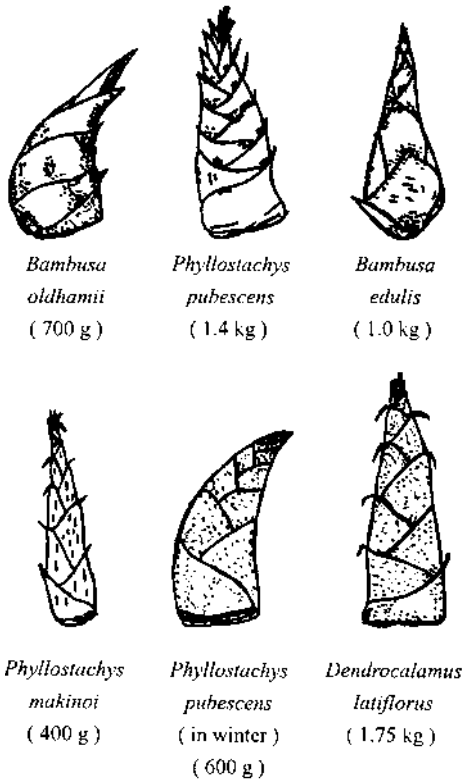


Figure 1 Bamboo shoots.

1. Boiling

The raw bamboo shoots are put in stainless tanks. A large volume of water is added and steam is introduced for boiling. Boiling specifications depend on the size and texture of the shoots: either continuous boiling at 100°C for 4 hours (by far the most common method) or at 120° for 40–60 minutes is necessary. To prevent damage to the shoot bodies, strong metal cages with open-and-close bottoms are used. The cages are easily hung up with chain pulleys while the boiling water is drained from the tanks.

2. Cooling and Floating

Cool water is flushed into the tanks; the boiled shoots float and their centers cool rapidly. About 10–20 hours are required to complete this step. Insufficient cooling will result in bacterial growth and pH decline, turning the shoots from white-yellow to pink-brown. Floating the shoots too long, however, will likely also degrade color, flavor, and nutrition. In addition to making dehulling and cutting easy, cooling and floating also remove tyrosine, a compound contained in bamboo shoots that would otherwise cause juice turbidity in finished canned products.

3. Dehulling, Cutting the Base Part, and Chamfering

Hulls are outer protective layers of bamboo shoots; after cooling and floating, they should be torn off either by hand or by dehullers. Dehulling by machine is much faster, but the tip shoots are more easily injured, so the action must be done carefully. Longer shoots will also require that the

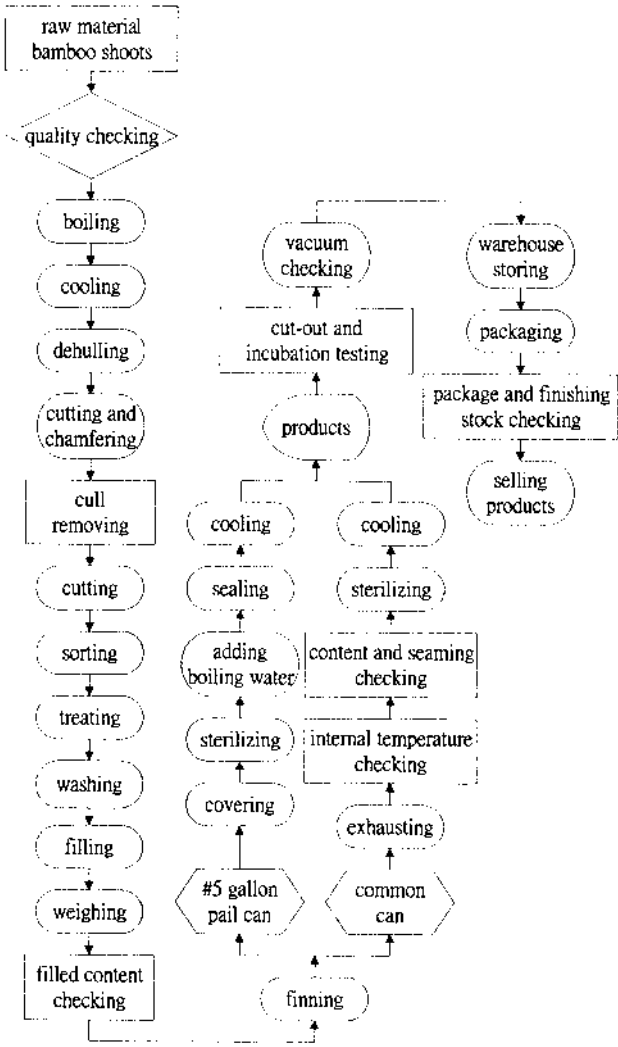


Figure 2 A flow sheet for processing of canned bamboo shoots.

bottoms of their base parts, which are not suitable for canning, be cut off. This is done manually with a knife. The cut should be done close to the bottom of the base so that no cavity appears in cross section. Chamfering follows, using a bow-shaped bamboo strip drawn with nylon line to remove the soft cuticle and remaining epidermis.

4. Sorting/Grading and Cutting

Shoots are sorted to separate out faulty shoots and are then graded according to size and length. Measuring by shoot base diameter, bamboo shoots are divided into four grades: LL, L, M, and S. The specifications of LL, L, M, and S are shown in Table 1.

The shoots are then cut eight ways (Table 2) for products of different kinds and sizes. LL grade shoots are appropriate for canned #5 gallon or style "half," and L, M, S are for style "whole" (3–5).

Table 1 Canning Size Specifications for Bamboo Shoots According to Shoot Base Diameter

Size specification (code)	Diameter of bamboo shoot base part (cm)	Length of bamboo shoot (cm)
LL	Above 13.1	16.0–26.0
L	9.1–13.0	13.5–16.5
M	7.1–9.0	10.5–13.5
S	4.0–7.0	7.5–10.5

5. Weighing and Filling

The sorted and graded bamboo shoots are then weighed and put in cans. Similar shoot size in a can is important; as a basic rule, the size of the largest shoot should not be more than two times that of the smallest. Shoots are placed in alternating directions in the can, with bases and points touching. Then water is added to complete the filling. Content and drained weights for various can sizes are shown in Table 3 (3,5). Boiling time, floating time, and shoot size, shape, and texture may all affect drained weight; these factors must always be taken into account.

6. Exhausting, Sealing and Sterilizing

The filled cans are put into an exhausting box for a specified period of time and at a specified temperature. To reach the required vacuum degree, the temperature of the shoot centers should be above 70°C (or higher, depending on the exact product) after exhausting. Sometimes, the cans are drain-covered and turned over to discard the shoot juice (removes tyrosine). The cans are then refilled with hot water (over 80°C). After exhausting, cans are sealed with automatic sealing machines. They are then sterilized in a retort, with various sterilization specifications depending on can sizes. Table 4 displays exhausting and sterilization specifications for several bamboo-shoot product can sizes (6).

7. Quality Change During Storage of Canned Bamboo Shoot Products

Two types of quality degradation during storage of canned bamboo shoot products may occur (though rarely): soft spoilage and swelling with butyric acid–like odor (6). Both types of degradation are due to microorganisms present because of either improper sterilization or faulty closure, and both types render a product inedible.

Juice turbidity may also develop during storage. Affected products remain edible but decrease greatly in value, because the resulting sediment in the can affects the appearance of the juice and may frighten consumers. Juice turbidity is caused by shoot components such as pectin, hemicellulose, starch, and most importantly tyrosine, which form colloidal compounds in presence of Ca^{2+} or other inorganic ions (6). Proper boiling, cooling and floating, and exhausting effectively remove tyrosine.

II. CANNED WATER CHESTNUTS

A. Raw Materials

Grown mostly in Japan, Taiwan, mainland China, Thailand, and Australia, water chestnuts (*Eleochris plantaginea*) are tuber vegetables that resemble chestnuts in color and shape. Their

Table 2 Style of Bamboo Shoots Cut for Canning

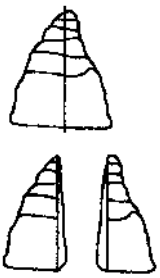
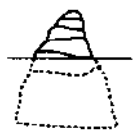
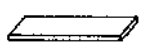
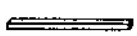
Style of cut	Appearance	Description of shoot after cut
Whole		Fleshy portion occupies whole length of shoot at over 1/4; short between knobs
Half		Whole cut lengthwise into two halves
Top or top whole		Long shoots almost without fleshy portion, 10–15 cm in length
Tip		Shoot tail part without fleshy portion, 5–10 cm in length
Lump		Shoot without tip and cut lengthwise into quarters
Sliced		Fleshy portion cut from long part of whole and cut into about 40 × 10 × 3 mm for length, width, and thickness, respectively
Strip		Fleshy portion cut from long part of whole and cut into about 60–80 × 2–4 × 2–4 mm for length, width, and thickness, respectively
Diced		Fleshy portion cut from long part of whole and cut into about 10 × 10 × 10 mm

Table 3 Contents and Drained Weights for Can Sizes of Bamboo Shoots in Taiwan, R.O.C (g)

Can size	#5 gallon	N#1	#1	#2	#3	#4	#5	Flat #2
Content	17,000	2,950	2,800	800	540	425	300	230
Drained weight	11,000	2,265	1,800	500	300	240	170	140

unique texture, interesting taste, and suitability for being cooked to varying degrees all combine to make them excellent ingredients in food dishes. Processed water chestnuts can also be eaten uncooked; simply drain the water from the can for a healthy and nutritious ready-to-eat snack. Two subspecies, red-skin and black-skin, possess a sweet and firm texture that make them suitable for canning. For both subspecies, quality is measured by size. First-grade raw materials have diameters above 32 mm when not peeled, and 25 mm once peeled. Diameters of 25–32 mm unpeeled and of 20–25 mm peeled merit the second grade, while water chestnuts below 25 mm unpeeled and 20 mm peeled are considered unacceptable for canning (3). The yield from raw materials ranges from 60 to 75%, depending mostly on size specifications: the larger the unpeeled diameters, the greater the yield. Time is also a factor: harvested raw materials should be processed within 24 hours to prevent rotting.

B. Processing Procedures

Figure 3 is a flow sheet for canning water chestnuts. Below are the crucial steps and key points to be heeded in order to obtain quality products (3,4).

1. Washing and Peeling

Water chestnuts should first be washed to remove adhering soil, which could cause bacterial contamination should it come in contact with peeled materials. Rotary washers are usually used for this step. Peeling follows; the small size of the water chestnut makes this step labor intensive. Automatic peelers have been developed but are not widely used because they too often fail to remove all bits of skin and also sometimes crush the materials. Though more time-consuming, manual peeling avoids these problems and also allows for the removal of rotten water chestnuts and those with worm disease or mottles. Once peeled, the water chestnuts are left in running water

Table 4 Exhausting and Sterilization Conditions for Bamboo Shoots by Can Size

	Exhausting			Sterilization (min)		
				Pressure process[a]		Normal
Can size	Temperature (°C)	Time (min)	Central temperature of shoots (°C)	0.2 kg/cm^2	1.2 kg/cm^2	pressure process 100°C
#1	98	30	70	80	50	100
#2	98	20	70	70	40	80
#3	98	15	80	60	35	70
#4	98	10	80	50	30	60
Flat #2	98	10	85	45	30	60
#5 Gallon	Boiling for 90–120 min					

[a] Gauge pressure.

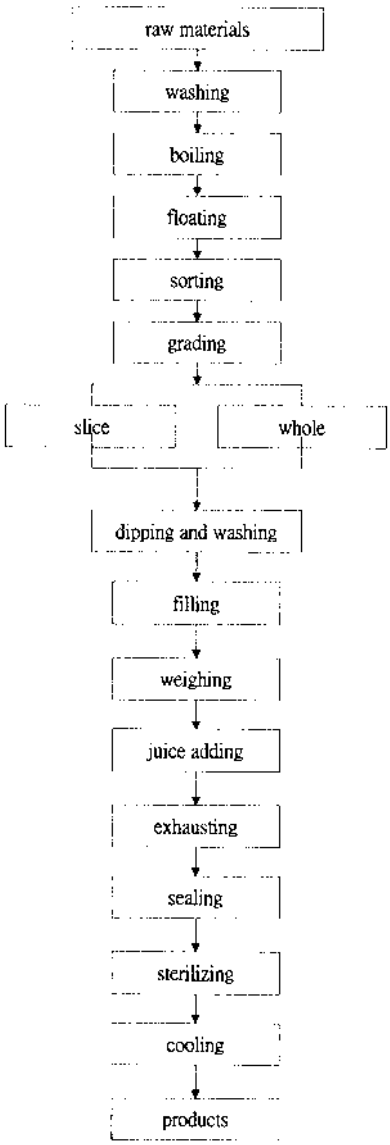


Figure 3 A flow sheet for canning water chestnuts.

for 10–16 hours. This procedure further cleans them, removes some starches, and allows for easy removal of still-adhering bits of peel.

2. Blanching and Cooling

Water chestnuts are blanched by boiling in water for 15 minutes, a step that gelatinizes and dissolves starches. The blanching water is then discarded and the water chestnuts are cooled, usually in running water for 30 minutes. If standing water is used, it must be changed several times because it tends to interact with airborne bacteria to produce acid. Care must be taken not to cool too long as this will decrease flavor.

III. CANNED MUSHROOMS

A. Raw Materials

Mushrooms are fungal fruit bodies. In addition to their use as fresh vegetables, a large quantity of mushrooms is used as raw materials for canned products. Mushrooms do not tolerate lengthy storage: they are perishable and their quality changes easily (7). Six species are cultured worldwide: common mushrooms *Agaricus brunnescens*, paddy straw mushrooms *Volvariella volvacea*, golden mushrooms *Flammulina velutipes*, forest mushrooms *Lentinus edodes*, abalone mushrooms *Pleurotus abalonus*, and oyster mushrooms *Pleurotus ostreatus*. Below are key steps involved in processing the first three species listed above, beginning with common mushrooms. Processing of the latter three species is very similar to the processing of common mushrooms.

B. Processing Procedures for Canned Common Mushrooms

Common mushrooms, in particular the white, the milky, and the brown subspecies, are widely cultivated all over the world. The white subspecies is the most widely grown and canned, owing to good color and shape (1). Common mushrooms are bed-cut or pulled up with their roots intact and must be harvested at tight-cap maturity, about twelve hours before the velum opens. To avoid color change, freshly harvested mushrooms must be transported quickly to a processing plant for heat treatment. Ideally, heat treatment should be performed within one hour after harvesting, thus yielding maximum volume and quality. Delays may occur, however; then mushrooms must be refrigerated at 2–3°C and in high humidity (RH over 90%). The specifications for common mushrooms used in can processing are given in Table 5 (3,8).

Figure 4 is a flow sheet for canning common mushrooms (3). Though most processing steps are similar to those for canned bamboo, a few are not. Below are several special steps involved in canning mushrooms.

1. Determination of Mushroom Worm Bodies

Mushrooms from some places contain worms due to culturing conditions, including fertilizer use, temperature, and sunlight. Invisible to the naked eye and detrimental neither to taste nor to health, worm bodies are not cause for import rejection except in the United States, where no more than fifteen worms per 130 g of raw common mushrooms are allowed. Procedures used for determining the number of worm bodies are as follows (9):

1. Put 130 g mushrooms in a blender along with 300 mL of water. Blend them at 3,500 rpm until the mushroom pieces are 3–5 mm in diameter.
2. Put the blended mushrooms on three overlapping sieves with a No. 20/No. 40/No. 140 top-to-bottom order of mesh.
3. Wash the blended mushroom tissues with pressurized tap water through the No. 20 sieve for two to three minutes.
4. Discard the residue remaining on the No. 20 sieve, then wash the blended mushroom tissues with pressurized tap water through the No. 40 sieve for about one minute.
5. Discard the residue remaining on the No. 40 sieve, then wash the residue remaining on the No. 140 sieve into a beaker, and add water so that the beaker's contents total 100 mL.
6. Add 5 mL of crystal violet solution (13.7 g crystal violet dissolved in 350 mL of 95% alcohol and diluted to 1,000 mL with distilled water).

Table 5 Specifications for Mushrooms Used for Canning

Grade	Diameter of pileus	Shape	Texture	Appearance	Stem
1st grade	12.7–38.1 mm	Tight-cap; no malformation, disease, insect damage, or other injuries	Fresh, firm, not withered, no cavity in internal stem	Clean; white prior to washing, without spots, and not discolored	Without hypha or soil; clean; cut surface flat; length from the end of stem to the top of pileus less than the diameter of pileus
2nd grade	Same as 1st grade	Same as 1st grade	Same as 1st grade	Clean; white, with light discoloration; water injury and/or other defects covering not over 1/3 of the pileus surface	Without hypha or soil; clean; cut surface not flat; stem a bit long
Unacceptable	1. Open velum 2. Broken or malformed pileus or stem 3. Disease or insect-damaged; serious discoloration or black spots 4. Not fresh: withering or hardening 5. With soil or compost 6. With serious water (or other) injuries 7. Have been washed or dipped in water				

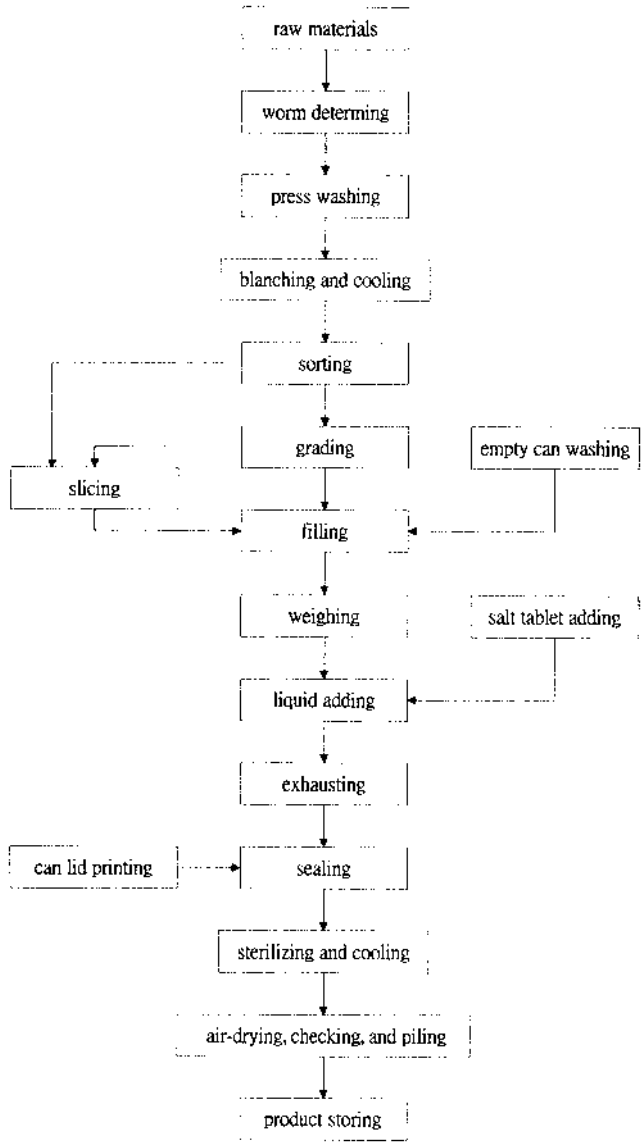


Figure 4 A flow sheet for canning common mushrooms.

7. Heat the mixture almost to boiling, thus dying the tissue; then cool to 40°C.
8. Bleach completely the tissues with a washing bottle filled with 10% bleaching solution (100 g bleaching powder dissolved in 1,000 mL distilled water). The worm bodies will remain purple and will now be apparent.
9. Put the bleached tissues with worm bodies on lined filter paper atop a Buchner funnel and perform aspirating filtration.
10. Count the number of worms under a microscope, making calculated guesses as to the number of worms from partial worm bodies.

2. Blanching

The principal purpose of blanching is to prevent enzymatic color degradation. Additionally, blanching excludes air present in mushroom tissues, thus shrinking them and permitting easier filling later. Blanching may be done with water or steam, with the choice and heat specifications depending on the size and freshness of the mushrooms. Proper specifications are 4–8 minutes in boiling water, 8–15 minutes in 85°C water, or 5–7 minutes at 96°C. Steam-blanching of mushrooms turns them slightly brown in color but retains better flavor. If whiteness is sought, 0.01–0.05% sodium sulfite may be added to water for washing (the step prior to blanching) or to the hot water if the mushrooms are to be blanched. Sodium sulfite in food, however, is prohibited in some countries for health reasons; citric acid or ascorbic acid may be used instead (3).

3. Sorting and Cutting

Once blanched, sorting is done by size with an automatic sieve separator to which a ductile material such as gum or plastic is applied to the sieve holes in order to prevent damage to the mushrooms. Figure 5 shows some operations in canning common mushrooms including the sieve separator. A typical set of size standards in Taiwan, R.O.C., is shown in Table 6 (3,8). After sorting, the mushrooms are then trimmed for various kinds of products. The style of cut chosen depends on quality factors such as tightness of cap, injury, discoloration, and stem length. Table 7 shows six styles and specifications of cutting for canned mushroom products: whole, buttons, sliced whole, sliced buttons, random sliced whole, and stems and pieces.

4. Filling

The mushrooms are put into cans along with water and a salt tablet is added; the resulting brine has a salt content of 1.5–2.0% by weight. Ascorbic acid, citric acid, and monosodium glutamate are also sometimes added to improve color and flavor.

C. Canned Paddy Straw Mushrooms

Paddy straw mushrooms were first cultured by the Chinese and are thus called Chinese mushrooms (1). Those of gray-brown color and with closed vela of a diameter between 16 and 60 mm are used for canned products. The shape and size of canned contents must be uniform, with the largest mushroom not exceeding three times the weight of the smallest one. The velum diameter is 30–45 mm for size 'L', 23–29 mm for size 'M', and 16–22 mm for size 'S'. Figure 6 is a flow sheet for paddy straw mushroom canning operations (3), and Fig. 7 shows some operations during processing.

Figure 5 Some operations in canning common mushrooms, including the sieve operator.

Table 6 Size Standards for Common Mushrooms (Taiwan Specification)

Grain shape	Diameter of velum (mm)
No. 5 (extra large; E)	41
No. 4 (large; L)	29–41
No. 3 (medium; M)	22–19
No. 2 (small; S)	16–22
No. 1 (tiny; T)	13–16
No. 0 (midget; m)	Below 13
Blend of sizes	Mix with two sizes of grains

D. Canned Golden Mushrooms

Golden mushrooms, called enokitake mushrooms in Japan, have a long stalk and a golden cap and are grown either in low temperature regions or in controlled-atmosphere conditions designed to simulate autumn (10). Their caps and stems contain polysaccharides, which help prevent tumors and provide a boost for the immune system. In Taiwan, R.O.C., most of the golden mushrooms are not processed but rather are used as dish materials for hot pots. In order to boost consumption, however, retort pouch seasoned products have also been developed and are increasingly being promoted. Figure 8 shows a flow sheet for acidified seasoned retort pouch golden mushrooms (11).

IV. IMITATION VEGETARIAN PRODUCTS

A. Imitation Products

Recently, imitation food, also called copy food, has appeared on supermarket shelves and is becoming increasingly popular (12,13). Imitation food products imitate both plant and animal products in flavor, texture, color, and even shape. They are manufactured with materials from both animal and plant sources, and their degree of similarity to the imitated product can be astonishing.

The products usually cost less and often have better nutrition than the product imitated. Some products also offer vegetarians the opportunity to enjoy a meat taste while maintaining their nonmeat diet. It is important to understand, however, that the term vegetarian is defined in different ways in different countries (see definitions below), and that imitation vegetarian products may in fact contain not only eggs or dairy materials but also seafood materials. One of the first and still most popular such products developed, for example, is crab-flavor kamaboko (imitation crab legs), which, along with soy protein (the major ingredient) and various other constituents, contains cod-surimi (to improve gelation properties), crab extract, and crab flavoring (12). Imitation vegetarian products are thus best defined as products that (a) contain vegetable materials and (b) meet one of the definitions for vegetarian food given in the next section.

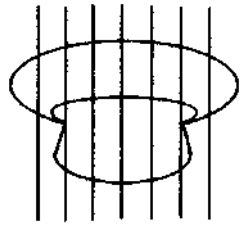
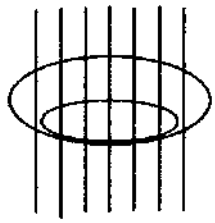
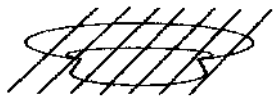
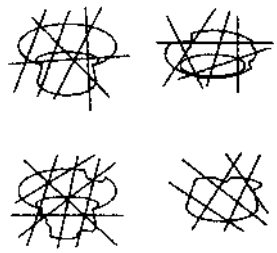
Copy (imitation) scallops, ikura (salted fish eggs of salmon or trout), dried mullet roe, and ice cream are other imitation vegetarian products which have become commercially important.

B. Vegetarian Products

1. Definition

The definition of vegetarian products varies by country, with some definitions being recognized in some countries and not in others. In total, there are six kinds of vegetarian products (14,15):

Table 7 Styles of Mushroom Products

Styles	Appearance	Specifications
Whole		Without opened velum; stem is horizontally cut and above 3.2 mm in length remaining; distance from top of velum to end of stem is not over diameter of velum
Buttons		Without open velum; stem is horizontally cut and 90% within 3.2 mm in length, 10% not over 6.4 mm
Sliced whole		Slices obtained by straightly cutting whole mushrooms along with shaft; thickness 2–8 mm; regular slices over 80% in total weight; detached and crushed stems not over 5%
Sliced buttons		Slices obtained by straightly cutting button mushrooms along with shaft; thickness 2–6 mm; regular slices over 80% in total weight; detached and crushed stems not over 5%
Random sliced whole	 	Slices obtained by random cutting from whole mushrooms; detached and crushed stems not over 15%
Stems and pieces		Irregular shape and size of stems and pieces; stems not over 40% in weight

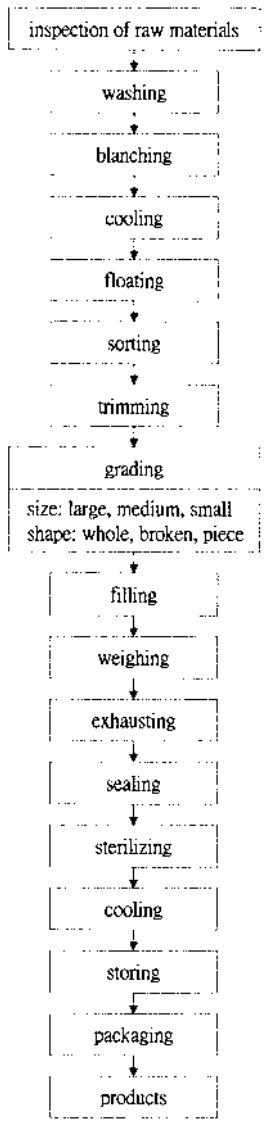


Figure 6 A flow sheet for paddy straw mushroom canning operations.

1. Pure vegetarian products: plant products free of any animal source materials, including even honey.
2. Egg vegetarian products: plant products, with eggs included.
3. Dairy vegetarian products: plant products, with dairy products included.
4. Dairy and egg vegetarian products: plant products, with eggs and dairy products included.
5. Dairy, egg, and fish vegetarian products: plant products, with fish and either/both dairy products and eggs included.
6. Religious (Buddhist) vegetarian products: most often these are pure (by definition); however, they are not permitted to contain onions, garlic, or leeks.

Figure 7 Some operations in canning paddy straw mushrooms.

2. Development and Use of Imitation Vegetarian Food

Western sour pickles and Oriental cured vegetables are recognized as the original vegetarian products. In the course of history, further products were developed to meet consumer desire for multiplicity. Thus, in rough historical order of development and use, the following became

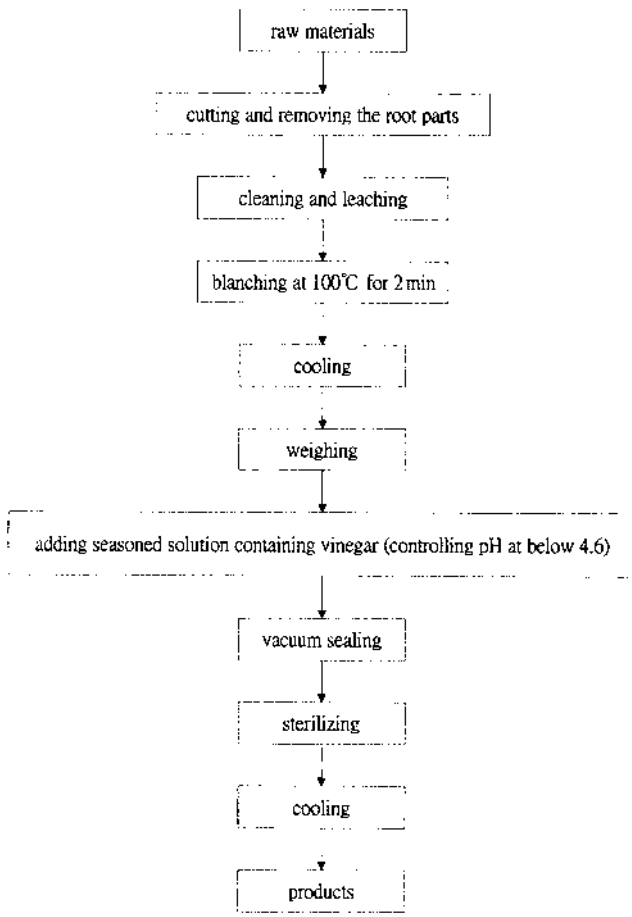


Figure 8 A flow sheet for acidified seasoned retort pouch golden mushrooms.

fundamental materials in vegetarian products: soybean products such as tofu (a coagulated curd of soybean milk), dried tofu, yuba (film-type products formed by heating soybean milk) and soybean proteins including both concentrated and isolate; wheat flour products such as gluten (a residual of wheat flour dough washed in water); mushrooms such as common mushrooms, shiitake fungus, and golden mushrooms; konjac (a powder made from the tuber elephant foot). Vegetarian products must be in balanced amounts if the nutrients necessary for optimum human health are to be obtained. Further, vegetarian materials alone can supply ample and sufficient nutrients, provided they are consumed in proper and complete enough combinations. It is necessary to consider how nutritive aspects of vegetarian food, including carbohydrates, proteins, fats, vitamins, and minerals are affected during processing (13,16).

C. Processing Procedures

As noted above, earlier imitation products—chiefly, imitation crab-flavored kamaboko, dried mullet roe, and fried scallops—used animal-source materials together with plant materials to obtain optimal flavor and texture. Imitation products that are solely made from plant sources, such as imitation filled milk, coffee whitener, cheese, ice cream, and hamburger, however, are becoming increasingly popular and important (12). Table 8 shows the raw materials used for making the above listed imitation products (including several animal source materials); Table 9 shows the functional properties of the most commonly used plant materials (12,13,15,17).

It should be noted that pure vegetable products such as bamboo shoots, water chestnuts, and mushrooms are rarely copied; imitation products would not be cheaper to produce. Similarly, pure vegetarian dishes are not copied either. Whereas such pure vegetarian products often are packaged in cans, imitation vegetarian products are not. Instead, they are packaged in vacuum-sealed plastic bags and preserved either through refrigeration or freezing; the choice and processing procedures depend on which and what combination of animal and plant proteins the product contains. Figure 9 shows a typical flow chart for processing of copy food containing soybean proteins (17).

D. Labeling of Imitation Vegetarian Food

As is the case with other foods, imitation vegetarian food is packaged with attention given to hygiene, maximizing the length of preservation, carrying convenience, and increasing commodity value through attractiveness of packaging. Many processed food items have identity specifications that must be certified by government inspectors or associations to which such authority has been delegated. Similarly, imitation vegetarian food has to be made in accordance with standard operation (processing) processes and it is recommended to put the word “imitation” on the

Table 8 Raw Materials Used for Making Imitation Products (Including Animal Source Materials)

Imitation products	Raw materials
Crab flavored kamaboko	Frozen cod surimi, starch, egg white, crab extract, crab flavor, various condiments
Hamburger steak	Texturized soybean protein, powder vegetable protein, salad oil, egg white, gelatin, bread crumbs, onion, beef extract, various condiments
Coffee whitener	Vegetable oil, protein, corn syrup, emulsifier, buffer agent, stabilizer
Cheese	Casein, vegetable proteins, whey protein, flour, starch, vegetable oil, cheese flavor, other additives
Shrimp meat	Konjac, carrot, alkali liquor

Table 9 Functional Properties of Raw Materials Frequently Used in Imitation Vegetarian Products

Raw materials	Functional properties
Soybean proteins	Solubility; gelation; viscosity and elasticity increasing; water holding capacity; oil absorptiveness; emulsification; binding capacity; whipping property
Gluten	Solubility; viscosity and elasticity increasing; binding capacity
Konjac	Water thickening; forming heat-stable gel; forming cooking resistant thin layers; interacting with carageenan, xanthan gum, and starch to improve processing quality
Starch	Viscosity and elasticity increasing; water holding capacity

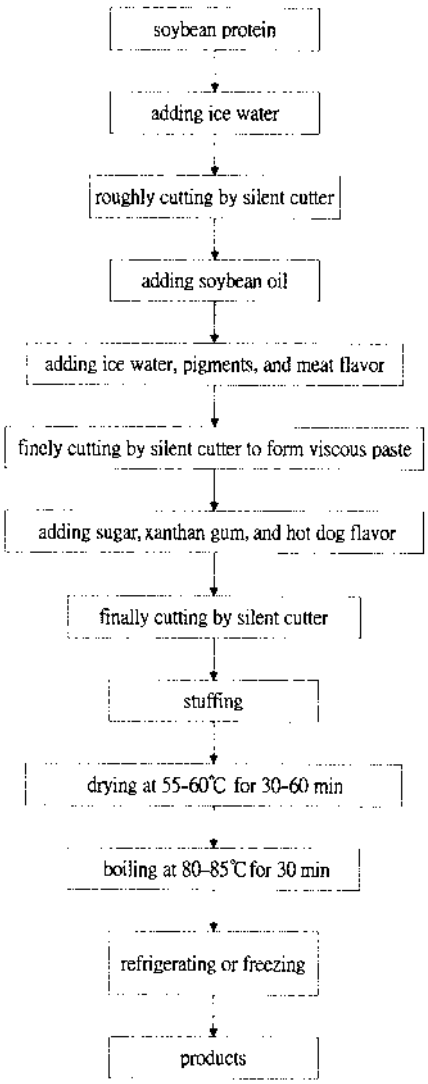


Figure 9 A typical flow chart for processing of copy food containing soybean proteins.

product package. Vegetarian products, whether imitation or pure, may be labeled “Vegetarian”, “Edible for Vegetarians”, “Appropriate for Vegetarians.” In some Asian countries, a picture of the Buddha, a monk, or even a reverse swastika (sometimes to the distaste of adherents of Buddhism) is used to distinguish vegetarian food. In some countries, though, there are no such regulated labeling practices, and it may be difficult for a consumer to discern which food products on supermarket shelves are vegetarian.

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6
Canned Tomatoes: Production and Storage

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I. INTRODUCTION

This chapter first covers the steps required to produce canned whole, sliced, or diced tomatoes. This is followed by a section specifically for diced tomatoes. Next, quality changes during processing and storage of canned tomatoes are reviewed. Finally, a list of useful government websites for reference material is given. The history, biology, growth, harvesting, production statistics, and nutritional value are not covered. These subjects, as well as the production and quality changes during processing of tomato paste and sauces, are covered in the chapter on freezing tomato products in this book.

II. ECONOMICS

Fresh tomatoes are the fifth most popular vegetable consumed in the United States (16.6 pounds per capita), after potatoes (48.8), lettuce (23.3), onions (17.9), and watermelon (17.4) (1). Canned tomatoes are the most popular canned vegetable, at 74.2 pounds per capita in the United States. In the condiment category, salsa and ketchup are number one and two, respectively. The popularity of tomato products explains why the tomato ranks number one in nutritional contribution to the U.S. diet (2).

Processed tomatoes are an important product both for the domestic market and for export. In general, both exports and imports of tomato products are increasing. Exports of canned whole tomato products, paste, ketchup, and sauces are all increasing, while juice exports have been relatively constant (Fig. 1.) The import market has seen some large fluctuations in recent years, but over the last ten years, imports of canned tomato products have been increasing, while imported paste has decreased.

III. PROCESSING STEPS: CANNED WHOLE OR SLICED TOMATOES

A. Grading

Tomatoes for canning whole, sliced, or diced are graded on the basis of color, firmness, defects, and size. Solids content is unimportant, unlike in tomatoes for juice or paste. Graders must be

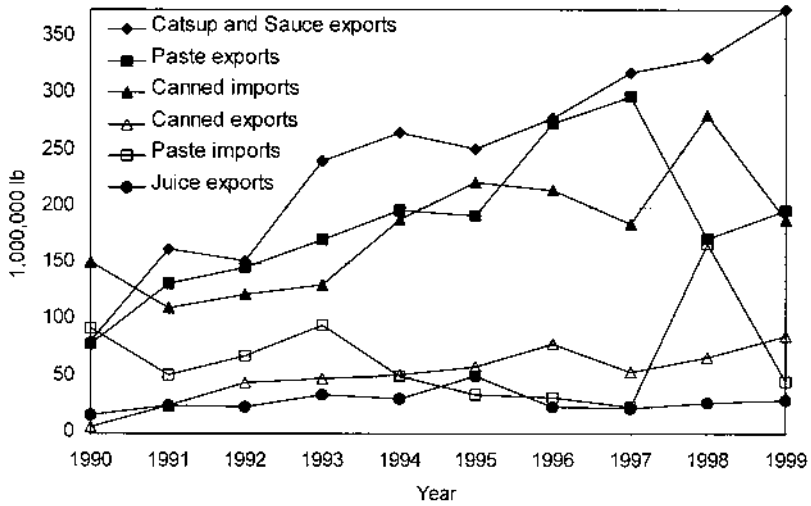

Figure 1 Trends in processed tomato imports and exports. (Adapted from Ref. 1.)

trained to evaluate and score color and firmness. Color should be a uniform red across the entire surface of the tomato. It is graded using USDA issued plastic color comparators, the Munsell colorimeter or the Agtron colorimeter, or the tomato is ground into juice and used in a colorimeter with a correlation equation to convert it to the Munsell. Firmness, or character, is important to be sure the tomato will survive canning. Soft, watery cultivars or cultivars possessing large seed cavities give an unattractive appearance and therefore receive a lower grade. Defects include worm, mold, insect, freezing, mechanical damage, and the presence of extraneous material. Size is not a grading characteristic per se, but all tomatoes must be above a minimum agreed upon size.

Some processors grade based on their own standards, while others use the USDA voluntary grading standards for Italian type tomatoes for canning (3) or for tomatoes for processing (4). Both standards are similar, though tomatoes for canning must be above a minimum agreed-upon size. Tomatoes for processing may be graded on either whole or juice color.

B. Washing

Tomatoes must be thoroughly washed to remove dirt and contaminants from the fields. There is little problem with drosophila eggs and mold, since canned tomatoes are typically peeled. However, washing is still an important step to remove dirt and reduce microbial counts. Tomatoes are soaked for several minutes in tanks with paddles or aeration to agitate the tomatoes and loosen adhering dirt. After soaking, a rinse step using overhead sprays removes any remaining dirt.

C. Sorting

Several kinds of sorters are used. Some plants use all of these while others use only the photoelectric sorters. The less common sorters include the hydrosorter, size sorter, and texture sorter. Hydrosorters are used to remove immature fruit while doubling as a washing step. In the hydrosorter, tomatoes go through a water tank. The immature fruit floats while the ripe fruit sinks. Immature fruit are discarded or may be diverted to the juice line. Size sorters remove excessively small tomatoes, which would be undesirable in the can. The small tomatoes are diverted to the

juice or crushed tomato line. Texture sorters remove excessively soft tomatoes. Firm tomatoes will jump the gap between two conveyors, while soft tomatoes will fall between them, again to be diverted to the juice line. Photoelectric sorters are used in almost all tomato plants and are commonly installed both before and after peeling. The initial sorter removes green tomatoes. The second sorter is used on the peeled tomatoes to remove the pink tomatoes. Green or pink tomatoes are ejected by a pneumatic finger as the tomatoes fall between conveyor belts. The green tomatoes can be diverted to the juice line, but pink tomatoes will decrease the color score of the juice.

D. Coring and Trimming

In the past, tomatoes were cored by machine, or more frequently by hand to remove the stem scar. Modern tomato varieties have been bred with very small cores so that this step is no longer needed. Trimming to remove rot or green portions is not practiced in the United States owing to the high cost of labor.

E. Peeling

Tomatoes are almost always peeled before further processing. The FDA standard of identity does allow for canned unpeeled tomatoes if the processor so desires, though this is not common on the market. This is likely because the peel is very tough and undesirable to the consumer, and unpeeled tomatoes would show many blemishes that are hidden from the consumer by peeling. Some easy peeling varieties have been bred; they may be suitable for canning with the peel on, since the peel is less tough. However, these varieties also have less resistance to insect and microbial attack on the plant and so are not typically used by growers.

There are two commonly used peeling methods: steam and lye. In California most peeling is done by steam, while in the Midwest U.S. and Canada peeling is done with a hot lye solution. In steam peeling, the fruit are placed on a moving belt one layer deep and pass through a steam box in a semicontinuous process. Steam peeling is done at 24–27 psig, which equals about 260°F (127°C), for 25–40 seconds. Peel removal is possible because of the rupture of the cells just underneath the peel. Due to the high temperature and pressure, the temperature of the water inside these cells exceeds the boiling point but remains in a liquid state. When the pressure in the chamber is released, the water changes to steam, bursting the cells. Time and temperature are the most critical factors to control to optimize the peeling process. The higher the temperature the shorter the time required and the more complete the peel removal. At higher temperatures there is also less mushiness in the fruit due to cooking. The process uses relatively little water and produces little waste effluent. The waste peels that are produced can be used as fertilizer or animal feed or processed into other products such as lycopene extract.

In lye or caustic peeling, the tomatoes pass on a conveyor belt under jets of hot lye (sodium hydroxide) or through a lye tank in a continuous operation. The tomatoes go through a solution of 12–18% lye at 185–212°F (85–100°C) for 30 seconds followed by holding for 30–60 seconds to allow the lye to react. The lye dissolves the cuticular wax and hydrolyzes the pectin. The hydrolysis of the pectin in the middle lamella causes the cells to separate from each other, or rupture, causing the peel to come off. This produces a wastewater containing a high organic load and high pH. Potash, or potassium hydroxide, can be used instead of lye. The advantage of potash peeling is that the potash waste can be discarded in the fields since it does not contain the sodium ion that is detrimental to soil quality. One processor has done this for several years with no apparent detrimental effect. In some cases, potassium hydroxide can be used at almost half the concentration of sodium hydroxide to produce the same result (5). Time in the lye, temperature of

the bath, and concentration are the three major controllable factors that determine peeling efficiency. Increasing any of these factors increases the extent of peel removal. Time and temperature are linearly correlated, while time and concentration are correlated exponentially (6).

With lye peeling, various additives are frequently added to the lye bath to improve peeling. These additives work by removing the wax (7), speeding the penetration of lye into the peel, or decreasing the surface tension of water, increasing the wettability of the cuticle. C6–C8 saturated fatty acids, especially octanoic acid, have been claimed to be very effective (8). One processor tried octanoic acid but reported that the odor was so objectionable that the workers threatened to quit. Wetting agents are typically used at a level of approximately 1/2 percent in the lye bath. Lye peeling typically produces a higher yield of well-peeled tomatoes than steam peeling, but disposal of the lye wastewater can be difficult (9). Steam gives a higher total tomato yield but removes much less of the peel than lye (10). For this reason, lye is used exclusively in the Midwest U.S., where peeled tomatoes are the most important tomato product produced.

After either steam or lye peeling, the tomatoes pass through a series of rubber disks or through a rotating drum under high-pressure water sprays, to remove the adhering peel. Fruit with irregular shape and wrinkled skins are difficult to peel and result in excessive loss during the peeling step. Thus varieties prone to these characteristics are undesirable. Over peeling is undesirable because it lowers the yield, results in higher waste, and strips the fruit of the red, lycopene-rich layer immediately underneath the peel, exposing the less attractive yellow vascular bundles.

Both fruit variety and maturity affect the efficiency of the peeling process. One study attempted to determine how well a tomato would peel based on physical structure (11). They found that an abrupt cell size change in the pericarp and the absence of small cells in the mesocarp correlated to better peeling.

Other proposed peeling methods include freeze heat peeling and hot calcium chloride. Freeze heat peeling submerges the tomatoes in liquid nitrogen, refrigerated calcium chloride, or Freon to rupture the cells, releasing pectolytic enzymes. The tomatoes are then transferred into warm water to encourage enzyme activity (12–15). The hot calcium chloride process is similar to peeling in boiling water, which was the standard before the discovery of lye peeling. The disadvantages of the process are that it is patented, that the tomatoes may take up more calcium than allowed in the standards of identity, and that the method requires trained operators to adjust conditions based on maturity and variety (16,17). These methods have been tested in laboratories but never put into commercial practice. The other peeling method, no longer used in the U.S., is to blanch the tomatoes in boiling water and then hand peel them.

F. Manual Sorting

Peeled tomatoes are inspected by hand before filling into the can. Sorters are mainly looking for rotten parts that cannot be detected by the photoelectric sorters. The main defects of concern are those included in the USDA grading standards for canned product: presence of peel, extraneous vegetable material, blemished areas, discolored portions, and objectionable core material (18). Inadequately peeled, blemished, small, and misshapen fruit are diverted to the juice line. For greatest efficiency, roller conveyors should be used to turn the tomatoes as they travel, exposing all sides to the sorters.

G. Filling, Additives, and Containers

Cans may be filled by hand, but owing to labor costs almost all manufacturers use mechanical filling. The container must be filled to not less than 90% of the container volume, and drained

weight must be at least 50% of the water weight, to meet standards of identity (19). The exact drained weight affects the USDA grade (18). A headspace is left in the can to allow for expansion during retorting.

Because of the acidic nature of the fruit, enameled cans and lids are used. When unenameled cans are used, hydrogen swells may occur. These are caused by a reaction between the metal of the can and the acid in the fruit. Glass can also be used, but it is not common in the market. The tomatoes are packed into the can and filled with tomato juice. FDA standards of identity require that some form of tomato juice or puree be used as the packing medium (19). Alternatively, tomatoes may be in a solid pack, where no packing medium is used, though this product is not currently on the market.

Heating softens the tomatoes, so calcium is typically added. Calcium can be added in the form of calcium chloride, calcium sulfate, calcium citrate, or monocalcium phosphate. The final amount of calcium cannot exceed 0.045% by weight in whole tomatoes or 0.08% in dices, slices, and wedges (19). The calcium ion migrates into the tomato tissue, creating a salt bridge between methoxy groups on adjacent pectin chains and forming calcium pectate or pectinate. This minimizes the softening that occurs during canning. The calcium may be mixed with the cover juice or added directly to the can. Tablets may be added directly, but typically the calcium is mixed with the juice. The amount of calcium added is adjusted based on the firmness of the tomatoes. The typical range is 0–1%, with an average of $\frac{1}{2}$%.

Most tomatoes are naturally high-acid foods; however, overly mature tomatoes and certain cultivars can result in a higher pH. The standard of identity allows organic acids to be added to lower the pH as needed. Citric acid is most common, although malic and fumaric acids are also used. Sugar may be added to offset the tartness from the added acid. Sodium chloride is frequently added for taste. The standard of identity allows calcium, organic acids, sweeteners, salt, spices, flavoring, and vegetables to be added (19). Because of the presence of other natural components that inhibit botulinum growth, the U.S. allows tomatoes up to a pH of 4.7 to be canned as high-acid foods, rather than a pH 4.6 as for other foods.

H. Exhausting and Sealing

Cans are typically exhausted and sealed at the same time. The old style of filling the tomatoes cold and then conveying the cans through an exhaust box to be heated before sealing is seldom used. Tomatoes peeled by either steam or lye are already hot; they are immediately filled, cover juice is added, and the cans are sealed. Steam is injected into the headspace of the can as the can is sealed. When the steam condenses, a partial vacuum is created, preventing "flippers", which suggest spoilage to the consumer. A headspace is critical if the product is going to be retorted, since the product will expand during heating. Without adequate headspace the ends of the can will bulge out. This is referred to as a "flipper" if the end can be pushed back down, or a "hard swell" if it cannot.

I. Canning

Because tomatoes are a high-acid food, they do not have to be sterilized. Tomato products can be hot filled and held, or they can be processed in a retort as needed to minimize spoilage. Most tomato products receive a retort process to ensure an adequate shelf life. Of the retorts, the continuous rotary retort is the most commonly used for tomato products. This retort provides agitation of the product and can handle large quantities in a continuous process. Because tomatoes are a high-acid food, the retort may operate at boiling water temperatures, 212°F (100°C). Continuous rotary retorts set at 220°F (104°C) for 30–40 minutes are also common. Exact

processing conditions depend on the product being packed, the size of the can, and the type and brand of retort used. The key is for the internal temperature of the tomatoes to reach at least 190°F (88°C).

Based on experience, spoilage of tomato products other than juice and whole tomatoes is caused by non–spore forming aciduric bacteria (20). These bacteria are readily destroyed by processes in which the inside of the can reaches at least 185°F (85°C). Spoilage of whole tomatoes can be caused by these same microorganisms, but they are also susceptible to spoilage by spore-formers such as *Clostridium pasteurianum*. Juice is commonly spoiled by *Bacillus coagulans* (formerly *Bacillus thermoacidurans*.) In the past, flat sour spoilage due to *B. coagulans* was a big problem in tomato products. Flat sour spoilage causes off-flavors and odors, and the pH of the juice drops to 3.5. The spores of these microbes are too resistant to heat to be destroyed by practical heat treatments at 212°F (100°C) if they are present in high numbers and so must be controlled by limiting initial levels or processing at temperatures about the boiling point. These organisms occur in the soil and grow on some equipment (20). The National Canners Association recommends $F_{200°F} = 10$ minutes when the pH is above 4.3, and $F_{200°F} = 5$ minutes when the pH is below 4.3, against clostridium spores. Against spores of *B. coagulans* the recommendation is $F_{25°F} = 0.7$ minutes at pH 4.5 (21).

Historically, the occurrence of swelled cans is most commonly due to either hydrogen swells or growth of *C. pasteurianum*. *C. pasteurianum* produces carbon dioxide, so determination of the type of gas in the headspace is one way to determine the cause.

J. Cooling

After canning, the product must be cooled to 100°F (30–40°C) to minimize quality loss. The product may be cooled by water or by air. When cooling water is used, it should be chlorinated to 2–5 ppm free chlorine to prevent contamination of the product while the seals are soft (22). Even though the cans are sealed, spoilage rates increase when the water is not chlorinated. The vacuum that forms as the contents cool must draw some microorganisms into the can. A rotary water cooler may be used in a continuous process after a rotary retort. Water cooling is more efficient than air cooling, so longer retort process times are recommended when water cooling is used than when air cooling is used (9).

K. Waste and Wastewater

By volume, approximately half of the wastewater in a tomato processing plant comes from tomato washing, a third from peeling, and a fifth from canning (23). Most of the waste and wastewater produced during tomato processing is biodegradable and can be disposed of on the fields (24). Lye peeling wastewater is the major exception. This wastewater can be disposed of in the sewer system but it has a high organic load and thus is expensive. Some treatment plants also object to the high pH. Some processors report that they have disposed of their potash peeling solution on their fields without any adverse effects. It has also been proposed that the lye peeling waste be treated with HCl and reclaimed as salt for use in canning, though this is not done in practice. In most cases, lye peeling wastewater must be disposed of in the sewer system.

Several treatment methods have been tried to reduce the organic load before its disposal in the sewer system. These methods are used to decrease the amount the plant is charged for

wastewater treatment, or because local laws restrict the BOD and volume of wastewater that can be discharged into the public sewer system. Treatment methods include microbial digestion, coagulant chemicals (25), and membrane filtration (26).

L. Final Grading

The United States Department of Agriculture sets grading standards for canned tomatoes, as well as ketchup, juice, paste, puree, and sauce. Canned tomato products are graded A, B, C, or substandard based on their average drained weight, character (firmness), color, wholeness, flavor, odor, and lack of defects (18). The tomatoes themselves may be whole, diced, sliced, halved, or in wedges.

IV. PROCESSING STEPS: CANNED DICED TOMATOES

Diced tomatoes have become very popular because of the increase in salsa consumption. Dices are processed in a similar manner to canned tomatoes. The major difference is that the peeled tomatoes are diced into 3/8", 1/2", or 1" cubes, inspected to remove green or blemished dices, then calcified. Calcification can occur by direct addition of calcium to the container or by conveying the dices through a calcium bath. The dices are then packed into cans for thermal processing or aseptically packed. In the past, 80% of dices were thermally processed in #10 cans (27). Cans are still common, but aseptic processing has increased the amount of dices sold in 55 and 300 gallon containers. Dices have an 18 to 24 month shelf life.

Calcium salts can be added as needed to increase firmness and drained weight, but the final amount of calcium cannot exceed 0.08% by weight (19). These salts are typically in the form of calcium chloride, calcium sulfate, calcium citrate, or monocalcium phosphate. For direct addition, the calcium can be added in the form of a tablet or mixed with the cover juice. For immersion, the dices are conveyed through a calcium bath, or mixed with the solution that is drained off after a holding period. Immersion causes a significant loss of acid and sugar compared to addition of calcium to the can; however immersion results in significantly firmer tomatoes for the same final calcium content (28).

A number of studies have attempted to determine the best conditions for immersion of the dices. The best conditions have been determined to be dipping in 0.75% calcium for one minute (29) or 0.43% calcium for 3.5 minutes (27). The resulting firmness is dependent on calcium concentration and time, but not temperature (27). The drained weight is dependent on the calcium concentration, time, and temperature (29). In general, calcium concentration in the dipping solution is the most important factor. The firmness and drained weight are linearly related to the calcium content and dipping time, though the changes in firmness are much larger than the changes in drained weight (28).

Experimentally, it has been shown that the addition of pectin methylesterase (PME) further increases the firmness of the dices (30). The PME activity deesterifies the galacturonic acid subunits, making them available to bind to the calcium ions. The firmness of the dices can be doubled with the addition of PME. This can be done more economically by processing the dices in a dip solution at a higher pH (7.5) for longer times (5 minutes) to allow the natural enzymes to act within the tomato (31).

Based on sensory evaluation, dices become inedible at approximately 1.5 times the legal limit of calcium in the dices (29). It has been reported that an adverse effect can be observed as low as 0.045–0.050% (28). The lower the calcium content, the higher the dices score in sweetness and natural taste (29). The higher the calcium, the higher the acidity taste and the lower the pH.

V. QUALITY CHANGES DURING PROCESSING

A. Nutritional Value

The type of process is important in determining how much quality loss occurs. For the same F value, significantly more vitamin C is lost during thermal processing of whole peeled tomatoes in a rotary pressure cooker than in an HTST process (32). Similarly, the texture is significantly firmer after the HTST (32). During canning the nutrient content remains fairly stable (Table 1). The already small lipid content decreases because of the removal of the skin. The calcium and sodium contents increase because the processors add them to improve the firmness and flavor of the tomatoes. The vitamin A content is fairly constant, while the vitamin C content is reduced by 45%. Bioavailable lycopene content increases, because processing makes the carotenoid more available to the body (33,34).

B. Color, Texture, and Flavor Changes

There is little problem with color changes during processing. The red color of tomatoes is mainly determined by the carotenoid lycopene (Fig. 2). Lycopene is very stable to heat. Texture does

Table 1 Nutrition Composition of Tomatoes, Value per 100 g of Edible Portion

	Raw	Canned (salt added)	Daily values
Water (g)	93.76	93.65	
Protein (g)	0.85	0.92	50
Total lipid (g)	0.33	0.13	65
Carbohydrate, by difference (g)	4.64	4.37	300
Fiber, total dietary (g)	1.1	1.0	25
Ash (g)	0.42	0.93	
Minerals			
Calcium, Ca (mg)	5	30	1000
Iron, Fe (mg)	0.45	0.55	18
Magnesium, Mg (mg)	11	12	400
Phosphorus, P (mg)	24	19	1000
Potassium, K (g)	222	211	3500
Sodium, Na (mg)	9	148	2400
Zinc, Zn (mg)	0.09	0.16	15
Copper, Cu (mg)	0.074	0.110	2.0
Manganese, Mn (mg)	0.105	0.127	2.0
Selenium, Se (mcg)	0.4	0.7	70
Vitamins			
Vitamin C (mg)	19.1	14.2	60
Thiamin (mg)	0.059	0.045	1.5
Riboflavin (mg)	0.048	0.031	1.7
Niacin (mg)	0.628	0.735	20
Pantothenic acid (mg)	0.247	0.167	10
Vitamin B-6 (mg)	0.080	0.090	2.0
Folate, total (mcg)	15	8	400
Vitamin B-12 (mcg)	0.00	0.00	6
Vitamin A (IU)	623	595	5000
Vitamin E (mg)	0.380	0.20	30 IU

Source: Adapted from the USDA Nutrient Database.

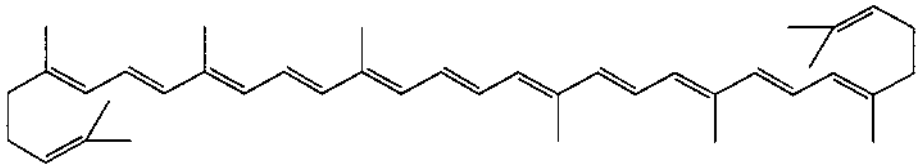

Figure 2 Lycopene.

change during processing, however. Canning significantly softens the fruit; therefore calcium is frequently added to increase the firmness. Varieties have been bred to be firm to withstand machine harvesting, which has also increased the firmness of canned tomatoes. During heat treatment, fresh tomato volatiles, especially cis-3-hexenal, are destroyed while cooked flavors due to compounds such as dimethyl sulfide and acetaldehyde are created (35). The characteristic tomato taste, mainly due to fructose, glucose, and citric acid, shows very little change during processing.

VI. QUALITY LOSSES DURING STORAGE

Sensory evaluation of flavor has been suggested to be the best predictor of the end of shelf life (36). The method that best correlated to the flavor was serum color.

A. Color and Lycopene

There is little problem with color changes during storage. When no oxygen is present, the red pigment lycopene slowly degrades by an autocatalytic mechanism. No loss of lycopene was seen in tomato puree stored up to a year, which had undergone a hot break process (37). Cold break puree did show a loss of lycopene, likely due to enzymatic activity (37). In addition to degradation of lycopene, darkening occurs during storage due to nonenzymatic browning (38).

Typically the color does not change during storage if the product is kept at room temperature or below (39,40). No difference in serum color was seen after 300 days at 68°F (20°C), for either hot or cold break tomato paste (41). When stored at 88°F (31°C), cold break paste did darken faster than hot break paste (41). Extreme conditions of twelve months at 88°C were required to reduce the color of tomato juice to grade C (42). Lower temperatures or shorter times were still grade A.

B. Flavor

Changes in flavor are the most sensitive index to quality deterioration during storage, followed by color (36). The Maillard reaction is the major mode of deterioration during storage of canned fruit and vegetable products in general and leads to a bitter off-flavor (43).

A number of studies have used hedonic measurements to determine the end of shelf life for tomato products. However, many of them did not go on long enough to find the end of shelf life. No significant differences were found in the flavor of tomato concentrates stored for 6 months at 40 or 70°F (4 or 21°C) (44). The samples at 100°F (38°C) were significantly different but, neither

the fresh nor the stored sample was preferred (44). Canned tomatoes stored for 3 years at 70°F (21°C) were rated fair, owing to a slightly stale, bitter, or tinny off-flavor (45,46). Storage at 70°F (21°C) should be limited to 24–30 months, and at 100°F (38°C) to less than a year.

C. Vitamin C

Vitamin C is the most labile of the nutrients, and so its degradation is used as an indicator of quality. No loss in natural vitamin C was found in tomato juice after 9 months of storage at up to 68°F (20°C) (42). In another study, some losses were seen at 88°F (31°C). After 1.2 years, some degradation of vitamin C was seen at storage temperatures of 43–52°F (6–11°C) (47), but at least 80% was still present when stored at 43–68°F (6–20°C). At 77°F (25°C), 55% remained. When samples were fortified with vitamin C, this added vitamin C degraded at storage temperatures as low as 35°F (2°C). This occurs because the vitamin C was not bound or protected in the juice the way the natural vitamin C is.

VII. USEFUL WEBSITES

USDA voluntary grading standards for Italian type tomatoes for canning and for tomatoes for processing: http://www.ams.usda.gov/standards/vegpro.htm

Code of Federal Regulations for Standard of identity for canned tomatoes: http://www.access.gpo.gov/nara/cfr/cfr-table-search.html

USDA Grading Standards for canned tomatoes: http://www.ams.usda.gov/standards/vegcan.htm

USDA Agricultural Statistics: http://www.usda.gov/nass/pubs/agstats.htm

U.S. Census Bureau Production, import and export statistics: http://www.census.gov/statab/www/

USDA nutrient composition database: http://www.nal.usda.gov/fnic/foodcomp/

California League of Food Processors: http://www.clfp.com/

California Tomato Growers Association: http://www.ctga.org/

World Processing Tomato Council: http://www.wptc.to/

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7
Canned Vegetables: Product Descriptions

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I. INTRODUCTION

This book is not the proper forum to present the manufacturing process for all categories of canned vegetables being marketed in the United States. Therefore, this chapter provides a short description for the major commercial canned vegetables.

In the United States, two federal agencies have the responsibility to make sure that the canned vegetables in the market are safe and do not pose any economic fraud. The U.S. Food and Drug Administration issues regulations to achieve both goals. The U.S. Department of Agriculture issues voluntary guides to achieve the same goals. The information in this chapter has been modified from such regulations and guidelines.

II. CANNED CORN

Canned sweet corn is the product prepared from clean, sound kernels of sweet corn packed with a suitable liquid packing medium that may include water and the creamy component from corn kernels. The tip caps are removed. The product is of the optional styles.

For more details on canned corn products, see Chapter 8 and Appendix A.

III. CANNED GREEN BEANS AND CANNED WAX BEANS

A. General Description

Canned green beans and canned wax beans are the foods prepared from succulent pods of fresh green bean or wax bean plants conforming to the characteristics of *Phaseolus vulgaris* L. and *Phaseolus coccineus* L. Such food is so processed by heat, in an appropriate manner before or after being sealed in a container, as to prevent spoilage.

Requirements are provided for optional color and varietal types, styles of pack, ingredients, and labeling:

Optional color types are green or wax. Optional varietal types include

1. Round. Beans having a width not greater than $1\frac{1}{2}$ times the thickness of the bean
2. Flat. Beans having a width greater than $1\frac{1}{2}$ times the thickness of the bean.

Optional styles of pack:

1. Whole. Whole pods of any length.
2. Shoestring or sliced lengthwise or French style. Pods sliced lengthwise.
3. Cuts. Transversely cut pods not less than 19 mm (0.75 in.) long as measured along the longitudinal axis, which may contain the shorter end pieces that result from cutting such pods.
4. Short cuts. Pieces of pods cut transversely, of which 75 percent, by count, or more are less than 19 mm (0.75 in.) in length and not more than 1 percent by count are more than 32 mm ($1\frac{1}{4}$ in.) in length.
5. Diagonal cuts. Pods cut in lengths as specified, except that the pods are cut at an angle approximately 45° to the longitudinal axis.
6. Diagonal short cuts. Pods cut in lengths as specified, except that the pods are cut at an angle approximately 45° to the longitudinal axis.
7. Mixture. Any mixture of two or more of the styles specified.

Optional ingredients:

1. Salt
2. Monosodium glutamate
3. Disodium inosinate
4. Disodium guanylate
5. Hydrolyzed vegetable protein
6. Autolyzed yeast extract
7. Nutritive carbohydrate sweeteners
8. Spice
9. Flavoring (except artificial)
10. Pieces of green or red peppers or mixtures of both, either of which may be dried, or other vegetables not exceeding in total 15 percent by weight of the finished product
11. Vinegar
12. Lemon juice or concentrated lemon juice
13. Gluconodeltalactone
14. Mint leaves
15. Butter or margarine in a quantity of not less than 3 percent by weight of the finished product
16. When butter or margarine is added, emulsifiers or stabilizers or both added
17. No spice or flavoring simulating the color or flavor imparted by butter or margarine

Labeling: The name of the food is “green beans” or “wax beans” as appropriate. Wax beans may be additionally designated “golden” or “yellow.”

A declaration of any flavoring that characterizes the product:

1. A declaration of any spice, seasoning, or garnishing that characterizes the product, e.g., “with added spice,” or, in lieu of the word “spice,” the common name of the spice, e.g., “seasoned with green peppers.”
2. The words “vacuum pack” or “vacuum packed” when the weight of the liquid in the container is not more than 25 percent of the net weight, and the container is closed under conditions creating a high vacuum in the container.

3. The name of the optional style of bean ingredient, if a product consists of a mixture of such styles, the words "mixture of _____," the blank to be filled in with the names of the styles present, arranged in the order of decreasing predominance, if any, by weight of such ingredients.
4. If the product consists of whole beans and the pods are packed parallel to the sides of the container, the word "whole" may be preceded or followed by the words "vertical pack," or if the pods are cut at both ends and are of substantially equal lengths, the words "asparagus style" may be used in lieu of the words "vertical pack."
5. If the product consists of short cuts or diagonal short cuts, a numerical expression indicating the predominate length of cut in the finished food may be used in lieu of the word "short," e.g., "$\frac{1}{2}$ inch cut."

The following may be included in the name of the food:

1. The word "stringless" if the beans are in fact stringless.
2. The name of the optional varietal type, or the specific varietal name, e.g., "Blue Lake Green Beans," or both.
3. If a term designating diameter is used, it should be supported by an exact graphic representation of the cross section of the bean pod or by a statement of the maximum diameter in common or decimal fractions of an inch and, optionally, by the millimeter equivalent stated parenthetically. The diameter of a whole, cut, diagonal cut, or short cut is determined by measuring the thickest portion of the pod at the shorter diameter of the bean perpendicular to the longitudinal axis.

IV. CANNED MUSHROOMS

A. Legal Requirement

The FDA has established a standard of identity for canned mushrooms. Some aspects are presented below.

1. Definition

Canned mushrooms are the food properly prepared from the caps and stems of succulent mushrooms conforming to the characteristics of the species *Agaricus* (*Psalliota*) *bisporus* or *A. bitorquis*, in one of the optional styles, packed with a suitable liquid medium, which may include water and may contain one or more safe and suitable optional ingredients. The food is sealed in a container and, is before or after sealing, so processed by heat as to prevent spoilage.

2. Styles

The optional styles of the mushroom ingredient are

1. Buttons—consisting of whole mushrooms with attached stems not exceeding 5 millimeters (0.2 in.) in length, measured from the bottom of the veil.
2. Whole—consisting of whole mushrooms with attached stems cut to a length not exceeding the diameter of the cap, measured from the bottom of the veil.
3. Quarters—consisting of buttons or whole style cut into four approximately equal parts.

4. Slices or sliced—consisting of buttons or whole style of which not less than 50 percent are cut parallel to the longitudinal axis of the stem and 2 millimeters to 8 millimeters (0.08 to 0.32 in.) in thickness.
5. Random sliced—consisting of buttons or whole style sliced in a random manner.
6. Pieces and stems—consisting of pieces of caps and stems of irregular shapes and sizes.

3. Optional Ingredients

Optional ingredients are

1. Salt.
2. Monosodium glutamate.
3. Disodium inosinate
4. Disodium guanylate
5. Hydrolyzed vegetable protein.
6. Autolyzed yeast extract.
7. Ascorbic acid (vitamin C) in a quantity not to exceed 132 milligrams for each 100 grams (37.5 milligrams for each ounce) of drained weight of mushrooms.
8. Organic acids (except no vinegar is permitted), only where the inside metal of the container is fully enamel-lined and in glass containers with fully enamel-lined caps. Ascorbic acid is an example.
9. Calcium disodium ethylenediaminetetraacetate ($CaNa_2$ EDTA) in a quantity not to exceed 200 parts per million for use to promote color retention.

4. Fill of Container

1. The fill of the mushroom ingredient and packing medium container is not less than 90 percent of the total capacity of the container.
2. The drained weight of the mushroom ingredient is not less than 56 percent of the water capacity of the container.

B. General Processing

Canned mushroom is considered a low acid canned food, and there are stringent regulations govering its manufacture. This section provides some background information. A commercial processor must comply with basic federal requirements.

1. Types and Varieties

All cultivated mushrooms belong to the species *Agaricus campestris*. Various bracket fungi, puffballs, and other fungi have been used as food, but none have been grown commercially in this country. Mushrooms are classified as white, cream, or brown, depending on the color of the cap. Those grown for canning are almost exclusively of the white variety. In the East and Midwest the white variety is also the principal kind grown for fresh mushroom consumption, while in the West and in Canada a fair quantity of the cream variety is used. Of course, in the last two decades or so, many varieties of mushrooms are available from imports, e.g., from countries in the Pacific Rim.

2. Growing Requirements

Since mushrooms, like all fungi, do not possess chlorophyll with which to manufacture carbohydrates from CO_2 absorbed from the air, they must obtain carbohydrates and other nutrients by growing on organic material containing these ingredients. Compost is the favorite growing medium in commercial mushroom houses.

Unlike plants possessing chlorophyll, mushrooms can grow in tare in darkness. A cool, moist atmosphere is most favorable for their development. Caves and abandoned mines have been used extensively for the growing of mushrooms.

Most mushrooms are grown in houses constructed especially for the purpose. Cinder blocks are a favorite construction material. The houses should be well insulated against cold in winter and heat in summer, and should have heating facilities for use in winter and means for keeping the air moist when the outside humidity becomes low.

Most houses produce two distinct crops a year. Each crop consists of several "breaks." After the mushrooms are harvested the north beds are covered with a new layer of "casing" soil and watered down for the next growth of mushrooms. After several such "breaks," the beds are cleaned out and filled with fresh compost. The entire cycle areas may be completed in as little as three months or even less, up to as long as seven months, depending largely on temperature.

Higher temperatures usually mean a greater proportion of small land mushrooms.

Artificial air conditioning enables some growers to obtain three crops a year.

The months of October to May, inclusive, are the months of heaviest production. Harvesting is light during the warm weather months. A few growers maintain production during the summer by means of artificial air conditioning.

3. Harvesting and Delivery

Most canners grow the greater part of the mushrooms they use, purchasing the remainder of their requirements from other growers. Some canners grow for canning exclusively; others grow both for the fresh market and for processing.

Mushrooms are pulled from the beds with roots attached before the "veil" or membrane breaks open and exposes the "gills." Depending upon the contract between the packer and grower, the mushrooms may be delivered to the plant either with or without roots attached. In the latter case, the roots are cut from the mushrooms in the growing houses by the harvesters. In either case they are placed in baskets holding from three to as much as ten pounds for delivery to the plant. Obviously, large corporations use a more advanced system to handle this harvesting and delivery. However, small growers have not changed much.

Freshly harvested mushrooms with the root portion attached will remain fresh longer than if the root portion has been removed. Mushrooms frequently grow in clusters, which may contain from three to five or more units. The units may vary in size from tiny to large in the same cluster that developed from one root.

Mushroom deteriorate rapidly after picking, becoming discolored and wilted. They should be delivered to the cannery or processor promptly after picking. When mushrooms cannot be processed promptly after delivery to the cannery, they should be placed in a refrigerated room at a temperature of 36° to 37°F until needed. Refrigeration permits the supplies to be carried overnight to begin canning operations the following morning, or late weekend deliveries may be carried over to Monday morning.

Mushrooms must be handled carefully at all times to avoid bruising, which results in dark discolored areas.

C. Preparation and Canning

The following description of a canned mushroom operation is reasonably typical. The order, methods, and equipment may vary from plant to plant, especially a small versus a big one.

After delivery to the plant, mushrooms that cannot be processed immediately are placed in refrigerated storage until they can be processed.

The baskets of mushrooms are taken to the cutting line for the removal of root stubs and stems. In most plants, the cutting operation is performed mechanically, although some plants may still be cutting by hand. The stem may undergo one or two cuttings, depending on the style of mushrooms desired, whether whole or button.

In the case of whole mushrooms, only the root portion of the stem is removed by the mechanical cutter. If the style of buttons is desired, the cutter first removes the root portion of the stem, which is carried away for waste. The rest of the stem is then removed by cutting immediately below the veil. This portion of the stem is used in the style of stems and pieces.

1. Washing, Trimming, and Sorting

After cutting, both the caps and the stems are conveyed to a spray washer, which removes the clinging bits of casing soil or other dirt. The mushrooms then pass over an inspection belt where seriously blemished mushrooms may be trimmed or sorted out. Misshapen, blemished, trimmed, and broken mushrooms are sorted out and placed with other mushroom material for the stems and pieces style.

Mushrooms with partially open veils may be placed with the pieces, delivery material, or be added to the buttons or whole mushrooms intended for one of the sliced styles.

2. Sizing

Mushrooms intended for whole mushrooms or buttons are conveyed by means of water flume or other techniques to the sizers.

The mushrooms may be sized in a revolving drum sizer submerged in water. Rotary size graders that are not immersed in water may also be used. A submerged sizer minimizes bruising and gives the mushrooms an additional washing. The caps float upward from the sizer, and each size is floated off into a separate holding tank.

The buttons may be separated into six different sizes. The larger sizes are generally sliced and the smaller sizes packed as buttons. Price lists of packers may quote sizes in terms of the number of buttons per 8-ounce can as 20/40, 40/60, 60/80, or l00/120. The same size designations apply when the mushrooms are packed in smaller sized cans. For example, the 40/60 size would pack between 20 to 30 buttons in a 4-ounce can.

3. Slicing

Mushrooms intended for slicing are generally sliced prior to blanching; however, slicing may be performed after blanching. The mushrooms are passed through a mechanical slicer with circular knives, which cut them into slices of predetermined thickness. A shaker screen removes the small pieces after slicing.

Three styles of sliced mushrooms are produced: Sliced Whole, Sliced Buttons, and Random Sliced Whole.

Sliced Whole style is prepared by aligning the mushrooms prior to slicing so that the mushroom is sliced lengthwise from stem to apex.

Sliced Buttons style is prepared by positioning the mushrooms prior to slicing so that the mushroom is sliced parallel to the longitudinal axis.

Random Sliced Whole style is prepared by slicing the mushroom in any direction.

4. Blanching

The mushrooms are flumed from the holding tanks or slicer to the blancher. The purpose of blanching is to shrink the mushrooms in order to obtain the proper fill. Shrinkage is due to loss of mushroom juice. Mushrooms may shrink as much as 30 to 40 percent in size in blanching.

Mushrooms may be blanched by immersing in water at a temperature of 200°F or more. The usual method, however, is to pass the mushrooms through a continuous steam blancher where they are exposed to live steam for a period of 5 to 8 minutes. In some cases, the mushrooms may be filled into the cans and then blanched in the cans. Since iron tends to discolor mushrooms, the blancher should be made of stainless steel or other noncorrosive metal. During blanching, the color of some white varieties may change from near-white to a light tan or buff color.

5. Filling and Weighing

Whole or Button styles are generally filled into the can by hand, whereas a semiautomatic filler is usually used for slices and piece pack. After filling, the cans are moved by belt conveyor in front of the weighers, who weigh the individual cans and adjust the fill so that the finished product will meet the required minimum drained weight.

As a safety factor, weighers generally overfill the cans, usually in accordance with a schedule of overfill weights which vary according to can size and style of pack.

Cans may vary considerably in weight, particularly in the smaller sizes. Deficient drained weights have been found to be due in some cases to the use of an unusually light can as tare by the weigher. The weigher should choose a tare can of average weight.

6. Brining and Cooking

After weighing, a salt tablet, which may also contain ascorbic acid, is added and cans are moved under taps of hot water, the temperature of which may range from 190° to 200°F. The taps are adjusted to fill the cans to overflowing. A hot brine solution is sometimes used instead of the water and salt tablet. It is generally unnecessary to use an exhaust on the filled cans, since a sufficiently high vacuum is obtained for most purposes by the addition of hot water.

After closing, the cans are processed in retorts under steam pressure. After processing, the cans may be cooled by water in the retort or a cooling tank. The cans should be cooled to 90° to l00°F in order to check the cook but leave cans warm enough to dry off readily and prevent rusting.

7. Modern Technology and FDA Regulations

The information in this section on mushrooms must be interpreted in terms of the following premises:

1. Depending on the size and operation of a processor, the use of new equipment and machinery has eliminated a lot of problems that used to accompany the processing of mushrooms.
2. If used properly, food additives can contribute to the proper processing of mushrooms.
3. Always be concerned that mushrooms in a container are subject to the important regulations promulgated by the FDA for low-acid canned and acidified foods.

V. CANNED ONIONS

A. Production

1. Varieties

Yellow globe onions, a commercial term applied to several different varieties and strains of onions, are preferred by processors of onions. The more acceptable varieties are the Southport yellow globe and the yellow globe Danver. Western processors for the most part use only the yellow globe Danver.

2. Harvesting

The customary period at which to harvest onions for canning is in the fall, when the tops of the onions have begun to turn greenish yellow. Usually the crop is dug by a hoe or an implement that turns the ground, exposing the onions to the surface. After the onions are taken from the ground they are thrown in windrows or piles in the field, where they remain until the tops are completely dry. After curing sufficiently, the tops are cut or pulled off close to the bulbs. The onions are then placed in sacks or crates and are placed in storage or shipped.

B. Preparation and Canning

1. Receiving

Onions are usually delivered to the cannery in sacks or crates, and are placed in storage until used. Well cured onions will keep for several months if stored in a well-ventilated place. In some areas it may be necessary to store them in an enclosed shed for protection against freezing. Onions will sprout within a few months if stored in a warm place. Badly spoiled onions become soft. The fresh fruit and vegetable inspection service inspects a large volume of onions for shippers and buyers at time of shipment or in receiving markets. Onions delivered to canners may or may not have been officially inspected.

2. Presizing and Trimming

Generally the onions are emptied from sacks onto a belt conveyor carrying them to a sizer, which eliminates over- and under-sized onions. From the sizer the onions are placed in buckets or pans on a merry-go-round sorting table where ends of the onions are trimmed and onions possessing rot, decay, or other serious defects are discarded.

3. Peeling

From the merry-go-round sorting table, the onions are conveyed to a carborundum peeler, which tends to loosen the outer skin of the onion bulb. As the onions leave the carborundum peeler they pass through a continuous lye peeler containing a 3–10 percent lye solution, depending upon the variety and character of the onions, which further loosens the outer scales of the onion bulb.

4. Washing

Following the peeling process, the onions pass through a rotary screen washer where adhering portions of the outer loosened scales are washed off under a strong spray of water. A closely controlled check is necessary to assure complete removal of the lye solution from the onion bulbs.

5. Preremoving of Blemishes and Defects

After washing, the onions are moved by conveyer belt to an inspection table where onions containing blemishes are removed.

6. Sizing

Normally onions are separated into three size classifications: tiny, small, and medium. Each processor has developed his own particular sizing operation. However, for the most part onions exceeding an inch and one-half in diameter and those with a diameter of less than $\frac{5}{8}$ of an inch are not used for canning.

7. Final Removing of Blemishes and Defects

As the onions come from the sizer, they are conveyed onto a final inspection table where loosened scales, loose centers, onions possessing blemishes, or excessively discolored onions are removed.

8. Filling

The onions are then filled into cans or glass jars and a sufficient amount of hot brine is added for proper fill. After the cans or glass jars are filled they are quickly closed. In packing onions, the product is acidified to assure sterilization and to prevent spoilage. A pH of 4.5 is most desirable. The acid solution may be used as a dip, or it may be added directly to the containers in the filling operations.

9. Defects

a. General Immediately after ascertaining the uniformity of size and shape, segregate any defects in the following groups in accordance with the definitions outlined by the USDA.

b. Extraneous Vegetable Material Remove from each container the pieces present and arrange all the extraneous material such as loose skins and dried onion tops. Extraneous vegetable material refers to harmless vegetable material, and the material falling into this category is evaluated with respect to its effect on the overall requirements for the grade classification. No tolerance is provided for extraneous vegetable material of a different origin than the onion plants, such as weeds and weed seeds. When such extraneous material is found the supervisor should be contacted.

c. Blemished Onions A blemished onion is one that is affected by surface or internal discoloration to such an extent that the appearance or eating quality is materially affected. The following are examples of onions scoreable as being blemished:

1. **Staining**. Onions that show brown or streaked discoloration from lying on the ground.
2. **Seed Stems**. Onions often throw up stalks on which to bear seeds during the later part of their growth. When harvested, the seed stems are cut or broken off, leaving thick, tough stems extending through the centers of the onions. Onions possessing tough or woody seed stems should be considered as blemished onions.
3. **Sunburn**. Sunburn is a green discoloration caused by exposure of the bulb to the sun and is normally present only on the outer scale of the onion bulb. This condition should not be confused with the natural greening of certain varieties of onions wherein the green color may be present in the outer scales of the onion bulbs.
4. **Sunscald**. This injury takes place at harvest time when the bulbs are exposed to heat and bright sunlight. The tissue of the exposed area of the bulb will scald and become

soft and slippery. When temperatures are reduced and the onions are exposed to the air, the scalded tissue loses moisture by evaporation, and leatherlike areas are produced that may be bleached almost white.

5. **Freezing injury**. This injury is recognized by the water-soaked appearance, soft feel, and discoloration appearing in a portion of the scale or scales. The affected area normally has a translucent or paperlike appearance.
6. **Smudge**. Smudge is characterized by black blotches or aggregations of minute black or dark green dots on the outer scales. These dots are often arranged in concentric rings. Generally the lesions are on the outer scales, but they may also be found on inner scales. On the fleshy scale of the bulb the fungus produces sunken yellowish spots.
7. **Surface Molds**. Surface molds may be black, blue, or gray in color and may be found growing either on the outer scales or, frequently, between the outer scales of the bulb.
8. **Rot**. Several types of rot may be present in onions, envelopes of which are bacterial soft rot, blue mold rot, fusarium rot, and green mold rot. Normally, onion bulbs affected by rot have a water-soaked appearance with various discolorations of outer or inner scales. Canned onions should not contain any units showing rot other than an accidental unit.

d. Seriously Blemished Onions A seriously blemished onion is an onion that is affected by surface or internal discoloration to such an extent that the appearance or eating quality is seriously affected. Insect injury, wherever the insect bite extends through the scale of an onion bulb, is very noticeable and should be considered seriously blemished. Dark pathological areas that are unsightly are considered seriously blemished.

e. Mechanical Damage Onion bulbs mechanically damaged by crushing, gouging, or trimming should be classified as damaged only when the condition materially affects the eating appearance or quality of the bulb.

f. Loose Scales or Pieces of Scales Loose scales or pieces of scales are those not attached to an onion bulb. Do not aggregate pieces of scales to give the equivalent of one loose scale.

g. Detached Center Detached center is when the center portion of the onion bulb has become detached. The onion bulb thus damaged is scored as a defect and the loose centers that have become detached are disregarded.

10. Well Trimmed

Determining whether onions are well trimmed is judged entirely on an appearance basis. In meeting the requirement for well trimmed, the top and root of the onion should be neatly removed. Onion bulbs with off-slant cuts that materially affect the appearance of the unit are not considered well trimmed.

VI. CANNED PEAS AND DRY PEAS

Canned peas are the food prepared from fresh or frozen succulent seeds of the pea plant of the species *Pisum sativum* L. but excluding the subspecies macrocarpum. Only sweet wrinkled varieties, smooth-skin varieties, or hybrids thereof may be used. The product is packed with water or other suitable aqueous liquid medium to which may be added one or more of the other optional ingredients. Such food is sealed in a container and, before or after sealing, is so processed by heat as to prevent spoilage.

Optional ingredients. In addition to the optional packing media, the following safe and suitable optional ingredients may be used:

1. Salt.
2. Monosodium glutamate.
3. Disodium inosinate.
4. Disodium guanylate.
5. Hydrolyzed vegetable protein.
6. Autolyzed yeast extract.
7. One or any combination of two or more of the dry or liquid forms of sugar, invert sugar sirup, dextrose, glucose sirup, and fructose.
8. Spice.
9. Flavoring (except artificial).
10. Color additives.
11. Calcium salts, the total amount of which added to firm the peas should not result in more than 350 milligrams/kilogram (0.01 ounce/2.2 pounds) of calcium in the finished food.
12. Magnesium hydroxide, magnesium oxide, magnesium carbonate, or any mixture or combination of these in such quantity that the pH of the finished canned peas is not more than 8, as determined by the glass electrode method for the hydrogen ion concentration.
13. Seasonings and garnishes:
14. Pieces of green or red peppers or mixtures of both, either of which may be dried, or other vegetables not exceeding in total 15 percent of the drained weight of the finished food.
15. Lemon juice or concentrated lemon juice.
16. Mint leaves.
17. Butter or margarine in a quantity not less than 3 percent by weight of the finished food, or other vegetable or animal fats or oils in a quantity not less than 2.4 percent by weight of the finished foods.
18. When butter, margarine, or other vegetable or animal fats or oils are added, emulsifiers or stabilizers or both may be added, but no color, spice, or flavoring simulating the color or flavor imparted by butter or margarine may be used.

A. Labeling

The name of the food is "peas," and this may include the designation "green." The term "early," "June," or "early June" should precede or follow the name in the case of smooth-skin peas or substantially smooth-skin peas, such as Alaska type peas or hybrids having similar characteristics. Where the peas are of sweet green wrinkled varieties or hybrids having similar characteristics, the name may include the designation "sweet," "wrinkled," or any combination thereof. The term "petit pois" may be used in conjunction with the name of the food when an average of 80 percent or more of the peas will pass through a circular opening of a diameter of 7.1 millimeters (0.28 inch). If any color additive has been added, the name of the food should include the term "artificially colored."

The following should be included as part of the name or in close proximity to the name of the food:

1. A declaration of any flavoring that characterizes the food

2. A declaration of any spice, seasoning, or garnishing that characterizes the product, e.g., "seasoned with green peppers," "seasoned with butter," "seasoned with ____ oil," the blank to be filled in with the common or usual name of the oil, "with added spice," or, in lieu of the word spice, the common or usual name of the spice
3. The words "vacuum pack" or "vacuum packed" when the weight of the liquid in the container is not more than 20 percent of the net weight, and the container is closed under conditions creating a high vacuum in the container

VII. CANNED PUMPKIN AND CANNED SQUASH

A. Production

1. Varieties

The names pumpkin and squash are popularly applied to the fruits of the species of the genus Cucurbita, namely *C. pepo*, *C. maxima* and *C. moschata*. In general, the term pumpkin is applied to the late maturing or fall varieties of *C. pepo* and *C. maxima*. The principal varieties of *C. pepo* and *C. maxima* used for canning are the Connecticut field pumpkin, the Dickinson pumpkin, the Kentucky field pumpkin, the Boston marrow squash, and the Golden Delicious squash.

2. Harvesting

Pumpkin and squash should not be harvested for canning until fully matured. Harvesting is usually done after the leaves begin to turn yellow. Mature pumpkin or squash have a hard rind that can be dented only with difficulty with the thumbnail. If picked too green the under portions of the pumpkin will have a greenish color, and this may be carried over into the finished product. Pumpkin and squash are usually harvested starting approximately September 15 in the Midwest and the Northeast States, and October 1 in the Pacific Northwest.

B. Preparation and Canning

1. Receiving

Pumpkin and squash are usually delivered as harvested and stored at the cannery until used. Well-matured pumpkin or squash will keep for several weeks if stored in a well-ventilated place. In some areas it may be necessary to store them in an enclosed shed for protection against freezing. Normally no inspection is made of pumpkin or squash received by the plants.

2. Washing

Whole pumpkins or squashes are fed by hand or conveyed into a combined tank and spray washer, consisting of a rotary drum partially submerged in a tank of water. The combined soaking and rotary motion loosens adhering dirt, which is removed by strong sprays of water. Grit sometimes becomes embedded in the rind, necessitating thorough washing.

3. Trimming

From the washer the pumpkins or squash pass to the inspection belt where stems are knocked off by hand and blossom ends, scar tissue rot, and other blemishes are trimmed out.

4. Cutting

In some canneries the trimmers also cut the pumpkin or squash into halves or quarters with long knives and scrape out the seeds and stringy pulp by hand. In many plants mechanical cutters are used into which the whole units (or halves) are fed by a conveyor cutting the units into pieces. Strong sprays of water help to knock out most of the seeds, which drop from the cutter through small perforations.

Where the units are cut and the seeds and pulp removed in separate operations, the cut pieces pass to a revolving drum where they are tumbled under strong sprays of water, which remove most of the seeds and pulp.

Where seeds are to be saved for planting, they may undergo further washing to separate them from the pulp.

Cut pieces are in some cases passed over an inspection belt where imperfect pieces and internal rot, not visible from the outside, may be picked out by hand.

5. Wilting (Steaming)

The cut pieces are cooked in live steam until they are tender all the way through. The length of time necessary depends upon the size of the pieces and the nature of the equipment in which the steaming is done. The following are examples in which the wilting or steaming may be accomplished:

1. In metal baskets in retorts, either under pressure or at atmospheric pressure.
2. In continuous metal box wilters. The pieces are carried through on a continuous belt and are subjected to live steam.
3. In wilting towers. These are tall, cylindrical silolike structures into which the cut pieces are fed continuously at the top by conveyor and removed at the bottom by a screw conveyor. The pumpkin or squash is continuously treated with live steam as it passes through the wilting tower.

6. Pressing

The wilted pumpkin or squash is soggy with liquid which is a mixture of condensed steam and pumpkin or squash juice. The product is treated to remove excess liquid in order to attain the desired consistency in the canned product. This is done by putting the wilted pumpkin or squash through an adjustable press. In certain plants the pressing and wilting is done simultaneously by the use of augers inside of cone-shaped perforated screens.

7. Pulping

The pressed pumpkin or squash goes to the pulper or cyclone to remove hard particles, pieces of stems, seeds, fiber, and other extraneous material. In some cases the product is first put through a coarse, heavy cyclone to remove the bulk of the extraneous material and an ordinary cyclone to reduce the size of the particles. For the latter a screen with perforations $\frac{1}{8}$ inch in diameter is commonly used.

Some processors use what is commercially known as a Fitz mill. This machine, constructed with hammer and knife edges on opposite sides, reduces or pulps pumpkin by a combined impact mashing action.

8. Finishing

From the pulper the product goes to the finisher, which removes the finer bits of seeds or other material and gives the final product the desired physical character. There is a difference of opinion

among canners as to the most desirable size of the particles of pumpkin in the finished product. Some prefer a very smooth product which can be obtained by using a very fine finisher; others feel that the canned pumpkin or squash should have a noticeable amount of grainy structure and therefore use a finisher that is relatively coarse.

9. Preheating

The filling temperature of the prepared pumpkin or squash is an important part of processing. Heat penetration of the product is very slow because of its physical character, and the temperature at the beginning of the process is correspondingly important. By use of the preheater, it is possible to fill all of the cans at a uniform high temperature.

The preheater is usually a straight piece of pipe surrounded by a larger pipe. The product is pumped through the smaller internal pipe and the space between the two pipes is filled with steam, the temperature of which can be controlled. The rate of flow of the product through the pipe and the temperature of the steam determines the temperature at which it goes to the filler. The preheater normally raises the temperature of the product to 190–200°F. To prevent scorching the preheater is usually constructed so that it will shut off automatically if, for any reason, the flow through the inside pipe is stopped.

10. Filling

The hot pumpkin or squash goes directly to the filler and into cans. If the thickness of the product at this point is too great, the product may not be handled properly by the filler. If, for any reason, the filler or closing machine is forced to stop for any length of time, all of the pumpkin material should be put back with the material going though the preheater. Pumpkin or squash has a corrosive action on tinplate and should be packed in enamel-lined cans. It is important to fill the cans completely so that the product is in contact with the entire inner surface of the cover when the can is sealed. Even a small headspace may result in some discoloration after processing.

11. Processing

The filled cans should be processed promptly. High closing temperature may be offset by undue delay between closing and starting of the process time. A partially filled crate of cans should be sent at once to the retort rather than waiting any length of time for additional cans.

12. Cooling

Prompt and adequate cooling is especially important since canned pumpkin has a slow heating and cooling rate. Failure to cool the product promptly may result in overcooking and loss of color and may be directly responsible for spoilage by thermophilic bacteria. Cooling is usually accomplished by moving the metal retort baskets through a long tank of water by means of an overhead endless chain. The speed of the chain is regulated according to the degree of cooling desired. Cold water is kept continuously flowing into the tank to hold down the temperature. Immediately after cooking, while the cans are distended by heat and internal pressure, minute openings in the double seams may be present. Cooling water contaminated with bacteria may be drawn through seam openings as pressure in the cans is replaced by vacuum, so water in the cooling tank should be kept clean. Some canners cool by means of a water spray in order to reduce the contamination hazard.

VIII. CANNED VEGETABLES

Additional production descriptions are provided for the following vegetables: artichokes, asparagus, bean sprouts, beans, shelled, beans, lima or butter beans, beets, beet greens, broccoli, brussels sprouts, cabbage, carrots, cauliflower, celery, collards, dandelion greens, kale, mustard greens, leaves of the mustard plant, okra, onions, parsnips, peas, black-eye or black-eyed, field peas, green sweet peppers, red sweet peppers, pimientos (pimentos), potatoes, rutabagas, salsify, spinach, potatoes, sweet potatoes, Swiss chard, truffles, turnip greens, turnips.

Table 1 provides a basic description of each canned vegetable. Column I describes the canned vegetable. The vegetable ingredient in each such canned vegetable is obtained by proper preparation from the succulent vegetable described in column II of the table. If two or more forms of such ingredient are designated in column III of the table, the vegetable in each such form is an optional ingredient. To the vegetable additional ingredients (required or permitted) are added, and the food is sealed in a container and so processed by heat as to prevent spoilage.

Water is added to the vegetable ingredient, except that pimientos may be canned with or without added water, and sweet potatoes in mashed form are canned without added water. Asparagus may be canned with added water, asparagus juice, or a mixture of both. Asparagus juice is the clear, unfermented liquid expressed from the washed and heated sprouts or parts of sprouts of the asparagus plant, and mixtures of asparagus juice and water are considered to be water when such mixtures are used as a packing medium for canned asparagus. In the case of artichokes, a vinegar or any safe and suitable organic acid, which either is not a food additive as so defined or (if it is a food additive as so defined) is used in conformity with regulations established, is added in such quantity as to reduce the pH of the finished canned vegetable to 4.5 or below.

The following are optional ingredients in the cases of the vegetables in Table 1.

An edible vegetable oil, in the case of artichokes and pimientos. Snaps, in the case of shelled beans, black-eyed peas, and field peas.

In the case of all vegetables (except canned mashed sweet potatoes), one or more of the following optional seasoning ingredients may be added in a quantity sufficient to season the food.

1. Refined sugar (sucrose)
2. Refined corn sugar (dextrose)
3. Corn sirup, glucose sirup
4. Dried corn sirup, dried glucose sirup
5. Spice
6. A vinegar
7. Green peppers or red peppers, which may be dried
8. Mint leaves
9. Onions, which may be dried
10. Garlic, which may be dried
11. Horseradish
12. Lemon juice or concentrated lemon juice
13. Butter or margarine in a quantity not less than 3 percent by weight of the finished food

When butter or margarine is added, safe and suitable emulsifiers or stabilizers, or both, may be added. When butter or margarine is added, no spice or flavoring simulating the color or flavor imparted by butter or margarine is used.

In the case of all vegetables, the following optional ingredients may be added:

1. Salt
2. Monosodium glutamate

Table 1 Canned Vegetables, Source, and Optional Forms of Vegetable Ingredients

Name or synonym of canned vegetable	Source	Optional forms of vegetable ingredient
Artichokes	Flower buds of the artichoke plant	Whole; half or halves or halved; whole hearts; halved hearts; quartered hearts
Asparagus	Edible portions of sprouts of the asparagus plant, as follows:	
	$3\frac{3}{4}$ in. or more of upper end	Stalks or spears
	$3\frac{3}{4}$ in. or more of peeled upper end	Peeled stalks or peeled spears
	Not less than $2\frac{3}{4}$ in. but less than $3\frac{3}{4}$ in. of upper end	Tips
	Less than $2\frac{3}{4}$ in. of upper end	Points
	Sprouts cut in pieces	Cut stalks or cut spears
	Sprouts from which the tip has been removed, cut in pieces	Bottom cuts or cuts—tips removed
Bean sprouts	Sprouts of the mung bean	
Shelled beans	Seed shelled from green or wax bean pods, with or without snaps (pieces of immature unshelled pods)	
Lima beans or butter beans	Seed shelled from the pods of the lima bean plant	
Beets	Root of the beet plant	Whole; slices or sliced; quarters or quartered; dice or diced; cut; shoestring or French style or julienne
Beet greens	Leaves, or leaves and immature root, of the beet plant	
Broccoli	Heads of the broccoli plant	
Brussels sprouts	Sprouts of the Brussels sprouts plant	
Cabbage	Cut pieces of the heads of the cabbage plant	
Carrots	Root of the carrot plant	
Cauliflower	Cut pieces of the head of the cauliflower plant	
Celery	Stalks of the celery plant	Cut; hearts
Collards	Leaves of the collard plant	
Dandelion greens	Leaves of the dandelion plant	
Kale	Leaves of the kale plant	
Mustard greens Leaves of the mustard plant		

Okra	Pods of the okra plant	Whole; cut
Onions	Bulb of the onion plant	Whole; cut
Parsnips	Root of the parsnip plant	Whole; quarters or quartered; slices or sliced; cut; shoestring or French style or julienne
Black-eye peas or black-eyed peas	Seed shelled from pods of the black-eye pea plant, with or without snaps (pieces of immature unshelled pods)	
Field peas	Seed shelled from pods of the field pea plant (other than the black-eye pea plant), with or without snaps (pieces of immature unshelled pods)	
Green sweet peppers	Green pods of the sweet pepper plant	Whole; halves or halved; pieces; dice or diced; strips; chopped
Red sweet peppers	Red-ripe pods of the sweet pepper plant	
Pimientos or pimentos	Red-ripe pods of the pimiento, pimento, pepper plant	Whole; halves or halved; pieces; dice or diced; slices or sliced; chopped
Potatoes	Tuber of the potato plant	Whole; slices or sliced; dice or diced; pieces; shoestring or French style or julienne; French fry cut
Rutabagas	Root of the rutabaga plant	Whole; quarters or quartered; slices or sliced; dice or diced; cut
Salsify	Root of the salsify plant	
Spinach	Leaves of the spinach plant	Whole leaf; cut leaf or sliced; chopped
Sweet potatoes	Tuber of the sweet potato plant	Whole; mashed; pieces or cuts or cut (longitudinally cut halves may be named on labels as halves or halved in lieu of pieces or cuts or cut)
Swiss chard	Leaves of the Swiss chard plant	
Truffles	Fruit of the truffle	
Turnip greens	Leaves of the turnip plant	
Turnips	Root of the turnip plant	Whole; quarters or quartered; slices or sliced; dice or diced; cut

3. Disodium inosinate
4. Disodium guanylate
5. Hydrolyzed vegetable protein
6. Autolyzed yeast extract

In the case of all vegetables, flavoring (except artificial) may be added.

In the case of bean sprouts, lima beans, carrots, green sweet peppers, red sweet peppers, and potatoes, any safe and suitable calcium salts may be added as a firming agent.

In the case of canned artichokes packed in glass containers, ascorbic acid may be added in a quantity not to exceed 32 milligrams per 100 grams of the finished food.

In the case of canned asparagus, ascorbic acid, erythorbic acid, or the sodium salts of ascorbic acid or erythorbic acid may be added in an amount necessary to preserve color in the "white" and "green-tipped and white" color types.

In the case of canned asparagus packed in glass containers, stannous chloride may be added in a quantity not to exceed 15 parts per million calculated as tin (Sn), except that in the case of asparagus packed in glass containers with lids lined with an inert material, the quantity of stannous chloride added may exceed 15 parts per million but not 20 parts per million calculated as tin (Sn).

In the case of canned black-eyed peas, disodium EDTA may be added in a quantity not to exceed 145 parts per million.

In the case of potatoes, calcium disodium EDTA may be added in a quantity not to exceed 110 parts per million.

A vinegar or any safe and suitable organic acid for all vegetables (except artichokes, in which the quantity of such optional ingredient is prescribed by the introductory text) in a quantity which, together with the amount of any lemon juice or concentrated lemon juice that may be added, is not more than sufficient to permit effective processing by heat without discoloration or other impairment of the article.

The name of each canned vegetable is designated in column I of the table.

When two or more forms of the vegetable are specified in column III of the table, the label should bear the specified word or words, showing the form of the vegetable ingredient present; except that in the case of canned spinach, if the whole leaf is the optional form used, the word "spinach" unmodified may be used in lieu of the words "whole leaf spinach."

If the optional ingredient specified is present, the label should bear the statement "____ oil added" or "With added ____oil", the blank being filled in with the common or usual name of the oil.

If asparagus juice is used as a packing medium in canned asparagus, the label should bear the statement "Packed in asparagus juice."

If the optional ingredient specified is present, the label should bear the statement "With snaps."

The name of the food should include a declaration of any flavoring that characterizes the product as specified, and a declaration of any spice or seasoning that characterizes the product; for example, "with added spice," "seasoned with red peppers," "seasoned with butter."

Wherever the name of the vegetable appears on the label so conspicuously as to be easily seen under customary conditions of purchase, the words and statements specified should immediately and conspicuously precede or follow such name, without intervening written, printed, or graphic matter, except that the varietal name of the vegetable may so intervene.

IX. CANNED CHILI SAUCE

Product description. Chili sauce is the product prepared from mature, clean, sound tomatoes of the red or reddish varieties, which are peeled and chopped or crushed, or all (or a portion) of the tomatoes may be chopped, crushed, or macerated and the peelings screened out in a manner so that at least a substantial portion of the seed remains in the product, to which is added salt, spices, vinegar, and nutritive sweetening ingredients, and to which may be added vegetable flavoring ingredients such as chopped onion, chopped green or red pepper, chopped green tomatoes, chopped celery, and sweet pickle relish in such quantities as will not materially alter the appearance of the product with respect to the predominance of the tomato ingredient, and any other ingredients permissible under FDA regulations and standards. The chili sauce is processed in accordance with good commercial practice; is packed in hermetically sealed containers; and is sufficiently processed by heat, before or after sealing, to assure preservation of the product. The refractive index of the filtrate of the chili sauce at 20°C is not more than 1.3784.

A. Ingredients

1. Tomato Pulp

The primary ingredient in chili sauce is red tomatoes. The tomatoes may be hand peeled and broken up by stirring or they may be prepared by any one of a number of machines especially designed for the purpose, or there may be a combination of whole peeled tomatoes and more or less macerated tomatoes from which the peelings have been removed by screening. These machines are usually similar to the tomato pulper or finisher, except that the holes through which the tomato material is forced are usually quite large. They are not nearly as efficient as the usual finishing machine at removing the peeling and defects from the tomatoes. For economic reasons some manufacturers have resorted to using a large amount of cyclone pulp and a small amount of hand peeled or mechanically peeled tomatoes or tomatoes that have been forced through small openings. In general, the more of the larger pieces of tomato material are present, the better the pulp is for chili sauce.

2. Sugar

The use of any of the nutritive sweetening ingredients is permitted in this product. The usual sweetener is sugar (sucrose). The solids of chili sauce are usually brought up higher by the use of sugar and lowered by concentrating the tomatoes than the usual level of solids in catsup. Some manufacturers use as much as $\frac{1}{2}$ more sugar than they do with catsup yet finish at about the same point with respect to soluble solids.

3. Spices, Salt, and Acids

About the same spices are used as in the manufacture of catsup, except that garlic is seldom used in chili sauce. The proportions of the various spice ingredients are not standardized between manufacturers. Salt and vinegar are used in about the same proportions as with catsup.

4. Other Ingredients

The other ingredients, such as onion, bell peppers, celery, and sweet pickle relish, contribute to the flavor of the product and also provide body to the finished product; that is, they provide part of the consistency and most of the chewiness of the finished chili sauce. The ingredients used and the

proportions of the ingredients used vary widely from packer to packer, so quite a variety of flavors can be expected in chili sauces. The onion ingredient is often dehydrated onion flakes. Red or green diced dehydrated peppers are often used.

B. Manufacture

Most important in the manufacture of chili sauce is the preparation of the tomato pulp.

1. Tomato Pulp

Where peeled tomatoes are used for a part or all of the tomato pulp, they are usually taken from the regular canning lines after at least a partial preparation by mechanical or hand peeling, trimming, and coring. There is usually some selection of the raw tomatoes that are to be run through chili sauce preparation machines. Some packers divert very ripe tomatoes that need no trimming to the chili sauce lines, while others box-sort or load-sort the tomatoes and trim them on the conveyer belts. This trimming removes defective parts and stems that would become defects in the sauce. The trimmers may or may not remove most of the green portions of the tomatoes depending on the machinery used and the manufacturer's desires with respect to the appearance of the chili sauce. If green pepper, pickle relish, or green tomatoes are added, green shouldered tomatoes are not usually trimmed. Manufacture consists of combining the ingredients in a manner so that the finished chili sauce will have the desired qualities of color, consistency, finish, absence of defects, and flavor. The tomato pulp, whether from broken peeled tomatoes or from special chili sauce machines, or cyclone juice to which some tomato material containing tomato seed is added, is run to kettles, usually steam jacketed, and reduced by boiling to about one-half the original volume. Concentration in vacuum pans is particularly satisfactory for this operation.

2. Adding Other Ingredients

Onion is often added at the beginning of the boil. The other ingredients may be added at any time, but the sugar is usually added late to prevent caramelization. Spices, if in the form of oils or cream of spice, are usually added late to prevent evaporation of the flavor ingredients.

3. The Finishing Point

Because of the nature of the ingredients there is no accurate means of determining a correct finishing point that will apply to all formulae. The first batches when starting, or after any major change in formula, are dropped when they appear to be about correct. As with tomato catsup, the consistency of the hot sauce may be measured by any suitable device and the refractive index may be taken. Succeeding batches can then be adjusted by these instruments by increasing or decreasing the boiling or by adjusting the amounts of pulp and sugar to the desired result.

4. Processing

Chili sauce is usually closed at about 180 degrees, at which temperature further processing is usually not necessary. Foaming may occur at higher temperatures, and an additional process is usually given if the sauce is closed at lower temperatures.

X. CANNED TOMATOES

Canned tomatoes are the food prepared from mature tomatoes conforming to the characteristics of the fruit *Lycopersicum esculentum* P. Mill, of red or reddish varieties. The tomatoes may or may not be peeled, but they should have had the stems and calyces removed and should have been cored, except where the internal core is insignificant to texture and appearance.

Canned tomatoes may contain one or more of the safe and suitable optional ingredients, be packed without any added liquid or in one of the optional packing media, and be prepared in one of the styles. Such food is sealed in a container, and before or after sealing it is so processed by heat as to prevent spoilage.

Optional ingredients: One or more of the following safe and suitable ingredients may be used:

Calcium salts in a quantity reasonably necessary to firm the tomatoes, but the amount of calcium in the finished canned tomatoes is not more than 0.045 percent of the weight, except that when the tomatoes are prepared in one of the styles specified, the amount of calcium is not more than 0.08 percent of the weight of the food.

A. Organic Acids for the Purpose of Acidification

Dry nutritive carbohydrate sweeteners whenever any organic acid is used, in a quantity reasonably necessary to compensate for the tartness resulting from such added acid

Salt

Spices, spice oils

Flavoring and seasoning

Vegetable ingredients such as onion, peppers, and celery, that may be fresh or preserved by physical means, in a quantity not more than 10 percent by weight of the finished food

B. Packing Media

The liquid draining from the tomatoes during or after peeling or coring

The liquid strained from the residue from preparing tomatoes for canning consisting of peels and cores with or without tomatoes or pieces thereof

The liquid strained from mature tomatoes (tomato juice)

Tomato paste, or tomato puree, or tomato pulp complying with the compositional requirements

C. Styles

Whole

Diced

Sliced

Wedges

D. Name of the Food

The name of the food is "tomatoes," except that when the tomatoes are not peeled the name is "unpeeled tomatoes."

The following should be included as part of the name or in close proximity to the name of the food:

A declaration of any flavoring that characterizes the product as specified.

A declaration of any added spice, seasoning, or vegetable ingredient that characterizes the product [e.g., "with added ____" or "with ____," the blank to be filled in with the word(s) "spice(s)," "seasoning(s)," or the name(s) of the vegetable(s) used or in lieu of the word(s) "spice(s)" or "seasoning (s)" the common or usual name(s) of the spice(s) or seasoning(s) used] except that no declaration of the presence of onion, peppers, or celery is required for stewed tomatoes.

The word "stewed" if the tomatoes contain characterizing amounts of at least the three optional vegetables listed.

The styles: "Diced," "sliced," or "wedges" as appropriate.

The name of the packing medium: "tomato paste," "tomato puree," or "tomato pulp" or "strained residual tomato material from preparation for canning." The name of the packing medium should be preceded by the word "with."

The following may be included as part of the name or in close proximity to the name:

The word "whole" if the tomato ingredient is whole or almost whole, and the weight of such ingredient is not less than 80 percent of the drained weight of the finished food as determined in accordance with the method prescribed.

The words "solid pack" when none of the optional packing media are used.

The words "in tomato juice" if the packing medium is used.

Label declaration. The name of each ingredient used should be declared on the label as required.

The standard of quality for canned tomatoes is as follows:

The drained weight is not less than 50 percent of the weight of water required to fill the container.

The strength and redness of color is not less than that of the blended color of any combination of the color discs.

Blemishes per kilogram (2.2 pounds) of the finished food cover an area of not more than 3.5 cm (0.54 square inch), which is equivalent to 1.6 cm (0.25 square inch) per pound based on an average of all containers examined.

If the quality of canned tomatoes falls below standard with respect to only one of the factors of quality specified, there may be substituted for the second line of such general statement of substandard quality ("Good Food—Not High Grade") a new line to read as follows:

"Poor color" or "Excessive peel" or "Excessive blemishes."

E. Fill of Container

The standard of fill of container for canned tomatoes is a fill of not less than 90 percent of the total capacity of the container.

If canned tomatoes fall below the standard of fill of container, the label should bear the general statement of substandard fill: CANNED TOMATO JUICE

Tomato juice is the food intended for direct consumption, obtained from the unfermented liquid extracted from mature tomatoes of the red or reddish varieties of *Lycopersicum esculentum* P. Mill, with or without scalding followed by draining. In the extraction of such liquid, heat may be applied by any method that does not add water thereto.

Such juice is strained free from peel, seeds, and other coarse or hard substances, but contains finely divided insoluble solids from the flesh of the tomato in accordance with current good manufacturing practice. Such juice may be homogenized, may be seasoned with salt, and may be acidified with any safe and suitable organic acid. The juice may have been concentrated and later reconstituted with water and/or tomato juice to a tomato soluble solids content of not less than 5.0 percent by weight.

The food is preserved by heat sterilization (canning), refrigeration, or freezing. When sealed in a container to be held at ambient temperatures, it is so processed by heat, before or after sealing, as to prevent spoilage.

The name of the food is

"Tomato juice" if it is prepared from unconcentrated undiluted liquid extracted from mature tomatoes of reddish varieties.

"Tomato juice from concentrate" if the finished juice has been prepared from concentrated tomato juice as specified or if the finished juice is a mixture of tomato juice and tomato juice from concentrate.

Label declaration. Each of the ingredients used in the food should be declared on the label as required.

The standard of quality for tomato juice is

The strength and redness of color complies with specific requirement.

Not more than two defects for peel and blemishes, either singly or in combination, in addition to three defects for seeds or pieces of seeds, defined as follows, per 500 milliliters (16.9 fluid ounces):

1. Pieces of peel 3.2 millimeters (0.125 inch) or greater in length.
2. Blemishes such as dark brown or black particles (specks) greater than 1.6 millimeters (0.0625 inch) in length.
3. Seeds or pieces of seeds 3.2 millimeters (0.125 inch) or greater in length.

If the quality of the tomato juice falls below the standard, the label should bear the general statement of substandard quality.

In lieu of such general statement of substandard quality, when the quality of the tomato juice falls below the standard in one or more respects, the label may bear the alternative statement, "Below Standard in Quality ____", the blank to be filled in with the words:

1. "Poor color."
2. "Excessive pieces of peel."
3. "Excessive blemishes."
4. "Excessive seeds" or "excessive pieces of seed."

Fill of container. The standard of fill of container for tomato juice is not less than 90 percent of the total capacity, except when the food is frozen.

If the tomato juice falls below the standard of fill, the label should bear the general statement of substandard fill.

XI. CANNED TOMATO CONCENTRATES, "TOMATO PUREE," "TOMATO PULP," OR "TOMATO PASTE"

Tomato concentrates are the class of foods each of which is prepared by concentrating one or any combination of two or more of the following optional tomato ingredients:

The liquid obtained from mature tomatoes of the red or reddish varieties (*Lycopersicum esculentum* P. Mill).

The liquid obtained from the residue from preparing such tomatoes for canning, consisting of peelings and cores with or without such tomatoes or pieces thereof.

The liquid obtained from the residue from partial extraction of juice from such tomatoes.

Such liquid is obtained by so straining the tomatoes, with or without heating, as to exclude skins (peel), seeds, and other coarse or hard substances in accordance with good manufacturing

practice. Prior to straining, food-grade hydrochloric acid may be added to the tomato material in an amount to obtain a pH no lower than 2.0. Such acid is then neutralized with food-grade sodium hydroxide so that the treated tomato material is restored to a pH of 4.2 ± 0.2. Water may be added to adjust the final composition. The food contains not less than 8.0 percent tomato soluble solids as specified.

The food is preserved by heat sterilization (canning), refrigeration, or freezing. When sealed in a container to be held at ambient temperatures, it is so processed by heat, before or after sealing, as to prevent spoilage.

Optional ingredients. One or any combination of two or more of the following safe and suitable ingredients may be used in the foods:

1. Salt (sodium chloride formed during acid neutralization considered as added salt)
2. Lemon juice, concentrated lemon juice, or organic acids
3. Sodium bicarbonate
4. Water
5. Spices
6. Flavoring

The name of the food is

1. "Tomato puree" or "tomato pulp" if the food contains not less than 8.0 percent but less than 24.0 percent tomato soluble solids.
2. "Tomato paste" if the food contains not less than 24.0 percent tomato soluble solids.
3. The name "tomato concentrate" may be used in lieu of the names "tomato puree," "tomato pulp," or "tomato paste" whenever the concentrate complies with the requirements of such foods; except that the label should bear the statement "for remanufacturing purposes only" when the concentrate is packaged in No. 10 containers (3.1 kilograms or 109 avoirdupois ounces total water capacity) or containers that are smaller in size.
4. "Concentrated tomato juice" if the food is prepared from the optional tomato ingredient described and is of such concentration that upon diluting the food according to label directions as required, the diluted article will contain not less than 5.0 percent by weight tomato soluble solids.

The following should be included as part of the name or in close proximity to the name of the food:

The statement "Made from" or "Made in part from," as the case may be, "residual tomato material from canning" if the optional tomato ingredient is present.

The statement "Made from" or "Made in part from," as the case may be, "residual tomato material from partial extraction of juice" if the optional tomato ingredient is present.

A declaration of any flavoring that characterizes the product and a declaration of any spice that characterizes the product, e.g., "Seasoned with ____," the blank to be filled in with the words "added spice" or, in lieu of the word "spice," the common name of the spice.

The label of concentrated tomato juice should bear adequate directions for dilution to result in a diluted article containing not less than 5.0 percent by weight tomato soluble solids; except that alternative methods may be used to convey adequate dilution directions for containers that are larger than No. 10 containers (3.1 kilograms or 109 avoirdupois ounces total water capacity).

1. Fill of Container

The standard of fill of container for tomato concentrate, as determined by the general method for fill of container, is not less than 90 percent of the total capacity, except when the food is frozen.

XII. TOMATO CATSUP

Catsup, ketchup, or catchup is the food prepared from one or any combination of two or more of the following optional tomato ingredients:

1. Tomato concentrate as described.
2. Lemon juice, concentrated lemon juice, or safe and suitable organic acids may be used in quantities no greater than necessary to adjust the pH.
3. The liquid derived from mature tomatoes of the red or reddish varieties *Lycopersicum esculentum* P. Mill.
4. The liquid obtained from the residue from preparing such tomatoes for canning, consisting of peelings and cores with or without such tomatoes or pieces thereof.
5. The liquid obtained from the residue from partial extraction of juice from such tomatoes. Such liquid is strained so as to exclude skins, seeds, and other coarse or hard substances in accordance with current good manufacturing practice. Prior to straining, food-grade hydrochloric acid may be added to the tomato material in an amount to obtain a pH no lower than 2.0. Such acid is then neutralized with food-grade sodium hydroxide so that the treated tomato material is restored to a pH of 4.2 ± 0.2.

The final composition of the food may be adjusted by concentration and/or by the addition of water. The food may contain salt (sodium chloride formed during acid neutralization should be considered added salt) and is seasoned with optional ingredients (see above).

The food is preserved by heat sterilization (canning), refrigeration, or freezing. When sealed in a container to be held at ambient temperatures, it is so processed by heat, before or after sealing, as to prevent spoilage.

Ingredients. One or any combination of two or more of the following ingredients in each category is added to the tomato ingredients.

1. Vinegars.
2. Nutritive carbohydrate sweeteners.
3. Spices, flavoring, onions, or garlic.
4. Labeling.
5. The name of the food is “Catsup,” “Ketchup,” or “Catchup.”

The following should be included as part of the name or in close proximity to the name of the food:

1. The statement “Made from” or “Made in part from,” as the case may be, “residual tomato material from canning” if the optional tomato ingredient or tomato concentrate containing the ingredient is present.
2. The statement “Made from” or “Made in part from,” as the case may be, “residual tomato material from partial extraction of juice” if the optional tomato ingredient or tomato concentrate containing the ingredient is present.

The name “tomato concentrate” may be used in lieu of the names “tomato puree,” “tomato pulp,” or “tomato paste” and when tomato concentrates are used.

1. Fill of Container

The standard of fill of container for catsup is not less than 90 percent of the total capacity except when the food is frozen, or when the food is packaged in individual serving-size packages containing 56.7 grams (2 ounces) or less.

8
Canned Corn: Standard and Grade

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In the United States, two federal agencies have the responsibility to ensure that the canned vegetables in the market are safe and do not pose any economic fraud. The U.S. Food and Drug Administration (FDA) issues regulations to achieve both goals. The U.S. Department of Agriculture (USDA) issues voluntary guidelines, which, in addition to achieving the same goals, are aimed at facilitating commerce. The information in this chapter has been modified from such regulations and guidelines.

This chapter will present the complete FDA requirements for canned corn (21 CFR 155.130 Canned Corn).

I. IDENTITY

A. Definition

Canned sweet corn is the product prepared from clean, sound kernels of sweet corn packed with a suitable liquid packing medium, which may include water and the creamy component from corn kernels. The tip caps are removed. The product is of the optional styles specified in paragraph B of this section. It may contain one, or any combination of two or more, of the optional ingredients set forth in paragraph C of this section. Such food is processed by heat, in an appropriate manner, before or after being sealed in a container so as to prevent spoilage.

B. Styles

The optional styles referred to in paragraph A of this section consists of succulent sweet corn of the yellow (golden) or white color type, conforming to *Zea mays* L. having sweet corn characteristic as follows:

1. Whole kernel or whole grain or cut kernel consisting of whole or substantially whole cut kernels packed with a liquid medium
2. Cream style consisting of whole or partially whole cut kernels packed in a creamy component from the corn kernels and other liquid or other ingredients to form a product of creamy consistency

C. Optional Ingredients

The following safe and suitable optional ingredients may be used:

1. Salt
2. Monosodium glutamate
3. Disodium inosinate
4. Disodium guanylate
5. Hydrolyzed vegetable protein
6. Autolyzed yeast extract
7. Nutritive carbohydrate sweeteners
8. Spice
9. Flavoring (except artificial)
10. Citric acid
11. Starch or food starch-modified in cream style corn when necessary to ensure smoothness
12. Seasonings and garnishes

a. Mint leaves.
b. Pieces of green peppers or red peppers, or mixtures of both, either of which may be sweet or hot and may be dried, or other vegetables, not exceeding 15 percent by weight of the finished food.
c. Lemon juice or concentrated lemon juice.
d. Butter or margarine in a quantity not less than 3 percent by weight of the finished food. When butter or margarine is added, emulsifiers or stabilizers, or both, may be added. When butter or margarine is added, no spice or flavoring simulating the color or flavor imparted by butter or margarine is used.

D. Labeling

The name of the food is "corn" or "sweet corn" or "sugar corn" and shall include a declaration of any flavoring that characterizes the product as specified in 21 CFR 101.22 and a declaration of any spice, seasoning, or garnishing that characterizes the product, for example, "With added spice," "Seasoned with red peppers," "Seasoned with butter." The name of the food shall also include the following:

1. The optional style of the corn ingredient as specified in paragraph B of this section.
2. The words "vacuum pack" or "vacuum packed" when the corn ingredient is as specified in paragraph B.1 of this section and the weight of the liquid in the container, as determined by the method prescribed in paragraph II.B.1 of this section, is not more than 20 percent of the net weight, and the container is closed under conditions creating a high vacuum in the container.
3. The color type used only when the product consists of white corn.
4. The color type used only when the product consists of white corn.

E. Label Declaration

Each of the ingredients used in the food shall be declared on the label as required by the applicable sections of parts 21 CFR 101, 130.

II. QUALITY

A. The Standard of Quality for Canned Corn

1. When tested by the method prescribed in paragraph II.B of this section, canned whole-kernel corn (paragraph I.B.1 of this section) (a) contains not more than seven brown or black discolored kernels or pieces of kernel per 400 g (14 ounces) of drained weight; (b) contains not more than 1 cubic centimeter of pieces of cob for each 400 g (14 ounces) of drained weight; (c) contains not more than 7 square centimeters (1.1 square inch) of husk per 400 g (14 ounces) of drained weight; and (d) contains not more than 180 mm (7 inches) of silk per 28 g (1 ounce) of drained weight.

2. When tested by the method prescribed in paragraph II.3 of this section, canned cream style corn (paragraph I.B.2 of this section) (a) contains not more than 10 brown or black discolored kernels or pieces of kernel per 600 g (21.4 ounces) of net weight; (b) contains not more than 1 cubic centimeter of pieces of cob per 600 g (21.4 ounces) of net weight; (c) contains not more than 7 square centimeters (1.1 square inch) of husk per 600 g (21.4 ounces) of net weight; (d) contains not more than 150 mm (6 inches) of silk for each 28 g (1 ounce) of net weight; and (e) has a consistency such that the average diameter of the approximately circular area over which the prescribed sample spreads does not exceed 30.5 cm (12 inches), except that when the washed drained material contains more than 20 percent of alcohol-insoluble solids, the average diameter of the approximately circular area over which the prescribed sample spreads does not exceed 25.4 cm (10 inches).

3. (a) The weight of the alcohol-insoluble solids of whole-kernel corn (paragraph I.B.1 of this section) does not exceed 27 percent of the drained weight, when tested by the method prescribed in paragraph II.B of this section. (b) The weight of the alcohol-insoluble solids of the washed drained material of cream style corn (paragraph I.B.2 of this section) does not exceed 27 percent of the drained weight of such material, when tested by the method prescribed in paragraph II.C of this section.

B. Method of Testing

The method referred to in paragraph II.A of this section for testing whole-kernel corn (paragraph I.B.1 of this section)

1. Determine the gross weight of the container. Open and distribute the contents of the container over the meshes of a U.S. No. 8 circular sieve that has previously been weighed. The diameter of the sieve is 20.3 cm (8 inches) if the quantity of the contents of the container is less than 1.36 kg (3 pounds), and 30.5 cm (12 inches) if such quantity is 1.36 kg (3 pounds) or more. The bottom of the sieve is woven-wire cloth that complies with the specifications for such sieve set forth in the "Definitions of Terms and Explanatory Notes" prescribed in "Official Methods of Analysis of the Association of Official Analytical Chemists," 13th ed. (1980), Table 1, "Nominal Dimensions of Standard Test Sieves (U.S.A. Standard Series)," under the heading "Definitions of Terms and Explanatory Notes," which is incorporated by reference. Without shifting the material on the sieve, so incline the sieve at approximately a 17–20 deg. angle to facilitate drainage. Two minutes from the time drainage begins, weigh the sieve and the drained material. Record, in g (ounces), the weight so found, less the weight of the sieve, as the drained weight. Dry and weigh the empty container and subtract this weight from the gross weight to obtain the net weight. Calculate the percent of drained liquid in the net weight.

2. Pour the drained material from the sieve into a flat tray and spread it in a layer of fairly uniform thickness. Count, but do not remove, the brown or black discolored kernels or pieces of

Table 1 Sampling Plan

Acceptable quality level (AQL) 6.5		
	Size of container	
Lot size (primary containers)	*n*	*c*
Net weight equal to or less than 1 kg (2.2 lb)		
4800 or less	13	2
4801 to 24,000	21	3
24,001 to 48,000	29	4
48,001 to 84,000	48	6
84,001 to 144,000	84	9
144,001 to 240,000	126	13
Over 240,000	200	19
Net weight greater than 1 kg (2.2 lb) but not more than 4.5 kg (10 lb)		
2400 or less	13	2
2401 to 15,000	21	3
15,001 to 24,000	29	4
24,001 to 42,000	48	6
42,001 to 72,000	84	9
72,001 to 120,000	126	13
Over 120,000	200	19
Net weight greater than 4.5 kg (10 lb)		
600 or less	13	2
601 to 2,000	21	3
2001 to 7,200	29	4
7201 to 15,000	48	6
15,001 to 24,000	84	9
24,001 to 42,000	126	13
Over 42,000	200	19

n = number of primary containers in sample.
c = acceptance number.

kernel and calculate the number per 400 g (14 ounces) of drained material. Remove pieces of silk more than 12.7 mm (one-half inch) long, husk, cob, and any pieces of material other than corn. Measure the aggregate length of such pieces of silk and calculate the length of silk per 28 g (1 ounce) of drained weight. Spread the husk flat, measure its aggregate area, and calculate the area of husk per 400 g (14 ounces) of drained weight. Place all pieces of cob under a measured amount of water in a cylinder that is so graduated that the volume can be measured to 0.1 cubic centimeter. Take the increase in volume as the aggregate volume of the cob and calculate the volume of cob per 400 g (14 ounces) of drained weight.

3. Comminute a representative 100 g sample of the drained corn from which the silk, husk, cob, and other material that is not corn (e.g., peppers) have been removed. An equal amount of water is used to facilitate this operation. Weigh to the nearest 0.01 g a portion of the comminuted material equivalent to approximately 10 g of the drained corn into a 600 cubic centimeter beaker. Add 300 cubic centimeters of 80 percent alcohol (by volume), stir, cover beaker, and bring to a boil. Simmer slowly for 30 minutes. Fit a Buchner funnel with a previously

prepared filter paper of such size that its edges extend 12.7 mm (one-half inch) or more up the vertical sides of the funnel. The previous preparation of the filter paper consists of drying it in a flat-bottomed dish for 2 hours at 100 deg C, covering the dish with a tight fitting cover, cooling it in a desiccator, and promptly weighing to the nearest 0.001 g. After the filter paper is fitted to the funnel, apply suction and transfer the contents of the beaker to the funnel. Do not allow any of the material to run over the edge of the paper. Wash the material on the filter with 80 percent alcohol (by volume) until the washings are clear and colorless. Transfer the filter paper with the material retained thereon to the dish used in preparing the filter paper. Dry the material in a ventilated oven, without covering the dish, for 2 hours at 100 deg C. Place the cover on the dish, cool it in a desiccator, and promptly weigh to the nearest 0.001 g. From this weight subtract the weight of the dish, cover, and paper as previously found. Calculate the remainder to percentage.

C. Method for Testing

The method referred to in paragraph II.A of this section for testing cream-style corn (paragraph I.B.2. of this section) is as follows: (i) Allow the container to stand at least 24 hours at a temperature of 68 deg F to 85 deg F. Determine the gross weight, open, transfer the contents into a pan, and mix thoroughly in such a manner as not to incorporate air bubbles. (If the net contents of a single container is less than 510 g (18 ounces), determine the gross weight, open, and mix the contents of the least number of containers necessary to obtain 510 g (18 ounces). Fill level full a hollow, truncated cone so placed on a polished horizontal plate as to prevent leakage. The cone has an inside bottom diameter of 7.62 cm (3 inches), inside top diameter of 5.08 cm (2 inches), and height of 12.30 cm ($4\frac{27}{32}$ inches). As soon as the cone is filled, lift it vertically. Determine the average of the longest and shortest diameters of the approximately circular area on the plate covered by the sample 30 seconds after lifting the cone. Dry and weigh each empty container and subtract the weight so found from the gross weight to obtain the net weight. (ii) Transfer the material from the plate, cone, and pan onto a U.S. No. 8 sieve as prescribed in paragraph II.B.1 of this section. The diameter of the sieve is 20.3 cm (8 inches) if the quantity of the contents of the container is less than 1.36 kg (3 pounds), and 30.5 cm (12 inches) if such quantity is 1.36 kg (3 pounds) or more. Set the sieve in a pan. Add enough water to bring the level within 9.53 mm (three-eighth inch) to 6.35 mm (one-fourth inch) of the top of the sieve. Gently wash the material on the sieve by combined up-and-down and circular motion for 30 seconds. Repeat washing with a second portion of water. Remove sieve from pan, incline to facilitate drainage, and drain for 2 minutes. (iii) From the material remaining on the U.S. No. 8 sieve, count, but do not remove, the brown or black discolored kernels or pieces of kernel and calculate the number per 600 g (21.4 ounces) of net weight. Remove pieces of silk more than 12.7 mm (one-half inch) long, husk, cob, and other material which is not corn (i.e., peppers). Measure aggregate length of such pieces of silk and calculate the length per 28 g (ounce) of net weight. Spread the husk flat and measure its aggregate area and calculate the area per 600 g (21.4 ounces) of net weight. Place all pieces of cob under a measured amount of water in a cylinder that is so graduated that the volume may be measured to 0.1 cubic centimeter. Take the increase in volume as the aggregate volume of the cob and calculate the volume of cob per 600 g (21.4 ounces) of net weight. Take a representative 100 g sample of the material remaining on the U.S. No. 8 sieve (if such material weighs less than 100 g, take all of it) and determine the alcohol-insoluble solids as prescribed in paragraph II.B.3 of this section for whole kernel corn.

D. Determine Compliance as Specified in Sec. 155.3(b).

E. Quality of Canned Corn

If the quality of canned corn falls below the standard prescribed in paragraph II.A of this section, the label shall bear the general statement of substandard quality specified in 21 CFR 130.14 (a), in the manner and form therein specified; however, if the quality of the canned corn falls below standard with respect to only one of the factors of quality specified by paragraphs II.A.1 (a) to (d) of this section, or by paragraphs II.A.2 (a) to (e) of this section, there may be substituted for the second line of such general statement of substandard quality, "Good food—not high grade," a new line as specified after the corresponding subdivision designation of paragraph II.A of this section, which the canned corn fails to meet:

1(a) or 2(a) "Excessive discolored kernels."
1(b) or 2(b) "Excessive cob."
1(c) or 2(c) "Excessive husk."
1(d) or 2(d) "Excessive silk."
2(e) "Excessive liquid."

III. FILL OF CONTAINER

A. The Standard of Fill of Container for Canned Corn is

1. Except in the case of vacuum pack corn the fill of the corn ingredient and packing medium, as determined by the general method for fill of container prescribed in 21 CFR 130.12(b) of this chapter, is not less than 90 percent of the total capacity of the container.

2. In whole kernel corn, the drained weight of the corn ingredient, determined by the procedure set forth in 21 CFR 155.3, shall not be less than 61 percent of the water capacity of the container.

B. Determine Compliance as Specified in Sec. 155.3(b).

C. If canned corn falls below the standard of fill of container prescribed in paragraphs III.A and B of this section, the label shall bear the general statement of substandard fill specified in 21 CFR 130.14(b), in the manner and form therein specified.

For a food processor to comply with the above requirements for standardized canned corn, the FDA has provided the following definitions (21 CFR 155.3).

For the purposes of this part:

1. The procedure for determining drained weight is set forth in the *Official Methods of Analysis of the Association of Official Analytical Chemists*, 13th ed. (1980), Secs. 32.001–32.003, which is incorporated by reference.

2. Compliance means the following: unless otherwise provided in a standard, a lot of canned vegetables shall be deemed in compliance for the following factors, to be determined by the sampling and acceptance procedure as provided in paragraph IV of this section, namely:

a. Quality. The quality of a lot shall be considered acceptable when the number of defectives does not exceed the acceptance number (IV) in the sampling plans.
b. Fill of container. A lot shall be deemed to be in compliance for fill of container (packing medium and vegetable ingredient) when the number of defectives does not exceed the acceptance number (IV) in the sampling plans.

c. Drained weight. A lot shall be deemed to be in compliance for drained weight based on the average value of all samples analyzed according to the sampling plans.

IV. THE SAMPLING AND ACCEPTANCE PROCEDURE

A. Definitions

1. Lot. A collection of primary containers or units of the same size, type, and style manufactured or packed under similar conditions and handled as a single unit of trade.
2. Lot size. The number of primary containers or units in the lot.
3. Sample size. The total number of sample units drawn for examination from a lot.
4. Sample unit. A container, a portion of the contents of a container, or a composite mixture of product from small containers that is sufficient for the examination or testing as a single unit. For fill of container, the sample unit shall be the entire contents of the container.
5. Defective. Any sample unit shall be regarded as defective when the sample unit does not meet the criteria set forth in the standards.
6. Acceptance number (c). The maximum number of defective sample units permitted in the sample in order to consider the lot as meeting the specified requirements.
7. Acceptable quality level (AQL). The maximum percent of defective sample units permitted in a lot that will be accepted approximately 95 percent of the time.

B. Sampling Plans

See Table 1.

9
Fermentation: Principles and Microorganisms

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I. INTRODUCTION

The use of microorganisms to process or preserve foods is an ancient technique. Yeast was the first microorganism used in the production of wine and beer and the leavening of dough. These techniques have been known for at least 4000–5000 years. When these processes are underway, bubbles form as in gentle boiling. This bubbling is due to the liberation of carbon dioxide from the degradation of sugar. The word fermentation signifies the gentle bubbling or boiling condition in these processes.

The nature of the fermentation reaction did not become clearly understood until the late part of the nineteenth century when Louis Pasteur discovered the relationship between living cells and fermentation. In 1854, Pasteur demonstrated the relationship between yeast and this reaction. The word fermentation became associated with microorganisms. Pasteur also showed that true fermentation occurs only in the absence of free oxygen. He called life without air anaerobiosis. Actually, the definition of fermentation in biochemistry is the extraction of energy from carbohydrates and other organic substrates without using O_2 as an electron acceptor. Hence fermentation is an energy-yielding catabolic pathway that proceeds with no net change in the oxidation state of the products compared to that of the substrate. The common usage of the word fermentation frequently overlooks the strict biochemistry definition. A broad sense was adopted, that is, a process in which microorganisms produce chemical changes in organic substrates through the action of enzymes produced by these microorganisms. According to the common usage, the term fermented foods is used to describe a special class of foods that contain a complex mixture of carbohydrates, proteins, fats, etc., undergoing simultaneous modification under the action of a variety of microorganisms and enzymes. Reactions involving carbohydrates and carbohydratelike materials are referred to as fermentative. Changes in proteinaceous materials are designated proteolytic, and the breakdown of fatty substances are described as lipolytic. When complex foods are fermented under natural conditions, they invariably undergo different degrees of each type of change. Whether fermentative, proteolytic, or lipolytic end products dominate will depend upon the nature of the food, the types of microorganisms present, and the environmental conditions affecting their growth and metabolic patterns.

The basic concept of fermentation is to facilitate the proliferation and predomination of desirable microorganisms in raw plant materials. The desirable microorganisms will metabolize sugars into chemicals such as lactate, ethanol, and acetate that infuse the plant materials with various characteristics. The addition of salt and the inoculation of a defined microbial culture are

the two basic methods for controlling the growth of microorganisms during fermentation. In this chapter, we will describe the predominant bacterial strains occurring in some popular fermented vegetables, illustrate their sugar metabolic reactions, and discuss how fermentation is manipulated with these organisms.

II. THE FERMENTATION OF VEGETABLES

At present only cabbage (sauerkraut and Korean kimchi), cucumbers (pickles), and olives are of real economic importance. In this chapter, the discussion is focused on these vegetable products. In addition to these vegetables, fermented carrots, the potential new products, and fermented bamboo shoots will be described.

A. Cabbage Fermentation

Sauerkraut is a fermented product made from fresh cabbage. In the cabbage fermentation process lactic acid bacteria are favored. The addition of 2.25–2.5% salt restricts the activities of undesirable gram-negative bacteria. The fermentation is started by *Leuconostoc mensenteroids.* This bacterium converts sugar to lactic acid, acetic acid, alcohol, CO_2, and other products that contribute to the flavor of sauerkraut. CO_2 helps maintain the anaerobic conditions necessary in fermenting cabbage. As the acids accumulate, *Leu. mensenteroids* is inhibited, but the fermentation continues with *Lactobacillus brevis, Pediococcus cerevisiae*, and finally, *Lactobacillus plantarum. Lb. plantarum* and *Lb. brevis* effect the final stages of sauerkraut production. *P. cerevisiae* and *Enterococcus faecalis* may also contribute to product development (1).

Kimchi is a traditional Korean fermented vegetable product. Kimchi fermentation is the Korean method for preserving a fresh and crispy vegetable texture for consumption during the winter, when fresh vegetables are not available. Although the history of kimchi fermentation in Korea can be traced to the 3rd and 4th centuries, the earliest description of the processing methods is found in 17th century works of literature (2). A fresh cabbage is cut in half or shredded, soaked in brine with an approximately 10% salt concentration overnight, and then washed and drained. The minor ingredients (garlic, red pepper, green onion, ginger) are chopped and mixed with shredded radish and stuffed between the salted cabbage leaves. The kimchi is packed in an earthen jar, buried in the ground, and pressed with a stone placed inside in order to keep the ingredients immersed in the juice. Before ripening, *Lu. mensenteroides* is the dominant microorganism, while *Lactobacillus* spp. are the major organisms in over-ripened kimchi. *Lactobacillus* species may be dominant in the later stages of kimchi fermentation depending on the temperature (2).

The difference between sauerkraut and kimchi is that of the of fermentation end-point. The best-tasting kimchi is attained before *Lb. brevis* and *Lb. plantarum* overgrowth occurs with an optimal pH of 4.5. The *Lb. brevis* and *Lb. plantarum* overgrowth diminishes the product quality, but sauerkraut production depends on these organisms.

B. Cucumber Fermentation

In the natural fermentation of pickles, selected cucumbers are placed in brine with about 5% NaCl. The brine strength is gradually increased during fermentation until it reaches around 16% NaCl. The sugars that diffuse from the cucumbers are fermented sequentially by *Leu. mensenteroides*, *P. cerevisiae*, *Lb. brevis*, and *Lb. plantarum*. Depending on the fermentation condition, about 0.6 to 1.2% lactic acid is formed in about 7 to 14 days. When the pH is lowered to

3.2, the metabolism of *Lb. plantarum* is inhibited and the fermentation is completed. In this process, the high salt level is used to protect against spoilage. The fermented cucumber must be desalted before being used in products. However, the NaCl level in the desalting solution creates a serious dumping problem. Procedures have been developed for brining cucumbers in closed anaerobic tanks at substantially lower salt concentrations (3). This approach to fermentation may allow cucumber fermentation and storage at sufficiently low salt concentrations that require no desalting.

In natural fermentation, bloating in defective pickles often occurs. Bloating is due to the accumulation of CO_2 gas inside the cucumber during fermentation. The respiration of cucumber tissue and fermentation by *P. cerevisiae* and *Lb. plantarum* produces sufficient CO_2 to cause bloating (4). The degradation of malic acid to lactic acid is a major source of CO_2 when *Lb. plantarum* ferments brined cucumbers. Research has demonstrated that using a mixed culture with a malolactic-deficient mutant and normal malolactic strain of *Lb. plantarum* in brined cucumber fermentation could reduce the level of released CO_2 (5).

In cucumber fermentation, yeasts have conventionally been viewed as undesirable because it produces CO_2. However, when N_2 is used in purging cucumber fermentation tanks to prevent bloater damage, using yeast (*Saccharomyces cerevisiae* or *S. rosei*) in the mixed culture can facilitate complete sugar metabolization (6).

Softening in defective pickles is another problem. Softening is attributed to pectinolytic enzymes that degrade the cucumber tissue. The source of these enzymes may be the microorganisms growing in or on the cucumbers. To reduce fermentation defects, a controlled fermentation process is used. The controlled fermentation method employs a chlorinated brine with a 25° salinometer, acidification with acetic acid, the addition of sodium acetate, and inoculation with *P. cerevisiae* and *Lb. plantarum* (7).

C. Olive Fermentation

Olive fermentation is similar to that in sauerkraut except that the olives are soaked in a 1.6 to 2.0% lye solution before brining. The lye treatment is necessary to remove oleuropein, a bitter factor in olives. The olives are brined in containers following the complete removal of lye by rinsing the olives in fresh water. The brine concentration varies from 5 to 15%, depending on the variety and size of the olives (8). Lactic acid bacteria become prominent during the intermediate stage of fermentation. *Leu. mensenteroides* and *P. cerevisiae* are the first lactic acid bacteria to become prominent. These bacteria are followed by lactobacilli, with *Lb. plantarum* and *Lb. brevis* being the most important (9). The lye treatment may affect the microbial flora. Inoculation with *Lb. plantarum* may be required. A study has showed that using a strain of *Lb. plantarum* with the capability to produce bacteriocin as a starter controls lactic acid fermentation much better (10). The entire fermentation process may take 2 weeks to several months. The acid content of the final product varies from 0.18 to 1.27% (11).

D. Carrot Fermentation

Carrots are not a traditional vegetable for fermentation. Until 1969, carrots were fermented using a home-based process (12). Fermentation provides a simple method of preserving raw carrots. The raw carrot slices contain a high level of reducing sugar that might cause Maillard reactions and produces dark compounds with a burnt smell during thermal processes. Using lactic acid fermentation, the reducing sugar content in the raw carrot can be decreased to a level that allows

the carrot slices to be processed using hightemperature deep frying to yield chips. The deep-fried carrot chips have a light red–yellow color and pleasant taste that makes them a potential new product (13).

A mixed culture of *Lb. plantarum*, *Lb. brevis*, P. cerevisiae, and *Leu. mesenteriodes* is used to ferment carrots (14). Use of carrot-adapted inocula significantly reduced the lag period for early acid production despite the salt concentration. The repressive effects of increased salt concentrations on the rate of fermentation means that carrots treated with the lowest level of salt, 1.5%, require only 10 days incubation to produce a 1.0% acid level, whereas a 3.0% salt concentration requires 18 days incubation to reach a similar acid value. The acidic properties of fermented brines resemble the fermentation properties of the cabbage head brining solution (15).

A new process for carrot fermentation using an alkaline treatment with lye before inoculating a pure culture of *Lb. plantarum* was developed (16). The alkaline treatment helps inoculum establishment over the natural flora in the fermentation. However, most of the sucrose remains unmetabolized after 7 days of fermentation. Thus long-term stability in the fermented carrots is not ensured. A high risk of secondary fermentation may present in the package product. This process was further modified using a mixed culture of *Lb. plantarum* and *S. cerevisiae* to replace the single culture of *Lb. plantarum.* The result indicated that the mixed culture was able to completely use up all of the sugars and, at same time, improve the flavor of the fermented carrots (17).

E. Bamboo Shoot Fermentation

People in the bamboo-growing regions of Asia have traditionally consumed fermented bamboo shoots. The dried Ma bamboo (*Dendrocalamus latiflorus*) shoot is a special product of Taiwan (18). Mesu is a similar product from India (19). Both are produced by using nonsalted fermentation with natural cultures.

Using mesu as a pickle and as the base for curry is a tradition in the Darjeeling hills and Sikkim area of India. A study has shown that a total of 327 strains of lactic acid bacteria, representing *Lb plantarum* and *Lb. pentosaceus* were isolated from 30 samples of mesu. These species were present in all of the raw bamboo shoot samples tested. Mesu is dominated by *Lb. plantarum* followed by *L. brevis. P. pentosaceus* was isolated less frequently and recovered from only 40–50% of the mesu samples. Fermentation is initiated by *P. pentosaceus*, followed by *L. brevis*, and finally succeeded by *L. plantarum* species. During the fermentation, the titratable acidity increased from 0.04 to 0.95%, resulting in a decline in pH from 6.4 to 3.8 (20). Ma-bamboo shoots are fermented using a traditional natural culture. After 10 days of fermentation, the fermented bamboo shoots contain about 10^9cfu/g of lactic acid bacteria, and 10^4–10^6 cells/g of yeast and mold. The final pH was 3.3 to 4.1, and the titratable acid was 1.05–1.20% (19).

III. FERMENTATION TECHNIQUES

The procedures for vegetable fermentation are varied and complicated. Basically, vegetable fermentation can be considered as a three-staged process.

A. Stage 1: The Pretreatment Steps

In this stage, the common operations include sorting and grading raw vegetables, cleaning the selected vegetables, specific pretreatment, such as peeling carrots, blanching green beans, shredding cabbage, or lye-treating olives.

B. Stage 2: The Fermentation Environment Adjustment Operation

Adding salt and inoculating the defined starter culture are two methods to set up a suitable environment around the vegetables to allow the desirable microflora to proliferate and predominate. Salt addition is necessary in most kinds of vegetable fermentation. The major contributions of salt are to inhibit the growth of pathogens and destructive spoilage microorganisms, to exert a selective effect on the microorganisms present on vegetables, to enhance the release of tissue fluids from the fermenting vegetables, and to impose a special flavor on the fermented vegetables. The amount of salt used depends on the particular vegetables. In the fermentation of cucumbers and olives, the salt concentration is 5–8% at equilibrium. For cabbages, the salt concentration is less than 2.5% at equilibrium. The difference in salt concentration between that used in sauerkraut fermentation and that used in pickle fermentation probably accounts for the difference in the types of lactic acid bacteria that grow in each fermentation environment (21).

The application of a defined starter culture is an another method of facilitating the predomination of desirable microflora in the fermenting vegetables. The lactic acid bacteria used for this purpose include *Lactobacillus* species (*Lb. plantarum* and *Lb. casei* are the most often used.), *Lactococcus lactis*, and *Leu. mensenteroides.* The defined starter cultures are capable of growing rapidly and are highly competitive under the environmental conditions used to ferment products.

C. Stage 3: The Vegetable Fermentation Process

Temperature, pH value, and anaerobiosis maintenance are major factors that influence the course of fermentation. The temperature range for vegetable fermentation is 16 to 35°C. Vegetables fermenting at 10°C lead to good quality products. Usually, the optimal temperature is between 15 and 20°C. Various microorganisms may dominate a mixed fermentation depending on the temperature. For sauerkraut fermentation, the preferred temperature is 18°C or lower. The predominant strain *Leu. mensenteroides* grows optimally at a lower temperature than the homofermentative *Lb. plantarum*, presumably resulting in a higher ratio of volatile to nonvolatile acids than at higher temperatures. For cucumber fermentation, the predominant cultures of *P. pentosaceus* and *Lb. plantarum* are capable of rapid growth at 18°C (22). The optimal temperature for vegetable fermentation depends on the predominant cultures during the fermentation.

The buffering capacity of the vegetable affects the extent of proliferation of the predominant culture used to ferment the natural sugars. Several methods have been adopted to maintain the pH during fermentation. Sodium acetate (23) and calcium acetate (24) have been used as buffering agents to assure complete sugar utilization during the primary fermentation of cucumbers. Acid neutralization during fermentation with a pH controller has also been used to assure complete sugar utilization (25). In the fermentation of carrots, sodium hydroxide treatment of peeled and trimmed carrots is a useful alternative to pasteurization to achieve controlled fermentation. Subsequent neutralization of the NaOH by adding acetic acid to the brine could lead to the formation of a buffer system in the brine. The buffer system benefits greater utilization of the fermentable sugars by the starter culture (26). For preserving fermented vegetables for long periods of time, the pH should be controlled below 4.0 (27).

During fermentation, to maintain anaerobic conditions the plant materials must be totally covered by the brine in the vessels. Open filled vessels are normally covered with plastic sheets or wooden plates weighted down with stones or heavy matter to exclude oxygen from the air. For

cucumber fermentation, anaerobic tanks provide more suitable anaerobic conditions (23). Anaerobic tanks replaced open tanks in the olive fermentation industry of the USA and Spain many years ago (28).

IV. VEGETABLE FERMENTATION MICROORGANISMS

Fresh plant material harbors numerous and varied types of microorganisms. The microflora in vegetables and fruits is largely made up of *Pseudomonas* spp., *Erwinia herbicola*, *Flaeobacterium*, *Xanthomonas*, and *Enterobacter agglomerans* as well as various molds. Lactic acid bacteria such as *Leu. mesenteroids* and *Lactobacillus* spp. are also commonly found, as are several species of yeasts (29). Between 40 and 75% of the bacterial flora in peas, snap beans, and corn was shown to consist of leuconostocs and streptococci, whereas many of the gram-positive, catalase-positive rods resembled corynebacteria (30,31). An analysis of 30 different samples of white cabbage from four growing seasons has shown that the microflora normally is dominated by aerobic bacteria (e.g., pseudomonads, enterobacteria, and coryneforms) and yeasts, while lactic acid bacteria represent 0.15 to 1.5% of the total bacterial population (32). Vegetable fermentation involves controlling specific microorganisms or a succession of microorganisms that dominate the microflora in vegetables. Although lactic acid bacteria are present as a small population, the metabolic activities of this microorganism are indispensable in the vegetable fermentation process. Lactic acid fermentation is the most important contribution to the fermentation of vegetables.

A. The Major Lactic Acid Bacteria in Vegetable Fermentation

The major lactic acid bacteria involved in vegetable fermentation are located in three genera, *Lactobacillus*, *Leuconostoc*, and *Pediococcus.* Among the lactobacilli, several species and strains have been isolated from fresh vegetables. These include the homofermentative species *Lb. plantarum*, *Lb. casei*, *Lb. arabinosus*, and *Lb. homohiochii*, and the heterofermenters *Lb. brevis*, *Lb. fermentum*, and *Lb. buchneri.* The genus *Pediococcus* comprises two species, *P. pentosaceus* and *P. acidilactici.* Currently, *Leuconostoc* comprises a single species, *Leu. mensenteroides* (33).

The lactic acid bacteria share some common features: they are Gram-positive; mesophilic, but some can grow at temperatures as low as 5°C or as high as 45°C; growing at pH 4.0–4.5, (some are active at pH 9.6 and others at pH 3.2); generally weakly proteolytic and lipolytic and require preformed amino acids, purine and pyrimidine bases, and B vitamins for growth; do not contain a citric acid cycle or a cytochrome system so no energy is derived from oxidative phosphorylation, but energy is obtained via substrate level phosphorylation during the fermentation of sugars into lactic acid, ethanol or acetate, and CO_2.

There are four important species of lactic acid bacteria associated with vegetable fermentation: *Leu. mensenteroides*, *Lb brevis*, *P. pentosaceus*, and *Lb plantarum.* These species are successively predominant during sauerkraut fermentation in the approximate order listed (7). *Lb brevis*, P. pentosaceus, and *Lb plantarum* have also been reported to ferment cucumbers (34) and olives (35). The properties of these four species are described as follows.

1. *Leu. mensenteroides*

The colorless bacterial cell is spherical or egg-shaped and appears usually in pairs. The size of the bacterium is 0.5–0.7 μm. *Leuconostoc* is distinguished among the lactic acid bacteria in being heterofermentative and also in lacking aldolase, a key enzyme in glycolysis. Under anaerobic

conditions, this bacterium metabolizes glucose via the phosphoketolase pathway and produces D-lactate. At the temperature range of 20 to 25°C, this bacterium produces dextrans from sucrose. This bacterium is capable of metabolizing citrate into CO_2 and diacetyl, which is an important flavor component in many dairy products.

2. *Lb. plantarum*

Lb. plantarum is the final and predominant lactic acid bacterium species at the completion of fermentation in many vegetables. This is attributed to its metabolic diversity and its tolerance for low pH conditions. The optimal growth temperature for this bacterium is 30°C. The bacterial cell is a short to medium rod usually single, but sometimes in pairs or short chains. The size of the bacterium is 0.9–1.2 (width) × 3–8 (length) μm. This bacterium is classified as a facultative heterofermenter according to the metabolism of hexoses (36). It possesses both aldolase and phosphoketolase. Its homofermentative action on glucose with aldolase results in producing up to 1.5% DL-lactate. The lactate can be further metabolized to acetoin, formate, and acetate under certain conditions. In the heterofermentation of pentose via the phosphoketolase pathway, this bacterium produces lactate, acetate, and CO_2. Strains are often adopted as acid producers in starter cultures. This bacterium is the first species recognized to possess the unique ability to protect against oxygen-free radicals by a nonenzymatic superoxide reduction mediated by manganese (37).

3. *Lb. brevis*

This bacterium has a short rod shape, occurring singly or in short chains. The size of the rod cell is 0.7–1.0 (width) × 2.0–4.0 (length) μm. The optimal temperature for growth is 30°C. This bacterium is heterofermentative and metabolizes glucose to DL-lactate, ethanol, acetate, and CO_2. This bacterium is able to reduce fructose to mannitol.

4. *P. pentosaceus*

This is a spherical bacterium, occurring in pairs, tetrads, or clusters. The size of the coccus is 0.8–1.0 μm in diameter. This bacterium cannot grow at temperatures over 45°C. The optimum growth temperature is in the range of 28–30°C. The optimum and final pHs are 6.5–6.0 and 4.0, respectively. This bacterium is homofermentative and produces DL-lactate from glucose. Most strains ferment arabinose, ribose, maltose, fructose, galactose, and glucose to produce DL-lactate. Strains that are capable of fermenting xylose and lactose are known. Some strains produce bacteriocins during fermentation.

B. The Lactococci in Vegetable Fermentation

Although lactococci are not major lactic acid bacteria in the fermentation of vegetables, these bacteria support the fermentation with proteolytic activity (38) and the capability to break down citrate (39). Recently, some strains of *Lactococcus lactis* subsp. *lactis* with the capability of producing bacteriocin were isolated from minimally processed fresh vegetable and fruit products. Some researchers have used these bacteriocin-producing lactococcal cultures as biopreservative in minimally processed fresh vegetables and fruits (40,41). Lactococci are spherical or ovoid cells that occur singly, in pairs, or as chains. They grow at 10°C but not at 45°C. They are homofermentative and produce L-lactate as the predominant end product of sugar fermentation.

C. The Yeasts in Vegetable Fermentation

Various groups of yeasts are present at the beginning of vegetable fermentation. Sometimes, these yeasts become predominant in the fermentation. For example, in the fermentation of olives, yeasts are the predominant microorganisms in spontaneous fermentation, because the polyphenol compounds in olives affect the microflora by inhibiting the growth of lactic acid bacteria but not yeasts (42). As a result, the final product has a shriveled form and a high salt content, and the principal bitterness does not disappear completely from the product. To limit the negative effects of yeast on the product quality, it is necessary to remove the polyphenols, acidify the cover brine, and lower the salt content to enhance lactic acid bacterial growth (43). It is well known that yeast can proliferate under low pH conditions, which usually inhibits the growth of lactic acid bacteria. In the spontaneous fermentation of tart carambola, which contains affluent organic acid with a pH is as low as 1.37–2.01, the yeasts *Candida pelliculosa*, *C. inconspicua*, *C. ciferrii*, and *S. cerevisiae* become predominant in the brine with 7–10% salt (44). In cucumber fermentation, yeasts can affect the fermentation by utilizing sugars that would otherwise be metabolized to lactic acid by the lactic acid bacteria. The yeasts can also utilize the produced lactic acid, raise the pH, and allow other microorganisms to grow. The yeasts produce large amounts of gas. This is associated with pickles that are bloated or have hollow defects. Although fermentative yeasts have been viewed as undesirable in vegetable fermentation, yeasts may facilitate the removal of fermentable sugars. In cucumber fermentation, when N_2 is used to purge the cucumber fermentation tanks to prevent bloater damage, a selected yeast (*S. cerevisiae* or *S. rosei*) in a mixed culture with *Lb. plantarum* can help to exhaust the fermentable sugars rapidly and improve the quality of the products (6).

V. FERMENTATION BIOCHEMISTRY

Lactic acid bacteria are the dominant microflora in most fermented vegetables. Under normal food fermentation conditions, the main product from lactic acid bacteria metabolism is lactic acid with other products formed as by-products, such as acetic acid, acetaldehyde, ethanol, and diacetyl. All of these products contribute to control the growth of spoilage microorganisms and the specific flavor of the fermented products. Lactic acid bacteria are divided into two groups based on glucose metabolism end products. Those that produce lactic acid as the major or sole product of glucose fermentation are designated homofermentative. *Pediococcus*, *Lactococcus*, and some lactobacilli belong to this group (homolactics). Those organisms that produce equal molar amounts of lactate, carbon dioxide, and ethanol from hexoses are designated heterofermentative. *Leuconostoc* and some lactobacilli are heterofermentative (heterolactics). The major metabolic pathways of these organisms are described as follows.

A. Carbohydrate Metabolism

In general, approximately 75% of the solids in plants are carbohydrates. Total carbohydrates generally consist of simple sugars, starches, pectic substances, lignin, and cellulose. Cellulose, pectic substances, and lignin occur in all plants as the principal structural components of the cell walls. These structural polysaccharides contribute greatly to the characteristic texture of plant foods. These structural polysaccharides are usually not fermentable. The most common fermentable carbohydrates in vegetables are glucose, fructose, sucrose, and starch.

1. Glucose Metabolism

Glucose is the major fermentable sugar in vegetables. Homolactics metabolize glucose via the glycolytic pathway to yield pyruvate. Pyruvate is further reduced to lactic acid via the enzyme lactate dehydrogenase. The pathway that converts glucose to lactic acid is called lactic acid fermentation.

Heterolactics produce lactic acid via the phosphoketolase pathway. This pathway involves the initial splitting of CO_2 from the glucose molecule, followed by a further splitting of the resulting pentose (xylulose-5-phosphate) into two-carbon and three-carbon fragments in a phosphoroclastic reaction catalyzed by phosphoketolase, yielding glyceraldehyde-3-phosphate and acetylphosphate, respectively. The three-carbon fragment is eventually reduced to lactate in the same way as homolactics, and the two-carbon fragment is reduced to ethanol. Products other than lactate are generated, and the pathway is therefore called the heterofermentative pathway. Because lactic acid bacteria lack functional heme-linked electron transport chains and a functional Krebs cycle, they obtain energy via substrate level phosphorylation. In the heterofermentative pathway, 1 mole of ATP is produced per mole of glucose metabolized compared with 2 mol in the homofermentative pathway. Thus the fermentation of glucose via the heterofermentative pathway is only half as efficient as in the homofermentative pathway.

2. Fructose Metabolism

Fructose is the second major sugar substrate for lactic acid fermentation in vegetables. Lactic acid bacteria contain fructokinase and phosphoglucoisomerase to phosphorylate fructose to fructose-6-phosphate and then isomerize to glucose-6-phosphate. In the homofermentative pathway, glucose-6-phosphate is further metabolized to pyruvate via glycolysis. The pyruvate is then reduced to lactate via lactate dehydrogenase. In contrast to homolactics, heterolactics contain mannitol dehydrogenase, which catalyzes the reduction of fructose to mannitol and oxidizes NADH under anaerobic conditions (45). In this reaction a small amount of fructose is used as an electron acceptor with the remaining fructose converted to lactate, ethanol, acetate, and CO_2 (46).

3. Sucrose Metabolism

The sucrose content is less than the glucose and fructose content in most vegetables. The metabolism of sucrose in vegetable fermentation is usually incomplete in the final stage. For example, when beets containing 3.8% sucrose were fermented using *Lb. plantarum* for 12 days, the fermented beets still contained 2.8% residual sucrose. Using the same starter to ferment carrots for 35 days, 1.96% of the sucrose was reduced to 0.91%, but the glucose and fructose in the fermented carrots were exhausted at the same time (47). Sucrose does not seem to be an optimal fermentable sugar for lactic acid bacteria. Actually, only a few lactic acid bacteria possess the ability to ferment sucrose. A screen test report showed that among 14 strains of lactic acid bacteria, *Lb. cellobiosus* appeared to be the only species that metabolizes all of the sucrose in green bean juice. Under the same conditions, *Lb. buchnerii*, *Lb. fermentum*, and *Leu mensenteroides* ferment about half of the sucrose in green bean juice (48). These lactic acid bacteria are able to hydrolyze sucrose with β-glucosidase. These products, glucose and fructose, can be metabolized via the pathways previously mentioned.

4. Starch Metabolism

The starch content in most fermented vegetables is limited, hence the amylolytic ability of lactic acid bacteria is a characteristic with little demand. Although hydrolyzing starch to simple sugars is not important in traditional fermented vegetables, a few amylolytic lactic acid bacteria have been

isolated from starchy raw materials. An investigation of Mexican pozol, a fermented maize dough, indicates that lactic acid bacteria accounted for 90–97% of the total active microflora. Strains of lactic acid bacteria were isolated and identified, including *Leu mesenteroides*, *Lb. plantarum*, *Lb. confusus*, *L. lactis*, and *L. raffinolactis* (49). From sour cassava starch fermentation, *Lb. plantarum* and *Lb. manihotivorans* were isolated. *Lb. manihotivorans* grows and converts starch into lactic acid more rapidly and efficiently than *Lb. plantarum* (50,51). During fermentation, these amylolytic lactic acid bacteria degrade the starch first, and then the resulting sugars allow a secondary flora to develop. An acidophilic starch hydrolyzing enzyme secreted from a strain of *L. plantarum* was isolated and partially purified. This enzyme has a molecular mass of approx. 230 kDa and is capable of hydrolzsing soluble starch, amylopectin, glycogen, and pullan. The major reaction products from soluble starch were maltotriose, maltotetraose, and maltopentaose. These reaction products suggest that this enzyme may hydrolyze both α-1,6- and α-1,4-glucosidic linkages (52).

B. Organic Acid Metabolism

Citrate and malate are the most abundant organic acids in plants. Citrate metabolism is important in fermented dairy products, while malate metabolism is important in wine.

The organisms responsible for citrate metabolism in starter cultures are leuconostoc and Cit^+ lactococci. Citrate is hydrolyzed to oxaloacetate and acetate by citrate lyase. Citrate lyase is inducible in leuconostocs and constitutive in Cit^+ lactococci (53). The oxaloacetate is decarboxylated to pyruvate, which can undergo several further transformations to diacetyl, acetoin, and 2,3-butylene glycol (54).

Malic acid is fermentable by lactic acid bacteria. Both homolactics and heterolactics are able to decarboxylate malic acid to lactic acid and CO_2. Minimal CO_2 production has been considered beneficial in maintaining anaerobiosis in sauerkraut. In cucumber fermentation, CO_2 production causes bloater damage. The decarboxylation of malic acid is undesirable in cucumber fermentation. *Lb. plantarum* produces most of the CO_2 during cucumber juice fermentation via the decarboxylation of malic acid (55). Strains of *L. plantarum* that do not decarboxylate malic acid (MDC^-) might improve cucumber fermentation. Some MDC^- mutants have been obtained through *N*-methyl-*N*′-nitro-*N*-nitrosoguanidine mutagenesis of MDC^+ parent strains. These mutants did not produce significant amounts of CO_2 when they fermented cucumber juice containing native malate (56).

C. Biogenic Amine Biosynthesis

Fermented vegetables usually contain small amounts of biogenic amines. An excessive intake of biogenic amines may cause food poisoning. Biogenic amines may also be considered carcinogens because of their ability to react with nitrites to form potentially carcinogenic nitrosamines (57). Most biogenic amines present in fermented vegetables are formed by the action of microorganisms through the decarboxylation of amino acids during fermentation. Sauerkrauts and sauerkrautlike products are popular fermented vegetables in many countries. Thus sauerkraut could represent an important source of biogenic amines in daily diets. The biogenic amine content in commercial sauerkraut products is approximately 540 mg/kg (58). The main biogenic amines in sauerkraut are histamine, tyramine, putrescine, and cadaverine derived from histidine, tyrosine, ornithine, and lysine, respectively. Biogenic amine formation in the initial stage of a spontaneous fermentation is correlated with the growth of *Leu. mensenteroides. Pedicoccus* species are also responsible for the formation of biogenic amines. It was observed that the production of histamine was associated with the vigorous growth of the *Pedicoccus* species (32). *Lb. plantarum* starter

cultures were able to suppress the formation of tyramine, putrescine, and cadaverine by raising the pH to impede the growth of biogenic amine producers (59). Hence it is possible to decrease the biogenic amine content in fermented vegetables by using lactic acid bacteria inoculates.

VI. STARTER CULTURE IMPROVEMENT

In vegetable fermentation starter cultures with certain beneficial bacteria are desirable. Cultures with desirable characteristics can be achieved through genetic modifications. Artificial mutagenesis and DNA recombination techniques are two available methods to generate genetically modified strains.

References on using mutagenesis to improve starter cultures for vegetable fermentation are rare. One (60) of these researches describes procedures to obtain *L. plantarum* mutants that have lost the ability to decarboxylate malic acid (MDC^-) from the parent strain (MDC^+). In this research, the parent strain was mutagenized with *N*-methyl-*N'*-nitro-*N*-nitrosoguanidine, and the derived mutants were then screened with designed media to select the MDC^- mutants (60). The MDC^- mutants do not produce CO_2 from the degradation of malic acid. When using MDC^- culture in cucumber fermentation, the cucumbers were shown to be less susceptible to bloating (61). Another research involving mutation involved cultivating variant *L. delbrueckii* strains that were able to tolerate a high concentration of lactic acid (62). Treatment with ethyl methanesulfonate mutated the parent strain. The lactic acid tolerant mutants were then selected using an acclimation and selection procedure. This procedure was reported to be successful in consistently producing stable mutants with enhanced lactic acid production capacity.

Recently the DNA recombinant technique has superseded classic mutagenesis in the field of industrial strain improvement. In industrial food fermentation, new genetic techniques have already been applied to lactic acid bacteria to generate desirable starter cultures (63). No customized genetically modified strains for vegetable fermentation have yet been developed. However, some *Lb. plantarum* strains used as grass silage starters have been genetically modified by introducing heterologous genes to gain desirable attributes. Because *Lb. plantarum* is also a dominant microorganism in the fermentation of vegetables, the genetic modification of the silage starter *Lb. plantarum* will be a useful model for cultivating desirable vegetable fermentation cultures in the future.

It has been customary to add soluble carbohydrate to silage to facilitate rapid fermentation. If a starter with the ability to hydrolyze cellulose is used in the fermentation of silage, rapid fermentation might be achieved even without adding carbohydrates. According to this thinking, a genetically modified *Lb. plantarum* with the ability to degrade cellulose was cultivated. An *Lb. plantarum* strain was transformed by inserting the *cel*E gene coding endoglucanase from *Clostridium thermocellum* (64). A transformed *Lb. plantarum* strain possessing endoglucanase activity may be useful in improving the fermentation of olives and cabbage by producing acids rapidly, because this strain is able to supply mono- and disaccharides through the hydrolysis of cellulose.

A combination of polysaccharides metabolism and lactic acid fermentation trait is desirable for a starter strain to ferment plant material. For this objective, an *Lb plantarum* silage starter strain was transformed by electroporation with plasmids containing an α-amylase gene from *Bacillus stearothermophilus* and an endoglucanase gene from *Clostridium thermocellum* (65). The transformed *Lb plantarum* is a purely cellulolytic and amylolytic silage starter bacterium with the ability to produce lactic acid from the fermentation of cellulose and starch materials.

Increasing ethanol levels in lactic acid fermentation may be valuable in developing vegetable juice products. A strain of *Lb. plantarum* deficient in both D- and L-lactate

dehydrogenase activity was constructed by using a two homologous recombination processes (66). Following cloning, an alcohol dehydrogenase gene and a pyruvate decarboxylase gene originating from *Zymomonas mobilis* in this lactate dehydrogenase-negative strain resulted in an ethanol production of more than 400 mM (almost 2%).

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10
Leaf Mustard Pickles and Derived Products

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I. INTRODUCTION

Various leaf mustard cultivars (*Brassica juncea* Coss) are grown in Asia, India, and Africa. In southeastern China and Taiwan, leaf mustard is commonly grown in the fall and winter seasons when temperature and humidity are lower than in the other seasons. In Taiwan, the head-type mustards (Fig. 1) are cultivated as a winter crop following the fall crop of rice, and the cultivation period is about 3 months. Most of the harvested leaf mustards are dry-salted in wells or vats for fermentation to prepare leaf mustard pickles. After fermentation, the resultant yellowish pickles, bearing a crispy texture and a sound pickled flavor, are called Hum-choy, which means sour vegetable or salty vegetable in Chinese (Fig. 2). The products are popularly accepted as pickles and ingredients for Chinese food preparation. In this chapter, preparation of leaf mustard pickles and their derived products are described.

A. An Indigenous Means of Vegetable Preservation

The use of salt to preserve foods is part of our human heritage. Production of vegetables usually depends on season with appropriate climate and geographic situation. Brine fermentation is a traditional means of preserving harvested perishable and palatable products. The brine fermentation involves complex microbial, chemical, and physical reactions and gives the final products unique flavor characteristics. Mass-produced vegetables they are fermented include cabbage, leaf mustard, turnips, hot peppers, and a variety of other green produce (1). Almost all vegetable substances, whether they are leafy, tuberous, or fruits containing seeds, provide sufficient nutrients for the growth of fermentation-related microorganisms (1,2). The growth of certain fermentative microorganisms during brine fermentation results in sensory changes that are desired by their consumers.

B. Origin of Leaf Mustard Pickles

The origin of leaf mustard fermentation is hard to trace. It is generally believed that the origin is in the Orient. When Emperor Chin Shih Huang was constructing the Great Wall of China in the third century B.C., a portion of the coolies' rations consisted of a fermented mixture of vegetables, probably mustards, radishes, turnips, cabbages, cucumbers, beets, and other vegetables (1). When salt is introduced and mixed with leaf mustards, it has been observed that the withdrawn brine

Figure 1 Mature head-type mustards prior to harvest for leaf mustard pickle fermentation.

becomes cloudy and the product acquires an acidic and pleasant flavor and aroma. The unique characteristics of the salt-preserved vegetables have been inherited for generations.

When the fermented leaf mustards are further sun-dried in order to reduce weight and volume, the dehydrated products are stable and convenient for storage and carrying during traveling. During storage of the dehydrated products for a prolonged period, additional unique flavor and aroma have been generated. Fu-choy (Fig. 3) and mei-kan-choy (Fig. 4) are two typical products of this type.

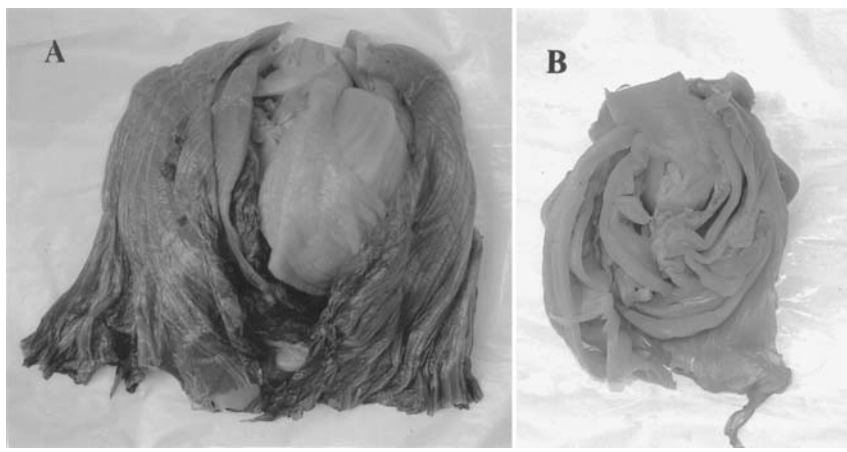

Figure 2 Leaf mustard pickles: (A) whole pickle; (B) inner head of leaf mustard pickle.

Figure 3 Fu-choy in bottles.

C. Microbiology of Leaf Mustard Fermentation

The microbiology of leaf mustard fermentation is similar to that of fermented vegetables popular in the West, such as sauerkraut and cucumber. The microorganisms responsible for the fermentation are lactic acid bacteria (LAB), *Leuconostoc mesenteroides* and *Lactobacillus* spp., and *Pediococcus* spp. (1,2). Usually, when the leafy vegetable is packed with dry salt or in brine

Figure 4 Mei-kan-choy made by dehydration of the outer leaves of leaf mustard pickles.

solutions, soluble nutrients are withdrawn and support the growth of LAB. The fermentation is initiated by *Leuconostoc mesenteroides* and continued by the other LAB species. When leaf mustards were fermented with 6, 9, 12, 15, and 18% NaCl, the populations of the acid-forming bacteria varied as affected by salt concentration and time interval. Growth of LAB was inhibited when fermented with 15 and 18% NaCl (3).

II. PREPARATION AND FERMENTATION OF LEAF MUSTARD PICKLES

The use of salt stock enables processors to handle large quantities of leaf mustards for fermentation and preservation within a rather short harvest time. The term brining is often used synonymously with the term fermentation, probably due to brining being an important step in fermenting vegetables. However, brining of vegetables can be done without eventual fermentation, in particular at a fairly high salt concentration, such as salt stock. In general, fermentation is desired for most vegetables that are given a brine treatment. The fermenting of vegetables serves two main functions. First, the growth of certain fermentable microorganisms results in sensory changes bearing unique characteristics to the vegetables. These changes are desirable by those consumers accustomed to eating fermented vegetables. A second and more important function of fermentation is its preservative effect. This is accomplished when fermentative microorganisms utilize most of the fermentable carbohydrates, thereby making these carbohydrates unavailable for spoilage organisms, especially human pathogens (4).

A. General Processing Steps of Leaf Mustard Fermentation

The steps involved in fermentation of most vegetables are basically similar to one another, although specific treatments may vary depending on a particular vegetable or desired finished product. The general processing steps of leaf mustard pickles are given in Fig. 5.

The mature leaf mustard (Fig. 1) is cut and inverted in the fields for wilting for a day. The wilted leaf mustards are then trimmed and shipped to fermentation wells, usually constructed underground on the roadside, or vats (Figs. 6 and 7). Prior to deposition of the leaf mustard, the base of a well is spread with dry salt, and the first layer of leaf mustard is placed in an upright position. For the following layers, leaf mustard is deposited at an inverted position, and each layer is spread with dry salt and pressed tightly. At the top of a well, the leaf mustard is covered with a heavy-duty plastic film and weights (Fig. 7A). After about 3 days, water is drawn out of the vegetable tissues by high osmotic pressure created by the added salt. The level of leaf mustard in the wells is lowered. Further depositions of leaf mustard and salt are repeated two or three times and finally covered and sealed with a heavy-duty plastic film and pressed with stones for long-term fermentation (Fig. 7B). The method used and the concentrations of salt needed for proper fermentation may vary mainly depending on fermentation intervals. In general, the longer the fermentation interval, the higher the salt content added. The product can be either marketed for consumer demand or hermetically sealed and sterilized in cans or pouches for local and overseas marketing.

B. Changes During Fermentation

During leaf mustard fermentation, a variety of microorganisms may develop. In the initiation stage, LAB species involve competition with other microorganisms for fermentable carbohydrates and eventually predominate, with a resultant drop in pH value and the exclusion of undesirable bacteria. When the leaf mustard was fermented with 6, 9, 12, 15, and 18% NaCl for

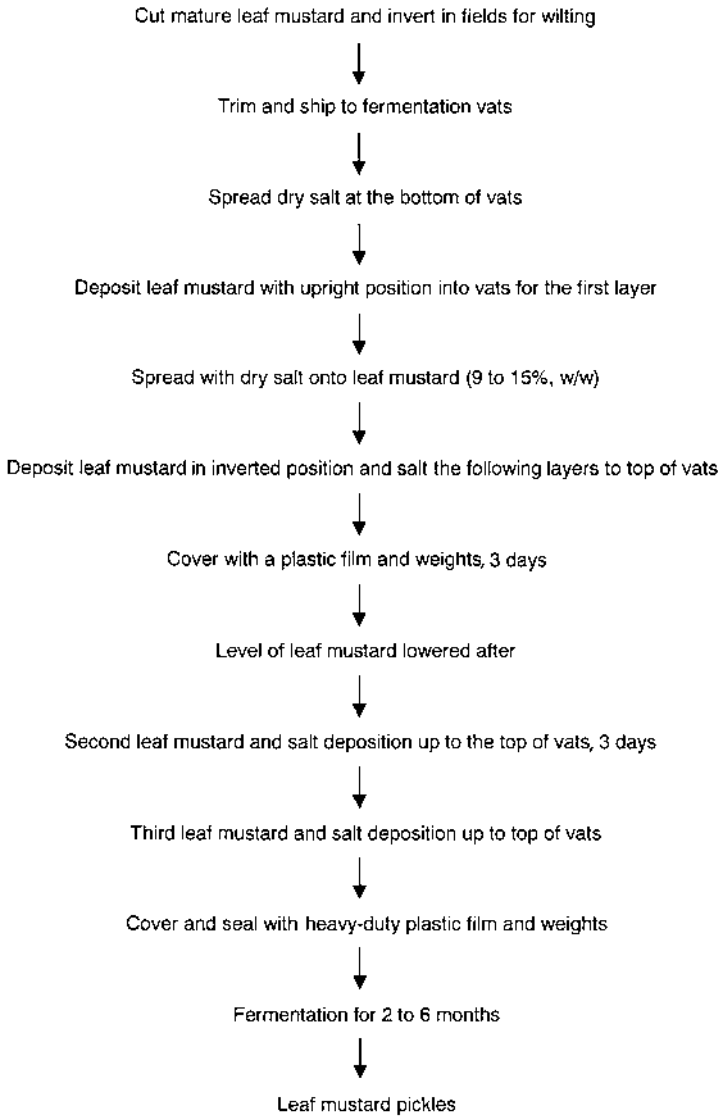

Figure 5 A general flow chart of leaf mustard pickle fermentation.

30 days, pH values changed from the initial value of 5.3 to 3.5, 3.5, 4.8, 5.0, and 5.2, respectively (3). In addition to fermentable carbohydrates, the contents of crude fiber, crude protein, free amino acids, and water-soluble vitamins including thiamine, riboflavin, and niacin were higher in leaf mustard pickles fermented with 15 and 18% NaCl than in pickles fermented with 9 and 12% NaCl (5). When leaf mustard was fermented with 6 and 9% NaCl for 20 days to reach the highest level of microbial population, the total populations, mainly LAB, were 3.2×10^7 and 1.2×10^7 CFU/mL, respectively. However, when leaf mustard was fermented with 12, 15, and 18% NaCl for 30 days, the microbial populations were 5.0×10^7, 4.6×10^7, and 4.6×10^7 CFU/mL, respectively (3). In addition to LAB, the growth of halophilic yeasts can

Figure 6 Vats for processing leaf mustard fermentation.

also prevent further spoilage by helping to exhaust the fermentable carbohydrates in the production of ethanol. The formation of ethanol may be responsible for improving the flavor of fermented vegetables.

III. PRODUCTS: FU-CHOY AND MEI-KAN-CHOY

Various derived products from leaf mustard pickles are common in the Orient. Fu-choy (Fig. 3) and mei-kan-choy (Fig. 4) are two of the most popular products. Fu-choy is a product that went through an in-container secondary fermentation, whereas mei-kan-choy is an intermediate moisture fermented product. The schematic flow chart of processing is shown in Fig. 8.

The initial procedure is the same as that of leaf mustard pickle preparation. After fermentation, the leaf mustard pickle is divided into inner heads (Fig. 2B) and outer leaves and subjected to solar drying. For large-scale production, the whole pickles are cut vertically through the stems and hung on bamboo sticks for sun drying (Fig. 9).

A. Fu-choy

For fu-choy production, the fermented mustard leaf is used as the raw material. After partial dehydration, the stems and inner leaves are cut into thin stripes (ca. 1 to 2 cm in thickness and 5 to 9 cm in length). The stripes are packed tightly in glass bottles (homemade styles) or various types of jars (Fig. 3). The neck of the container is filled with the partially dried leaves originating from the outer leaves and followed by sealing with caps or plastic films tied with ropes. The bottles or jars are aged in a bottom-up position for 2 to 3 months. During this period, unique flavor and aromas are developed. The products are stable at ambient temperature and can be stored and consumed for several months to a year.

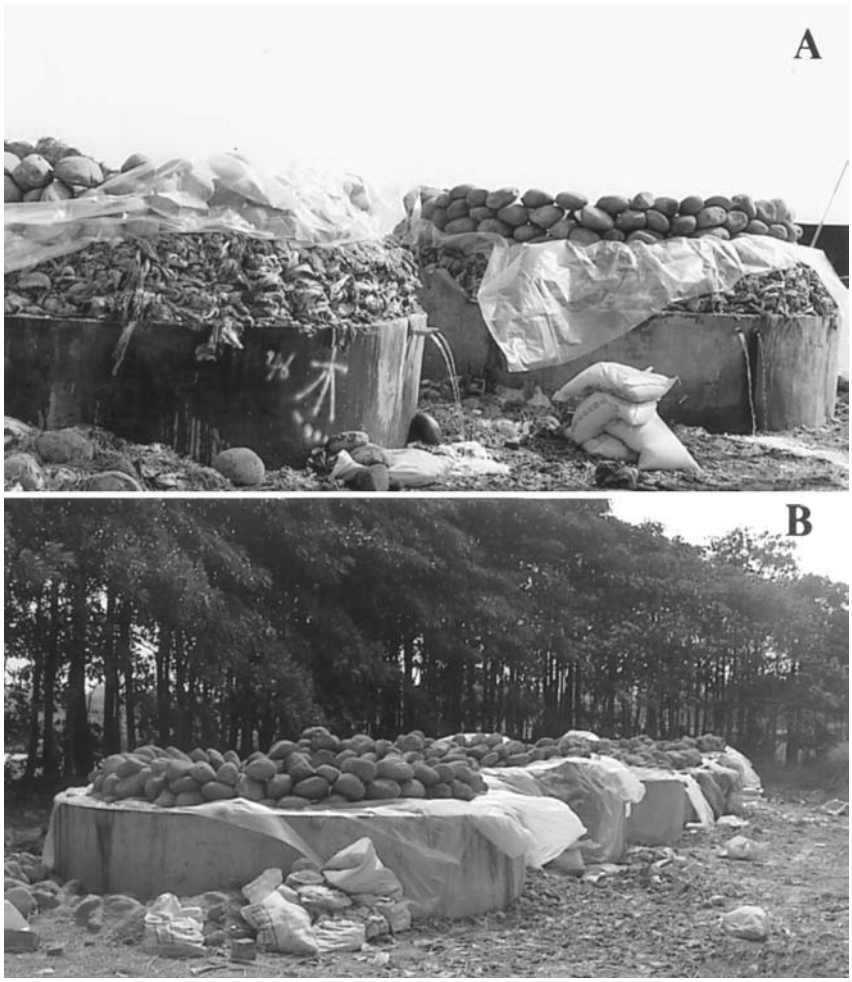

Figure 7 Mustards are deposited and spread with dry salt into wells for fermentation. (A) Mustards are deposited into wells and pressed by weights; (B) mustards are sealed and pressed by stones for fermentation.

B. Mei-kan-choy

Mei-kan-choy (Fig. 4) is usually made from the sun-dried outer leaves of leaf mustard pickles. After fermentation, the outer leaves are removed for sun drying or removed after sun-drying of the whole leaf mustards. The dried outer leaves are wrapped into bunches, packed, and stored at ambient temperature. After rehydration and cleaning, the leaves are commonly chopped into small pieces to cook with meats. In particular, it is an important ingredient to cook with pork slices or ground pork, such as mei-kan-ko-lo, a famous Chinese dish.

IV. PROCESSING INNOVATIONS OF LEAF MUSTARD PICKLES

Homemade leaf mustard fermentation has continued for centuries with little standardization and the household methods are generally passed on from one generation to the next. There was little

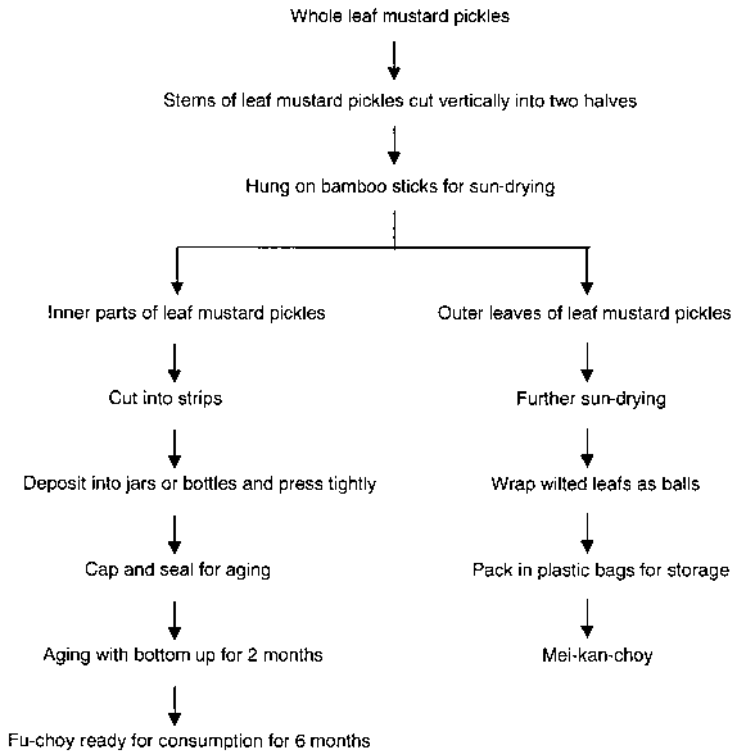

Figure 8 A general flow chart of fu-choy and mei-kan-choy preparation.

Figure 9 A large scale sun-drying of leaf mustard pickles in preparation of fu-choy and mei-kan-choy.

standardization of practice until the early period of the 20th century. The application of science to pickling and identification of the bacteria and yeasts present in fermenting vegetable substances in the early 1900s was a milestone of vegetable fermentation (1). Advancements in production methods and the development of superior and disease-resistant strains of vegetables have been largely responsible for providing adequate vegetables for preservation. The major improvements in vegetable fermentation during the past 50 to 60 years began with the development in microbiological science initiated about 100 years ago. These culminate with the conclusion that the addition of salt creates a specific environment and allows more than one species of LAB to contribute to leaf mustard fermentation.

A. Modified Dry-Salt and Brine Fermentation

A modified procedure for quality improvement of leaf mustard pickling was reported by Chen and Lee (6). Prior to depositing into vats, the leaf mustard was cleaned with water to remove dust and foreign materials. Based on the weight of fresh leaf mustard, 9 to 12% NaCl (w/w) were mixed and deposited into vats for 3 days. Then the partially dehydrated leaf mustard was replenished with 20% (v/w, based on the original leaf mustard weight) of the same salt solution (9 to 12% NaCl) to cover the leaf mustard. After tight sealing of the container and subject to fermentation at ambient temperature for 2 to 5 months, sound pickles are produced (5,6).

B. Low-Salt Fermentation of Leaf Mustard Pickles

In the conventional fermentation of leaf mustard pickles, waste disposal of the brine solution left in the fermentation wells or vats has been an environmental concern. Low-salt fermentation, the recovery of salt, and reusing the brine solution are possible options. A technique for the reduction of salt used in leaf mustard fermentation has been developed (7). Leaf mustard was dry-salted and fermented with 9% salt for 1 week. The uncured leaf mustard was hydraulically pressed to remove 60% of weight. Then the partially dehydrated leaf mustard was shredded and supplemented with 3% of dry salt and canned for further fermentation at ambient temperature for an additional 6 months. After fermentation in cans, the flavor and texture of the leaf mustard pickles were fairly acceptable.

V. OUTLOOK FOR LEAF MUSTARD PICKLES

Leaf mustard pickles are indigenous fermented foods. Since ancient times, most are prepared in homemade styles in order to obtain fresh products. Quality of the products varies widely owing to inconsistency in the harvested leaf mustard and in fermentation techniques (in particular, fermentation scale, salt concentration, and fermentation interval). In recent years, small- and medium-size industries of leaf mustard fermentation and marketing channels for the products have commenced. Fermentation techniques and standardization of the products have also been improved. Products such as freshly fermented or sterilized pickles (including ball-heads and shredded slides), fu-choy, and mei-kan-choy are popular items consumed in Chinese communities all over the world.

Currently and in the future, the continuous involvement of science and technology in leaf mustard production, optimization of fermentation, salt reduction, quality improvement, and enhancement of packaging and marketing is still needed. In addition to the unique pleasant pickle flavor, leaf mustard pickles containing rich edible fiber but low calorie contents renders the products favorable to the public. Based on the inevitable emergence of the global village,

knowledge and technology of leaf mustard cultivation, pickling, and product features will be highlighted and of benefit to people worldwide.

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11

Jalapeño Pepper Preservation by Fermentation or Pickling

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I. INTRODUCTION

Jalapeño pepper is a widely consumed product in Mexico. This is a scalded, pasteurized product, generally merchandized in cans or glass jars, with brine to which spice has been added. However, Jalapeño pepper shelf-life extension by fermentation or pickling is carried out only at a very small industrial level. Information regarding fermented or pickled vegetables is scattered, and there is no clear differentiation between pickled and fermented products (1). This chapter describes the processing of fermented and pickled Jalapeño pepper sold in cans or glass jars.

Pickling and fermentation are preservation methods that extend fruit and vegetable shelf lives via a simple and inexpensive technology. The processed material undergoes transformation resulting in a food more acceptable to the consumer.

Pederson (2) pointed out the various methods for fruit and vegetable preservation:

1. Pickling without undergoing fermentation
2. Fermentation in a low-concentration brine
3. Fermentation in a high-concentration brine
4. Preservation by dry salting at low salt concentration.

However, there is a controversy regarding whether the terms "pickling" and "fermentation" are equivalent. According to Pederson and Luh (3) pickled products are those to which edible acids have been added, either lactic or acetic (vinegar); on the other hand, fermented products are such that the acid present was produced from sugars by bacterial action. Both pickled and fermented vegetables are mainly preserved by the action of acid, which also improves the product's sensory characteristics and possibly its nutritive value. According to Pederson's classification (2), jalapeño pepper can be either fermented or pickled.

Undesirable microbial growth is inhibited by the acid as well as by salt concentration (4). Besides reduction in the spoilage-causing microbial population, the shelf-life extension of fermented or pickled vegetables also depends on the decrease of inhibition of enzymatic activity of the plant material involved in the ripening process. Control of both spoilage mechanisms in jalapeño peppers, enzymatic and microbial, is achieved by pickling and fermentation.

II. FERMENTED JALAPEÑO PEPPER

This preservation method is based on acid production by fermenting sugars in the plant material through the action of lactic acid bacteria such as *Lactobacillum plantarum*, although the presence of *Leuconostoc mesenteroides* also has a marked effect upon the fermentation and product quality (5,6). In addition to lactic acid bacteria activity, other fermentative bacteria, such as acetic acid–producing microorganisms, also carry out vegetable fermentation, which enhances shelf life and sensory characteristics (6). Undesirable microorganisms are inhibited by various mechanisms. Salt addition allows the growth of naturally present lactic acid bacteria, but the combined salt and acid action allows the selection of microflora associated with vegetable preservation. At the same time, fermentation reduces carbohydrate concentration, increasing acid production (7). In some cases, sugars are added to enhance the fermentation process (4). The most important conditions for an adequate vegetable fermentation are: anaerobiosis, salt concentration, temperature, and the use of suitable starters. Lactic acid bacteria can be present as native microflora in the pepper, but to assure a uniform fermentation, selected starters are usually added.

To obtain the best fermented jalapeño pepper quality, the raw material (*Capsicum annuum*) cv. Jalapeño must be recently harvested, still green, and without wounds or peduncle. Figure 1 shows the general flow diagram of fermented jalapeño pepper processing (8).

A. Preliminary Operations

Raw jalapeño peppers are selected according to their size and quality. They are washed, and small incisions are made in order to facilitate brine diffusion to the central part and to eliminate gas formed during fermentation. Washing diminishes the hot pepper fermentative ability; so it is necessary to add a starter culture (*Lactobacillum plantarum*). It is the same for pepper blanching.

III. FERMENTATION

Fermentation is carried out by facultative anaerobic homofermentative strains such as *Lactobacillum plantarum* and *Pediococcus cereviseae. L plantarum* produces acetic acids as well as ethanol and gas (CO_2 and H_2). The peppers are then immersed in 10% brine for 4 to 6 weeks, sometimes with 0.5 to 1% sucrose as well as hot pepper cell fluid containing carbohydrates, nitrogen compounds, and minerals among other things. The cell fluid from the peppers, however, tends to dilute the brine. For this reason, it is necessary to add 1% salt daily during the first week, and three times a week during the rest of the immersion time, in order to keep the desired brine concentration (18–20%). The peppers must be completely covered by the brine at all times.

Fermentation takes place in 4 to 6 weeks. It is carried out in closed tanks, with a vent to allow gas formed during the process to dissipate. At the end of the fermentation period, the peppers, originally bright green, turn into olive green. The plant tissue also changes, taking on a translucent aspect. Acid concentration increases from 0.8 to 1.5% (expressed as lactic acid), promoting a decrease in pH. The peppers are then washed to eliminate salt excess, classified according to their size, placed in glass jars or plastic bags, mixed with other vegetables, usually carrots and onions, and covered with vinegar.

Fermented jalapeño peppers are highly perishable if the vinegar has less than 3% acetic acid. In this case, pasteurization is necessary. It is carried out over 30 min at 71°C (for glass jars containing 280 g of product). Finally, the product is labeled, packaged, and stored in a similar way as for pickled (nonfermented) jalapeño peppers.

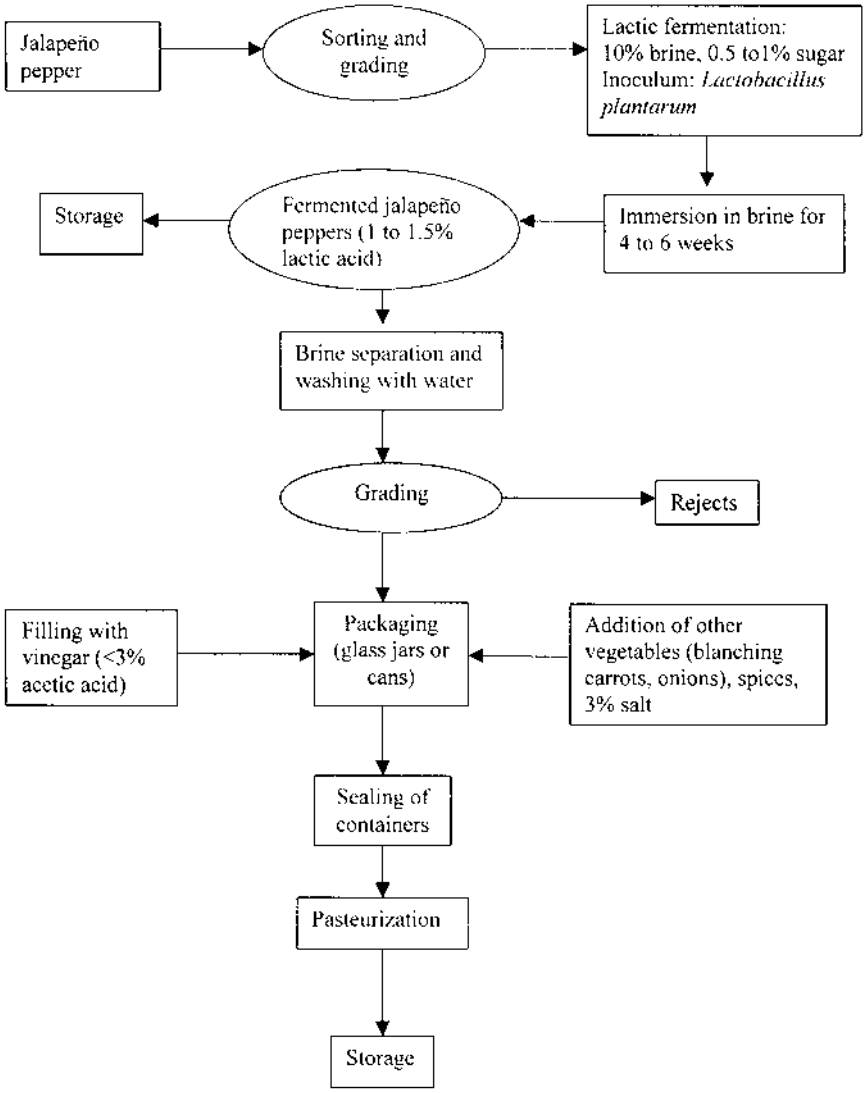

Figure 1 Fermentation of jalapeño pepper.

IV. PICKLED (NONFERMENTED) JALAPEÑO PEPPERS

Jalapeño peppers that are most widely sold in producing countries, such as Mexico, are pickled nonfermented products. They are sold in different can sizes and consist of whole cut peppers, mixed with scalded onions, carrots and mushrooms, with vinegar to which spice has been added (Fig. 2).

The main difference between this product and fermented peppers is that the raw material is fresh peppers or peppers preserved with salt (brine). According to its acidity, the product is then heat-treated (9). If it is an acidic food, spoilage can take place, so a further preservation method is necessary. The flow diagram for this process is shown in Fig. 3.

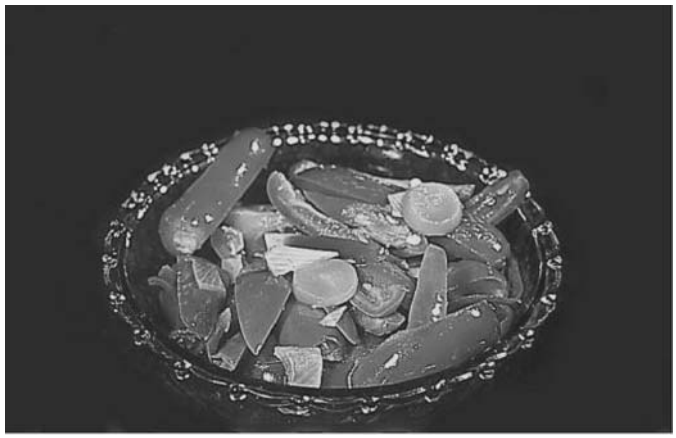

Figure 2 Pickled and cut jalapeño peppers.

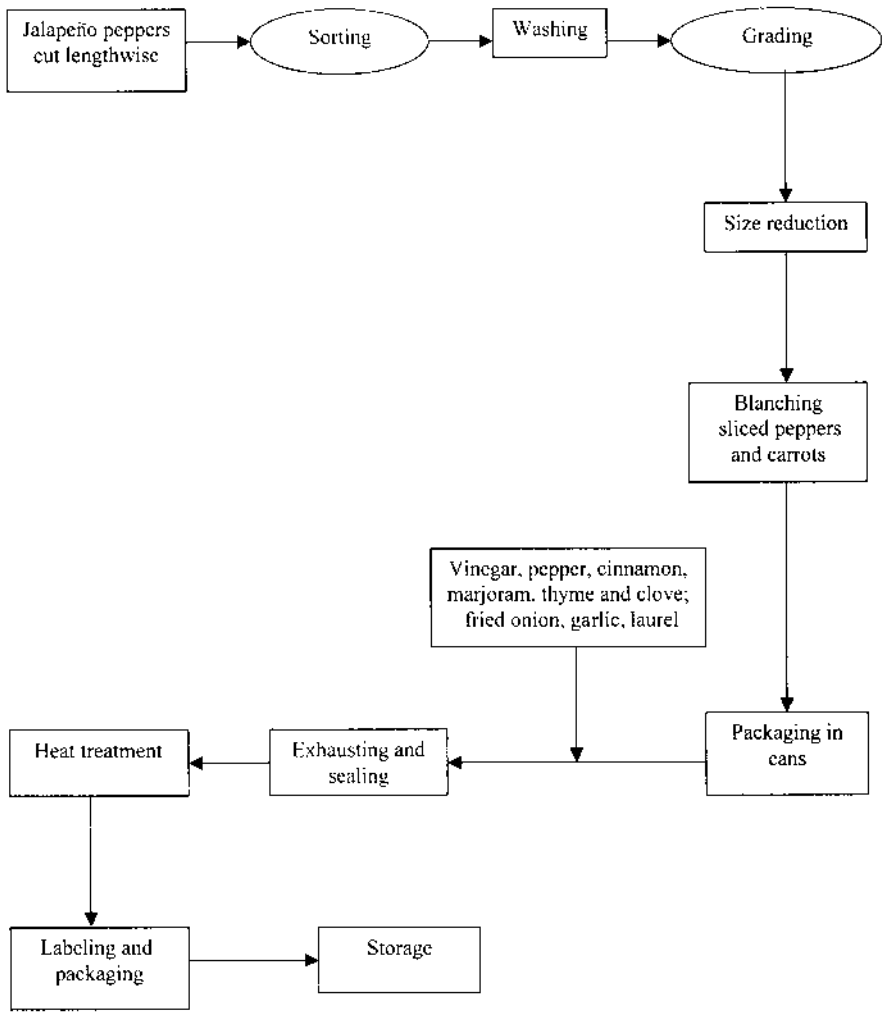

Figure 3 Jalapeño pepper: nonfermented pickling.

At the domestic level or in small industries, pickled jalapeño peppers are proposed by mixing scalded carrots, onions, and other vegetables with jalapeño peppers cut lengthwise, and adding vinegar previously flavored with pepper, cinnamon, marjoram, thyme, and clove, and other condiments (onion, garlic, and laurel fried in vegetable oil) (10).

A. Preliminary Operations

Contaminants or inedible components can be present when jalapeño peppers, carrots and onion are gathered for processing. Therefore it is necessary that the vegetables undergo one or more of the following: washing, selection, classification, size reduction, and scalding. Canning also ensures an adequate edible quality of the product.

After jalapeño peppers, carrots, and onions are transported into the processing plant, the vegetables are selected for processing or storage, according to their quality and stage of ripeness. Washing by immersion, spraying, or combined methods is done in order to eliminate various contaminants (11,12).

1. Washing

During immersion washing, the dirt that adheres to the vegetable surface is softened and eliminated together with stones, sand, and other abrasive material, which can damage the equipment during further operations. The immersion tanks are made of metal, mortar, or building materials suitable for easy cleaning and disinfection. In order to improve the washing efficiency, stirring is provided. Detergent or chlorine is also added to decrease the microbial load. During spray drying, vegetables are exposed to pressurized water, which is applied when the water supply is restricted.

2. Sorting and Grading

These operations are performed to discard products unsuitable for processing: damaged, unripe, overripe, or deformed vegetables. Deterioration occurs during harvesting, transportation to the processing plant, or cleaning.

Vegetables are selected according to size and quality and are directed to processing or direct consumption. In general, classification consists in simultaneous evaluation of various physical properties. In the case of hot peppers, onions, and carrots, classification is carried out manually. By this procedure it is possible to have a simultaneous evaluation of several attributes that would be difficult to evaluate in an automatic fashion. The advantage of classification is having uniform material to be directed to a specific operation, such as peeling, size reduction, or blanching. Grading also homogenizes the product, improving heat-processing efficiency. Trained personnel generally carry out quality classification.

3. Peeling

Peeling is a necessary operation during carrot and onion processing; to improve the product appearance, the elimination of inedible parts must be carried out, although it is important not to eliminate large portions of the vegetable. There are different peeling methods:

Abrasion: Carrot peeling is done by abrasion. In this way, skin is removed by friction; the product is in contact with carborundum rollers or placed into containers with the inside coated with an abrasive material such as silicon or carbon. The abrasive surface detaches the carrot skin, which is later removed by a water stream.

Flame peeling: Applied mainly to onions, it consists of placing the vegetables on a transportation band moving through an oven at >1000°C. As the vegetables pass, the outmost layer and fine roots are burnt and eliminated by high pressure water spraying.

4. Size Reduction

In this operation, the average size of a solid food material is reduced by the application of external forces such as impact, compression, or abrasion (11). In the case of jalapeño peppers, they are cut lengthwise into four parts and the peduncle and seeds are eliminated. Cutters consist of a series of rotating blades, and centrifugal force holds the product against the blades.

5. Spoilage Enzymes

Enzymes, endocellular, exocellular, or microbial, assume an active role in food deterioration. Microbial enzymes are also able to act on the food substrate even when the microbial cell is inactivated or dead (13). Insufficient scalding can result in an increase in food spoilage as heat applied can disrupt the tissues, liberating the substrate but not inactivating the enzymes. Scalding efficiency in vegetables is measured by inactivation of two enzymes: catalase and peroxidase. In processed jalapeño pepper, the time–temperature conditions for scalding are (9) jalapeño pepper: 8 to 10 min, water at 95°C; carrots: 6 to 8 min, water at 95°C.

6. Blanching

This heat process is applied prior to processing in order to inhibit enzymatic activity or decrease microbial populations. Blanching can be combined with other operations such as peeling or cleaning (11–13). An efficient enzyme inactivation is achieved by heating until calculated temperature–time conditions are reached and then fast-cooling to room temperature. The two blanching methods commonly used are saturated steam and immersion in hot water. At industrial levels, steam blanching is the most widely practiced method (11). It consists in applying steam to the vegetables on a conveyor belt going through a steam tunnel. Varying the speed of the conveyor belt controls the time of residence in the tunnel. In some cases a water spray is applied at the start and end of the conveyor in order to condense excess steam. During hot-water blanching, the vegetables are held for a given time at 70–100°C, with a further draining–cooling period afterwards.

B. Packaging

The aim of this operation is to keep the product, from processing to the consumer, in the same hygienic and quality conditions. Cans are made from three-piece tin sheets, coated on the inside with epoxyphenolic enamel (Fig. 4). The lids are also made of tinfoil and coated with the same epoxyphenolic enamel that is used in the can. The lids also have two or three circular expansion rings, providing resistance against deformation due to an increase in the internal pressure (14).

C. Pickle

According to Mexican regulations (15), pickle is a mixture of vinegar, vegetable oil, onion, carrots, laurel, garlic, salt, sugar, and spices. The last ingredient is optional. Vinegar includes 2% acetic acid and 5% sodium chloride.

Figure 4 Three-sheet tin cans covered inside with porcelain enamel.

D. Blanching Vegetables

Cut peppers, carrots, and onions must be approximately 60% of the total product weight, with peppers having a higher proportion.

E. Filling

Vegetable mix is first added to the can, previously washed with hot water; the brine (pickle) is then added at 82 to 85.6°C. Filling must be carefully controlled in order to assure that the correct amount of vegetable mix and pickle is added, and to fulfill specifications. Headspace must be 10% of total can volume. Filling is done when transported by the conveyors, which carry the cans to the vegetable mix filler and then to the liquid one.

F. Exhausting

When air is evacuated from the headspace before sealing, internal pressure is decreased during sterilization. At the same time, oxygen evacuation prevents tin corrosion and oxidation. During this operation, air is replaced by vapor, producing partial vacuum in the headspace after condensing. Exhaustion is carried out in tunnels (or exhausters), as shown in Fig. 5. Another way

Figure 5 Vapor tunnel or exhauster.

to promote exhaustion is by using steaming machines, which inject steam into the headspace before closing the cans (14).

G. Sealing

Sealing is carried out in a seaming machine. According to the design and speed of the operation, the basic stages of the operations are as follows: (a) the edges are folded; (b) the folded tin is pressed to form a hermetic seal, impermeable to air (16).

H. Heat Treatment

Cans or glass jars are subjected to heat treatment to sterilize or pasteurize their contents. It can be done in batches or by continuous retorting. Cans are heated at a time–temperature condition in vapor or hot water. Pasteurization of pickled jalapeño peppers destroys microorganisms resistant to high acetic acid concentrations, able to promote product alteration. Heat treatment also inhibits vegetable or microbial enzymes (17). Heat treatment of 93.3°C and 10 min are recommended for acid pickles (pH 4.3 to 4.5). However, a time–temperature process depends on the type of container, the volume, and the heat processing equipment.

1. Batch Processing

During this operation retorts are saturated with vapor and containers are placed in baskets. Retorts can be horizontal or vertical, and the cans can be still or rotating during the process. Can rotation promotes heat transfer, so that processing time is reduced and higher temperatures can be achieved.

2. Continuous Retorting

This type of equipment is fitted with hydrostatic closings before and after the pressurized sections. Processing can be also carried out by can rotation, where the cans move in and out of the pressurized section through hydrostatic water column seals, which equilibrate the internal pressure.

A variation of this equipment is the flame retort, working at atmospheric pressure throughout the operation. Flame retort equipment is fitted with direct heating, applied to the rotating retort. An advantage of this type of retorting is a high product quality due to mild heating conditions.

In all heat treatments, the final part is cooling the can with water to reach a final temperature not less than 38°C. Because the cans are not completely cooled down, water is eliminated from the outside, avoiding corrosion.

I. Marking, Labeling, and Packaging

Once the containers undergo heat treatment, each can or jar is marked with a code, a production date, a batch number, and a plant code. The label includes the product name, the commercial name, the drained and net weight, the ingredients, and other specifications required by the country's regulations (15). Packing is automatically carried out in cardboard boxes or high-density polyethylene bags, or other suitable packaging materials with enough resistance to protect the product and containers.

Table 1 Specification of Jalapeño Peppers (NOM-F-121-1982, 15)

Specification	Minimum	Maximum
Acidity (as acetic acid) (%)	0.75	2.0
Chlorides (as sodium chloride) (%)	2.0	7.0
pH	—	4.3
Filling (%)	90	—
Headspace (%)	—	10
Vacuum (mm Hg)	76.2	—

J. Storage

Heat-treated jalapeño peppers keep their quality characteristics at 18 to 21°C. At higher temperatures, acid products in cans without inner coating consume oxygen in the headspace faster than in coated cans. The result is a considerable loss in ascorbic acid content and fast product oxidation (17,18). On the other hand, canned jalapeño peppers have a longer shelf life if stored at 0 to 5°C (17).

V. REGULATIONS

A. Mexican Specifications

Mexico has quality bylaw (Norma Official) regulations for pickled jalapeño or Serrano peppers (NOM-F-121-1982, 15). This regulation includes six consumer presentations or styles and two quality levels.

The presentations are whole peppers, peppers without seeds, peppers in halves, peppers cut lengthwise, peppers cut in rings, and chopped peppers. There are two quality classifications for whole peppers only (minimum and maximum); for the rest of the presentations there is one quality classification. Table 1 shows physical and chemical specifications.

These specifications also include microbial characteristics, chemical contaminants, optional ingredients, sampling and specificity of quality degrees, labeling, containers, and packaging. Among optional ingredients are garlic, pepper, cinnamon, cloves, ginger, laurel, marjoram, thyme, and nutmeg. In defining the Mexican official specifications the main jalapeño pepper processing industries took part, such as Productos Del Monte, La Costeña, Herdez, Conservas San Miguel, Conservas Guajardo and Elías Pando.

B. International Specifications

The processed fruit and vegetable Committee of the Codex Alimentarius Commission FAO/OMS has elaborated a General Specification project for pickled products. At present, this project is at the sixth stage, that is, revision by all member countries. However, the project does not include pickled cucumbers or kimchi (19).

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Kimchi

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I. INTRODUCTION

The word kimchi is the generic term for Korean fermented vegetables, which is derived from the Chinese characters pronounced *chimchae*, meaning brined vegetables. Traditionally in Korea, large quantities of kimchi are prepared as an annual event, *kimjang*, for eating during the winter when the fresh vegetable supply is limited. Most of the vegetables cultivated in Korea are used as sources for making kimchi. Although 161 or 187 kinds of kimchi are currently reported, depending on the varieties and preparation methods of these vegetables (1,2), the most popular kimchi is made with Korean *baechu* cabbage (known to Westerners as Chinese cabbage). The various types of kimchi are prepared through a series of processes including the pretreatment of the main vegetables, spices, and other subingredients. The ingredients used for kimchi preparation, as well as the fermentation conditions such as temperature, air, salt content, and packaging materials, are important factors to increase the preservation period, taste, and functionality of kimchi (3). Fermented kimchi contains high levels of lactic acid bacteria (LAB, 10^{7-9} CFU/mL), organic acids, and various nutrients and functional components, that result from the ingredients and the fermentation process.

Properly fermented kimchi is flavorful, having the distinct savor of a combination of sour, spicy, hot, sweet, and carbonated-fresh tastes. For the Korean people, kimchi is consumed as the most favorable and frequent side dish accompanying cooked rice. Actually, Koreans have kimchi at the everyday diet table, every meal. During difficult times when no other side dishes were available, kimchi may have been the only side dish they had. During the 1950s (the post–Korean War period), the consumption of kimchi per person, per day was 200 to 300 g, decreasing to 124.4 g in 1998. This is 44 percent of the whole consumption of vegetables (248 g) for each Korean per day (4), which is still high compared to 50 years ago when Koreans were so economically depressed that they could not afford various side dishes.

Nutritionally, kimchi is an important source of vitamins, minerals, dietary fiber, and other functional nutrients and phytochemicals. Kimchi might help to increase appetite, reduce constipation, control intestinal flora, and have anticarcinogenic and antiaging effects and other health benefits (5). In the past, kimchi was prepared as a homemade product, but large quantities of kimchi are now produced commercially. A variety of kimchis are packaged in aluminum film bags, and plastic or glass jars for domestic consumption and for export.

II. THE HISTORY OF KIMCHI

Records indicate that salted vegetables as a type of macerated vegetable were consumed in Korea as early as the 3rd or 4th century A.D. (6). The first record of kimchi appears in the *Koguryojon* of China's *Weizdongyizhuan* region, *Samguozhi* (A.D. 289). The book states, "The Koguryo people [referring to the Korean people] are skilled in making fermented foods such as wine, soybean paste and salted and fermented fish." This passage indicates that fermented foods were widely enjoyed at that time. According to a Korean record, the *Samkuksaki*, published in A.D. 1145 during the Sinlla dynasty (about A.D. 720), fermented vegetables were prepared using a stone pickle jar, indicating that these foods were commonly available at that time. During the early Koryo dynasty (A.D. 918–1392), Buddhism accepted vegetarian diets while rejecting meat consumption. The preparation and the use of various added ingredients became more diverse with time. Records show that kimchi was garnished with garlic and with spices such as Chinese pepper, ginger, and tangerine peels.

For instance, the *Kapoyukyong*, from the *Dongkukisangkukjip* (A.D. 1241), states that white radish leaves in soy paste were used to prepare summer vegetables and salt for winter vegetables, making these kimchi preparations differently from the *jangajji* (vegetables pickled in soy paste or soy sauce). Also, the text states, "prepare kimchi for winter," suggesting a traditional custom of kimjang, the fall kimchi preparation. The kimchi cited here is similar to today's radish (i.e., a large broth-containing) kimchi and other similar kimchis like nabakji and dongchimi.

The word chimchae, the Chinese term for kimchi, appears for the first time in Yi Saek's *Mogunjip* (A.D. 1626). The *Dongkukisankukjip*, published in the 12th century, mentions fermented vegetables being consumed in winter. Until the Koryo dynasty, the main vegetable used to make kimchi was radishes rather than Korean baechu cabbages. Records also show that cucumber, eggplant, and green onions were used to make macerated vegetables at that time in addition to radishes.

During the early Choson dynasty (A.D. 1392–1600), many foreign vegetable species were introduced into Korean foods, and as a consequence, kimchi ingredients became more varied and the preparation methods more elaborate. In the *Choson Wangjoshillok* (A.D. 1409) there is mention of *chimjanggo* for the storage of kimchi. From this reference, a designated place was reserved for the kimchi for kimjang. The word kimjang originates from *chimjang*, indicating the storage of kimchi for winter.

During the mid-Choson dynasty (after A.D. 1600) many different vegetables were imported from foreign countries. Records of red peppers are first found in the *Jibongyusol* (A.D. 1613), and their use in kimchi was first recorded in the *Sallimkyongje* (A.D. 1715). Kimchi developed more complex yet harmonious tastes, with red pepper as one of the main subingredients. The number of vegetables used as main and subingredients of kimchi grew as well. Many kinds of salted and fermented fish came into use. The combined use of animal meats and vegetables in kimchi resulted in a great combination of tastes and nutrition. As the savory taste of kimchi improved, baechu cabbage and white radishes (similar to Japanese Daikon) became the main ingredients of kimchi. The most popular *tongbaechu kimchi* (meaning whole cabbage kimchi), evolved as a product of the 19th century. The variety of kimchi became diverse with offerings such as watery-mulkimchi, stuffed sobaegi, and mixed sokbakji kimchi.

The *Umshikdimibang* (A.D. 1670) describes the processing methods of seven types of vegetable pickles. In the *Jungbosallimkyongje* (A.D. 1776), 41 different kinds of kimchi are described, thereby making an invaluable documented record on the history of kimchi. In this book, tongbaechu kimchi was introduced, a kimchi containing meat and fish ingredients. During this time, many types of kimchis were introduced in written form for the first time in history. One

type is chonggak kimchi (pony-tail radish kimchi) that was made with a small radish, using all its leaves. Precursors of today's oisobaegi (stuffed cucumber kimchi), sokbakji (radish and cabbage in mixed form), and dongchimi (broth-based radish kimchi) also made their first appearance.

In the *Kyuhapchongso* (A.D. 1815), which is considered the first encyclopedia of the Choson dynasty, sokbakji-type kimchi is described. This variety is characterized by the use of more ingredients and a clear distinction among main components; it has secondary additives of salted and fermented fish. In the *Imwonshibyukji* (A.D. 1827) a wide variety of kimchi (97 varieties) is mentioned, emphasizing the use of red peppers for kimchi.

III. THE CLASSIFICATION OF KIMCHI AND RAW INGREDIENTS

Many types of kimchi are available depending on the raw ingredients used, processing methods, harvest seasons, and geographical regions. Although baechu (Korean cabbage) and radish are the most widely used in the making of kimchi, other vegetables are used depending on their seasonal availability. Because of the cold northern, and the mild southern Korean winters, the kimchi prepared in the north contains less salt, whereas the kimchi in the south requires more salt for long-term preservation. Also, people living near the sea naturally use more fish products in their kimchi.

Cho and Nam (7) reviewed published data on kimchi in Korea from 1959 to 1976, reporting 55 varieties of kimchi: 31 of kimchi, 8 of jangajji (sliced vegetables pickled in soy sauce), 4 of kaktugi (diced-radish kimchi), 2 of dongchimi (whole radish kimchi without red pepper), and 6 other types. In 1994, Park et al. (2) reported a total of 187 types of kimchi existing today in Korea.

Son (1) classified 161 varieties of kimchi into eight different groups based on the main, raw ingredients (Table 1). Briefly, the first group comprises baechu kimchi (12 types), of which tongbaechu kimchi is the most popular, followed by baek kimchi and bossam kimchi. In the second group are radish kimchis (17 types), with dongchimi and chonggak kimchi being the favorites. In the kaktugi group (25 types), radish kaktugi is the most popular. In the fourth group composed of sokbakji and nabak kimchi, there are 20 varieties including sokbakji and nabak kimchi. Green vegetables and stem vegetables comprise the fifth classification group of kimchis (27 types), which includes got (mustard leaf) kimchi and kodulbaegi kimchi. The sixth group includes fruit- and root-vegetable kimchi (27 varieties), among them cucumber kimchi and burdock kimchi. The green onion, garlic, and leek group contains 14 varieties. Leek kimchi and green onion kimchi are favorites that are usually prepared in Kyoungnam province, in the southern part of Korea. The eighth group has 19 varieties of kimchi composed of meat, fish, shellfish and seaweed.

A survey on the preference of kimchi prepared in Korean households shows that baechu cabbage kimchi is the most frequently prepared, followed by radish kaktugi, broth-containing dongchimi, and then miniature radish and stem chonggak kimchi (3). Thus, although both baechu kimchi and kaktugi are important kimchis, baechu cabbage kimchi is the far more popular and represents the common name of kimchi. Also, marketed kimchis are mainly baechu kimchis (>70 percent) and radish kimchis (around 20 percent).

The raw ingredients used to make these kimchis are listed in Table 2. The vegetables most frequently used to make kimchi are baechu cabbage, radish, miniature radish, cucumber, etc. The spices used to prepare kimchi are green onion, garlic, red pepper powder, ginger, leek, mustard, black pepper, onion, and cinnamon. Commonly used seasoning for kimchi are salt, salted and fermented shrimp, anchovies, soy sauce, vinegar, chemical seasoning agents, sweetening agents, sesame seed or its oil, and oyster; these are optionally added to kimchi to improve and vary flavor

Table 1 Classification of Kimchi by Raw Ingredients

Group	Varieties
1. Baechu kimchi (Korean baechu cabbage kimchi) (12 varieties)	Tongbaechu kimchi (whole cabbage kimchi), baek kimchi, bossam kimchi (wrapped-up kimchi), vegetables pickled right before eating, etc.
2. Radish kimchi (17 varieties)	Dongchimi, radish zangi, chonggak dongchimi, mupinul kimchi (slit-cut radish kimchi) chonggak kimchi, sunmu kimchi (turnip kimchi), chae kimchi (julienne radish kimchi), muchung dongchimi (radish leaf kimchi) musobagi (stuffed radish), pickled radish kimchi, musun kimchi (radish shoot kimchi), etc.
3. Kaktugi (25 varieties)	Radish kaktugi, radish and oyster kaktugi, radish and wild rocambole kaktugi, radish and leek kaktugi, radish and radish leaf kaktugi, cucumber kaktugi, chonggak kaktugi, radish and salted pollack guts kaktugi, parboiled radish kaktugi, yolmu kaktugi, radish and cod kaktugi, etc.
4. Sokbakji and nabak kimchi (20 varieties)	Sokbakji, wax gourd sokbakji, baby ginseng nabak kimchi, nabak kimchi (sliced cabbage and radish kimchi), chang kimchi, changzanji, etc.
5. Green vegetables and stem vegetables (27 varieties)	Shigumchi kimchi (Spinach kimchi), gat kimchi (mustard leaf kimchi), kodulbaegi kimchi (wild lettuce kimchi), kongnamul kimchi (soybean sprout kimchi, minari kimchi (dropwort kimchi), doraji kimchi (broad bellflower kimchi), dolnamul kimchi (sedum kimchi), young mustard leaf kimchi, etc.
6. Fruit and root vegetable kimchi (27 varieties)	Oi kimchi (cucumber kimchi), oi sobagi (stuffed cucumber kimchi), pickled cucumber, hobak kimchi (pumpkin kimchi), gaji kimchi (eggplant kimchi), koguma kimchi (sweet potato kimchi), putgochu kimchi (green pepper kimchi), uong kimchi (burdock kimchi), cucumber kimchi, kam kimchi (persimmon kimchi), etc.
7. Green onion, garlic, and leek kimchi (14 varieties)	Leek kimchi, green onion kimchi, green onion zanji, dalrae kimchi (wild rocambole kimchi), etc.
8. Meat, fish, shellfish, and seaweeds kimchi (19 varieties)	Meat kimchi, chicken kimchi, pheasant kimchi, earshell kimchi, green layer kimchi, oyster kimchi, codfish kimchi, dried pollack kimchi, squid kimchi, Alaska pollack kimchi, marine products kimchi, miyok kimchi (brown seaweed kimchi), etc.
Total 161 varieties	

Source: Ref. 1.

and taste depending on the type of kimchi. Additional kimchi ingredients are fruits (jujube, ginkgo nut, pine nut, chestnut, apple, orange, etc.), cereals (polished barley, glutinous rice, wheat flour, and malt), seafoods (oyster, squid, shrimp, and Alaskan pollack), and meats (beef and pork). Fish and meats are added to improve the flavor of kimchi, and cereals are added to enhance lactic fermentation.

IV. PROCESSING OF KIMCHI

Kimchi being fermented food, preparation methods differ depending on the ingredients used, family preference, regional customs, etc. The essential process consists of maceration of raw

Table 2 Raw Ingredients Used for the Preparation of Kimchi

Groups	Raw ingredients
Main raw vegetables	Baechu (Korean baechu cabbage), radish, pony-tail (chonggak) radish, young oriental radish, cucumber, green onion, lettuce, Western cabbage, leek, green pepper, etc.
Subingredients	
Spices	Red pepper, green onion, garlic, ginger, mustard, black pepper, onion, cinnamon, etc.
Seasoning	
Salt	Dry salt or brine solution
Salt-pickled seafood	Anchovy, small shrimp, clam, hairtail, yellow corbina, etc.
Other seasoning	Sesame seed, soybean sauce, monosodium glutamate, corn syrup, etc.
Other materials	
Vegetables	Watercress, carrot, crown daisy, parsley, mustard leaves, etc.
Fruits and nuts	Pear, apple, jujube, melon, ginkgo nut, pine nut, etc.
Cereals	Rice, barley, wheat flour, starch, etc.
Seafoods and meats	Shrimp, Alaska pollack, squid, yellow corbina, hairtail, oyster, beef, pork, etc.
Miscellaneous	Mushrooms, etc.

ingredients, mixing the ingredients, packaging, and fermentation. Pretreatment of raw ingredients includes grading, washing, and cutting. Other ingredients are also graded, washed, and cut, sliced, or chopped for the proper mixing.

Pretreated raw baechu cabbage or radish is brined at proper concentrations of dry salt (natural salt prepared from seawater with removal of Mg^{2+}), brine solution, or dry salt plus brine solution. Brine-treated (i.e., macerated), rinsed baechu cabbage is mixed together with a mixture of chopped or sliced subingredients (spices, seasonings, salt-pickled fishes, and other vegetables) and dry salt to make a final salt concentration of 2.5 percent. The blended preparation is then fermented under the appropriate conditions.

The major treatments used in the making of kimchi and the important steps that can affect its quality, taste, and functionality are as follows:

A. Selection and formulation of the raw ingredients
B. Salting, rinsing, and draining
C. Pretreatment of subingredients and mixing process
D. Placing in crocks (fermentation vessels)
E. Fermentation

A. Selection and Formulation of the Raw Ingredients

The quality and species of the major ingredients (Korean baechu cabbage, *Brassica campestris* sp. Pekinensis or oriental radish, *Raphabus satirus* L.) may significantly affect the product characteristics of kimchi. For example, only carefully selected baechu are used for baechu kimchi. The best baechu fit for a high-quality kimchi has a compact structure, an oval-shaped head, white tissue, and green leaves. Essential to this selection process are the evaluations among the cabbage varieties for their physicochemical and organoleptic properties (8). In addition to the quality of the raw ingredients, the cultivation method, the kind and type of the vegetables or salt-pickled seafood can also affect the fermentation behavior and quality characteristics of the kimchi.

There are two major ways to prepare baechu cabbages for kimchi. One is used for tongbaechu kimchi, a more elaborate baechu kimchi preparation using whole cabbages, preserved for the long-term winter season. The other method is used for chopped or cut matbaechu kimchi, a common preparation style for commercial products, export, and daily, informal family eating. The preparation of these two baechu kimchis is very similar, including ingredients and recipe, except for the cabbage preparation process. For the preparation of tongbaechu kimchi, graded and washed baechu cabbage is slit lengthwise into two or four parts with a knife inserted through the bottom of the cabbage head. The cabbage sections are treated with dry salt for several hours or with 10 percent brine for about 10 hours. The macerated cabbage is rinsed to remove excess salt and then drained. A premixture of spices and other ingredients, according to a given recipe, are packed between the layers of the cabbage leaves. The stuffed cabbages are then placed in a jar that allows for a facultative anaerobic condition for the fermentation. A flow chart for processing the baechu kimchi is shown in Fig. 1.

For chopped matbaechu kimchi preparation, cabbage is cut 3 to 5 cm in length, macerated in a salt solution (8 to 15 percent concentration) for 2 to 7 hours, rinsed with fresh water, and then drained. As an alternative salting method, a whole cabbage that is cut into two or four pieces is first macerated like tongbaechu kimchi before being cut into smaller sizes. Separately premixed sliced radish, cut green onion, chopped garlic, chopped ginger, red pepper powder, salt-pickled seafood, dry salt, etc. are combined to make a premixture of spices with other minor ingredients as directed by the recipe.

B. Salting, Rinsing, and Draining

The macerating step may be accomplished by using either a brine solution or dry salt. This treatment is the most important step for taste, texture, fermentation, and preservation. In general for baechu kimchi, brining is carried out over a wide time range (1 to 15 hours), depending on the salt concentration (5 to 18 percent) and salting temperature (8 to 25°C). Brining at a low temperature (5°C) provides better flavor than at a higher temperature (20–25°C) owing to the support of *Leuconostoc* growth during the brining. For radish kaktugi, dry salt is added to cubed radish for a given time without rinsing. However, salt-macerated cabbages for baechu kimchi are rinsed and drained before blending with the premixture of other ingredients. For baechu kimchi, the salt concentration is adjusted to 2.2 to 3.0 percent of the final product, which assures a less salty, better lasting, and crispy quality kimchi. If the concentration is less than 2.2 percent, fermentation would be too fast, which frequently causes quick acidification and/or softening of the cabbage tissue. On the other hand, if the salt concentration is higher than 6 percent, the kimchi would be too salty, have less flavor, and have a poor appearance.

Generally, the brining process sets the moisture concentration of macerated cabbage, the relative volume and weight, and the internal void space of cabbages. These changes are extremely important because the physical properties of cabbages can be markedly affected, especially for crunchiness of the tissue, which gives a typical textural freshness to the final product. Brining also reduces the content of water- or salt-soluble compounds such as Ca and Mg in the cabbage and increases the salt content in the tissue (9). Furthermore, as a result of brining, the total aerobic bacteria, yeast, and mold counts in salted cabbage are reduced; however, LAB may be increased because of the action of salt (10). It has also been suggested that salting with various commercially available products may affect growth of the microorganisms differently during kimchi fermentation. Heat-treated salt, especially bamboo salt (salt baked in bamboo), is known to reduce growth of *Lac. plantarum*, *Pichia membraraefaciens*, and *E. coli*, but not *Leu. mesenteriodes* (11).

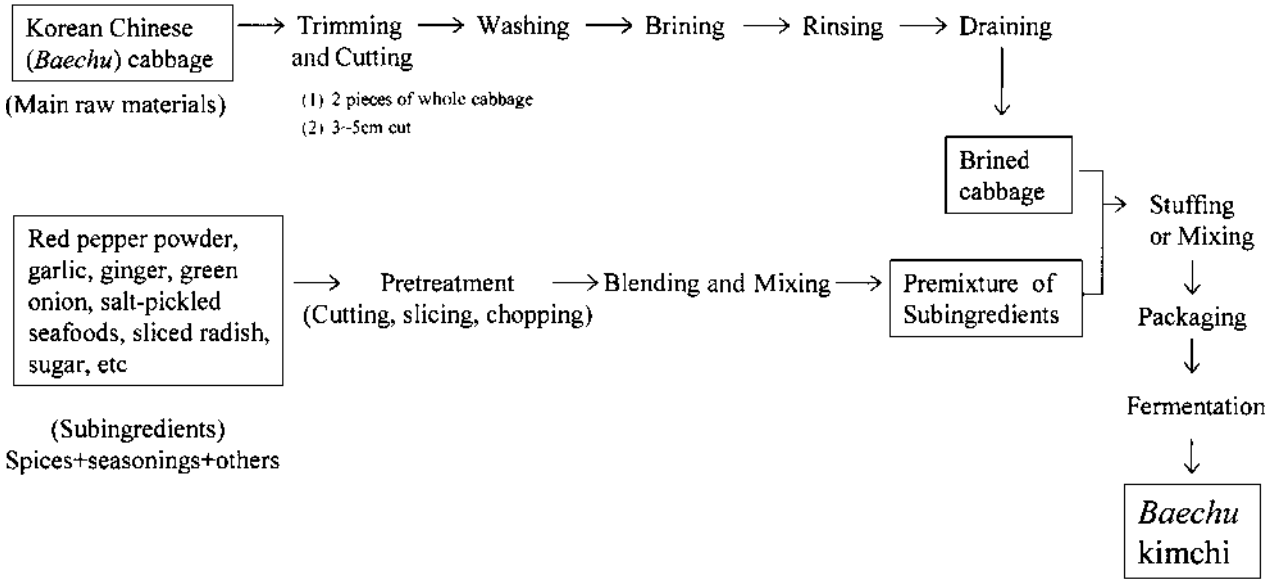

Figure 1 Flow chart for processing of baechu kimchi. (1) Tongbaechu kimchi; (2) matbaechu kimchi.

C. Pretreatment of Subingredients and Mixing Process

As shown in Fig. 1, the brined baechu cabbage is spiked with premixed subingredients of spices, seasonings, and other things. Red pepper powder, garlic, ginger, and green onions are the main spices added to the kimchi. These subingredients should be selected for their good quality, as they can substantially impact the final quality of the kimchi. For instance, appropriate amounts of capsaicin, the sugar content, and the color intensity of the red pepper are important factors in selecting a powdered red pepper. The skinned garlic and ginger are crushed and finely minced. Medium-size green onions are cut into 3 to 4 cm pieces. Radish pieces for a filler for the spice mixture should be less than 1 cm in size. The following ingredients can be added to the premixture as seasoning salt-pickled seafood, juice of fermented anchovy or small shrimp, and salt. These can be added to enhance or vary the flavor and to adjust the salt level. Rice paste as a carbohydrate source can be added to boost the microorganisms for fermentation. Sesame seed or MSG can also be included as fine adjustments to improve taste.

Various other taste-enhancing materials can also be added to the subingredient premixture, based on family tradition, economic situation, and seasonal and regional availability of the ingredients. For example, watercress, mustard leaves, pear, apple, pine nut, chestnut, ginkgo nut, cereals, and various fish and meats (Table 2) can be incorporated into kimchi. For elaborate tongbaechu kimchi, premixtures of subingredients are blended and then stuffed into macerated cabbages. For the simpler matbaechu kimchi, the premixtures are simply blended with brined, cut cabbages.

As an alternative method to the conventional kimchi manufacturing process, the brined baechu cabbage and kimchi seasoning mixture (premixtures of subingredients) are prepared separately and then stored (12). The brined cabbage and kimchi seasoning mixture can be mixed as needed. The kimchi seasoning mixture can safely be stored without microbial growth. Because sensory evaluation studies proved satisfactory, this new processing method of kimchi making will be useful for households and kimchi factories, since the sensory evaluation studies were satisfactory. However, further studies are needed for this process.

D. Placement in Crocks

The premixtures of subingredients for stuffed tongbaechu kimchi are either stored for ripening or packaged for sale. Traditionally, a large quantity of cabbage heads were used for making kimchi, which were stored in underground potteries for the winter. This practice is called kimjang, and it is a major annual event for the Korean family. Kimjang kimchi is the most traditional way to make baechu kimchi, and it is made between mid-November and early December, depending on the climate of the particular year and region. This kimchi is then consumed the following spring. The freshly prepared, unripened kimchi is tightly stacked into the large earthenware crocks (Fig. 2) and covered with the remaining leaves of the brined cabbage. To maintain the cabbages in a facultative anaerobic condition, large stones are used to weigh down the pottery. The tiny pores naturally found in crocks trap air and provide the facultative anaerobic condition for endogenous microorganisms needed during the fermentation. To maintain a constant temperature, crocks are buried underground (80 to 90 percent of the container's depth) and are covered with thick rice straw mats for protection from direct sunlight and cold air.

Recently, lesser amounts of winter kimchi are prepared, owing to the more ready availability of ingredient items, including meats, fish, and fresh vegetables as well as commercial kimchi products. Koreans now enjoy freshly fermented kimchi any time of the year owing to the year-round availability of fresh vegetables and of common household refrigerators and commercial kimchi products. It is common for Korean families to make small batches of kimchi as needed and to store it under refrigeration for short periods to extend its freshness.

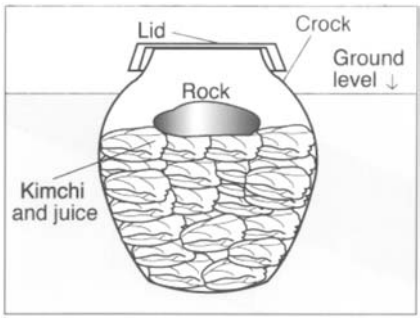

Figure 2 Traditional crock for kimchi storage that is buried in the ground.

Recently, home appliance companies have developed a kimchi refrigerator. This invention provides Korean households with better fermentation and storage by permitting a programmable low temperature fermentation as well as giving a convenient storage place in which to make a better quality of kimchi.

E. Fermentation

The fermentation of kimchi occurs mainly because of the raw materials' endogenous microorganisms, especially in brined cabbages. Although fermentation may be initiated by various microorganisms, LAB ferments sugars in the cabbage and other subingredients that gradually dominate other anerobic microorganisms by organic acid formation. Various chemical, physical, and biological factors also may contribute directly to the growth of microorganisms and to the extent of fermentation. Several factors influence kimchi fermentation: kinds of microorganisms, salt concentration, fermentable carbohydrates, other available nutrients, the presence of inhibitory compounds, the absence of oxygen, pH, and fermenting temperature. The salt concentration, temperature, and pH have a great effect on the rate and extent of the fermentation by LAB. it takes a shorter time to make optimally ripened kimchi when the temperature is increased and the salt concentration is decreased. Detailed microbiological characteristics and fermentation and preservation methods for kimchi are discussed in Sec. V.

F. Processing Methods for Major Kimchi

As mentioned, there are 161 to 187 varieties of kimchi; baechu kimchi is the most popular, and radish kaktuki and dongchimi are also frequently prepared. The processing methods for these three representative kimchis are briefly discussed below, and Table 3 shows the standardized recipes for these three.

1. Baechu Kimchi

The subingredients used for kimchi stuffing may vary depending on family recipes and the regions where it is made. Cho et al. (13,14) standardized the recipe for baechu kimchi processing based on cookbooks, scientific papers, and publications on kimchi from manufacturing factories, and based also on chemical and functional properties. The recommended percentages of ingredients is as follows for salted cabbages (100): radish (13.0), green onion (2.0), red pepper powder (3.5), garlic (1.4), ginger (0.6), anchovy juice (2.2), and sugar (1.0) in a final salt concentration of 2.5. Fermented shrimp is not included in the authors' recipe, though the use of

Table 3 Standardized Recipes of Major Kimchi

Raw ingredients	Weight ratio (%)		
	Baechu kimchi	Kaktugi	Dongchimi
Korean baechu cabbage	100	—	—
Radish	13	100	100
Green onion	2.0	5.1	3.3
Red pepper powder	3.5	3.9	
Garlic	1.4	2.3	1.0
Ginger	0.6	1.0	0.3
Fermented anchovy juice	2.2	—	—
Fermented shrimp and juice	—	4.1	—
Sugar	1.0	1.4	—
Fermented green pepper	—	—	3.3

fermented shrimp in kimchi is popular in the Seoul area and inland regions. The use of combined fermented shrimp and fermented anchovy juice is common (68 percent) in commercial kimchi factories (2).

2. Kaktugi

Kaktugi is fermented radish cubes mixed with various subingredients. Our laboratories have published a standardized recipe and processing method for kaktugi based on our experiments (15) and data from the literature. The recommended ingredient combination for kaktugi are the following for salted, cubed ($2 \times 2 \times 2$ cm) radishes (100): red pepper powder (39), fermented shrimp (4.1), garlic (2.3), ginger (1.0), green onion (5.1), and sugar (1.4) in a final salt concentration of 2.5 percent. Three different salt processing methods are used for the cubed radishes: pickled with dry salt, pickled with brine, and nonpickled. The pickled, brined radishes, in which kaktugi is prepared after salting the radish cubes with 7 percent brine for 30 min at 5°C, showed better flavor and texture. A draining time of 1 hour after brining works well. The salted radish cubes are then mixed with red pepper powder to give it a bright red color; then there is blending with the premixtures of subingredients. Radish mixture is then placed in a vessel for fermentation (15).

3. Dongchimi

Dongchimi, a whole oriental radish ($12–15 \times 7–10$ cm) kimchi, requires a large quantity of seasoned water. Whole radishes are salted with dry salt and then rinsed. The rinsed uncut radishes are mixed with other ingredients (shown in Table 3) in a large quantity of 3 to 4 percent brine solution and then fermented in a crock, completely immersed in the mixed ingredients and water. Green onion, garlic, and ginger are the main subingredients for dongchimi preparation. However, pears, fermented green peppers, and glue plant are frequently used. The crunchy taste of oriental pear, with its high saccharinity, and radishes combine to make the unique flavor of dongchimi when stored under 10°C for 20 days. When serving, remove the radishes from the container and slice them. Because dongchimi liquid is highly salty for storage, add water according to one's taste. The salt content of dongchimi is somewhat more than 4 percent (6).

V. FERMENTATION OF KIMCHI

A. Microorganisms and the Characteristics of the Fermentation

The fermentation of kimchi is carried out through a naturally controlled brining process. During kimchi fermentation, microorganisms should be tolerant to salt, acidity, anaerobic conditions, and endogenous antimicrobial compounds in the ingredients. The main microorganisms involved in kimchi fermentation are LABs, which are facultative anaerobes, microaerobes, or anaerobes. Several factors, such as salt concentration, temperature, pH, microorganism population, and air exposure control the kimchi fermentation process.

The microbiological sequence of lactic acid fermentation in kimchi is similar to that of the lactic acid fermentation of sauerkraut, but it is different owing to the other subingredients, as shown before. The brining process extracts the water from the raw materials by osmotic activity and suppresses the growth of undesirable bacteria that could spoil the kimchi ingredients. At the same time, the brining conditions offer a relatively favorable environment for LAB under increased salinity.

The number of total viable bacteria, yeasts, and molds is found to be markedly decreased by 11 to 16-fold for bacteria and 29 to 87-fold for yeasts and mold in varieties of baechu cabbages imbued with 10 percent NaCl for 10 hours. In contrast, LAB levels increased to 3- to 4-fold, indicating that the brining process removes the aerobes, yeasts, and molds but stimulates growth of LAB in cabbages (10). Kim et al. (9) also reported that counts of bacteria, molds, and yeasts decreased by 45%, 58%, and 40%, respectively, by the process of salting and washing, showing that fermentation is mainly carried out by cabbage LAB after the brining process. Other microorganisms of ingredients other than the cabbages may also be involved in the fermentation, but LAB from the brined cabbage seems to be the main microorganism (12).

For the proper fermentation of kimchi, it is important to keep anaerobic conditions correct to minimize the growth of aerobic microorganisms and stimulate the growth of LAB during the fermentation. The Korean traditional earthenware crocks (Fig. 2) are excellent fermentation vessels that provide facultative anaerobic conditions during fermentation. Figure 3 shows typical microbial changes in kimchi during the fermentation at 2 to 7°C. The number of anaerobic bacteria, usually LABs, increases, whereas aerobes, such as *Achromobacter*, *Flavobacterium*, and *Pseudomonas* species (16) usually decrease owing to the absence of air and salt content and acid formed during fermentation. Although the level of yeast is low, film-forming yeast increases in the later fermentation stages. The yeasts isolated from the kimchi were *Saccharomyces*, *Tolulopsis*, *Debaryomyces*, *Pichia*, *Rhodotorula*, *Endomycopsis*, *Kluyveromyces*, *Cryptococcus*, *Trichospora*, and others (17).

Kimchi fermentation is initiated by *Leu. mesenteroides* (*Leuconostoc* sp.), a heterofermentative LAB and a facultative anaerobe; it produces lactic acid, acetic acid, CO_2, and ethanol as major end products. As the pH drops to 4.6 to 4.9 because of organic acid accumulation, *Leu. mesenteroides* is relatively inhibited. As shown in Fig. 4, *Streptococcus* (*St. faecalis*) behaves similarly as *Leuconostoc* sp., but in lower numbers. The fermentation continues with more acid-tolerant LAB species such as *Pediococcus cerevisiae*, *Lactobacillus brevis*, *Lac. fermentum*, and *Lac. plantarum* (18). However, there is overlapping growth of the species. Also, the growth of each species depends on its initial numbers in the cabbage and other ingredients, the concentration of salt and sugar, the absence of oxygen, and the fermentation temperature, as already mentioned. *Lac. plantarum* is present in the greatest numbers following the initial fermentation and produces the maximum acidity at the later stages, especially at higher temperatures. *Lac. plantarum* is believed to be the main acidifying or deteriorating microorganism in kimchi fermentation (19).

The presence of yeast in the later stage of kimchi fermentation can produce various tissue-softening enzymes, including polygalacturonase, which destroy pectic substances and other tissue

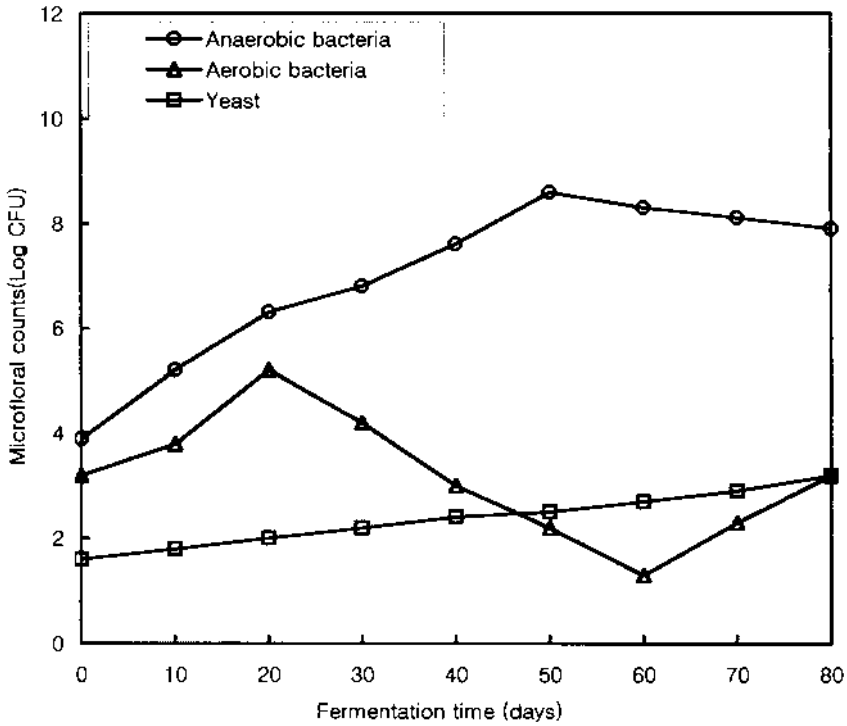

Figure 3 Microfloral changes in kimchi during fermentation at 2 to 7°C. (From Ref. 19.)

structures of cabbages and radishes that will downgrade the kimchi quality. Softening of baechu's texture is a problem due to excessive acidification of kimchi during the overripening stage of the fermentation and preservation processes (20).

Table 4 shows the frequency of gram-positive bacteria, mainly LAB isolated from kimchi fermentation at 5, 15, and 25°C, while *Leu. mesenteroides* and *Leu. paramesenteroides* dominate (65.2%) at the low temperature of 5°C. However, the level was 13.5% at 25°C. The *Lactobacillus* species, mainly *Lac. plantarum*, produces lactic acid (homofermentative LAB) and dominates (59.7%) at the high temperature of 25°C, dropping to 28% at 5°C (21). The levels of *Streptococcus* and *Pediococcus* species were lower than those of *Leuconostoc* and *Lactobacillus* species and were found to decrease considerably at lower temperatures. This suggests that a fermentation temperature of 5°C creates better conditions for producing more flavorful kimchi and extends the preservation period, mainly owing to the growth of *Leuconostoc*.

The kimchi fermentation process undergoes several distinct phases based on the changes in pH and acidity, CO_2 levels, and sugar content, all of which are temperature dependent. The first stage has a rapid decrease of pH and an increase of acidity and CO_2 levels. These changes are accompanied by a decrease of reducing sugars after the initial lag phase. The next stage shows a gradual drop in pH, a further increase in acidity and CO_2 levels, and a rapid disappearance of reducing sugars. The final stage of fermentation proceeds with no or only slight changes in pH, acidity, CO_2, and reducing sugars (3). The pH and acidity of optimally fermented kimchi are 4.2 to 4.5 and 0.4 to 0.8% as lactic acid, respectively.

By monitoring various fermentation temperatures, Shin et al. (22) studied the chemical changes, LAB, and yeast counts in kimchi prepared by a large-scale commercial manufacturer. The optimum pH of kimchi, around 4.2, was reached within 2 days at 25°C, 3 days at 15°C and 23

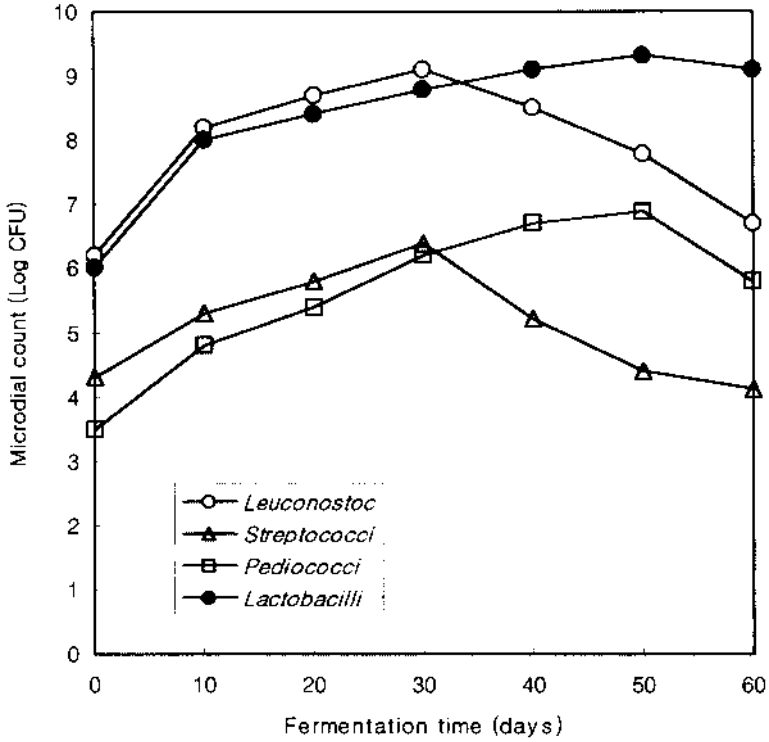

Figure 4 Microfloral changes of lactic acid bacteria during kimchi fermentation at 5°C. (From Ref. 18.)

days at 5°C. As shown in Fig. 5, the pH significantly decreased to 3.6 and stayed the same at 25°C. However, the pH decreased slowly to 4.1 and stayed at the same pH at 5°C. The acidity levels were opposite to the levels of pH at the different temperatures. The acidity increased up to 0.9% at 25°C after 8 days, but increased to 0.5% after 44 days, maintaining almost the same level for 80 days at 5°C. Thus a low temperature of 5°C fermentation produces the best flavor, microorganism status, and preservation conditions.

The salt content of kimchi is another important factor influencing the growth of microorganisms during fermentation. The optimum period of fermentation or the completion of the fermentation is shown in Table 5 (19). For baechu kimchi, at 3.5% salt concentration, fermentation takes 1 to 2 days and 2 days with a 5% salt concentration at 30°C. On the other hand, at the low temperature of 14°C, 5 to 12 days are required at a 3.5% salt concentration, and 10 to 18 days at a 5.0% salt concentration. If the salt content is too high at low temperature, the psychrotrophic LAB, the main microorganisms for fermentation, will not grow. Thus kimchi should be prepared at lower temperatures and lower salt concentrations and for longer times.

B. Safety of Kimchi and Bacteriocin Production

Kimchi has been eaten for centuries without causing any health problems. However, residual agricultural chemicals, pathogenic microorganisms, and NO_2 levels in cabbages are public concerns. One study reported that agricultural chemicals such as an insecticide, chloropyrifos(*O*,*O*-diethyl-*O*-(3,5,6-trichloro-2-pyridyl)-phosphorothioate), can be removed during the process of manufacturing kimchi (23). Baechu cabbages that were soaked in the chlorpyrifos

Table 4 Frequency (%) of Gram-Positive Bacteria Isolated from Kimchi Fermented at 5°C, 15°C, and 25°C

Genus	Species	Subspecies	5°C	15°C	25°C
Leuconostoc	*mesenteroides*	*mesenteroides*	31.5	12	6.3
	mesenteroides	*cremoris*	0	4	4.8
	mesenteroides	*dextranicum*	10.1	0	1.6
	paramesenteroides		23.6	0	0.8
	lactis		0	1	0
Streptococcus	*lactis*		4.5	0	1.6
	iniac		0	0	0.8
	agalactiae		0	0	0.8
	raffinolactis		0	0	11.1
Pediococcus	*pentosaccus*		0	0	4.0
	inopinatus		2.2	6	0
	acidilactici		0	1	0
Lactobacillus	*plantarum*		0	15	36.5
	maltaromicus		12.3	8	5.6
	homochiochii		0	7	4.8
	brevis		0	0	3.2
	curvatus		0	0	2.4
	minor		10.1	3	0.8
	sake		4.5	9	0.8
	confuses		0	0	0.8
	hilgardii		0	0	0.8
	fructosus		0	15	0.8
	farciminis		0	3	1.6
	coryniformis	*coryniformis*	0	0	0.8
	casei	*rhamnosus*	0	0	0.8
	divergens		1.1	0	0
	ailmentarius		0	4	0
	bavaricus		0	2	0
	yamanashiensis		0	4	0
	amylophilus		0	1	0
Bacillus	*cereus group*[a]		0	0	4.8
	circulans		0	0	4.0

[a]*B. cereus*, *B. anthracis*, *B. mycoides*, *B. thuringiensis.*
Source: Ref. 21.

Table 5 Time Required for Optimum Kimchi Fermentation at Different Salt Concentrations and Temperatures (days)

	Salt concentration (%)			
Temperature (°C)	2.25	3.5	5.0	7.0
30	1–2	1–2	2	2
20	2–3	2–3	3–5	10–16
14	5–10	5–12	10–18	12–32
5	35–180	55–180	90–180	No ripening

Source: Ref. 19.

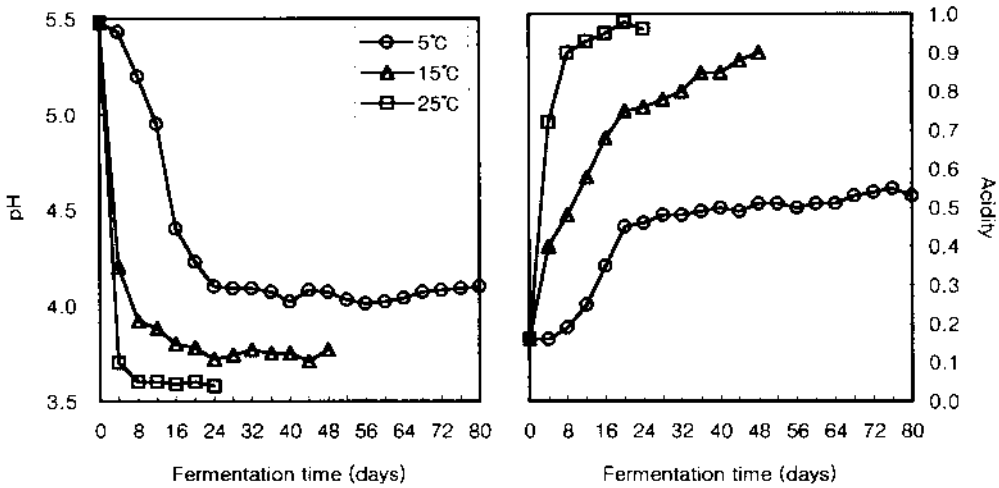

Figure 5 pH and acidity changes of kimchi during fermentation at different temperatures.

solution were used for kimchi preparation. The residual chlorpyrifos, at 0.161 ppm in raw cabbages, decreased to 0.0938 ppm after 4 washings and then further decreased to 0.0099 ppm during the four-week fermentation.

Pathogenic microorganisms of the kimchi ingredients can be eliminated during fermentation. Park (24) examined the pathogenic microorganisms of factory-manufactured kimchi during storage at 0°C and 8°C for 41 days. The author could not detect *E. coli*, *Staph. aureus*, or *Vibrio parahaemolyticus* during the whole storage period, although low levels of coliform bacteria were detected in the early stage of storage. The coliform bacteria level was 2.0×10^3 CFU/mL at 0 day but reduced to less than 10 count after 13 days at 8°C. The reduction of these microorganisms is likely due to the acidic and salt conditions and microbial competition during storage.

LAB in kimchi are known to inhibit the growth of pathogenic organisms. For example, *Ped. cervisiae* and *Leuconostoc* sp. are most effective in restricting the growth of pathogenic organisms, such as *E. coli*, *Staph. aureus*, and *Bacillus cereus* (25). *Ped. cervisiae* suppressed the growth of *E. coli*, *Strep. faecalis*, and *Lac. bulgaricus* (26). Using in vitro testing, the addition of ether extract from *Lac. plantarum* Lp2 isolated from kimchi culture broth completely inhibited the growth of *E. coli*, *Pseud. aeruginosa*, and psychrotrophic PC1 (27).

Cho et al. (28) reported that *Lac. brevis* was found to produce an antimicrobial substance (with a molecular size of 59 kDa). It showed a wide spectrum of inhibition against gram (+) and (−) bacteria and maintained the inhibitory activity between pH 4.0 and 9.0. Paik et al. (29) isolated *Lactococcus lactis* BH5 from kimchi and identified it as a bacteriocin producer with bactericidal activity against *Micrococcus flavus* ATCC 10240. It also showed a broad spectrum of activity against most of the nonpathogenic and pathogenic microorganisms as revealed by a modified deferred method and the spot-on-lawn method. It was found that lacticin BH5 (bacteriocin produced by *Lac. lactis* BH5, MW 3.7 kDa) is stable over a pH range of 2.0 to 9.0 and can withstand several organic solvents tested.

Baechu cabbage contains high levels of NO_3, 157−2500 ppm (30,31). One might suspect that NO_3 converts to NO_2, and then NO_2 reacts with secondary amines from fermented fishes in kimchi to form nitrosamines, which are carcinogens. Several studies have addressed the question of the safety of kimchi. Park and Cheigh (31) reviewed the subject of kimchi and nitrosamines and

concluded that the level of NO_3 reduces greatly during kimchi fermentation, and that the NO_2 content was only at trace amounts. Although *N*-nitrosodimethylamine (NDMA) can be a major nitrosamine found in kimchi, the levels were trace or not detected. Interestingly, vitamin C and other antioxidative compounds in kimchi and LAB were found to inhibit NO_2 and nitrosamine formations (31,32).

C. Kimchi Fermentation with Starter Cultures

In the hope of better quality control, there have been several attempts to ferment kimchi using starter cultures. *Lac. plantarum*, *Lac. brevis*, *Ped. cerevisiae*, and *Leu. mesenteroides* isolated from kimchi were used as starters (33). The starter cultures inoculated into kimchi increased fermentation rates compared to the control kimchi, even though the fermentation period was shortened by about 24 hours compared to the control at 25°C. Also, these studies showed that the sensory test score was greater than for noninoculated control for odor, flavor, and overall acceptability.

So et al. (34) used five strains of psychrotrophic LAB from kimchi as fermentation starters. Starter-inoculated kimchi showed sharp decreases in gram (−) and coliforms from the initial stage, but the control kimchi showed slow increases in those bacteria in the early stage and then sharp decreases after 10 days at 8°C. It took 10 days to reach the optimum ripened state in the control kimchi, but only 4 to 6 days in the *Leuconostoc*-inoculated kimchi and 2 days in the *Lactobacillus*-inoculated kimchi to reach the stationary phase of the growth. Moreover, the inoculations of all these starters did not cause overacidification. The quality of *Leuconostoc*-inoculated kimchi was found to be good compared to the control but not that of the *Lactobacillus*-inoculated kimchi.

Blanching of cabbages along with LAB inoculation to kimchi was employed in another trial (35). In this study, blanching treatment before the inoculation of the starter culture reduced number of the viable cells found in the raw materials. The pH of *Leu. mesenteroides*–added group rapidly decreased but stayed steady. Blanching and the inoculation with *Leu. mesenteroides* produced kimchi with good sensory acceptability, but the speed of fermentation in the *Bifidobacterium bifidum* groups was much retarded.

Ozone water or ozone gas treatment was adopted to control microorganisms in the raw materials (36). The survival ratio of total microflora was 6 to 20 percent by treating the kimchi seasoning mixtures with ozone gas and ozone water at 6 mg/L/s for 1 hour. More than 80 percent of total viable microflora in kimchi ingredients can be removed by the ozone treatment. Following the treatment, *Lac. acidophilus* was used as a starter culture, because it can survive in the human intestine. The ozone-treated kimchi with *Lac. acidophilus* stimulates the production of vitamin B_1 and vitamin C. The aerobic bacteria levels were greatly decreased, but the number of LAB significantly increased compared to the control. *Lac. acidophilus* produced β-galactosidase and polygalacturonase, which consumed polysaccharides in the cell wall of the cabbages, causing overripening and softening of the kimchi. Another LAB test, using a kimchi ozone sterilization combination, needs to be developed for the further study.

Single and mixed cultures of *Leu. mesenteroides* subsp. *mesenteroides* KFRI 819, *L. plantarum* KFRI 813, and *L. maltaromicus* KFRI 235 as starters for kimchi fermentation in garlic paste or skim milk as cryoprotectants at 4 and 10°C also were studied (37). The authors reported that the mixed microbial starters in 10% garlic paste showed a better quality than those in 10% skim milk, inoculated with the single culture. Since most of the raw materials used for making kimchi are heat-sensitive, new technologies must be developed to reduce initial microbial loads in the raw materials, and further research is needed on the appropriate starter cultures used in kimchi fermentation.

D. Controlled Fermentations of Kimchi to Extend Shelf Life

1. Temperature and Salt Content

Low-temperature and mild freezing storage of kimchi appear to be good choices for preservation over long periods. Table 6 shows the changes in total acidity of kimchi stored at −5 to 4°C (38). Kimchi stored at −5 to 0°C maintained 0.57–0.60% total acidity for 3 months, compared to 4°C for about 20 days. This indicates that the optimum temperature for the cold storage of kimchi is 0°C. Kimchi is traditionally prepared in early winter and stored for 3 to 4 months in pots buried underground during the winter season. One of the characteristics of the kimjang kimchi is ripening (i.e., fermentation) at low temperatures, using psychrophilic *Leu. mesenteroides*. To obtain the traditional and desirable taste of kimchi, a stepwise temperature lowering fermentation was explored. For instance, the temperature was lowered to 0°C, after a 48-hour fermentation at 20°C or for 72 hours at 15°C with 0.5% total acidity (39). Thus, at present, most Korean households use a specifically designed (i.e., temperature-programmed) refrigerator for kimchi, instead of the traditional ground-buried techniques.

There are many other ways to preserve kimchi, such as pasteurization, with and without preservatives, canning and bottling, utilization of food additives, and irradiation. Thermal processing is mainly designed to control *Lactobacillus* and other microorganisms that are responsible for overripening in the later stage of fermentation. The D-value and Z-value of related microorganisms in addition to thermal diffusability of kimchi in a retort pouch were studied (40). The canning process of kimchi was developed for several commercial products. However, the freshness of kimchi texture was totally lost owing to heat treatment. The thermal processing of kimchi has been used for the commercial distribution. This process was to destroy *Lactobacillus plantarum* or *Lactobacillus brevis*, which grow during the ripening of kimchi.

High levels of salt are another measure used to extend shelf life of kimchi. As mentioned earlier, fermentation speed is significantly delayed with increased levels of NaCl. Park and Kim (41) report that as NaCl concentration increases, CO_2 production and pH decrease significantly. Various kinds of salt manufactured in Korea affect fermentation differently; for example, heat-treated salts (guwoon salt, bamboo salt) were shown to retard the fermentation speed. Natural salt + KCl also was shown to extend the fermentation time without taste changes (42). Kim et al. (43) report that CA-A (NaH_2PO_4, Na_2HPO_4, Na_3PO_4) shortened fermentation time. Sodium phosphate and sodium citrate significantly inhibited the fermentation, while potassium phosphate had little effect. Thus the regulation of temperatures and salt levels, and their kinds and mixing techniques, are important factors for the preservation time. Therefore, a kimchi refrigerator can be used in the households that need to prepare and preserve it for long periods. The kimchi industry uses low temperature circulation. Keeping it at a low temperature is a convenient, widely used, and effective method of prolonging its shelf life.

Table 6 Change in Titratable Acidity of Cabbage Kimchi During Low-Temperature Storage

Storage	Storage period (days)									
Temperature (°C)	10	20	30	40	50	60	70	80	90	100
−5	0.57	0.58	0.59	0.58	0.58	0.59	0.59	0.60	0.60	0.62
0	0.58	0.61	0.60	0.61	0.59	0.60	0.59	0.60	0.61	0.62
4	0.61	0.61	0.64	0.68	0.68	0.70	0.69	0.70	0.72	0.72

Source: Ref. 38.

2. Subingredients and Natural Preservative Plants

a. Subingredients Kimchi subingredients were examined for their ability to inhibit the growth of microorganisms. An increased garlic concentration (0–6%) in the preparation decreased the number of aerobic bacteria but increased LAB levels at 2 days (early stage fermentation) at 21°C (44). A recipe of 2 percent garlic content in kimchi decreased the amount of aerobic bacteria significantly (50- to 1000-fold) compared to a kimchi recipe of 1% garlic. Cho and Jhon (45) also reported that 21 aerobic bacteria isolated from kimchi had inhibited growth in the presence of garlic extract. The isolated bacteria were 11 *Bacillus* sp., 2 *Staphylococcus* sp., 1 *Micrococcus* sp., 1 *Flavobacterium* sp., 2 *Enterobacteriaceae* and 4 *Vibrionaceae*. The 21 aerobic bacteria could not grow in the nutrient broth with a 4.5% garlic concentration at 30°C for 24 hours. Only one strain survived when the garlic concentration was 2.8%. Nine out of the 21 strains could survive in the 1% garlic concentration. Kim et al. (46) reported that garlic extract also significantly suppressed the growth of *E. coli* in tryptic soy broth (TBS). Based on the data, these investigators concluded that garlic is a major condiment having the ability to eliminate unnecessary microorganisms of aerobic bacteria and *E. coli* in kimchi.

Lee and Kim (47) report that red pepper, garlic, and ginger (the main subingredients of kimchi) also inhibited growth of the LAB at only the early stage of fermentation (2 days at 25°C), but thereafter the overall growth rate was the same or accelerated compared to the control.

On the other hand, sucrose, MSG, fresh oyster, and salt-fermented anchovy and shrimp increased the fermentation rate (48). MSG reduced kimchi the fermentation period, by the stimulatory growth of the LAB, but the pH changes were similar to the control (49). The addition of MSG to kimchi showed growth stimulation of LAB with a buffering action and a constant pH level. But MSG affected the stability of ascorbic acid, thiamine, and β-carotene. The MSG addition enhanced the flavor because of glutamic acid, which reduced the sour taste.

b. Natural Preservatives To develop a natural preservative that would extend the shelf life of kimchi, Moon et al. (50) screened 102 edible plants, 21 antimicrobial agents, and other related compounds for kimchi fermentation. *Baical skullcap* and *Assam indigo* from 42 oriental medicinal plants were shown to be effective for maintaining the fresh state of kimchi. Thirty-two herbs and spices, including peppermint, cinnamon, lemon balm, clove, hops, rosemary, sage, horseradish, and thyme showed high antimicrobial activity against the kimchi-fermenting microorganisms. Pine needles, persimmons, and oak leaves showed a significant bactericidal effect among the 28 fruits, vegetables, and related plants tested. Nisin and caffeic acid effectively slowed kimchi fermentation, making them good natural preservatives in extending the shelf life of kimchi. However, sensory evaluation is another important factor to consider for the selection of preservatives. Kim and Park (51) studied antimicrobial activities among 15 kinds of vegetables used as kimchi ingredients. Leek extracts showed particularly strong antimicrobial activities against *Ped. cervisiae* and *Lac. plantarum*, known to be a major microorganism for the acidification of kimchi during fermentation.

Saps from pine needles are reported to suppress fermentation (52), as the pine needles extend by almost double the time needed to reach a pH 4.3. The total viable number and the *Lactobacillus* cell number decreased when pine needle extract was added to kimchi, regardless of fermentation temperatures.

The addition of green tea in kimchi extended its shelf life by lowering the titratable acidity, lactic acid, and acetic acid contents (53). We studied the increased preservative and antimutagenic effects of green tea leaves added to baechu kimchi (green-tea-added kimchi, GK) (54). The fermentation period for the GKs was extended compared to the control kimchi (CK). Although the initial pH and acidity between GKs and CK were similar, the time for the kimchis to reach optimally ripened status (pH 4.3) was different. CK took 6 days, while GK2 and GK4 took 10 and 14 days at 10°C, respectively (Fig. 6). Accordingly, the growth of *Leuconostoc* sp. and

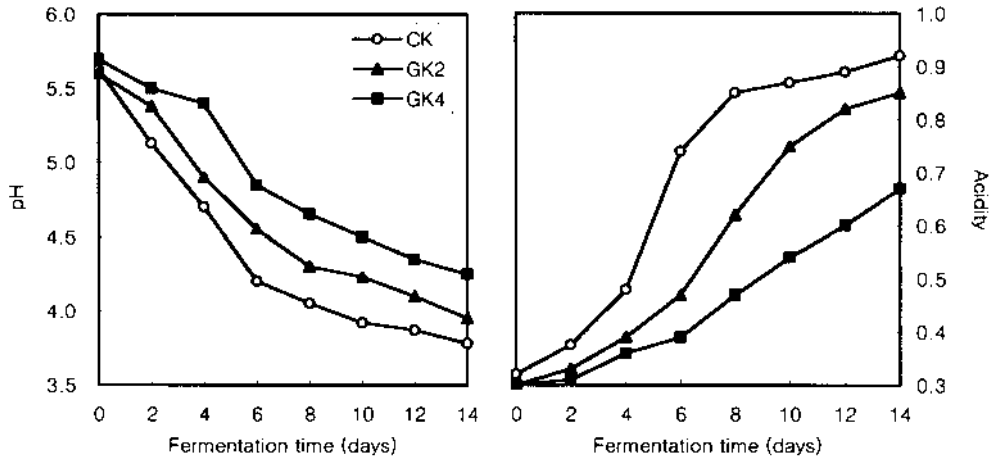

Figure 6 Changes in pH and acidity of control kimchi (CK) and green-tea-leaves-added kimchis (GK) during fermentation at 10°. GK2: 2% green-tea-leaves-added; GK4: 4% green-tea-leaves-added. (From Ref. 54.)

Lactobacillus sp. in the GKs was considerably delayed. As shown in Fig. 7, the growth of *Leuconostoc* sp. was greatly retarded, yet the levels are still high compared to the control. However, the population of *Lactobacillus* decreased with the addition of green tea levels, and the count was low compared to the control, indicating that *Leuconostoc* sp. was dominated to *Lactobacillus*, giving a better taste to the kimchi.

The addition of ginseng (2%) to the kimchi boosted both its shelf life and its quality. Ginseng-added kimchi showed a more favorable tissue texture, improved overall acceptability, and retarded the rancidity of the kimichi (55,56).

The effects of low temperature heating and the addition of mustard oil on pH and total acidity of kimchi during storage at 15°C were studied (57). Mustard oil showed antimicrobial

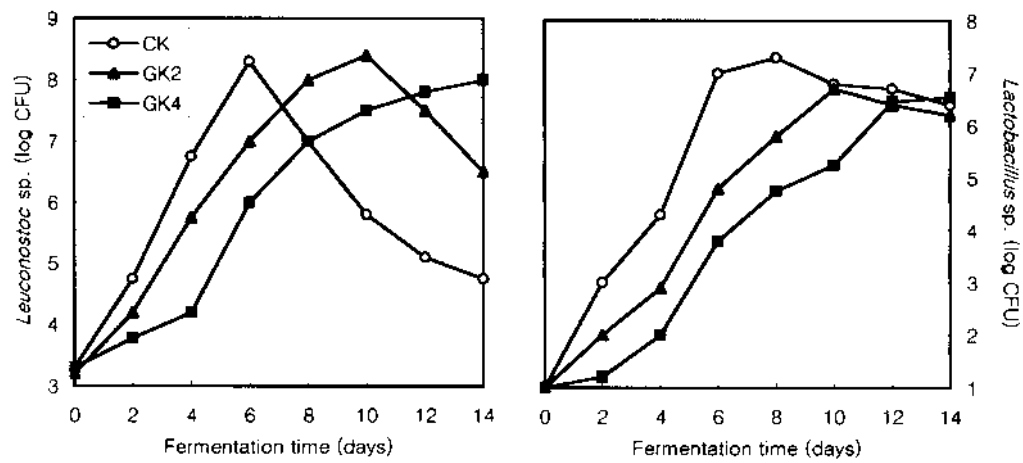

Figure 7 Changes in the numbers of *Leuconostoc* sp. and *Lactobacillus* sp. of control kimchi (CK) and green-tea-leaves-added kimchi (GK) during fermentation at 10°C. GK2: 2% green-tea-leaves-added; GK4: 4% green-tea-leaves-added. (From Ref. 54.)

acitivity for *Lac. plantarum*, *Lac. brevis*, *Leu. mesenteroides*, and *Ped. cervisiae*. The addition of 200 ppm mustard oil, 0.1% mustard powder, and 0.01% H_2O_2 to kimchi reduced the fermentation rate. Low-temperature heating (50°C) of salted cabbages and the addition of 200 ppm mustard oil and 0.01% H_2O_2 to seasonings extended the time to reach the optimum ripening of the kimchi, about 2.5 times compared to the control. A combination of preheating at a low temperature (50°C for 35 minutes) with addition of mustard oil and H_2O_2 to the seasoning and postheating at low temperature (65°C for 20 minutes) slowed the kimchi fermentation speed about 5 times, compared to the control.

Chitosan and oligochitosan decreased the fermentation rate. The pH was not lowered, and total acidity was lower, in the chitosan-added kimchi (58). The numbers of total viable cells, *Leuconostoc* sp. and *Lac. plantarum*, were lower in the chitosan-added kimchi than in the control. The sour and stale flavor of the kimchi was reduced by the chitosan addition. Our laboratories found that when the chitosan oligosaccharide is added (1%), the growth of LAB can greatly be inhibited, without a decrease of pH. The increase in total acidity was greatly retarded (more than twice) during fermentation at 15°C. More importantly, the taste of the final product received a high mark by the sensory evaluation test.

Chinese pepper also showed an antimicrobial property to extend the shelf life of kimchi. It is worth noting that experiments show that peppers have antimutagnic/anticancer activities in tests in vitro and in vivo (59). Choi et al. (60) studied the inhibitory effect of nisin (a bacteriocin produced by *Strep. lactis*) on kimchi fermentation at 15°C. The addition of 100 IU/g of nisin delayed fermentation by pH, total acidity, and LAB counts.

Bamboo leaves extract exhibited strong antimicrobial activity against *Brettanomyces custersii*, *Klebsiella oxytoca*, and *Pichia membranaefaciens*, which are responsible for softening the kimchi texture (61). The antimicrobial activity of bamboo leaves extract was better than 0.5% and 1.0% sorbic acid, and was stronger at pH 5 than at pH 7. The addition of bamboo leaves to radish-based dongchimi is an old tradition in prolonging the shelf life and improving the taste of kimchi (62).

3. Increased Shelf Life of Kimchi by Fermentable Sugar Reduction

Kim et al. (63) studied the sugar content of radishes to improve the storage stability of cubed radishes by monitoring the titratable acidity (TA) at the completion of fermentation. The final TA obtained at the end of fermentation was directly proportional to the sugar content of the radishes, with a value of $0.29x + 0.4428$, where x is the sugar content of the radish. These investigators also studied the relation between the soluble solids (SS) content of baechu cabbage and the final TA value of the kimchi (64). The results showed that the final TA in the kimchis studied was also directly proportional to the SS content (x) of the cabbage, showing that TA is equal to $0.3x + 0.7779$.

Yu et al. (65) also studied the extension of the shelf life of kimchi by reduction of the initial reducing sugar content (s_0). With initial sugar content reductions of 2.3%, 0.97%, and 0.6%, fermentation periods to produce 0.75% TA required 2, 7, and 12 days, respectively. Thus these researchers were able to estimate the fermentation period (T) to produce 0.75% acid in kimchi using the equation $T = -16.82 \log(s_0) + 7.66$. Kimchi with baechu cabbage devoid of about 80% of fermentable sugar can extend a storage period by 30 days at 25°C with 0.8% total acidity, but the score of sensory evaluation was low.

The reducing sugar content (5.7 mg/mL) of baechu cabbage using a salting and desalting process prior to kimchi fermentation took 6 days to reach 0.75% total acidity, but the control sample containing 15.1 mg/mL of sugar took 3 days of fermentation to reach the same level of total acidity, 0.75%. The hardness value of kimchi texture of the treatment was higher than that of the control during the fermentation period (66).

4. Preservation and Packaging During Marketing

Low temperature by refrigeration or mild freezing is a preferred preserving method during storage for marketing purposes. As already shown, kimchi stored at 4°C maintained a high quality for only 20 days, while kimchi stored at −5°C to 0°C keeps its quality for up to 3 months (38). The salinity of kimchi lowers the freezing point, but the texture of kimchi cabbage is not affected as low as −5°C even though the kimchi broth is frozen. Thus it is recommended that kimchi be fermented at a low temperature range (7 to 15°C) and stored at a lower temperature around −1°C (67). For storage longer than 4 months, quick freezing is recommended to prevent texture degradation. The texture of kimchi that is frozen at −15°C is damaged significantly after freezing and thawing, although little change in taste and flavor takes place. If kimchi products are packaged, and quickly placed in brine at −30°C to −38°C, and remain in a freezer, the texture will be well maintained (68).

In our experience, vacuum packaged bottled or canned kimchi had a longer shelf life than the control. Lee et al. (69) reported that zeolite sealed in 10 μm thick, high-density polyethylene film could considerably reduce pressure and volume increase by CO_2 production when included inside the kimchi packages at 15°C.

Kim et al. (70) evaluated the quality of kimchi affected by the packaging materials Ny/PE, Ny/CPP, Cryovac BK-1, BK-4, and PET/A1/PE films during storage at 5°C and 20°C. The CO_2 concentration of kimchi packaged with cryovac BK-1 and BK-4, which has higher gas permeability, increased to a maximum and then decreased owing to gas permeation during storage. It should be mentioned that LAB levels and the sensory evaluation of these products were not significantly different. Thus it is recommended that CO_2 permeable films be used rather than high gas-impermeable barrier films to avoid swelling of packaged kimchi during storage and distribution.

The Miraflash (71) plastic container (polyethylene + natural antimicrobial materials) was studied in comparison with polyethylene and aluminum film kimchi packaging characteristics. The Miraflash container was developed based the rationale that the synthetic materials may mimic the traditional Korean porous potteries. In addition, Miraflash has antimicrobial activity and no known environmental hormones. When kimchi is fermented in the Miraflash container, pH decreases and the total acidity increases slowed. Also, the *Lactobacillus* sp. counts were significantly decreased after the optimal ripening period. This artificial container seems to mimic traditional Korean pottery, thereby helping to extend preservation periods and preserve the traditional taste of the kimchi without the contamination of environmental hormones.

Hong and Park (72) developed color indicators on kimchi packages as an innovative way to monitor the ripeness of commercial kimchi products during storage and market distribution. In their design, Hunter b values of bromocresal purple type and Hunter a values of methyl red type appeared to be proportional to both the pH and the titratable acidity of kimchi. Kimchi was packed in a polypropylene (PP) tray with a nylon/cast polypropylene (Ny/CPP) lid, where the indicating sachet consisting of CO_2 absorbent and chemical dye (bromocresol purple and methyl red) was attached. This technique is an effective way to sense the ripeness of packaged kimchi products.

VI. BIOCHEMICAL, NUTRITIONAL, AND FUNCTIONAL PROPERTIES OF KIMCHI

A. Biochemical Changes During Kimchi Fermentation

1. Flavor Compounds

a. Organic Acids Organic acids produced during kimchi fermentation create the main flavor of kimchi. As shown in Table 7, lactic acid content increases, but other nonvolatile organic

Table 7 Organic Acids Content in Various Kimchi at 12–16°C (meq/100 g)

Sample fermentation period (days)	Kimchi A			Kimchi B			Kimchi C		
	1	4	7	1	4	7	1	4	7
Nonvolatile organic acids									
Lactic acid	0.07	0.14	0.33	0.08	0.62	0.99	0.19	0.83	1.64
Succinic acid	0.70	0.35	0.29	0.30	0.87	0.82	0.08	0.83	0.69
Fumaric acid	0.48	t	t	t	t	t	0.04	t	t
Malic acid	3.25	1.24	t	3.65	0.27	0.61	1.04	0.09	t
Volatile organic acids									
Formic acid	ND	t	ND	ND	ND	ND	ND	t	ND
Acetic acid	0.27	0.64	1.84	t	2.53	7.09	0.27	0.81	4.82
Propionic acid	0.16	0.23	0.54	1.62	1.43	0.23	1.51	1.50	1.62
Butyric acid + Valeric acid	0.51	0.76	0.82	0.38	0.54	0.41	0.44	0.76	0.68
Caproic acid	0.03	0.11	0.11	0.04	0.06	0.05	0.07	0.07	0.08
Heptanoic acid	0.04	0.11	0.11	0.03	0.04	0.05	0.05	0.26	0.08

Kimchi A: cabbage (100%); B: cabbage (100%) + garlic (4%); C: cabbage (100%) + red pepper 4 (%); t: trace, ND: Not detected.
Source: Ref. 73.

acids contents are high at the beginning and decrease during fermentation (73). The lactic acid content is highest in the red pepper-added kimchi and then in garlic-added kimchis, meaning that condiments added to the baechu cabbage stimulate the lactic acid production. Lactic acid and succinic acid contents are high at lower temperatures (6 to 7°C) than at higher temperature (22 to 23°C). Acetic acid is the main volatile organic acid produced during kimchi fermentation. Garlic-added kimchi produced highest levels of acetic acid. Levels of propionic acid, butyric acid, valeric acid, caproic acid, and heptanoic acid are relatively low. Heterofermentative LAB, such as *Leuconostoc mesenteroides* and *Lactobacillus brevis*, could produce acetic acid. These findings indicate that garlic likely supports the growth of heterofermentative LAB. The CO_2 content was also high in garlic-added kimchi. Chyun and Rhee (74) reported that low salt levels and low temperature support increased production of acetic acid.

b. Volatile Flavor Components Forty different aroma components have been identified in kimchi using the dynamic headspace concentration method (75). The major aroma components are ethanol, methyl allyl sulfide, acetic acid, dimethyl disulfide, camphene, 1-phellandrene, diallyl disulfide, methyl allyl trisulfide, α-zingibirene, etc. These compounds increase during the ripening period and then decrease. Methyl allyl sulfide content increased suddenly, 30-fold, and decreased gradually. The methyl allyl sulfide content correlated well by $r = 0.93$ by sensory scores. Thus the methyl allyl sulfide produced during fermentation seems to be a major volatile flavor compound in well-fermented kimchi.

c. Amino Acids Contents The amino acids that form during fermentation are other flavor-generating sources for kimchi. Table 8 shows free amino acid contents in kimchi that was fermented at 20 to 22°C for 44 to 47 hours, with and without fermented anchovy liquid (76). Glutamic acid, arginine, lysine, aspartic acid, and alanine were the major amino acids found in well-ripened kimchi. Amino acids are affected mainly by the addition of ingredients such as salt-pickled seafoods and meats. Though microorganisms consume some amino acids during fermentation, amino acids accumulate via protein hydrolysis of the ingredients.

Table 8 Free Amino Acid Content in Kimchi Fermented at 20–22°C for 44 to 47 h with and Without Addition of Fermented Anchovy Solution

Amino acid	Kimchi[a] without fermented anchovy solution	Kimchi with fermented anchovy solution	
		10 mL[b]	15 mL[c]
Lysine	0.21 (7.5)[d]	1.10 (14.5)	1.32 (12.0)
Histidine	0.07 (2.4)	0.01 (0.2)	0.11 (1.0)
Arginine	0.29 (10.3)	0.40 (5.3)	0.60 (5.5)
Tryptophan	0.22 (7.7)	0.12 (1.5)	0.27 (2.5)
Aspartic acid	0.17 (5.8)	0.78 (10.4)	1.20 (10.9)
Threonine	0.40 (14.0)	0.65 (8.6)	0.69 (6.3)
Serine	—	0.46 (6.1)	0.58 (5.3)
Glutamic acid	0.27 (9.7)	0.94 (12.5)	1.50 (13.7)
Proline	0.11 (3.8)	0.24 (3.2)	0.35 (3.2)
Glycine	0.07 (2.5)	0.22 (2.9)	0.34 (3.1)
Alanine	0.52 (18.4)	0.86 (11.4)	1.22 (11.2)
Valine	0.15 (5.2)	0.49 (6.5)	0.78 (7.2)
Methionine	0.02 (0.5)	0.16 (2.2)	0.26 (2.3)
Isoleucine	0.10 (3.4)	0.30 (4.0)	0.47 (4.3)
Leucine	0.10 (3.7)	0.49 (6.5)	0.76 (6.9)
Tyrosine	0.08 (2.7)	0.12 (1.6)	0.17 (1.6)
Phenylalanine	0.07 (2.5)	0.22 (2.9)	0.32 (2.9)
Total	2.83 (100)	7.57 (100)	10.94 (100)

[a]10 mL of 15% table salt solution added.
[b]10 mL of fermented anchovy solution (salt concentration 24% added).
[c]15 mL of fermented anchovy solution (salt concentration 24% added).
[d]% in total amino acid.
Ingredient ratio of kimchi: 100 Chinese cabbage, 4 leek, 2 garlic, 1 ginger, 2 red pepper flour, 1 sugar.
Source: Ref. 76.

The total free amino acid levels increased greatly by the addition of fermented anchovy juice. The contents of lysine, aspartic acid, glutamic acid, valine, methionine, isoleucine, and leucine resulted in significant increases and serve as flavor enhancers for the kimchi (Table 8). Park et al. (2) indicated that commercial kimchi factories are using fermented anchovy juice for the production of glutamic acid and other amino acids to give a better flavor.

2. Vitamins

Kimchi is known to be a good source of vitamins in the Korean diet. The raw ingredients used for kimchi preparation contain high levels of vitamins, but some vitamins can be synthesized during the fermentation.

Table 9 shows vitamin contents of common kimchi, the average contents of vitamins in three different starter-inoculated kimchis, and the common kimchi during fermentation at 3 to 7°C (77). The levels of vitamin B_1, B_2, B_{12}, and niacin are all increased during the course of fermentation. The vitamin levels of the common kimchi without inoculation of the starters increased similar to the preparation with starter cultures. Vitamin B_1 level increased twice, but B_2 increased almost four times, and vitamin B_{12} and niacin also increased. The maximum levels of

Table 9 Vitamin Contents of Common Kimchi and Average Vitamin Contents of 4 Different Kimchi During Fermentation at 3–7°C

Fermentation time (week)	Carotene (μg%)	Vitamin B_1 (μg%)	Vitamin B_2 (μg%)	Vitamin B_{12} (μg%)	Niacin (μg%)	Vitamin C (μg%)
0	49.5[a]	41.7	66	0.17	740	28.9
1	44.0 (35.4)[b]	41.6 (40.1)	47 (54)	0.009 (0.09)	781 (747)	25.0 (25.3)
2	32.0 (30.4)	70.9 (61.9)	110 (99)	0.19 (0.20)	928 (861)	27.8 (28.5)
3	26.6 (26.9)	79.1 (87.5)	230 (157)	0.25 (0.33)	901 (792)	23.6 (22.3)
4	21.0 (25.3)	62.7 (70.8)	35 (95)	0.20 (0.26)	591 (525)	16.7 (16.0)
5	24.2 (20.1)	53.3 (49.1)	40 (37)	0.10 (0.16)	—	11.6 (11.0)

[a]Naturally fermented baechu kimchi.
[b]Average levels of four different kimchis; common kimchi + 3 different starter inoculated kimchis.
Source: Ref. 77.

these vitamins were in the optimally ripened kimchi state of 2 or 3 weeks. Carotene levels of the kimchi gradually decreased during fermentation. The initial content of 49.5% decreased to 27% after 3 weeks. The vitamin C level slightly decreased at an early stage of fermentation but rebounded to the optimally ripened states, indicating synthesis of vitamin C during fermentation. Another experiment also showed the same result for vitamin C content. The vitamin C content was 15 mg% at the beginning but increased 17 mg% after a slight decrease (3).

3. Acidification and Overfermentation

Various biochemical changes occur during fermentation along with the formation of acceptable flavor and texture. However, undesirable fermentation or overfermentation after ripening may produce a poor-quality kimchi, resulting in acidification and cabbage tissue softening (78). Because the raw materials contain sufficient sugar to convert to organic acids, excessive acid can be formed with continuous fermentation by more acid-tolerant microorganisms. The tissue softening problem is associated with the decomposition of pectic substances in the tissues of cabbages or radishes (79). Polygalacturonase, which is responsible for tissue softening, shows a higher activity during the later fermentation period and is known to be excreted primarily from aerobic and surface-film-forming microorganisms. Also, changes in chlorophyll compounds and other substances occur during the storage of fermented kimchi.

B. Nutritional Characteristic of Kimchi Ingredients and Kimchi

1. Kimchi Ingredients

The nonfibrous carbohydrate that is consumed by endogenous LAB is high in red pepper powder and garlic, even though the main sugar source is baechu cabbage. Most subingredients for kimchi contain Ca and P. Especially high amounts are found in red pepper powder, fermented shrimp, and fermented anchovy. Carotenoids and bioflavonoids are found in baechu cabbage, green onion, carrot, and red pepper powder. Baechu cabbages and red pepper powder are the main sources of vitamin C. Ginger contains gingerol, which stimulates appetite, blood circulation, perspiration, and antimicrobial function, and can be a source of niacin and vitamin K. Oysters are a main source of vitamin B complex. Garlic is known to have various health benefits. For example, allin, one of the major active ingredients of garlic, converts to allicin by the action of alliinase. Allicin by

combining with vitamin B_1 makes allithiamine, which makes vitamin B_1 available in the body for the production of energy. It is known that allicin, S-containing compounds, and methyl linoleate in garlic exert antimutagenic and anticancer effects (80,81).

Fermented anchovy juice is source of protein, amino acids, Ca, P, and Fe. Radishes offer sugar, niacin, Ca, and isothiocyanate during fermentation. Green onion is a source of vitamins A and C and chlorophyll. In addition, kimchi ingredients contain large amounts of phytochemicals (82).

2. Kimchi

Kimchi has a low caloric content, but it is rich in minerals, vitamins, and dietary fiber. The protein and lipid contents can be increased with various subingredients like fish, clams, oysters, and meat, which give kimchi its characteristic savor. Triglycerides, polar lipids, free fatty acids, monoglycerides, hydrocarbones, sterol, and about 18 various free fatty acids were found; among the major fatty acids (44 to 60%) are linoleic and linolenic acid. The vitamin C and carotene content in kimchi are from the vegetables, while vitamin B complex comes from fermented fish and is synthesized during fermentation (77).

Some phytochemicals such as benzylisothiocyanate, indole compounds, thiocyanate, and sitosterol have been found in kimchi and are known to have antimicrobial and anticancer functions. The total dietary fiber (DF) content of kimchi is about 24% on a dry basis. The contents of SDF (soluble dietary fiber) and IDF (insoluble dietary fiber) are 7.8% and 16.2%, respectively (83). The nutritional composition of baechu kimchi, kaktugi, and dongchimi, the most popular *kimchis*, are shown in Table 10 (84). Because kimchi is made with a mixture of ingredients, the mixing ratios and the variety of the ingredients cause individual nutritional characteristics.

Although energy sources are low (11 to 18 kcal/100 g), baechu kimchi and kaktugi are especially good sources for Ca (37 to 47 mg), P (40 to 58 mg), and K (300 to 400 mg). There are

Table 10 Nutritional Value[a] per 100 g of Major Kimchi

Composition	Baechu kimchi	Kaktugi	Dongchimi
Energy, kcal	18	33	11
Moisture, %	90.8	88.4	94.2
Protein, g	2.0	1.6	0.7
Fat, g	0.5	0.3	0.1
Nonfibrous carbohydrate, g	2.6	6.7	2.5
Fiber, g	1.3	0.7	0.5
Ash, g	2.8	2.3	2.0
Calcium, mg	47	37	18
Phosphorus, mg	58	40	17
Iron, mg	0.8	0.4	0.2
Potassium, mg	300	400	120
Vitamin A, RE	48	38	15
β-carotene, μg	290	226	88
Vitamin B_1, mg	0.06	0.14	0.02
Vitamin B_2, mg	0.06	0.05	0.02
Niacin, mg	0.8	0.5	0.2
Vitamin C, mg	14	19	9

Source: Ref. 84.

0.06 and 0.14 mg of vitamin B_1, 0.06 and 0.05 mg of vitamin B_2, 0.8 and 0.5 mg of niacin, and 14 and 19 mg of vitamin C in 100 g of baechu kimchi and kaktugi, respectively. The nutritional value of dongchimi is low as this kimchi contains large amounts of water.

Thus kimchi are low in calories, low in sugar and lipids, and high in vitamins, minerals, dietary fibers, and organic acids, especially LAB (10^7 to 10^9/g). Also, various condiments may be added to kimchi, thereby enhancing particular nutrients or specific functional ingredients.

C. Functional Properties of Kimchi

As already shown, the main ingredients of kimchi are yellow and green vegetables, which have been claimed to prevent cancer, increase immune functions, slow the aging process, and prevent constipation. In addition, kimchi augments the taste of the raw vegetables and is a good probiotic food as in yogurt.

Table 11 summarizes the functionality of kimchi. Kimchi increases the appetite owing to its flavor, texture, color, etc. The fresh taste of its vegetables, the taste from lactic acid bacteria fermentation, and the flavors of the condiments, including red pepper powder, garlic, ginger, and fermented anchovy, all contribute to kimchi's characteristic flavors. It is also known to prevent constipation and colon cancer owing to the high content of organic acids, LAB, and dietary fiber. The content of dietary fiber in kimchi is high, about 24% (83); dietary fiber plays roles in the prevention of hypertension, diabetes, constipation, and cancer.

The LAB in kimchi can be a good source of probiotics. Several cell wall components of LAB have been shown to increase the immune function and to prevent cancer (85). The intake of kimchi reduces the level of *E. coli* and increases LAB, especially *Lactobacillus* and *Leuconostoc* in the human intestines (86). The freeze-dried cell bodies of LAB found in kimchi revealed strong antimutagenic activity against 4-NQO (4-nitroquinoline-1-oxide) and MeIQ (87,88). *Leu. mensenteroides. Lac. plantarum* and *Lac. fermentum* from kimchi showed almost same strength of antimutagenicity as *Lac. acidophilus* from dairy products. Kimchi intake significantly reduced β-glucosidase and β-glucuronidase, toxic enzymes known to transform precarcinogens into carcinogens in the human colon, and decreased pH (82). This fact is well correlated with the low incidence of colon cancer among Koreans.

Kimchi intake reduces serum cholesterol and increases fibinolytic activity (89), and thereby shows antiatheroscleotic activity. Kimchi may retard skin aging processes (90) owing to its antioxidative properties from vitamin C, β-carotene, phenolic compounds, chlorophyll, and so forth. Kimchi also contains β-sitosterol, PUFA derivatives, glucosinolates, isothiocyanates, indoles, and allyl compounds. These compounds play various roles in the prevention of cancer and the increasing of immune function (80,82).

Table 11 Nutritional and Health Benefits of Kimchi

1. Increase in appetite
2. Control of body weight
3. Prevention of constipation and colon cancer
4. Good source of probiotics (lactic acid bacteria)
5. Decrease in serum cholesterol, and increase in fibrinolytic activity
6. Antioxidative effect (antiaging, prevention of skin aging)
7. Anticancer effect (antimutagenic and antitumor effect)
8. Increase in immune function

Since various subingredients can be added to kimchi, conceivably one can formulate a functional kimchi that provides many health-benefiting ingredients such as vitamin-C-enhanced kimchi, anticancer kimchi, antiaging kimchi, etc. Certainly, kimchi can be considered as a protective food, since it contains high levels of vitamins, especially C, and minerals.

1. Control of Body Weight

Kimchi is shown to reduce body weight in rats. The capsaicin in red pepper stimulates spinal nerves and activates the release of catecholamine in the adrenal gland (91), a hormone known to increase metabolism. As shown in Table 12, when rats were fed a diet containing red pepper powder plus a high fat content, these animals had a decrease in body weight, compared to rats fed only a high fat diet (92,93). When the rats are fed kimchi that contained the same level of red pepper powder plus high fat as in the previous diet, it was found that the rats had a further decrease in weight after 4 weeks. Regarding individual organ weight, kimchi plus a high-fat diet significantly reduced liver weight in rats compared to rats fed the high-fat diet. The liver weight of the kimchi-fed rats was even lower than that of the nontreated group. However, the weights of spleen and kidney were not significantly different among the treatment groups (93). The epididymal fat pad and perirenal fat pad were also reduced in animals fed red pepper powder and kimchi added diets, compared to the control group, fed the high-fat diet. The body weights of the rats in the kimchi diet group significantly decreased, especially the weight of the perirenal fat pad, compared to both the red pepper powder diet group and the high-fat diet group (93). The reduction of body weight by kimchi might be due to the red pepper powder, garlic, dietary fibers, among other things.

2. Anticancer Effect of Kimchi

a. Antimutagenic/Anticarcinogenic Effect Kimchi showed antimutagenic activities against aflatoxin B_1 in Ames test, SOS chromotest in vitro (94–96). The kimchi extract also showed antimutagenic activity in the *Drosophila* wing hair spot test in vivo (97). Kimchi also exhibited anticlastogenic activity in mitomycin C–induced mice, using the in vivo supravital staining micronucleus assay (98).

C3H/10T1/2 cells are mouse embryo cells that form foci in culture media when exposed to carcinogens. The foci, developed as type II and type III, are well correlated with tumor formations in C3H mice, 50% and 85%, respectively (99). The transformation of C3H/10T1/2 cells markedly decreased when kimchi extract (methanol soluble fraction, MSF) was added to the test

Table 12 Changes in Body Weight and Food Intake of Rats Fed Experimental Diet after 4 Weeks

	Normal	High-fat diet (HFD)	HFD + 5% red pepper powder	HFD + 10% kimchi
Body weight (g)				
Initial weight	171.4 ± 11.9^{ns}	170.3 ± 10.0	170.7 ± 6.3	171.4 ± 4.1
Final weight	305.7 ± 12.7^{b}	338.7 ± 13.4^{a}	311.0 ± 9.5^{b}	302.6 ± 11.3^{b}
Food intake (g/day)	19.1 ± 0.9^{ns}	19.9 ± 0.8	19.5 ± 1.1	19.4 ± 0.9

[a,b]Means with different letters in the same row are significantly different ($p < 0.05$) by Duncan's multiple range test.
ns: not significant.
Source: Ref. 93.

system (100). When MSF (200 μg/mL) from 3-week-fermented kimchi at 5°C was added along with 3-methylcholanthrene (MCA) to the cells, then the numbers of type II and III foci formed substantially decreased from 7.4 (MCA only) to 0.8.

b. Anticancer Effect The kimchi extracts inhibited the survival or growth of human cancer cells (AGS gastric cancer cells, HT-29 colon cancer cells, MG63 osteocarcinoma cells, HL-60 leukemia and Hep 3B liver cancer cells) in the SRB (Sulforhodamine B) assay, the MTT (3-(4,5-dimethyl-thiazol-2-yl)-2,5-diphenyl tetrazolium bromide) assay, and the growth inhibition test (59,94). The kimchi fraction inhibited the ^{3}H thymidine incorporation in the cancer cells (101). In our studies, sarcoma 180 cells were transplanted to the Balb/c mouse followed by kimchi extract injection, and the MSF (methanol soluble fraction) of the kimchi treated group resulted in the smallest tumor weight of 1.98 ± 1.8 g compared to the control group of 4.32 ± 1.5 g (102). MSF from 3-week-fermented kimchi reduced malondialdehyde (as lipid peroxidation marker) formation, and the hepatic cytosolic xanthine oxidase activity in sarcoma-180 treated Balb/c mouse. On the other hand, MSF increased the hepatic cytosolic glutathione content and the activities of glutathione S-transferase and glutathione reductase, indicating that kimchi might be involved in detoxification of the xenotoxic materials in the liver.

Kimchi extracts also enhanced immune functions of NK (natural killer) cells and macrophages (94). Conceivably, the antimutagenic, anticancer, and antimetastatic activities of kimchi could be increased by manipulating the kinds and levels of the ingredients and the fermentation method (42,103,104). In our studies (see Table 13), the lung metastasis with colon 26-M3.1 cells was significantly reduced by subcutaneous (sc) administration of kimchi extract (0.05 to 1.25 mg/mouse) in mice following the tumor cell inoculation. The functional kimchi that we developed exhibited strong antimetastatic activity.

VII. COMMERCIAL KIMCHI PRODUCTION AND TRADE

A. Commercial Kimchi

The commercial production of kimchi started in the 1960s when it was supplied to the Korean army stationed in Vietnam. Kimchi production has increased considerably for commercial purposes since the 1970s. Kimchi was one of the official foods selected for the 1988 Seoul Olympic games, the 1992 Barcelona Olympic games, and the 1996 Atlanta Olympic games.

Table 13 Inhibitory Effect of Methanol Extracts from Common Kimchi and Functional Kimchi on Tumour Metastasis Induced by Colon 26-M3.1 Cells

Treatment	Dose (mg/mouse)	No. of lung metastasis (inhibition, %)	
		Mean ± SD	Range
Control		162 ± 7[a]	153–172
Common kimchi	0.05	157 ± 13[a] (3)*	142–172
	0.25	147 ± 8[ab] (9)	138–157
	1.25	139 ± 5[bc] (14)	131–144
Functional kimchi	0.05	119 ± 4[d] (27)	114–123
	0.25	99 ± 8[e] (39)	89–110
	1.25	83 ± 6[f] (49)	73–91

[a–f]Means with different letters are significantly different ($p < 0.05$) by Duncan's multiple range test.
*Inhibition rate (%).
Source: Ref. 42.

Koreans consume 1526,000 tons of kimchi per year, of which 115,000 tons (7.5%) was produced by commercial kimchi manufacturers in 1992, increasing to 408,000 tons (27.1%) in 1997, about a fourfold increase in five years. The general consumption of commercially made kimchi has increased by more than 10 times (105). Most kimchi products sold in the domestic market were packaged in plastic bags, pouches, or glass/plastic jars (106). Kimchi products consist of 70 percent baechu cabbage kimchi, 20 percent diced radish kaktugi kimchi, and 10% others (2).

The kimchi industry in Korea has shown rapid growth with the increasing domestic and overseas demand for kimchi. The number of kimchi factories has increased to meet the demand for the domestic supply and for export, but most are small-scale plants. Although 459 kimchi processing factories are now operating in Korea, only a few plants have more than 100 employees.

B. International Trade in Kimchi

Since the 1988 Seoul Olympic Games, the international trade in kimchi has been steadily increasing by 25–30% yearly. Commercial kimchi products are exported to over 33 foreign countries; most of it is exported to Japan because of the frequent cultural exchange between Korea and Japan, as well as the similar dietary tastes and the health benefits of kimchi. The types of kimchi exported consist of 92.3% baechu cabbage kimchi, 6.1% radish kaktugi, 1.0% chonggak kimchi, and 0.6% other (105).

The food inspection criteria for kimchi comply with the Codex standards under the WTO foundation and its SPS agreement (Agreement of Application on Sanitary and Phytosanitary Measures). These measures are needed for the elaboration of the international kimchi standard to protect consumers' health and to ensure fair practices in the food trade. The Codex standardization for kimchi was passed at the 24th Codex Assembly in Geneva, Switzerland in 2001. Thus more kimchi products are likely to be traded worldwide.

VIII. CONCLUSIONS

Kimchi is one of the most popular Korean traditional foods as evidenced by its long history and by the increasing demand for it in other foreign countries. Nutritionally, kimchi is a probiotic food with a distinct taste, and it has a promising future as an excellent functional food. The kimchi recipe calls for high quality raw materials for better quality kimchi. Elaborated fermentative processes also are needed. For example, a brining process that reduces unnecessary aerobic, pathogenic yeasts and molds is needed, but also one that stimulates the growth of LAB. Although starter cultures can be induced for kimchi fermentation, the proper technique for the removal of endogeneous microorganisms, without damaging the texture of the fermented cabbages, has yet to be established. Further research on various fermentation techniques is needed for the optimization of an extended preservation period that increases both functionality and taste. Additional research is needed on modern and appropriate kimchi containers that mimic the old-fashioned earthenware crocks that provided the best kimchi fermentation conditions over a long storage period. The development of new packaging materials and packing techniques that will ensure stable shelf-life are key to the successful internationalization of kimchi. To make kimchi more appealing to foreigners' taste, a variety of kimchis must be developed.

The potential efficacy of kimchi for its anticancer, antiatherosclerotic, weight control, and antiaging properties is interesting and needs more systematic and careful research to establish its potential. The Codex standardization of kimchi that is required for trading allows kimchi to be

distributed worldwide, so more intensified research on Kimchi processing, fermentation, taste improvement, and nutritional functionality is needed for further development in the quality of Kimchi.

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13
Sauerkraut

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I. INTRODUCTION

Sauerkraut or kraut is prepared from sound, well matured heads of the cabbage plant (*Brassica oleracea* var. capitata L) which have been properly trimmed and cut; to which salt (2 to 3%) is added and which is cured by natural fermentation. The finished product contains not less than $1\frac{1}{2}$ percent of acid, expressed as lactic acid. The product may be canned by processing sufficiently by heat to assure preservation in hermetically sealed containers, or it may be packaged in sealed containers and preserved with or without the addition of benzoate of soda or any other ingredient approved by the FDA (1).

II. SAUERKRAUT PRODUCTION

A. Cabbage Varieties

A number of cabbage varieties have been used for sauerkraut production. The five commonly used commercial varieties are Dutchmaster Ferry Morse 6201, King Cole, Roundup, Glory 61, and Large Glory. New hybrids of cabbage suitable for sauerkraut production have been investigated (2).

B. Chemical Composition of Cabbage

Stamer et al. (2), in analyzing eleven fermentable cabbage varieties, found 35.0 to 49.0% fermentable carbohydrate, 2.3 to 3.5% protein nitrogen, 7.0 to 9.0% ash, 0.28 to 0.45% inorganic phosphorus, 0.27 to 0.49% inorganic sulfur, and 5.3 to 7.1% solids.

C. Sauerkraut Process

The sauerkraut process is described by Hang et al. (3) as follows: the cabbage is delivered to the factory by truck. It is then transported via conveyor to the coring machine. Following this, the cored head is conveyed to the trimming table where outer leaves and bad spots are removed. This latter operation represents a source of solid wastes.

Next the cabbage is shredded and transported to the fermentation vat. Salt, 2.25 to 2.5 kg per 100 kg of cabbage, is applied evenly as the shreds are distributed in the vat. Juice is released from

the cabbage almost immediately after addition of the salt. To assure a maximum fill of cabbage into a vat, much of this "early brine" may be withdrawn from the vat and discarded during or shortly after the filling. This early brine can be a significant source of liquid waste in the sauerkraut process.

After the vat is filled, it is covered with a plastic sheet that is weighted with water. The fermentation is considered complete when the titratable acidity, expressed as lactic acid, has reached 1.5%, and the shreds are fully cured. This requires four or more weeks.

The final step is the filling of the fermented cabbage and brine into retail packages (cans, jars, or flexible pouches). Only a portion of this "late brine" is added to the packages; the remainder, which must be discarded, represents a second important source of liquid waste.

D. Microorganisms Involved in Sauerkraut Fermentation

Sauerkraut fermentation is a complex microbiological process involving a sequence of growth of various types of microorganisms. Raw cabbage contains sufficient numbers of desirable lactic acid bacteria for spontaneous fermentation. In the early stage of fermentation, most of the lactic acid bacteria are the heterofermentative (gas-forming) species such as *Leuconostoc mesenteroides*. The carbon dioxide creates an anaerobic environment that promotes the growth of desirable lactic acid bacteria but excludes the presence of oxidative fungi. After 8 days of fermentation, most of the lactic acid bacteria are the homofermentative (nongas-forming) species such as *Lactobacillus plantarum* (4). Other homofermentative lactic acid bacteria, *Lactobacillus brevis* and *Pediococcus cerevisiae*, also play an important role in the conversion of shredded cabbage to sauerkraut of high quality (5).

E. Chemical Changes During Sauerkraut Fermentation

Cabbage contains 4.69% total sugars (0.25% sucrose, 2.38% glucose, and 2.05% fructose). During fermentation, sugars were rapidly converted to lactic acid by the lactic acid bacteria present on raw cabbage. Other important products formed during the fermentation are carbon dioxide, mannitol, acetic acid, and ethanol (4).

F. Factors Affecting Sauerkraut Fermentation

It has been shown that growth and fermentation patterns are affected by (a) the variety of cabbage, (b) the temperature, and (c) the salt concentrations.

1. Variety of Cabbage

Stamer et al. (2) evaluated the ability of 13 varieties of cabbage, including 5 commonly used commercial varieties and 8 newly developed hybrids, to undergo lactic acid fermentations. Eleven of the 13 varieties could undergo normal fermentation, but two varieties (G27 X G51 and G60 XW-1) failed to support adequate fermentation and consistently resulted in sauerkraut of poor quality. The inability of these varieties to undergo normal fermentation may be due to the presence of growth inhibitory substances or the lack of nutritional factors essential for the growth of lactic acid bacteria.

2. Temperature

The temperature of shredded cabbage has a profound influence on the rate of fermentation. The heterofermentative species, *Leuconostoc mesenteroides*, that initiates the fermentation can grow

at relatively low temperatures (5). At 7.5°C, for example, this organism produces 0.4% and 0.8 or 0.9% lactic acid in about 10 days and less than a month, respectively. At 18°C, *Leuconostoc mesenteroides* and other homofermentative species, *Lactobacillus brevis*, *Lactobacillus plantarum*, and *Pediococcus cerevisiae*, grow in a natural sequence and can produce more than 1% lactic acid in a few weeks and about 2% in about 2–3 months. The rate of sauerkraut fermentation is rapid at 32°C and 1.8 to 2% lactic acid can be produced in 8–10 days. In general, sauerkraut fermented at lower temperatures has a better color, flavor, and character than sauerkraut fermented at higher temperatures.

3. Salt Concentrations

It is important to add a proper amount of salt to the shredded cabbage prior to fermentation. Salt is added to withdraw nutrients from cabbage for proper fermentation and to inhibit the growth of undesirable microorganisms. A salt concentration of 2.25% favors the growth of desirable lactic acid bacteria in their natural sequence and results in a finished product with the proper balance of salt to acid (5). A salt concentration of 3.5% or more is detrimental to the growth of the heterofermentative species, *Leuconostoc messenteroides*, that initiates sauerkraut fermentation. Excessive salt causes a significant reduction in the rate of acid production and yields a sauerkraut with an undesirable ratio of salt to acid. A salt concentration of less than 2% can cause some softening of the finished product due to the activity of pectinolytic enzymes.

G. Types of Spoilage

1. Pink Kraut

Pink kraut poses considerable economic losses to food processors. Pink kraut is caused by a condition associated with excess salt in the fermentation tank. Yeasts have been reported to impart color to kraut (6). Gorin and Jans (7) have reported that the color in pink kraut is probably attributable to the formation of a leucoanthocyanidin. Stamer et al. (8) have shown that *Lactobacillus brevis* plays an important role in the production of a water-soluble red pigment that is presumably responsible for imparting a highly objectionable discoloration to sauerkraut.

2. Soft Kraut

Soft kraut is caused by a condition associated with insufficient salt. Sufficient salt must be added to draw enough juice from the shredded cabbage to promote the growth of desirable lactic acid bacteria in their proper sequence. Lactic acid and salt are required to prevent the softening of sauerkraut due to the activity of pectinolytic enzymes.

3. Rotted Kraut

Rotted kraut may be caused by the presence of undesirable microorganisms. To exclude air and to prevent the growth of undesirable types of bacteria, yeasts and molds, it is important to cover the shredded cabbage with a plastic sheet at the time of packing and place water in the plastic cover to cause it to be immersed in the brine.

4. Off-Flavor Kraut

Off-flavor kraut may be caused by too rapid a fermentation at high temperatures. Aerobic yeasts and molds can also grow and produce undesirable flavors and odors. The finished product is of inferior quality. The product is like esters kraut and usually has low concentrations of acetic acid, ethanol, and esters.

III. CHEMICAL ANALYSES (9)

A. pH

The pH of sauerkraut brine is determined with a pH meter. Sauerkraut has a pH range of about 3.3 to 3.8.

B. Titratable Acidity

The titratable acidity of sauerkraut brine expressed as lactic acid is determined by titrating the sample with 0.1 N NaOH using phenolphthalein as an indicator or titrating it to pH 8.2 with a pH meter. For example, the titratable acidity of a 10 mL sample can be calculated by

$$\text{mL of } 0.1\,\text{N NaOH used} \times 0.090 = \%\ \text{titratable acidity expressed as lactic acid}$$

C. Salt (Sodium Chloride)

The salt content of sauerkraut brine is determined by titrating the sample with 0.171 N silver nitrate using 0.5% dichlorofluorescein as an indicator. One mL of 0.171 N silver nitrate is equal to 1 g of salt per 100 mL of sample.

IV. PROCESSING OF SAUERKRAUT

The finished product is heated in hot brine to above 74°C (165°F) and placed in cans, glass jars, or plastic bags. The filled containers are then conveyed to an exhaust box and to a container sealer. The sealed containers are water-cooled to about 38°C (100°F) and then stored in a cool place (10).

V. QUALITY FACTORS AND GRADES FOR SAUERKRAUT (1)

Factors that affect the quality of sauerkraut are color, cut, defects, character, and flavor. The relative importance of each factor rating is expressed numerically on the scale of 100. The maximum number of points that may be given each such factor is color, 30; cut, 10; defects, 20; character, 10; and flavor, 30.

The USDA Standards for Grades recognize four U.S. grades of canned kraut. The grades are "U.S. Grade A" or "U.S. Fancy," "U.S. Grade B" or "U.S. Extra Standard," "U.S. Grade C" or "U.S. Standard," and "Substandard."

U.S. Grade A or U.S. Fancy is the quality of kraut that possesses a good color; that is well cut; that is free from defects; that possesses a good character; that possesses a good flavor; and that, for those factors that are scored in accordance with the scoring system (Table 1), the total score is not less than 90 points.

Table 1 Score Points for USDA Standards for Grades for Sauerkraut

Factor		Score points for grade			
		A	B	C	Substandard
Color	30	27–30	24–26	21–23	0–20
Cut	10	9–10	8	7	0–6
Defects	20	18–20	16–17	14–15	0–13
Character	10	9–16	8	7	0–6
Flavor	30	27–30	24–25	21–23	0–20

Source: Ref. 1.

U.S. Grade B or U.S. Extra Standard is the quality of kraut that possesses a reasonably good color; that is reasonably well cut; that is reasonably free from defects; that possesses a reasonably good character; that possesses a reasonably good flavor; and that, for those factors that are scored in accordance with the scoring system, the total score is not less than 80 points.

U.S. Grade C or U.S. Standard is the quality of kraut that possesses a fairly good color; that is fairly well cut; that is fairly free from defects; that possesses a fairly good character; that possesses a fairly good flavor; and that, for those factors that are scored in accordance with the scoring system, the total score is not less than 70 points.

Substandard is the quality of canned kraut that fails to meet the requirements of U.S. Grade C or U.S. Standard.

VI. WASTE MANAGEMENT

A. Material Balance of Sauerkraut Production

Data on material balance (Table 2) show the quantity of sauerkraut produced from 100 tons of cabbage. It can be seen that about 29% of the salted shredded cabbage is discarded as brine (liquid waste). The data also show that there is a problem of solid as well as liquid waste in the manufacture of sauerkraut. The trim loss of 35.3 tons is an average of 16 different loads of cabbage; individual values ranged from 28.7 to 41 tons. The solid wastes are generally returned to the growing field. The average yield of sauerkraut is 46.9 kg per 100 kg of cabbage fermented.

Table 2 Material Balance of Sauerkraut Production

Materials	Tons
Raw cabbage	100.00
Solid waste (trim loss)	35.30
Shredded cabbage in vat	64.70
Salt added	1.70
Liquid wastes	
Early brine	11.00
Late brine	8.50
Total	19.50
Yield of sauerkraut	46.90

Source: Ref. 3. (Reprinted with permission from the *Journal of Milk and Food Technology.* Copyright held by the International Association for Food Protection, Des Moines, IA, U.S.A.)

Data in Table 3 show the characteristics of liquid wastes generated in sauerkraut production. In addition to early and late brines, other sources of waste effluents are the vat soak water, vat wash water. Because of their low BOD values, both vat soak water and vat wash water should be readily biologically treatable. The surplus sauerkraut brines present the greatest problem with respect to treatment because of their strength. These high BOD brines may require their segregation for separate treatment.

B. In-Plant Treatment of Liquid Waste

As shown in Table 2, about 20 tons of brine are generated by fermentation of 100 tons of shredded cabbage. This is characteristic of the sauerkraut process. The discarded brine poses serious environmental problems because of its high BOD, acid, and salt contents. A simple yeast process has been developed for in-plant treatment of liquid wastes (11,12). The sauerkraut wastewater is treated in a bioreactor with a food yeast under aerobic conditions. Upon completion of the treatment, the mixed liquor is allowed to settle, and the supernatant fraction can be discharged to a municipal waste treatment plant. The settled yeast cells can serve as an inoculum for treatment of another batch of sauerkraut wastewater. The yeast is capable of rapidly converting the organic matter to yeast cells and thus can reduce the BOD by as much as 93%. The reductions of nitrogen and phosphorus are more than 75 and 90%, respectively. As a result of metabolism of the lactic acid by the yeast, the sauerkraut waste effluent is neutralized. This has economic significance, since acid waste effluents generally require neutralization before they can be treated in a secondary waste treatment system such as an activated sludge process or a trickling filter.

VII. BY-PRODUCT RECOVERY

A. Food Yeasts

Sauerkraut brine is a favorable substrate for the cultivation of food yeasts, *Saccharomyces cerevisae*, *Candida utilis*, and *Kluyveromyces fragilis* (13). The brine contains sufficient nutrients for support of yeast growth. The yield of yeast cells is greater than 65 g per 100 g of the BOD removed. The freeze-dried cells of the yeast, *Candida utilis*, for example, contain 40.80% protein, 0.65% fat, 43.41% carbohydrates, 6.18% ash, 6.20% fiber, and 2.76% moisture.

B. Enzymes

Food yeasts grown in sauerkraut brine have been reported to exhibit considerably high activities of beta-fructofuranosidase, beta-galactosidase, acetoin reductase, and diacetyl reductase (14). These enzymes may have value in a variety of commercial applications.

C. Carotenoids

Carotenoids can be produced by *Rhodotorula rubra* NRRL Y-15596 from sauerkraut brine under controlled growth conditions. The maximal yield of carotenoids expressed as beta-carotene is 131 μg per g of yeast dry weight or 1041 μg liter of sauerkraut brine with an initial BOD value of 11,000 mg/liter (15).

Table 3 Characteristics of Sauerkraut Wastes

Source	pH	COD (mg/L)	BOD (mg/L)	Lactic acid (mg/L)	NaCl (mg/L)	Total N (mg/L)	Total P (mg/L)
Vat soak water	7.5	64	60	—	—	—	—
Vat wash water	10.4	303	236	—	—	—	—
Early brine	5.2	17,730	11,100	926	36,800	555	106
Late brine	3.5	28,960	24,300	18,600	28,600	1,090	189

Source: Ref. 3. (Reprinted with permission from the *Journal of Milk and Food Technology.* Copyright held by the International Association for Food Protection, Des Moines, IA, U.S.A.)

VIII. CURRENT DEVELOPMENTS

Lactic acid and acetic acid are the major products of sauerkraut fermentation, and their concentrations in the finished product are highly variable. Research is needed for improvement in the uniformity of sauerkraut quality. Possible methods for controlling the level of acidity in the finished product include (a) pasteurization of the product when it reaches the desired acidity, (b) development of cabbage varieties with a low concentration of fermentable sugars, (c) dilution of the product with water to the desired level of acidity, (d) neutralization of the finished product, and (e) controlled fermentation and storage of sauerkraut (Fleming and McFeeters, Ref. 16).

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14

Pickle Manufacturing in the United States: Quality Assurance and Establishment Inspection

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I. QUALITY ASSURANCE

A. Introduction

This section is not designed to explain how pickles are manufactured in the United States. Rather, it is designed to show you the critical factors you should look for in assuring the quality of your pickles. The information has been modified from a document issued by the United States Department of Agriculture, *United States Standards for Grades of Pickles*. Consult the original document for complete details.

This section contains 11 tables, numbered 1 to 11, and they do not appear in the same order as the text references to them.

B. Product Description

Pickles are a product prepared entirely or predominantly from cucumbers (*Cucumis sativus* L). Clean, sound ingredients are used that may or may not have been previously subjected to fermentation and curing in a salt brine. The product is prepared and preserved through natural or controlled fermentation or by direct addition of vinegar to an equilibrated pH of 4.6 or below. The equilibrated pH value must be maintained for the storage life of the product. The product may be further preserved by pasteurization with heat or refrigeration and may contain other vegetables, nutritive sweeteners, seasonings, flavorings, spices, and other permissible ingredients as defined by the U.S. Food and Drug Administration (FDA). The product is packed in commercially suitable containers to assure preservation.

C. Styles of Pickles

1. Whole style means the pickles are whole and are relatively uniform in diameter as indicated in a latter discussion.
2. Whole, mixed sizes style means the pickles are whole pickles of mixed sizes.
3. Sliced lengthwise style means the pickles are cut longitudinally into halves, quarters, or other triangular shapes (spears, strips, or fingers), or otherwise into units with parallel surfaces with or without ends removed.

4. Sliced crosswise, crosscut, or waffle cut style, means that the pickles are cut into slices transversely to the longitudinal axis. The cut surfaces may have flat-parallel or corrugated-parallel surfaces.
5. Cut style means the pickles are cut into chunks or pieces that are of various sizes and shapes.
6. Relish style means finely cut or finely chopped pickles containing no less than 60 percent of cucumber ingredient and may contain other vegetable ingredients (cauliflower, onions, pepper, tomatoes, cabbage, olives, mustard, or any other suitable vegetable).

D. TYPES OF PACK

Cured type. The pickles are cured by natural or controlled fermentation in a salt brine solution and may contain the dill herb or extracts thereof. The pickle ingredient may be partially desalted. The pickles may be further processed or preserved by the addition of vinegar and may contain other ingredients (spices, flavorings, firming and preserving agents) that constitute the characteristics of the particular type of pickle. The pickles are preserved by acidification to maintain an equilibrated pH of 4.6 or below. The characteristics of the various types of cured pickles are as follows:

1. Dill pickles (natural or genuine) are cucumbers that are cured in a brine solution with dill herb and other flavoring agents.
2. Dill pickles (processed) are brine-cured pickles that have undergone a freshening process and are packed in a vinegar solution with dill flavoring and other flavoring agents.
3. Sour pickles are cured pickles that are packed in a vinegar solution with or without spices.
4. Sweet pickles and mild sweet pickles are cured pickles that are packed in a vinegar solution with suitable nutritive sweetening ingredient(s).
5. Sour mixed pickles are cured pickles that are packed in a vinegar solution. The pickles may be of any style or combination of styles other than relish and may contain other vegetable ingredients as outlined in Table 1 or any other suitable vegetable.
6. Sweet mixed pickles and mild sweet mixed pickles are cured pickles that are packed in a vinegar solution with suitable nutritive sweetening ingredient(s). The pickles may be of any style or combination of styles other than relish and may contain other vegetable ingredients as outlined in Table 1 or any other suitable vegetable.
7. Sour mustard pickles or sour chow chow pickles are cured pickles of the same styles and ingredients as sour mixed pickles except that the pickles are packed in a prepared mustard sauce of proper consistency with or without spices and flavorings.
8. Sweet mustard pickles or sweet chow chow pickles are cured pickles of the same styles and ingredients as sweet mixed pickles except that the pickles are packed in a sweetened prepared mustard sauce of proper consistency with or without spices and flavorings.
9. Sour pickle relish consists of finely cut or chopped cured pickles that are packed in a vinegar solution. Sour pickle relish may contain other chopped or finely cut vegetable ingredients as listed in Table 1 and may contain a stabilizer such as a starch or gum.

Table 1 Proportions of Pickle Ingredients in Certain Types and Styles

Pickle ingredients and styles	Cured, fresh-pack, and refrigerated types (percentage by weight of drained weight of product)	
	Sour mixed; sweet mixed; mild sweet mixed; sour mustard or sour chow chow; sweet mustard or sweet chow chow	Sour pickle relish; sweet pickle relish; dill relish; hamburger relish; mustard relish
Cucumbers, any style other than relish	60 to 80%	—
Cucumbers, chopped or finely cut	—	60 to 100%
Cauliflower pieces	10 to 30%	—
Cauliflower, chopped or finely cut	—	30% maximum (optional)
Onions, whole (maximum diameter of $1\frac{1}{4}$ inches), sliced or cut	5 to 12%	—
Onions chopped or finely cut	—	12% maximum (optional)
Green tomatoes, whole or pieces	10% maximum (optional)	—
Green tomatoes, chopped or finely cut	—	10% maximum (optional)
Red, green, or yellow peppers, or pimientos, cut, finely cut or pieces	Optional	Optional
Celery	Optional	Optional
Cabbage	Optional	Optional
Olives	Optional	Optional
Tomato paste	Optional	Required in hamburger relish
Mustard or prepared mustard	Required in chow chow and mustard pickles	Required in mustard relish, optional in hamburger relish

10. Sweet pickle relish and mild sweet pickle relish are finely cut or chopped cured pickles that are packed in a vinegar solution with a suitable nutritive sweetening ingredient(s). Sweet pickle relish and mild sweet pickle relish may contain other chopped or finely cut vegetable ingredients as listed in Table 1 and may contain a stabilizer such as a starch or gum.
11. Hamburger relish consists of relish style pickles and other chopped or finely cut vegetable ingredients as listed in Table 1 with tomato product added.
12. Mustard relish consists of sweet pickle relish with mustard and other chopped or finely cut vegetable ingredients as listed in Table 1.
13. Dill relish consists of relish style pickles containing dill flavoring and other chopped or finely cut vegetable ingredients as listed in Table 1.

Fresh-pack type. The pickles are prepared from uncured, unfermented cucumbers and are packed in a vinegar solution with other ingredients to produce the characteristics of the particular type of pack. The pickles are preserved by acidification to maintain an equilibrated pH of 4.6 or below. In addition, the pickles are sufficiently processed by heat to assure preservation of the product in hermetically sealed containers. The distinguishing characteristics of the various types of fresh-pack pickles are as follows:

1. Fresh-pack dill pickles are pickles that are packed in a vinegar solution with dill flavoring.
2. Fresh-pack sweetened dill pickles are pickles that are packed in a vinegar solution with suitable nutritive sweetening ingredient(s) and dill flavoring.
3. Fresh-pack sweetened dill relish consists of finely cut or chopped pickles packed in a vinegar solution with suitable nutritive sweetening ingredient(s) and dill flavoring. The relish may contain other finely cut or chopped vegetable ingredients as listed in Table 1.
4. Fresh-pack sweet pickles and fresh-pack mild sweet pickles are pickles that are packed in a vinegar solution with nutritive sweetening ingredient(s).
5. Fresh-pack sweet pickle relish and fresh-pack mild sweet pickle relish consist of finely cut or chopped pickles that are packed in a vinegar solution with suitable nutritive sweetening ingredient(s). The relish may contain other finely cut or chopped vegetable ingredients as listed in Table 1.
6. Fresh-pack hamburger relish consists of relish style pickles and other chopped or finely cut vegetable ingredients as listed in Table 1 with tomato product added.
7. Fresh-pack mustard relish consists of sweet pickle relish with mustard and other chopped or finely cut vegetable ingredients as listed in Table 1.
8. Fresh-pack dill relish consists of relish style pickles containing dill flavoring and other chopped or finely cut vegetable ingredients as listed in Table 1.
9. Fresh-pack dietetic pickles are pickles that are packed with or without the addition of sweetening ingredient(s), salt (NaCl), or other suitable ingredient(s) as declared and permitted under FDA regulations.

Refrigerated type. The pickles are prepared from fresh cucumbers and are packed in a vinegar solution with other ingredients to produce the fresh crisp characteristic of the refrigerated type. The pickles are preserved by acidification to maintain an equilibrated pH of 4.6 or below. They are stored, distributed, and displayed under refrigeration and may or may not contain one or more chemical preservatives. The various types of refrigerated pickles are the same as the types listed for the fresh-pack type with respect to ingredients except that they conform to the requirements for the refrigerated type.

E. SIZES OF WHOLE PICKLES

Sizes of whole pickles are based on the diameter and the relationship of the diameter to the count per gallon. Size designations, applicable counts, and diameters are outlined in Table 2. The diameter of a whole cucumber is the shortest diameter at the greatest circumference measured at right angles to the longitudinal axis of the cucumber.

F. Definitions of Terms

For an interpretation of this standard, some definitions of terms are given here. Analytical definitions refer to analytical laboratory requirements.

1. Acid means total acidity calculated as acetic acid in accordance with the Official Methods of Analysis of the Association of Official Analytical Chemists (AOAC).
2. Brix value (Brix) means the percent sugar, by weight, corrected to 20°C (68°F), as determined with a sugar scale Brix hydrometer or other instrument that gives equivalent results.
3. Degrees Baumé means the density of the packing medium determined with a Baumé hydrometer (modulus 145) corrected to 20°C (68°F).
4. Equalization means the natural (osmotic) or simulated blending between the soluble solids of the pickle ingredient and the packing medium.

Natural equalization means equalization brought about after a period of time has elapsed after processing as follows. Sweetened pickles are considered to be equalized 15 days or more after processing. If the pickles have been sweetened in a tank prior to packing, the pickles will be considered equalized 15 days after the sweetening process began. Sour and dill pickles are considered to be equalized 10 days or more after processing.

Simulated equalization means a method of simulating equalization by comminuting the finished product in a mechanical blender, filtering the suspended material from the comminuted mixture, and making the required tests on the filtrate.

5. Total chlorides or salt means the salt content expressed as grams NaCl (sodium chloride) per 100 milliliters packing medium; except that total chlorides in mustard pickles and chow is determined and expressed in grams NaCl per 100 grams of product.

Blemished means any unit that is affected by discoloration, pathological injury, insect injury, or similar causes to the extent that the appearance or edibility of the product is adversely affected.

1. Slightly—those blemishes which detract only slightly from the appearance of the unit;
2. Seriously—those blemishes which strongly detract from the appearance or edibility of the unit.

Color.

1. Good color in the cured type means that the typical skin color of the pickles ranges from a translucent light green to dark green and is practically free from bleached areas. Not more than 10 percent, by weight, of the pickles may vary markedly from such typical color. In mixed pickles, chow chow pickles, and pickle relish, all of the ingredients possess a practically uniform color typical for the respective ingredient. The pickles and other vegetable ingredients shall be free of off-colors.

Table 2 Sizes of Processed Whole Pickles Approximate Counts

Word Designation	Diameter	Glass			Metal	
		1 qt.	$\frac{1}{2}$ gal	1 gal	No. 10	No. 12 (1 gal)
Midget	19 mm (0.75 in) or less	67 or more	135 or more	270 or more	202 or more	270 or more
Small gherkin	Up to 2.4 cm (0.94 in)	33–66	67–134	135–269	101–201	135–269
Large gherkin	Up to 2.7 cm (1.06 in)	16–32	32–66	65–134	48–100	65–134
Small	Over 2.7 cm (1.06 in) but not over 3.5 cm (1.38 in)	10–15	20–31	40–64	30–47	40–64
Medium	Over 3.5 cm (1.38 in) but not over 3.8 cm (1.50 in)	6–9	13–19	26–39	19–29	26–39
Large	Over 3.8 cm (1.50 in) but not over 4.4 cm (1.73 in)	4–5	9–13	18–25	13–18	18–25
Extra large	Over 4.4 cm (1.73 in)	2–3	6–8	12–17	9–12	12–17

2. Good color in fresh-pack and refrigerated types means the typical skin color of the pickles ranges from an opaque yellow-green to green. Not more than 15 percent, by weight, of the pickles may vary markedly from such typical color. In pickle relish, all of the ingredients possess a good uniform color typical for the respective ingredient. The pickles and other vegetable ingredients shall be free of off-colors.
3. Reasonably good color in the cured type means that the typical skin color of the pickles ranges from light green to dark green and is reasonably free from bleached areas. Not more than 25 percent, by weight, of the pickles may vary markedly from such typical color. In mixed pickles, chow chow pickles, and pickle relish, all of the ingredients possess a reasonably uniform color typical for the respective ingredient. The pickles and other vegetable ingredients shall be free of off-colors.
4. Reasonably good color in fresh-pack and refrigerated types means that the typical skin color of the pickles ranges from light yellow-green to green. Not more than 30 percent, by weight, of the pickles may vary markedly from such typical color. In pickle relish, all of the ingredients possess a good, fairly uniform color typical for the respective ingredient. The pickles and other vegetable ingredients shall be free of off-colors.
5. Poor color in all types of pickles means the pickles fail to meet the requirements for good or reasonably good color for the respective type.

Also see the definition of misshapen.

Crooked pickles mean whole pickles that are curved at an angle greater than 60 degrees as illustrated by Fig. 1.

Curved pickles mean whole pickles that are curved at an angle of 35 to 60 degrees when measured as illustrated by Fig. 2.

Diameter in whole style means the shortest diameter measured transversely to the longitudinal axis at the greatest circumference of the pickle. Diameter in crosscut style is the shortest diameter of the largest cut surface.

Defect means an imperfection such as curved, misshapen, mechanically damaged, discolored, or other imperfection that affects the appearance or edibility of the product.

End cut means a pickle unit intended for crosscut (sliced crosswise) style that has only one cut surface.

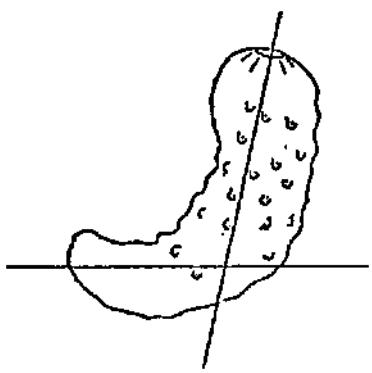

Figure 1 Crooked pickles. (also see the definition of misshapen).

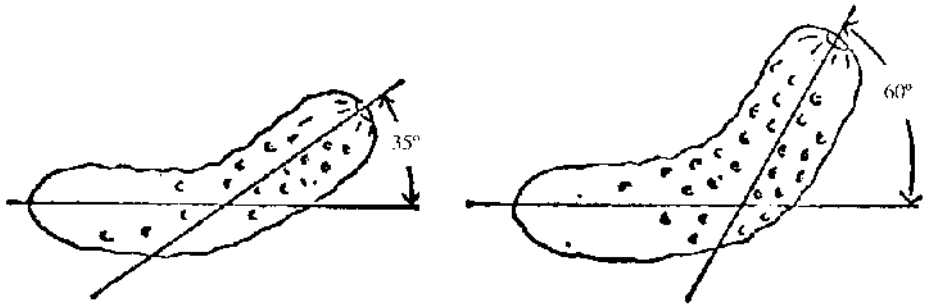

Figure 2 Curved pickles.

Extraneous vegetable material (EVM) means any harmless vegetable material, other than stems, that is not normally part of the pickle ingredient. EVM such as leaves or other vegetable material not associated with proper pickle preparation or packaging is considered a defect if it affects the appearance or edibility of the product, either

Slightly—Practically free of EVM and does not more than slightly affect the appearance or edibility

Materially—Reasonably free of EVM and does not more than materially affect the appearance or edibility.

Flavor and odor.

1. Good flavor and odor mean characteristic flavor and odor (e.g., characteristic dill flavor or the like) typical of properly processed pickles, for the type, that are free from objectionable flavor and odor of any kind.
2. Reasonably good flavor and odor mean flavor and odor that may be lacking in characteristic flavor for the type but are free from objectionable flavor and odor.
3. Poor flavor and odor mean flavor and odor that fail to meet the requirements for good or reasonably good flavor and odor.

Length in sliced lengthwise style means the longest straight measurement at the approximate longitudinal axis.

Mechanical damage refers to crushed or broken units that affect the appearance of the units. In relish, mechanical damage refers to units which are poorly cut and have a ragged or torn appearance.

Misshapen pickles mean whole pickles that are crooked or otherwise deformed (such as nubbins). Also see the definition for crooked pickles.

A nubbin is a misshapen pickle that is not cylindrical in form, is short and stubby, or is not well developed.

Texture means the firmness, crispness, and condition of the pickles and any other vegetable ingredient(s) and freedom from large seeds, detached seeds, and tough skins that may be present. The following terms also relate to texture:

1. Hollow centers in whole style, mean that the pickles, when cut transversely to the longitudinal axis, are missing 1/3 or more of the seed cavity.
2. Soft, shriveled, and slippery units refer to pickles that are wrinkled, not crisp, slick, flabby, or lack firmness.

3. Good texture means that the pickle units have been properly processed and possess a texture that is firm and crisp.
4. Reasonably good texture means that the pickle units have been properly processed but lack some of the firmness and crispness that is characteristic for the style and type of pack.
5. Poor texture means that the pickle units do not meet the requirements for good or reasonably good texture.

Uniformity of size (relish style only).

1. Practically uniform in size means that the size of the units may vary moderately in size but not to the extent that the appearance or the eating quality is seriously affected.
2. Poor uniformity of size means that the units fail the requirements for practically uniform.

Unit means one whole, half, slice, or piece of pickle as applicable for the style.

Units missing 1/3 or more of the seed cavity in crosscut style mean pickles that have lost a substantial portion of the seed cavity such as a crosscut unit missing 1/3 or more of the seed cavity portion.

G. Recommended Fill of Container

The recommended fill of container is not a factor of quality for the purposes of these grades. Each container of pickles should be filled with pickle ingredient, as full as practicable, without impairment of quality. The product and packing medium should occupy not less than 90 percent of the total capacity of the container.

H. Quantity of Pickle Ingredient

The recommended minimum quantity of pickle ingredient is designated as the percentage of the declared volume of product in the container for all items except pickle relish. Minimum quantity of pickle relish is designated as a relationship of the drained weight of the pickle ingredient to the declared volume of the container. The minimum quantities recommended in Tables 3 and 4 are not factors of quality for the purposes of these grades.

The percent volume of pickle ingredient is determined for all styles, except relish, by one of the following methods in accordance with the procedures prescribed by the USDA:

1. Direct displacement (overflow-can method)
2. Displacement in a graduated cylinder

Table 3 Recommended Pickle Ingredients (All Styles Except Relish)

Type of pack	Minimum fill (volume) (%)
Cured	55
Fresh-pack	57
Refrigerated	57

Table 4 Recommended Drained Weight to Container Volume, Relish

Type of pack	Minimum fill (weight/volume) (%)
Cured	
Sweet	92
Other than sweet	88
Fresh-pack	
Sweet	85
Other than sweet	80

3. Measurement of pickle liquid
4. Any other method that gives equivalent results and is approved by the USDA

Drained weight/volume. The percent weight/volume (w/v) of relish, shown in Table 4, is determined as follows:

The drained weight of pickle relish of all types is determined by emptying the contents of the container upon a U.S. Standard No. 8 circular sieve of proper diameter containing 8 meshes to the inch (0.0937 inch ± 3 percent, square openings) so as to distribute the product evenly, inclining the sieve slightly to facilitate drainage, and allowing to drain for 2 minutes. The drained weight is the weight of the sieve and the pickles, less the weight of the dry sieve. A sieve 8 inches in diameter is used for 1 quart and smaller size containers, and a sieve 12 inches in diameter is used for containers larger than 1 quart in size.

I. Sample Unit Size

For all styles of pickles and types of pack, the sample unit used in analyzing the quality factors is the entire contents of the container unless otherwise specified by USDA regulations.

J. Grades

1. U.S. Grade A is the quality of pickles that meets the applicable requirements of Tables 5–11 and scores not less than 90 points.
2. U.S. Grade B is the quality of pickles that meets the applicable requirements of Tables 6–11 and scores not less than 80 points.
3. Substandard is the quality of pickles that fails the requirements of U.S. Grade B.

K. Factors of Quality

The grade of pickles is based on the following quality factors:

1. Analytical requirements in Table 5
2. Flavor and odor
3. Color
4. Uniformity of size
5. Defects
6. Texture

Table 5 Analytical Requirements[a], Cured Type Pickles, All Styles

	Total acidity expressed as acetic acid g/100 mL, unless otherwise indicated, maximum	Total chlorides expressed as NaCl grams/100 mL, unless otherwise indicated, maximum	Degrees Brix, minimum	Degrees Baumé, minimum
Cured Type, all styles				
Dills (natural, genuine, or processed)	1.1	5.0	—	—
Sour, sour mixed, dill pickle relish, sour relish	2.7	5.0	—	—
Sweet whole, sweet mixed, and sweet relish	2.7	3.0	27.0	15.0
Mild sweet, mild sweet mixed, mild sweet relish	—	—	20.0	12.0
Sour mustard or sour chow chow	2.7[b]	3.0[b]	—	—
Sweet mustard or sweet chow chow	2.7[b]	3.0[b]	28.0	15.5
Fresh-pack and refrigerated types, all styles				
Dills and sweetened dills	1.1	4.25	—	—
Sweetened dill relish	1.1	4.25	—	—
Sweet and mild sweet relish	1.65	2.75	—	—
Sweet and mild sweet pickles	1.65	2.75	—	—
Dietetic	—	—	—	—

[a]All pickle products must have an equilibrated pH of 4.6 or below.
[b]Expressed as grams/100 grams.

Table 6 Quality Requirements, Whole Style Pickles

	Grade A		Grade B	
	Maximum (by count)	Score	Maximum (by count)	Score
Flavor and odor	Good	—	Reasonably good[a]	—
Color	Good	18–20	Reasonably good[a]	16–17
Uniformity of size[b]	—	18–20	—	16–17
Diameter variation	—	—	—	—
Midget and gherkin [over 8 mm (0.31 in)]	10%	—	20%	—
Small and medium [over 10 mm (0.39 in)]	10%	—	20%	—
Large and extra large [over 12 mm (0.47 in)]	10%	—	20%	—
Defects	Practically free	27–30	Reasonably free[a]	24–26
Blemished (slightly and seriously)	15%	—	25%	—
Blemished (seriously)	5%		10%	—
Curved pickles	10%	—	20%	—
Misshapen	5%	—	15%	—
Mechanical damage	10%	—	15%	—
Attached Stems [over 2.5 cm (0.98 in)]	10%	—	20%	—
Extraneous vegetable material (EVM)	Practically free	—	Reasonably free[a]	—
Texture	Good	27–30	Reasonably good[a]	24–26
Large seeds, detached seeds, tough skins	Practically free	—	—	—
Soft, shriveled, and slippery units	5%	—	10%	—
Hollow centers	15%	—	25%	—
Total score (minimum)	90 points		80 points	

[a]Cannot be graded above U.S. Grade B, regardless of the total score.
[b]Pickles that are substandard for uniformity of size cannot be graded above U.S. Grade B, regardless of the total score.

Table 7 Quality Requirements, Whole Style Pickles, Mixed Sizes

	Grade A		Grade B	
	Maximum (by count)	Score	Maximum (by count)	Score
Flavor and odor	Good	—	Reasonably good[a]	—
Color	Good	18–20	Reasonably good[a]	16–17
Defects	Practically free	27–30	Reasonably free[a]	24–26
Blemished (slightly and seriously)	15%	—	25%	—
Blemished (seriously)	5%	—	10%	—
Curved pickles	10%	—	20%	—
Misshapen	5%	—	15%	—
Mechanical damage	10%	—	15%	—
Attached stems [over 2.5 cm (0.98 in)]	10%	—	20%	—
Extraneous vegetable material (EVM)	Practically free	—	Reasonably free[a]	—
Texture	Good	27–30	Reasonably good[a]	24–26
Large seeds, detached seeds, tough skins	Practically free	—	Reasonably free	—
Soft, shriveled, and slippery units	5%	—	10%	—
Hollow centers	15%	—	25%	—
Total score (minimum)[b]	90 points		80 points	

[a]Cannot be graded above U.S. Grade B, regardless of the total score.
[b]Total score is adjusted by dividing the total score by 0.80 to allow for the absence of the quality factor of uniformity of size in whole mixed sizes style.

Table 8 Quality Requirements, Sliced Lengthwise Style Pickles

	Grade A		Grade B	
	Maximum (by count)	Score	Maximum (by count)	Score
Flavor and odor	Good	—	Reasonably good[a]	—
Color	Good	18–20	Reasonably good[a]	16–17
Uniformity of size[b]	—	18–20	—	16–17
Length variation [over 2.6 cm (1.02 in)]	10%	—	20%	—
Defects	Practically free	27–30	Reasonably free[a]	24–26
Blemished (slightly and seriously)	15%	—	25%	—
Blemished (seriously)	5%	—	10%	—
Mechanical damage	10%	—	15%	—
Attached stems [over 2.5 cm (0.98 in)]	10%	—	20%	—
Extraneous vegetable material (EVM)	Practically free	—	Reasonably free[a]	—
Texture	Good	27–30	Reasonably good[a]	24–26
Large seeds, detached seeds, tough skins	Practically free	—	Reasonably free[a]	—
Soft, shriveled, and slippery units	5%	—	10%	—
Total score (minimum)	90 points		80 points	

[a]Cannot be graded above U.S. Grade B, regardless of the total score.
[b]Pickles that are substandard for uniformity of size cannot be graded above U.S. Grade B, regardless of the total score.

Table 9 Quality Requirements, Sliced Crosswise or Crosscut Style Pickles

	Grade A		Grade B	
	Maximum (by count)	Score	Maximum (by count)	Score
Flavor and odor	Good	—	Reasonably good[a]	—
Color	Good	18–20	Reasonably good[a]	16–17
Uniformity of size[b]	—	18–20	—	16–17
Diameter [over 5.4 cm (2.13 in)]	10%	—	20%	—
Defects	Practically free	27–30	Reasonably free[a]	24–26
Blemished (slightly and seriously)	15%	—	25%	—
Blemished (seriously)	5%	—	10%	—
Mechanical damage	15%	—	25%	—
Broken pieces and end cuts	10%	—	15%	—
Thickness over 10 mm (0.38 in)	10%	—	15%	—
Attached stems [over 2.5 cm (0.98 in)]	10%	—	15%	—
Units missing $\frac{1}{3}$ seed cavity	10%	—	15%	—
Extraneous vegetable material (EVM)	Practically free	—	Reasonably free[a]	—
Texture	Good	27–30	Reasonably good[a]	24–26
Large objectionable seeds, detached seeds, and tough skins	Practically free	—	Reasonably free[a]	—
Soft, shriveled, and slippery units	5%	—	10%	—
Total score (minimum)	90 points		80 points	

[a]Cannot be graded above U.S. Grade B, regardless of the total score.
[b]Pickles that are substandard for uniformity of size cannot be graded above U.S. Grade B, regardless of the total score.

Table 10 Quality Requirements, Cut Style Pickles

	Grade A		Grade B	
	Maximum (by count)	Score	Maximum (by count)	Score
Flavor and odor	Good	—	Reasonably good[a]	—
Color	Good	18–20	Reasonably good[a]	16–17
Uniformity of size[b]	—	18–20	—	16–17
Small pieces 5 g or less	5%	—	10%	—
Defects	Practically free	27–30	Reasonably free[a]	24–26
Blemished (slightly and seriously)	15%	—	25%	—
Blemished (seriously)	5%	—	10%	—
Mechanical damage	10%	—	15%	—
Attached stems [over 2.5 cm (0.98 in)]	10%	—	15%	—
Extraneous vegetable material (EVM)	Practically free	—	Reasonably free[a]	—
Texture	Good	27–30	Reasonably good[a]	24–26
Large objectionable seeds, detached seeds, and tough skins	Practically free	—	Reasonably free[a]	—
Soft, shriveled, and slippery units	5%	—	10%	—
Total score (minimum)	90 points		80 points	

[a]Cannot be graded above U.S. Grade B, regardless of the total score.
[b]Pickles that are substandard for uniformity of size cannot be graded above U.S. Grade B, regardless of the total score.

Table 11 Quality Requirements, Relish

	Grade A		Grade B	
	Maximum (by weight)	Score	Maximum (by weight)	Score
Flavor and odor	Good	—	Reasonably good[a]	—
Color	Good	18–20	Reasonably good[a]	16–17
Uniformity of size	—	18–20	—	16–17
Overall appearance	Good	—	Reasonably good[a]	—
Defects	Practically free	27–30	Reasonably free[a]	24–26
Blemished (slightly and seriously)	15%	—	25%	—
Blemished (seriously)	5%	—	10%	—
Poorly cut	10%	—	15%	—
Loose stems over 3.0 mm (0.12 in)	10%	—	15%	—
Extraneous vegetable material (EVM)	Practically free	—	Reasonably free[a]	—
Texture	Good	27–30	Reasonably good[a]	24–26
Large objectionable seeds, detached seeds, and tough skins	Practically free	—	Reasonably free[a]	—
Soft, shriveled, and slippery units	5%	—	10%	—
Total score (minimum)	90 points		80 points	

[a]Cannot be graded above U.S. Grade B, regardless of the total score.

L. Requirements for Grades

See Tables 5–11.

II. ESTABLISHMENT INSPECTION

The United States Food and Drug Administration has issued guidelines for the inspection of a pickle processing plant. Some of the information is provided in this chapter. The quality control officer in such a plant should use the information to implement its in-plant inspection procedure.

The information is presented in the teacher/student format for ease of reference.

1. Direct special attention to the following areas when inspecting these types of food establishments. If the establishment is producing acidified fresh-pack pickles, determine if the establishment is complying with the requirements of 21 CFR 114, Acidified Foods.
2. Salt stations and salt stock tanks.
3. Insects that breed in decomposed pickles or other decaying organic matter, such as the lesser or little house fly, the latrine fly, the house fly, the rattailed maggot, and drosophila, are of major sanitary significance. Examine 25% of the tanks for insect filth.
4. "Mill run" salt may be used but workers should not walk in the salt.
5. Tanks should be skimmed daily for debris and insects, and the skimmings should be properly disposed of.
6. In newly salted stock ferments, scum growth should be removed regularly and disposed of so that insects are not attracted.

A. Pickle Products

1. Examination of Raw Materials Used in Relish

1. Obtain the usual composition of relish in percent by weight of cucumbers as well as other ingredients to help appraise the filth load found in the sample.
2. Salt stock used for relish may consist of poor quality pickles, i.e., deformed, bloated, or blemished. In the absence of filth, grit, or partly/wholly rotted pickles, there is no objection to their use. Mushy pickles are caused by certain pectin-splitting enzymes during fermentation. Soft pickles may be invaded by bacteria and fungi, but it is frequently difficult to determine if any mold or bacteria are present by field examination.
3. Examination of cucumber salt stock for relish—when whole pickles or large pieces are used, examine a representative sample of 100 units going to chopper.
4. Segregate and list objectionable pickles as follows:

Class	Number	Percent
1. With rot spots over $\frac{1}{2}$ in	_____	_____
2. Insect infested or damaged	_____	_____
3. Mushy or very soft	_____	_____

1. For class 1 pickles, make a further determination of the surface area of the rot spots by size; up to 1 inch; from 1 inch to half of the pickle; and over half of the pickle. Take close-up color photographs of objectionable pickles. Collect exhibits of pickles showing typical rot and insect damage.
2. Laboratory examination of mushy pickles for mold is necessary to establish if they are objectionable. If over 5% of the units are mushy, cut a thin cross section from each pickle. Place the slices in a quart jar with water and add 20 cc formaldehyde for later examination.
3. When small pieces of salt stock cucumbers, cauliflower, and peppers are used, rot determination by count is impractical. If rotten pieces are observed, collect a separate quart of each pickled vegetable. Preserve the samples with 20 cc formaldehyde. At the same time collect a sample totaling half a gallon of finished relish.

B. Peppers

1. Check for insect larvae (maggots or larvae of the pepper weevil) in fresh and salt stock peppers and figure percent of infestation on a representative sample. Examine any fresh-pack peppers in which infested stock was used.
2. If peppers with rot are found, evaluate in the same fashion as for cucumbers.
3. Examine vinegar storage tanks for drosophila infestation and for vinegar eels.
4. Insect filth in sweet stock pickles—insects, particularly drosophila, are attracted to the sweetening tanks and may be found in the finished sweet pickle products.
5. Sweet brine is frequently circulated within a tank and from one tank to another dispersing insects in the circulating brine. It is sometimes difficult to estimate the number of insects and parts in such circulating brine. Close examination of the inside tank walls may reveal drosophila above the brine level. These are the best indices of infestation in a tank.

When insects are found in a sweetening tank,

1. Determine whether sweet brine in the tank is an intermediate or a finishing brine and if it is circulated within the tank or between sweetening tanks.
2. If the finishing brine is used as a packing medium, determine whether it is filtered prior to use and evaluate the filtration step.
3. If sweet stock is held in infested tanks, determine anticipated date of packing.
4. Evaluate tank covers used.
5. List quantitatively the extent of insect infestation by the collection of representative samples of filth from a definite area, e.g., square feet of the walls of the tank on the sweet stock and in a specified amount of brine from different areas of the tank if the infestation is widespread. If infestation seems to be isolated, collect specimens showing the types of insects.

C. Other Points of Interest

1. Grit in pickles—excessive grit is frequently found in fresh-pack pickles and in midget sweet pickles. Salt stock may occasionally contain excessive grit. If dirty cucumbers are packed, collect in-line and finished product samples.
2. Use of color and preservatives—green artificial color is sometimes used in relish without label declaration. Ascertain if the color is permitted for use and declared on the label.

3. Sorbic acid may be used in salt stock, to prevent yeast growth, and in finished pickle products, as a preservative. Where sorbic acid is present in the finished product, determine if it is declared on the label.
4. Examination of warehouse stocks—examine for evidence of spoilage, particularly in fresh pack pickles which may have been inadequately pasteurized.
5. If heavy insect infestation is found, examine 24 jars of the pickle product (other than relish) most likely to contain insects by inverting jars under strong light. Collect jars containing insects as a factory sample.

D. Sample Collection

1. Bulk Salt Stock for Filth

If in barrels, collect a minimum of 12 half-gallon jars of salt with their brine, two from each of six previously unopened barrels, to make six duplicate subs. Collect 1 sub from the top and the other sub from the bottom, if possible. If in tank cars, collect a minimum of twelve half-gallon jars of salt stock and brine. If live flies are observed inside tank during sampling, note and estimate their number.

2. Finished Pickle Product—All Types

a. Filth and Grit

Quarts and smaller jars	Minimum to collect
Up to 100 cases in lot	24 jars
More than 100 cases	48 jars

Gallon jars	Minimum to collect
Up to 100 cases	12 jars
More than 100 cases	24 jars

b. Undeclared Color and Chemical Additives Collect 6 quarts or 12 pints for examination.

15

Fermented Soy Products: Tempeh, Nattos, Miso, and Soy Sauce

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I. INTRODUCTION

In Asian countries, the soybean has been processed into various products, such as tofu, tempeh, miso, nattos (Itohiki-natto and Hama-natto), soy sauce, and other related products. These products are used as protein supplements, vegetables, or seasoning ingredients in meal preparation. Of these products, tofu, tempeh, and natto are often consumed as vegetables and/or as protein supplements, whereas miso and soy sauce are used as seasonings. Tofu and its related products will be covered in a separate chapter of this book. This chapter will discuss five kinds of fermented soy products: tempeh, Itohiki-natto, Hama-natto, miso, and soy sauce.

II. TEMPEH

A. Introduction

Tempeh is a very popular fermented soybean-based food, that has been produced by Indonesians for four or five centuries. Tempeh is a white mold-covered cake produced by fungal fermentation of dehulled, hydrated (soaked), and cooked soybeans (1).

Under natural conditions in the tropics, tempeh production involves two distinct fermentations. The first, which occurs during hydration (soaking), is bacterial and results in acidification of the beans. During bacterial acid fermentation, the pH of the beans falls to a range of 4.5 to 5.3, and thus the development of undesirable bacteria that might spoil the tempeh is prevented. The second fermentation is fungal and results in overgrowth of the beans by the mold mycelia. The beans are tied together by the hypha that binds the beans so firmly together that the product can be cut into thin slices (1). Packets of traditional tempeh wrapped in wilted banana leaves or in perforated plastic bags are sold on the market in Indonesia (Fig. 1).

The best quality tempeh is made solely from soybeans, but lower cost and lower quality tempehs may contain young papaw fruit grits, cassava grits, soybean seedcoats, soymilk or tofu (soybean curd) residues (okara), and (rarely) coconut press-cake along with the soybeans.

Tempeh is consumed by slicing it, dipping the slices in soy or fish sauce or in 5 to 10% w/v salt brine, and deep frying. Alternatively, the sliced tempeh can be dipped in a batter made from rice or corn flour and coconut milk, before deep frying, or it may be soaked in tamarind pulp

Figure 1 Tempehs sold in an Indonesian market.

diluted with boiling water. Tempeh can also be used as a meat substitute in soups containing potatoes, hot peppers, and other vegetables (1). Tempeh serves not only as a protein-rich meat substitute but also as a potential source of vitamin B-12 and other nutrients.

B. Method of Tempeh Production

The technology for producing tempeh includes the stages of boiling, dehulling, soaking with acid, washing, inoculation with starter, packing, and fermentation. The flow diagram in Fig. 2Z shows a common process for tempeh production (2).

Partial cooking should be carried out to destroy contaminating bacteria, to destroy trypsin inhibitor, and to release some of the nutrients required for mold growth. Traditional cooking times vary from 10 min to 3 h boiling (1).

After partially cooking, it is essential to dehull the beans, so that lactic acid can first penetrate the beans and then allow the fungal mycelium to grow into the beans during

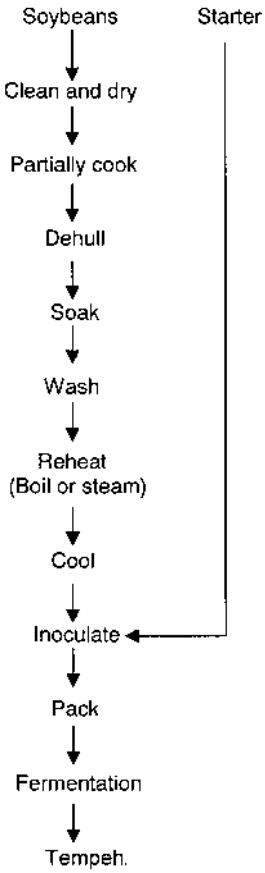

Figure 2 A flow diagram for the production of tempeh.

fermentation. The fungus is unable to penetrate the soybean husk owing to its strong cellulose structure. If the husks are not removed, the resultant tempeh cake will be weak and not held together properly (2).

The objective of soaking is to hydrate the beans and lower the pH by the growth of natural lactic acid bacteria. The low pH, ideally between 3.5 and 5.2, inhibits the growth of potentially pathogenic contaminant bacteria and spoilers. In addition, it prepares the beans to the optimum pH for mold growth.

Natural lactic acid bacteria not only acidify the beans but also produce certain metabolic products that contribute to the nutritional composition of the tempeh. Natural lactic acid bacteria also add a unique aroma and flavor that improve the organoleptic qualities of the tempeh. Mulyowidarso et al. (3) reported that microorganisms reached levels of 10^7 to 10^9 cell/mL during soaking. The pH fell to 4.5. *Lactobacillus casei*, *Streptococcus faecium*, and *Streptococcus epidermidis* were responsible for most of the pH drop.

After reheat treatment, a heat-stable and water-soluble mold inhibitor is leached out in the boiling water, which is discarded (4). The bitter soya taste also disappears in ≤ 15 min at 95°C (5). The starter mold is sprinkled over the surface of the beans, which have been drained, cooled, and then mixed thoroughly before packing.

Traditionally, tempeh is fermented using an inoculum derived from a sporulating fungus adhering to the hibiscus leaf (when used as an inoculum this is called usar). Generally 1 to 3 g of dried powdered tempeh are used to inoculate 1000 g of soybeans with satisfactory results (1). The essential microorganism in the tempeh fungal fermentation is a mold belonging to the genus *Rhizopus*. These include *R. oligosporus*, *R. stolonifer*, *R. oryzae*, and *R. arrhizus* (6,7). The best of the molds so far discovered is *R. oligosporus* NRRL strain 2710 (8).

The inoculated soybeans are packed for fermentation. Banana leaves are usually scored lightly with a knife for ventilation, although the pores in the leaves also allow the entry of oxygen. Almost any container—leaf, plastic, wooden, or stainless steel—can also be used for the fermentation (1). Tempeh takes the shape of its fermentation container. Flexible pouches or rough-surfaced leaves will result in tempehs with irregular surfaces, whereas smooth polythene sheets, or metallic or hard-plastic boxes, give tempeh with straight edges and smooth, shiny surfaces (9).

Fermentation can be carried out at any temperature between 20°C and 37°C for 1–3 days. As the mold begins to grow rapidly during tempeh fermentation, the temperature of the fermenting bean mass generally rises 5 to 7°C above room temperature. Care must be taken that the temperature within the fermenting bean mass does not rise above approximately 42°C, for the high temperature may damage subsequent growth of the mold and allow the growth of thermophilic spoilage bacteria (9).

The ideal fermentation time is 36 h, which allows for the maximum synthesis of nutritional components, and texture and flavor attributes.

The tempeh should be harvested as soon as the beans have been completely overgrown and knitted into a complete cake (Fig. 3). 1 kg of soybeans can make approximately 2 kg of tempeh.

At an early stage, it should remain in good conditions for another 24 to 48 hours without refrigeration. If tempeh is not going to be consumed immediately, it should be deep-fried, in which form it remains stable for a considerable time, or it should be steamed and refrigerated. Another alternative is to cut the tempeh into thin strips and to sun dry it (1). Tempeh also can be stored in a freezer (below −18°C) for about one year.

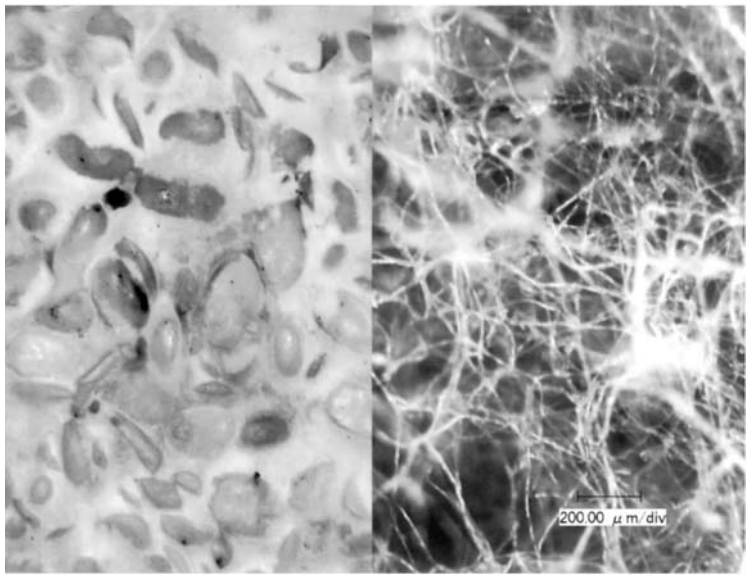

Figure 3 The surface of tempeh. Left: beans tied together by the hyphae; right: network structure of hyphae.

C. Quality Aspects of Tempeh

The composition of tempeh is shown in Table 1.

Conversion of soybeans into tempeh is accompanied by a dramatic improvement in the texture, flavor, and aroma of the product. Whereas plain boiled soybeans have a distinctively unpleasant beany smell, this is lost during fermentation. A pleasant aroma is created by the action of the fungal mycelium (11). Enzymes are produced by the growing mold during fermentation and bring about changes in all three major food components, protein, fat, and carbohydrate. The longer the fermentation, the stronger the smell becomes until ammonia is finally liberated after extensive protein breakdown.

The pH, which starts out at about 5 in the soaked and partially cooked beans, rises to above 7 (1).

As several vitamins are synthesized by microorganisms grown in tempeh, B vitamins, niacin, biotin, folate, and pantothenate contents increase during fermentation (11–13).

An antimicrobial compound active against bacteria is also synthesized within tempeh (14).

The role of tempeh as a health food has been researched. Tempeh reduces total cholesterol and LDL cholesterol, while HDL cholesterol is raised, and it may therefore be of benefit as a protective agent against cardiovascular disease (15).

Free isoflavones such as daizein and genistein, which are presumed to be antioxidants, are synthesized in tempeh (16). They are important in the body for the protection against free radical damage and may therefore help toward preventing various degenerative diseases (17).

D. Future Outlook

Tempeh is a popular traditional fermented soy food originally developed from Central Java over four hundred years ago and commonly associated with Javanese culture. It has now spread to all parts of Indonesia and has been growing in popularity in the Netherlands, Japan, Australia, Singapore, Malaysia, and other areas in the world, particularly for vegetarians.

Since the shelf life of fresh tempeh is very much limited, canned tempeh and dried tempeh powder are made, and it is used in other foods such as cookies, bread, croquettes, and miso.

Tempeh is easy to make and its production cost is low. Tempeh may have the potential to be a healthy substitute for meat in the future.

III. TRADITIONAL NATTO (ITOHIKI-NATTO)

A. Introduction

Traditional natto (Itohiki-natto) is thought to have originated in China's Yunnan province; according to Japanese legend, Itohiki-natto was invented by accident in Japan's Tohoku region in the 11th century when boiled beans that were going bad were eaten and found to be rather tasty.

Traditional natto is usually eaten for breakfast by mixing it in a bowl with condiments, egg, and shoyu (soy sauce) and then spreading the mixture over cooked rice (18). Itohiki-natto shows a

Table 1 Composition of Tempeh and Boiled Soybeans (%)

Food	Moisture	Protein	Fat	Carbohydrate	Ash
Tempeh	57.8	15.8	9.0	15.4	2.0
Boiled soybeans	63.5	16.0	9.0	9.7	1.8

Source: Ref. 10.

unique alkaline fermentation dominated by *Bacillus natto*, which rises in pH with the liberation of ammonia related to the extensive hydrolysis of soybean protein to peptides and amino acids (19). Foods that use the same category of alkaline fermentation also can be seen in thua-nao (Thailand) (20), kinema (Nepal) (21–23), and certain African foods such as dawadawa, soumbara, iru, or ogiri (19).

Japanese Itohiki-natto is gray to tan in color, is covered with a viscous, sticky textured fluid, and has a persistent unique flavor that make some people find nonpalatable. Natto has been recently regarded not only as a low-cost and highly nutritious food but also as a health food: the consumption of it is increasing in all parts of Japan.

B. Method of Itohiki-Natto Production

The technology required to make natto is quite simple. It includes the stages of soaking, cooking, cooling, inoculation with starter, packing, and fermentation. One kilogram of soybeans makes approximately 2 kg of Itohiki-natto. The flow diagram in Fig. 4 shows a common process for Itohiki-natto production.

Whole dry soybeans are washed and soaked overnight in water (bean : water, 1 : 3 w/w). Small, uniform size beans with smooth surfaces are preferred for a good quality of product.

During soaking for 12 h (summer) to 20 h (winter) at room temperature, the beans absorb 110–130 parts water. The soaked beans are boiled for 5 h or steamed at 121°C for 30 min (24). The cooked beans are soft and should be crushed easily when pressed with the fingertips.

Cooked beans are cooled to approximately 80°C, and then the starter culture of *Bacillus natto* is inoculated and thoroughly mixed to distribute the starter over the surface of all the beans. Although 5–10% fresh Itohiki-natto can be used as a starter, dry powder or liquid culture of *B. natto* is commercially used (10^3 spores/1 g soybeans) (Fig. 5). *B. natto* is an aerobic gram-positive, spore-forming rod, closely related to *B. subtilis*.

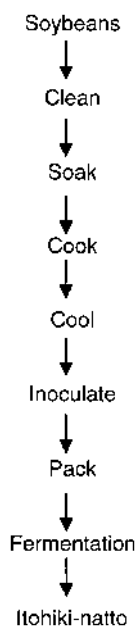

Figure 4 A flow diagram for the production of natto.

Figure 5 The culture of *B. natto* is sprinkled over the cooked and cooled soybeans.

In the traditional making of Itohiki-natto, the cooked soybeans are wrapped with straw, which makes inoculation unnecessary because *B. natto* naturally adheres to straw. Inoculation became necessary when straw was eliminated from the process. The inoculated beans are filled into small, shallow polystyrene trays or paper cups and fermentated at 40–42°C for 16–18 h.

During fermentation, a whitish cell mass of *B. natto* is formed on the surface of the soybeans, and a unique odor and a stringy mucous material are formed (19) (Fig. 6).

Since Itohiki-natto contains 10^9 cells of *B. natto* per g, the shelf life is limited to approximately 1 week in the refrigerator. Most natto is sold within 2 to 3 days of production. When the fresh Itohiki-natto is placed under room temperature, further digestion of beans continues. The release of ammonia and the color change to dark tan make them unpalatable (19)

C. Quality Aspects of Itohiki-Natto

The average composition of natto is shown in Table 2.

Although total nitrogen during fermentation is fairly constant, water soluble nitrogen, amino nitrogen, and ammonia nitrogen increase as a result of the proteolysis of the soybeans (25).

The fat content is relatively constant, and reducing sugars decrease. The mucilaginous material that is synthesized by *B. natto* during fermentation is composed of 58% gamma-polyglutamic acid and 40% polysaccharide-fructan (26).

D. Future Outlook

Recently, Itohiki-natto has become more popular in Japan, and its consumption has increased year by year. This is closely related to the perception that Itohiki-natto is a healthy food. Positive results were reported for the reduction of blood pressure and the prevention of thrombosis, cancer, and osteoporosis (27).

Figure 6 Itohiki-natto with its viscous, sticky texture.

IV. JAPANESE HAMA-NATTO (DAIFUKUJI-NATTO, DAITOKUJI-NATTO, TERA-NATTO, SHIOKARA-NATTO)

A. Introduction

Hama-natto is another type of fermented soybean, different from Itohiki-natto. The fermentation of Hama-natto is carried out by the mold *Aspergillus oryzae*. The type of Hama-natto originated in China over 2200 years ago was introduced into Japan via Korea during the Nara period (A.D. 710–794) by a Buddhist priest (18). It is now commercially produced in extremely restricted areas of Hamamatsu city, Mikkabi town in Shizuoka Prefecture, and Kyoto city. The taste and flavor resemble miso and shoyu. Its blackish color and relatively high market price (US$2.7 per 100 g) may be the causes of its lack of popularity (Fig. 7).

B. Method of Hama-Natto Production

The technology to produce Hama-natto includes the stages of soaking, cooking, inoculation with starter mold, mycelial fermentation, drying, and second fermentation (aging). The flow diagram in Fig. 8 shows the process of Hama-natto production.

Table 2 Average Composition of Itohiki-Natto (%)

Food	Moisture	Protein	Fat	Carbohydrate	Ash
Natto	59.5	16.5	10.0	12.1	1.9

Source: Ref. 10.

Figure 7 Hama-natto produced in Hamamatsu city, Japan.

Whole dry soybeans are washed and soaked in water for 3 h at room temperature. Large, uniform size beans with smooth surfaces are preferred. The soaked beans are boiled for 5 h or steamed at 121°C for 30 min. After the cooked beans are cooled to approximately 30°C, they are thoroughly mixed with roasted barley flour and starter mold *Aspergillus oryzae* (called tane-koji). In the case of the Yamaya Brewery in Hamamatsu city, the amounts of cooked beans, roasted barley flour, and tane-koji are 1000 kg, 50–60 kg, and 50 g, respectively.

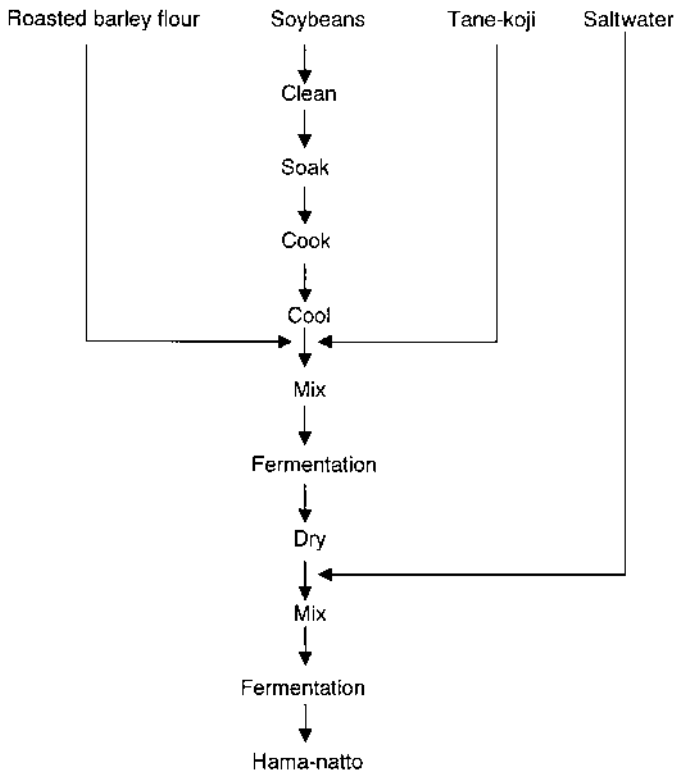

Figure 8 A flow diagram for the production of Hama-natto.

The mixture is spread in a wooden tray and incubated in the fermenting room at 25–30°C for 3–4 days (Fig. 9).

During the fermentation, *A. oryzae* grows on the surface of the beans covered with barley flour, until sporulation occurs.

The molded beans are dried in the sun for approximately 1 week and then mixed with 15% salt water (600–700 liters) and transferred into wooden buckets with ginger and/or Japanese pepper to enhance the flavor of the product.

The mixture is covered with a wooden lid, and a stone weight is put on the lid (Fig. 10). During the second fermentation for 3 to 6 months, the color of the beans changes to black. Hydrolysis of the substrates also occurs, and the resultant flavor resembles miso and shoyu (24).

C. Quality Aspects of Hama-Natto

The composition of Hama-natto is shown in Table 3.

Since Hama-natto contains a high salt concentration, it has an excellent keeping quality for 1 year or longer. It was originally made in Buddhist temples as a protein source for Buddhist monks.

D. Future Outlook

Nowadays, Hama-natto is consumed with tea and alcoholic drinks as a relish or eaten with rice in Japan. If the dark blackish color can be improved, and if the product becomes less costly, it could become a more popular food in Japan.

Figure 9 *A. oryzae* is grown on the surface of the mixture of cooked beans and roasted barley flour.

Figure 10 Fermentation (aging) is carried out for 3–6 months.

V. MISO

A. Introduction

Miso is a very popular fermented soybean-based paste food; it has been produced in all parts of Japan for at least 1300 years (28,29). It has now been industrialized, and 1355 manufacturers made 544,000 tons of it in the year 1999 (30).

There are several hundred kinds of miso, depending on the material used and on the different processing conditions. Miso can be classified into three large groups according to the different methods of koji making. Koji is a solid substrate such as rice, barley, or soybeans overgrown with a mold (koji kabi), which is selected to provide the enzymes essential for the fermentation.

Table 3 Composition of Hama-Natto (%)

Food	Moisture	Protein	Fat	Carbohydrate	Ash	Salt
Hama-Natto	24.4	18.6	8.1	31.5	17.4	14.2

Source: Ref. 10.

Mugi-miso (barley/soybean miso) is produced in western Japan and accounts for 7.3% of the total production. Fermentation is relatively short, about 2–3 months. The product is a light brownish yellow color with a sweet taste and a low concentration of salt. Therefore its shelf life is limited.

Kome-miso (rice/soybean miso) is produced throughout Japan. This type is the most popular and has many variations. It accounts for 78.6% of the total production.

Mame-miso (soybean miso) is produced in central Japan and accounts for 4.8% of the total production. It contains a high concentration of salt and requires 2 years aging; and it has long shelf life (29,31) (Fig. 11).

Miso is very important for the daily preparation of miso soup in Japanese homes. Miso soup is made by dissolving a lump of miso paste in boiling water containing vegetables such as radish, green onion, onion, taro, bean sprouts, tofu, fried bean curd, mushroom, seaweed, fresh-water clam, short-neck clam, and various other soup ingredients (18,31).

Besides miso soup, it is used as a seasoning for meats, fish, shellfish, vegetables, and fruits. It is also a thickening agent and an absorbent that decreases unpalatable flavor (31).

B. Method of Miso Production

The technology for producing miso includes the stages of soaking, boiling, inoculation, and fermentation. Manufacturers prefer large, light yellow soybeans with a white hilum (31). The flow

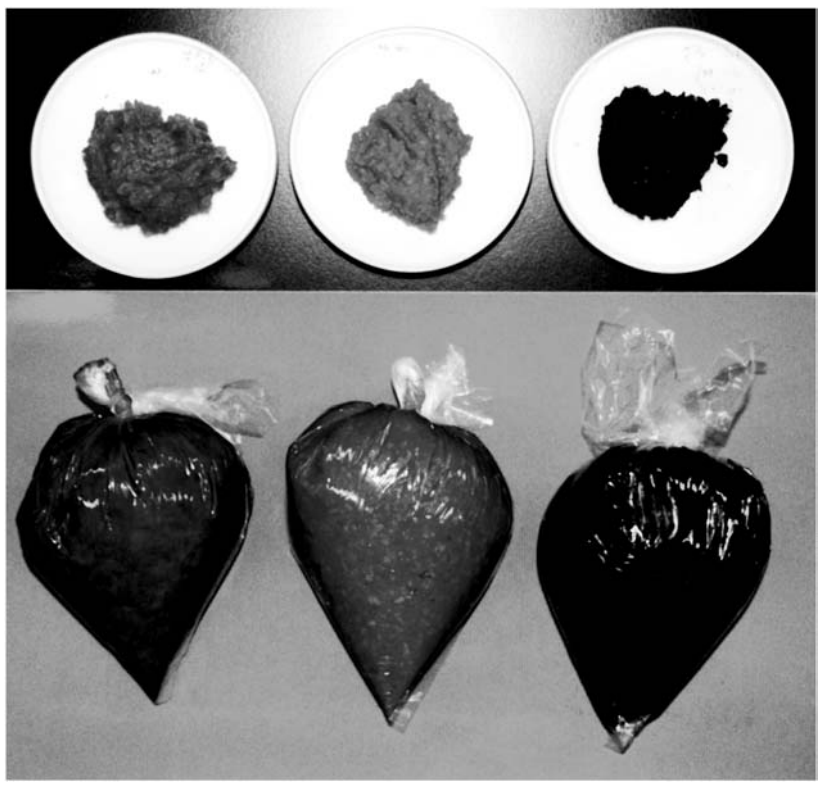

Figure 11 Three kinds of miso produced in Japan. Left: mugi-miso (barley/soybean miso); center: kome-miso (rice/soybean miso); right: mame-msio (soybean miso).

diagram in Fig. 12 shows a common process for kome-miso (rice/soybean miso), which is the most popular type in Japan.

Koji is a fermented product of *Aspergillus oryzae* or *A. soyae* grown on the surface of steamed rice. It can be made according to the following procedure. Polished rice is soaked in water, cooked in steam, cooled to 35–40°C and inoculated with *A. oryzae* (tane-koji), which is commercially available. The inoculated rice is spread in wooden trays and allowed to ferment at 30–35°C. After incubation for 48 h, a mold grows and covers the surface of the rice. The fermentation should be stopped before sporulation occurs (Fig. 13).

Soybeans that are soaked, steamed, and cooled are mixed thoroughly with prepared koji and salt, and then coarsely crushed using a crusher. The mixture is transferred into a wooden or stainless steel tub, and the surface is covered with a wooden lid; then a stone weight is placed on the lid. Fermentation is carried out for 10–15 days for sweet miso and 2–12 months for salty miso. When fermentation is completed, the mixture is mashed again to make a fine and smooth paste; then it is filled into various types of packaging (Fig. 14).

Mugi-miso and mame-miso are made using koji that is prepared from barley and soybeans, respectively, with the growth of *A. oryzae*. During the fermentation process, fungal enzymes break down soybean components. This not only allows the resultant miso to be much more easily digested than soybeans but also improves the flavor and aroma of miso (31).

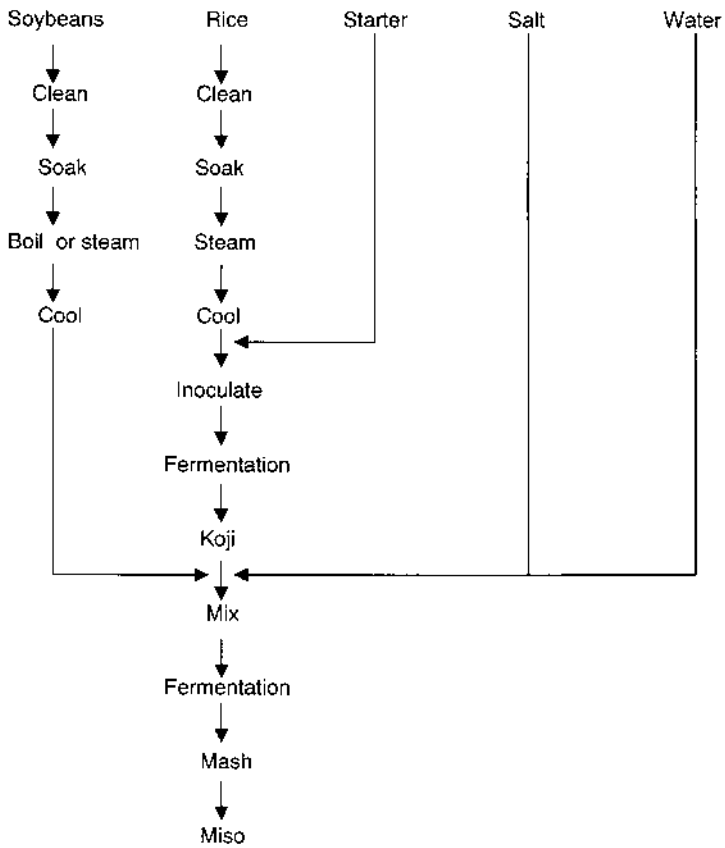

Figure 12 A flow diagram for the production of kome-miso.

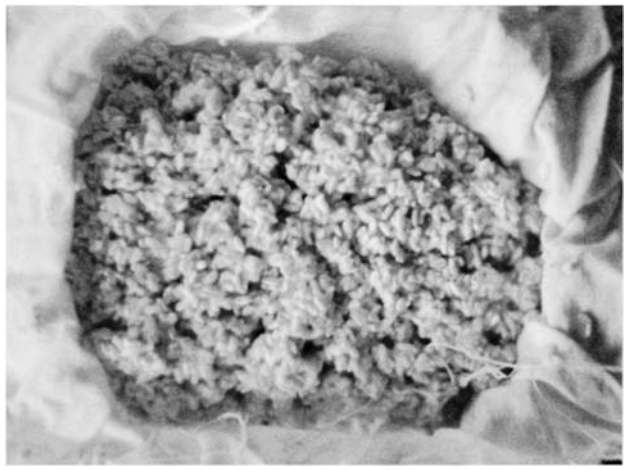

Figure 13 A koji (*A. oryzae* grows on the surface of cooked rice).

C. Quality Aspects of Miso

The composition of various types of miso is shown in Table 4. The enzymes for the fermentation (maturation or aging) of miso production comes from koji in which the mycelia of *A. oryzae* (*A. soyae*) overgrow on rice and the yeast *Saccharomyces rouxii* and lactic acid bacteria such as *Pediococcus halophilus* or *Streptococcus faecalis*, which are naturally present in the fermentation

Figure 14 After fermentation (aging), the mixture is mashed and filled into a container. (Courtesy of Nobunkyo, Tokyo, Japan.)

Table 4 Average Composition of Various Types of Miso

Foods	Moisture	Protein	Fat	Carbohydrate	Ash	Salt
Kome-miso						
Sweet type	42.6	9.7	3.0	37.9	6.8	6.1
Light yellow type	45.4	12.5	6.0	21.9	14.2	12.4
Dark yellow type	45.7	13.1	5.5	21.1	14.6	13.0
Mugi-miso	44.0	9.7	4.3	30.0	12.0	10.7
Mame-miso	44.9	17.2	10.5	14.5	12.9	10.9

Source: Ref. 32.

room and/or container. These enzymes (amylases, proteases, and lipases) act upon the components of rice and soybeans for the synthesis of nutritional components, as well as texture and flavor attributes to the desired level of intensity.

Table 5 shows the major compositional changes and contributing microorganisms. The starch in the koji is hydrolyzed to dextrins, maltose, and glucose. The protein in the soybeans is hydrolyzed to peptones, peptides, and amino acids, and fatty acids are liberated from the fat with the action of lipase. The net protein utilization (NPU) of miso is about 72, which is higher than the NPU of its ingredients (rice, 70; barley, 60; and soybean, 61). Sixty percent of the total nitrogen is water-soluble and easily digested. Vitamin B-2 and vitamin B-12 are synthesized during fermentation (31).

During miso fermentation, the color also changes from dark yellow to bright or dark brown or even black, depending on the kind of soybeans, the temperature of cooking, and the length of fermentation.

Miso is not only palatable and nutritious but also considered to be helpful in preventing many forms of cancer, stomach ulcer, and osteoporosis, and in reducing blood cholesterol levels (33–35). Free isoflavones such as daizein and genistein are presumed to be the antioxidants that are important in protecting against free radical damage (16).

No aflatoxin was produced by 238 commercial strains, and aflatoxin was not found in 28 koji from miso factories or in 30 homemade miso samples (36).

Miso can also be dehydrated by freeze-drying, spray-drying, or drum-drying. The powdered product is conveniently consumed as an ingredient for miso soup with various freeze-dried soup ingredients.

Table 5 Major Compositional Change During Miso Fermentation

Reaction	Microorganism	Substrate	Product	Flavor
Amylolysis	*A. oryzae* (*A. soyae*)	Starch	Sugar	Sweetness
Alcoholic fermentation	Yeast	Sugar	Alcohol	Ester, Fragrance
Esterification				
Acid formation	Lactic acid bacteria	Sugar, protein, fat	Organic acid	Acidic
Proteolysis	*A. oryzae* (*A. soyae*)	Protein	Amino acid	Umami

D. Future Outlook

Miso is one of the three major soybean foods [the other two being shoyu and tofu (soybean curd)], and as such is indispensable in the Japanese daily diet. It is used for seasoning and for the preparation of miso soup in Japan. 1355 factories made over half a million tons of miso in 1995, and the annual per capita consumption is approximately 5 kg.

Miso has been recently regarded as a health food and contributes the high average longevity of the Japanese people. Miso may have the potential to be distributed to other foreign countries.

VI. SOY SAUCE

A. Introduction

Soy sauce (shoyu) is a very important fermented soybean-based food for the Japanese daily diet, just like miso. Soy sauce originated in China over 3000 years ago and was brought to Japan by the Buddhists over 1000 years ago (37).

Shoyu is used as a seasoning to increase the appetite and to add a delicious, spicy flavor and color (38). It is a light brown to black liquid with a meatlike, salty flavor produced by hydrolyzing soybeans, with or without the addition of wheat or barley, using enzymes produced by *Aspergillus oryzae* (*A. soyae*) and the action of lactic acid bacteria and yeast in salt water of high concentration (38,39).

Shoyu has been industrialized, and 1883 manufacturers made 1.05 million kL (1999) in Japan. The five largest manufacturers produce about one-half of the total production, and the largest, Kikkoman, has 27% of the market (40).

Although shoyu is a traditional Asian food, it has developed from a symbol of cultural exchange to one of cultural fusion and is now made in many other countries in the American and on the European continent (41).

B. Method of Making Shoyu

Over 2200 kinds of shoyu are produced all over Japan. According to the Japan Agricultural Standard (JAS), shoyu is classified into five groups as the result of differences in the cereal grains used (wheat, barley, or no cereal grains), the proportion of cereal to soybean, the salt concentration used, and the cooking and fermentation times. Of these, koikuchi-shoyu is the most commonly produced, accounting for 85% of the total shoyu in Japan (40).

The flow diagram in Fig. 15 shows a common process for koikuchi-shoyu, the most popular type in Japan.

A two-stage fermentation is carried out (38). Aerobic, solid-state mold fermentation for koji making is followed by submerged fermentation by lactic acid bacteria and yeast in salt water of high concentration. A tane-koji (*A. oryzae* or *A. soyae*) is inoculated into the mixture of soaked and boiled soybeans, and a lightly roasted cracked wheat. During the fermentation for 3 days, mold is grown and covers the surface of the mixture, which is called koji (Fig. 16). Then the koji is mixed with high concentration salt water (approximately 18% w/v), followed by fermentation at room temperature for 8–10 months.

During the fermentation process, fungal enzymes break down the soybean and cereal components. The source of enzymes is the koji in which the mycelia of *A. oryzae* (*A. soyae*) (Fig. 17) grow on the cereal, and salt-tolerant homofermentative lactic acid bacteria, principally *Pediococcus cerevisiae* (*P. soyae*) or *Lactobacillus delbrueckii*, and salt-tolerant yeasts, primarily

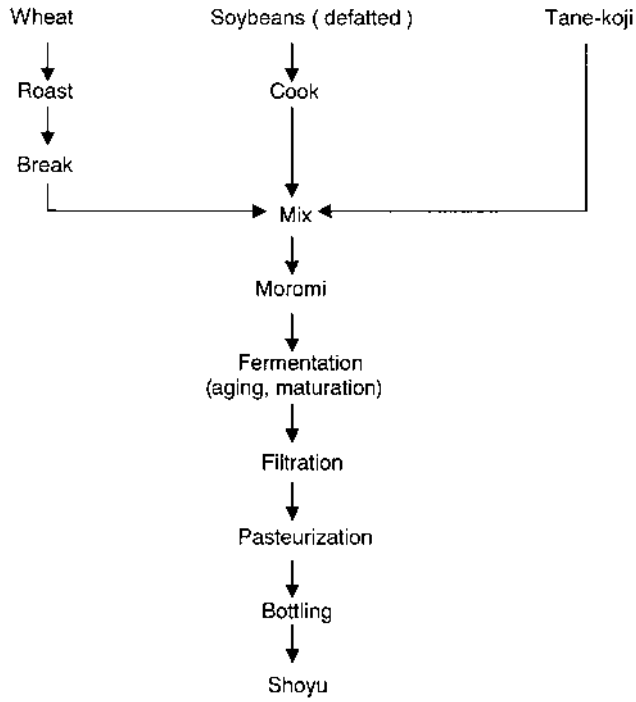

Figure 15 A flow diagram for the production of Koikuchi-shoyu.

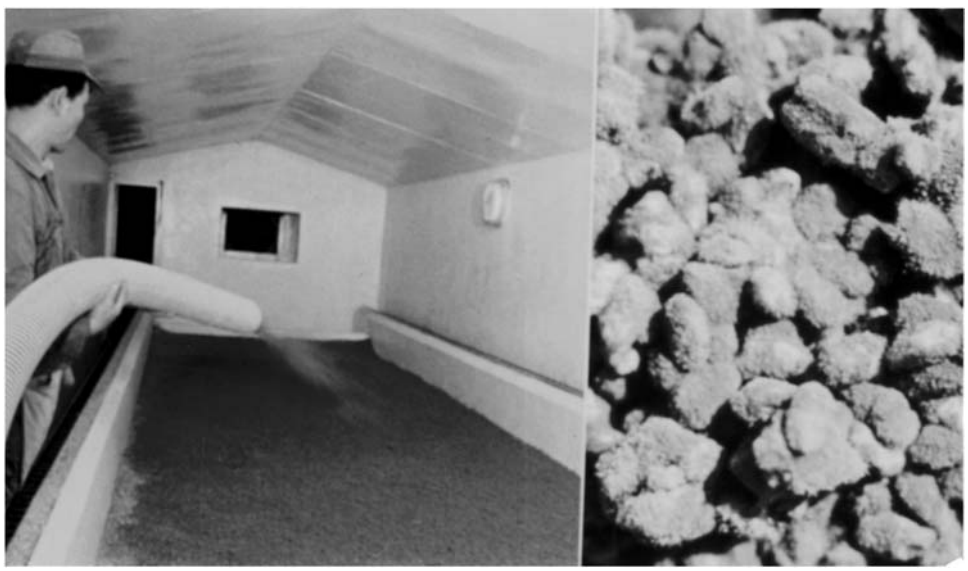

Figure 16 Koji making. Left: cooked and cooled soybeans are mixed with roasted flour and koji-mold; right: koji-mold grown on the surface of beans, which are covered with roasted flour. (Courtesy of Nobunkyo, Tokyo, Japan.)

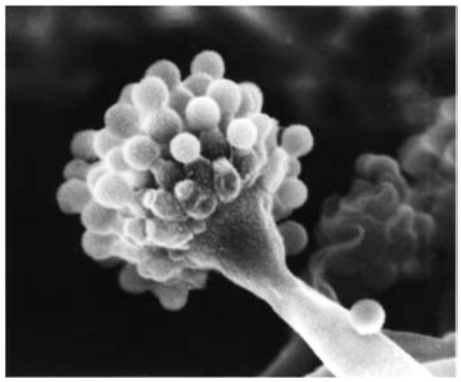

Figure 17 An electronograph of *A. oryzae.* (Courtesy of Kikkoman Co., Tokyo, Japan.)

Saccharomyces rouxii (*Zygosaccharomyces soyae* and *Z. major*), which are naturally present and grow in the mixture (moromi). Once *P. soyae* grows and acidifies the moromi to a pH of below 5.0, the growth of *S. rouxii* is stimulated (42).

After fermentation, the moromi is filtered under high pressure, and the filtrate is heated to 80°C (called hi-ire). According to the heat treatment, the filtrate is pasteurized, and various enzymes are inactivated so that the flavor is enhanced. The final product is usually filled into PET bottles (Fig. 18).

C. Quality Aspect of Shoyu

The composition of koikuchi-shoyu is shown in Table 6. The enzymes of *A. oryzae* and other microorganisms act upon the components of cereal and soybeans, just as in miso fermentation, for the synthesis of nutritional components and flavor attributes to the desired level of intensity.

Good quality shoyu contains 1.5–1.8% (g/100 mL) total nitrogen, of which 40–50% is lower peptides and peptones, and 40–50% amino acids, of which approximately 20% is glutamic acid. It contains 2–5% reducing sugar, 60% of which is glucose; 1–2% v/v alcohol, 1–2% organic acids (60–80% of which is lactic acid); 18% v/v (15% w/w) sodium chloride; and a pH of 4.6–4.9 (38,44).

The well-balanced mixture of each flavor component such as salt, amino acids, organic acids, alcohols, esters, carbonyl compounds, phenols, etc. contributes to the palatable, meatlike flavor of shoyu. Shoyu flavor components number over 300 kinds, and 4-ethyl-guaiacol is listed to give a most characteristic flavor of shoyu (45).

The color of shoyu is mainly due to the browning reactions between amino acids and reducing sugars. These browning reaction products are also important for the shoyu flavor (39).

A. oryzae has been shown to be a nonaflatoxin producer by many researchers (36, 46–50). Other mycotoxins such as aspergillic acid, kojic acid, β-nitro-propionic acid, oxalic acid, and formic acid were also checked at detection levels of 3.5 ppb, and the results indicated that it is safe (36).

The bactericidal activity in shoyu was attributed to its acidity, high osmotic pressure, and some chemical components (51).

Melanoidine, which is the product of browning reaction, acts as an antioxidant. Shoyu was shown to lower blood pressure level and to reduce the damage from radioactive substances, such as cobalt-60, and to inhibit carcinogen-induced forestomach neoplasia in the experiment of animals (52,53).

Figure 18 Koikuchi-shoyu and PET bottle.

D. Future Outlook

Shoyu has played an important role in various Japanese cuisines, including such daily dishes as simmered vegetables, beans, and yams, as well as other foods, such as pickles. It is often referred to as an all-purpose fermented seasoning, as it incorporates the five basic tastes of sweetness, saltiness, sourness, bitterness, and umami (41).

Table 6 Composition of Koikuchi-Shoyu (%)

Food	Moisture	Protein	Fat	Carbohydrate	Ash	Salt
Koikuchi-shoyu	67.1	7.7	0	10.1	15.1	14.5

Source: Ref. 43.

The various aromas and the spiciness of shoyu give an international appeal to it, and shoyu is now used in a wide variety of dishes such as pizza, teriyaki chicken and salmon, steak with shoyu-based sauce, salad dressing, and meatloaf. Shoyu has the potential for use in more different forms of cooking all over the world.

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16
Frozen Vegetables: Product Descriptions

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I. INTRODUCTION

This book is not the proper forum for discussing the manufacture of every processed vegetable available in the market. However, regulatory agencies such the U.S. Department of Agriculture (USDA) and the U.S. Food and Drug Administration (FDA) have issued some minimal criteria for each processed vegetable such as what they are, what types and styles are available, and so on. The information in this chapter describes each available frozen vegetable product and has been modified from the product grades (USDA) and product standards (FDA). Product standards and product grades are established to achieve two objectives: to assure product safety and to minimize economic fraud.

The information provided here has one major objective: to remind a commercial processor of what each frozen vegetable is and of other applicable criteria for a particular product.

II. FROZEN ASPARAGUS

Frozen asparagus consists of sound and succulent fresh shoots of the asparagus plant (*Asparagus officinalis*). The product is prepared by sorting, trimming, washing, and blanching as necessary to assure a clean and wholesome product. It is then frozen and stored at temperatures necessary for preservation.

A. Types

1. Green or all-green consists of units of frozen asparagus that are typically green, light-green, or purplish-green in color.
2. Green-white consists of frozen asparagus spears and tips that have typical green, light-green, or purplish-green color to some extent but which are white in the lower portions of the stalk.

B. Styles

Spears or stalks style consists of units composed of the head and adjoining portion of the shoot that are 3 inches or more in length. Tips style consists of units composed of the head and adjoining

portion of the shoot that are less than 3 inches in length. Center cuts or cuts style consists of portions of shoots (with or without head material) that are cut transversely into units not less than one-half inch in length and that fail to meet the definition for cut spears or cuts and tips style.

Cut spears or cuts and tips style consists of the head and portions of the shoot cut transversely into units 2 inches or less but not less than one-half inch in length. To be considered this style, head material should be present in these amounts for the respective lengths of cuts:

1. $1\frac{1}{4}$ inches or less. Not less than 18 percent (average), by count, of all cuts are head material.
2. Longer than $1\frac{1}{4}$ inches. Not less than 25 percent (average), by count, of all cuts are head material.

II. FROZEN LIMA BEANS

Frozen lima beans are the frozen product prepared from the clean, sound, succulent seed of the lima bean plant without soaking, by shelling, washing, blanching, and properly draining. They are then frozen in accordance with good commercial practice and maintained at temperatures necessary for the preservation of the product.

A. Types

1. Thin-seeded such as Henderson, Bush, and Thorogreen varieties.
2. Thick-seeded Baby Potato such as Baby Potato, Baby Fordhook, and Evergreen. Thick-seeded, such as Fordhook variety.

IV. FROZEN BEANS, SPECKLED BUTTER (LIMA)

Frozen speckled butter (lima) beans are the frozen product prepared from the clean, sound, freshly-vined (but not seed-dry) seed of the speckled butter (lima) bean plant (*Phaseolus limensis*). The skins of the seed are pigmented, and the external colors range from a variegated speckling of green, pink, red, and/or lavender to purple. The product is prepared by shelling the pods; by washing, blanching, and properly draining the seeds that have been sorted and blended or otherwise prepared in accordance with good commercial practice. They are frozen in accordance with good commercial practice and maintained at temperatures necessary for the preservation of the product.

V. FROZEN BROCCOLI

Frozen broccoli is the product prepared from the fresh, clean, sound stalks or shoots of the broccoli plant [*Brassica oleracea* (Italica group)] by trimming, washing, blanching, sorting, and properly draining. The product is frozen in accordance with good commercial practice and maintained at temperatures necessary for its preservation.

A. Styles

1. Spears or stalks are the head and adjoining portions of the stem, with or without attached leaves, which may range in length from 9 cm (3.5 in.) to 15 cm (5.9 in.). The spears or stalks may be cut longitudinally.
2. Short spears or florets are the head and adjoining portions of the stem, with or without attached leaves, which may range in length from 2.5 cm (1 in.) to 9 cm (3.5 in.). Each short spear or floret must weigh more than 6 g (0.2 oz). The short spears or florets may be cut longitudinally.
3. Cut spears or short spears are cut into portions that may range in length from 2 cm (0.8 in.) to 5 cm (2 in.). Head material should be at least 62.5 g (2.2 oz) per 250 g (8.8 oz), and leaf material should not be more than 62.5 g (2.2 oz) per 250 g (8.8 oz).
4. Chopped spears or short spears are cut into portions that are less than 2 cm (0.8 in.) in length. Head material should be at least 12.5 g (0.4 oz) per 50 g (1.8 oz), and leaf material should not be more than 12.5 g (0.4 oz) per 50 g (1.8 oz).
5. Pieces or random cut pieces are cut or chopped portions of spears or short spears or other units that do not meet the requirements for cut or chopped styles.

VI. FROZEN BRUSSELS SPROUTS

Frozen brussels sprouts are the frozen product prepared from the clean, sound succulent heads of the brussels sprouts plant (*Brassica oleracea* L. var. gemmifera) by trimming, washing, blanching, and properly draining. The product is frozen in accordance with good commercial practice and maintained at temperatures necessary for its preservation.

VII. FROZEN CARROTS

Frozen carrots are the clean and sound product prepared from the fresh root of the carrot plant (*Daucus carota*) by washing, sorting, peeling, trimming, and blanching; they are frozen in accordance with good commercial practice and maintained at temperatures necessary for the preservation of the product.

A. Styles

Wholes (or whole carrots) retain the approximate form of a whole carrot.

Halves or halved carrots are cut longitudinally into two units.

Quarters or quartered carrots are cut longitudinally into four approximately equal units. Carrots cut longitudinally or cut longitudinally and crosswise into six or eight units approximating the size and appearance of quartered carrots are also permitted in this style.

Slices or sliced carrots are sliced transversely to the longitudinal axis.

Diced carrots consist of approximately cube-shaped units.

Double-diced carrots consist of approximately rectangular shapes that resemble the equivalent of two cube-shaped units.

Strips are carrots that consist of approximate French-cut shapes, with flat-parallel or corrugated-parallel surfaces, one-half inch or more in length.

Chips are carrots that consist of predominantely small-sized units (such as less than one-half cube) and variously shaped pieces or slivers in which the longest-edge dimension approximates not more than one-half inch.

Cut carrots consist of cut units that do not conform to any of the forgoing styles.

VIII. FROZEN CAULIFLOWER

Frozen cauliflower is prepared from fresh flower heads of the cauliflower plant (*Brassica oleracea botrytis*) by trimming, washing, and blanching and is frozen and maintained at temperatures necessary for preservation of the product.

A. Styles and Requirements

1. Clusters are individual segments of trimmed and cored cauliflower heads, which measure not less than 20 mm (0.75 in.) in the greatest dimension across the top of the unit. A maximum of 10% by weight of clusters less than 20 mm (0.75 in.) in the greatest dimension across the top of the unit are allowed.
2. Nuggets or Small Clusters are individual segments of trimmed and cored cauliflower heads, which measure from 6 mm (0.25 in.) to less than 20 mm (0.75 in.) in the greatest dimension across the top of the unit. A maximum of 20% by weight of clusters, 20 mm (0.75 in.) or greater, and a maximum of 10% by weight of clusters less than 6 mm in the greatest dimension across the top of the unit are allowed.

IX. FROZEN CORN ON THE COB

Frozen corn on the cob is the product prepared from sound, properly matured, fresh, sweet corn ears by removing husk and silk and by sorting, trimming, and washing to assure a clean and wholesome product. The ears are blanched and then frozen and stored at temperatures necessary for the preservation of the product.

A. Styles

1. Trimmed. Ears trimmed at both ends to remove tip and stalk ends and/or cut to specific lengths.
2. Natural. Ears trimmed at the stalk end only to remove all or most of the stalk.

B. Lengths

1. Regular. Ears that are predominantly over $3\frac{1}{2}$ inches in length.
2. Ears which are predominantly $3\frac{1}{2}$ inches or less in length.

Colors of frozen corn on the cob: Golden (or yellow); white.

X. FROZEN LEAFY GREENS

Frozen leafy greens are the frozen product prepared from the clean, sound, succulent leaves and stems of any one of the plants listed below by sorting, trimming, washing, blanching, and properly draining. The product is processed by freezing and maintained at temperatures necessary for its preservation. Any functional, optional ingredient(s) permissible under the law may be used to acidify and/or season the product.

A. Types

Beet greens
Collards
Dandelion greens
Endive
Kale
Mustard greens
Spinach
Swiss chard
Turnip greens
Any other "market accepted" leafy green

B. Styles

1. Leaf consists substantially of the leaf, cut or uncut, with or without adjoining portion of the stem.
2. Chopped consists of the leaf with or without adjoining portion of the stem that has been cut into small pieces less than approximately 20 mm (0.78 in.) in the longest dimension but not comminuted to a pulp or a puree.
3. Pureed consists of the leaf with or without an adjoining portion of the stem that has been comminuted to a pulp or a puree.

XI. FROZEN OKRA

Frozen okra is the product prepared from the clean, sound, succulent, and edible fresh pods of the okra plant (*Hibiscus esculentus*) of the green variety. The product may or may not be trimmed, is properly prepared and properly processed, and is then frozen and stored at temperatures necessary for preservation.

A. Styles

1. Whole okra consists of trimmed or untrimmed whole pods of any length that may possess an edible portion of the cap. The length of a whole pod is determined by measuring from the outermost point of the tip end of the pod to the outermost point of the stem end of the pod, exclusive of any inedible stem portion that may be present.
2. Cut okra is trimmed or untrimmed whole pods, which may possess an edible portion of cap, and which have been cut transversely into pieces of approximately uniform length. The length of a unit of cut okra is determined by measuring the longitudinal axis of the unit.

XII. FROZEN ONION RINGS, BREADED, RAW OR COOKED

Frozen breaded onion rings, hereinafter referred to as frozen onion rings, is the product prepared from clean and sound, fresh onion bulbs (*Allium cepa*) from which the root bases, tops, and outer skin have been removed. The onion bulbs are sliced and separated into rings, coated with batter (or breaded), and may or may not be deep fried in a suitable fat or oil bath. The product is prepared and frozen in accordance with good commercial practice and maintained at temperatures necessary for the proper preservation of the product.

A. Types

The type of frozen onion rings applies to the method of preparation of the product, and includes

1. French fried onion rings that have been deep fried in a suitable fat or oil bath prior to freezing.
2. Raw breaded onion rings that have not been oil blanched or cooked prior to freezing.

XIII. FROZEN PEAS

Frozen peas is the food in "package" form, prepared from the succulent seed of the pea plant of the species *Pisum sativum* L. Any suitable variety of pea may be used. It is blanched, drained, and preserved by freezing in such a way that the range of temperature of maximum crystallization is passed quickly. The freezing process should not be regarded as complete until the product temperature has reached −18°C (0°F) or lower at the thermal center, after thermal stabilization. Such food may contain one, or any combination of two or more, of the following safe and suitable optional ingredients.

For more details see

1. Chapter 20 on frozen peas: standard and grade
2. Appendix B

XIV. FROZEN PEAS, FIELD AND BLACK-EYED

Frozen field peas and frozen black-eyed peas, hereafter referred to as frozen peas, are the frozen product prepared from clean, sound, fresh seed of proper maturity of the field pea plant (*Vigna sinensis*), by shelling, sorting, washing, blanching, and properly draining. The product is frozen and maintained at temperatures necessary for preservation. Frozen peas may contain succulent, unshelled pods (snaps) of the field pea plant or small-sieve round-type succulent pods of the green bean plant as an optional ingredient used as a garnish.

For more details see

1. Chapter on frozen peas: standard and grade
2. Appendix B

XV. FROZEN PEPPERS, SWEET

Frozen sweet peppers are the frozen product prepared from fresh, clean, sound, firm pods of the common commercial varieties of sweet peppers, which have been properly prepared, may or may not be blanched, and are then frozen in accordance with good commercial practice and maintained at temperatures necessary for the preservation of the product.

A. Types

Type I, green; Type II, red; Type III, mixed (green and red)

B. Styles

1. Whole stemmed: whole unpeeled pepper pods with stem and core removed
2. Whole unstemmed: whole unpeeled pepper pods with stems trimmed to not more than 1/2 inch length
3. Halved: whole stemmed, unpeeled pepper pods that have been cut approximately in half from stem to blossom end
4. Sliced: whole stemmed, unpeeled pepper pods or pieces of pepper pods that have been cut into strips
5. Diced: whole stemmed, unpeeled pepper pods or pieces of pepper pods that have been cut into approximately square pieces measuring 1/2 inch or less
6. Unit: a whole unpeeled pepper pod or portion of a pepper pod in frozen sweet peppers

XVI. FROZEN POTATOES, FRENCH FRIED

Frozen French fried potatoes are prepared from mature, sound, white or Irish potatoes (*Solanum tuberosum*). The potatoes are washed, sorted, and trimmed as necessary to assure a clean and wholesome product. The potatoes may or may not be cut into pieces. The potatoes are processed in accordance with good commercial practice which includes deep frying or blanching in a suitable fat or oil and which may include the addition of any ingredient permissible under the law. The prepared product is frozen and is stored at temperatures necessary for its preservation.

A. Types

Frozen French fried potatoes are of two types, based principally on intended use, as follows:

1. Retail type. This type is intended for household consumption. It is normally packed in small packages that are labeled or marked for retail sales. It may be otherwise designated for such use.
2. Institutional type. This type is intended for the hotel, restaurant, or other large feeding establishment trade. Primary containers, usually 5 pounds or more, are often not as completely labeled as for retail sales.

B. Styles

They are grouped under: general, strips, slices, dices, Rissolé.

1. General

The style of frozen French fried potatoes is identified by the general size, shape, or other physical characteristics of the potato units. Styles with cut units may be further identified by substyles as follows:

1. Straight cut refers to smooth cut surfaces.
2. Crinkle cut refers to corrugated cut surfaces.

2. Strips

This style consists of elongated pieces of potato with practically parallel sides and of any cross-sectional shape. This style may be further identified by the approximate dimensions of the cross-section, for example:

$1/4 \times 1/4$ inch
$3/8 \times 3/8$ inch
$1/2 \times 1/4$ inch
$3/8 \times 3/8$ inch

Shoestring refers to a strip, either straight cut or crinkle cut, with a cross-section predominantly less than that of a square measuring $3/8 \times 3/8$ inch.

3. Slices

This style consists of pieces of potato with two practically parallel sides, and which otherwise conform generally to the shape of the potato. This style may also contain a normal amount of outside slices.

4. Dices

This style consists of pieces of potato cut into approximate cubes.

5. Rissolé

This style consists of whole or nearly whole potatoes.

Any other individually frozen French fried potato product may be designated as to style by a description of the size, shape, or other characteristic that differentiates it from the other styles.

C. Length Designations

1. General

The length designations described in this section apply to strip styles only.

2. Criteria for Length Designations of a Sample Unit

Frozen French fried potato strips are designated as to length in accordance with the following criteria. Percent, as used in this section, means the percentage, by count, of all strips of potato that are $1/2$ inch in length or longer.

1. Extra long. Eighty (80) percent or more are 2 inches in length or longer; and 30 percent or more are 3 inches in length or longer.

2. Long. Seventy (70) percent or more are 2 inches in length or longer; and 15 percent or more are 3 inches in length or longer.
3. Medium. Fifty (50) percent or more are 2 inches in length or longer.
4. Short. Less than 50 percent are 2 inches in length or longer.

XVII. FROZEN POTATO, HASH BROWNED

Frozen hash browned potatoes are prepared from mature, sound, white or Irish potatoes (*Solanum tuberosum*) that are washed, peeled, sorted, and trimmed to assure a clean and wholesome product. The potatoes so prepared are blanched, may or may not be fried, and are shredded or diced or chopped and frozen and stored at temperatures necessary for their preservation.

A. Styles

1. Shredded. Shredded potatoes are cut into thin strips with cross-sectional dimensions from 1 mm by 2 mm to 4 mm by 6 mm and formed into a solid mass before freezing.
2. Diced. Diced potatoes are cut into an approximately cube shape from 6 mm to 15 mm on an edge and loose frozen. They contain not more than 90 grams, per sample unit, of units smaller than one-half the volume of the predominant size unit.
3. Chopped. Chopped potatoes are random cut pieces predominantly less than 32 mm in their greatest dimension and loose frozen.

XVIII. FROZEN VEGETABLES, MIXED

Frozen mixed vegetables consist of three or more succulent vegetables, properly prepared and properly blanched; may contain vegetables (such as small pieces of sweet red peppers or sweet green peppers) added as garnish; and are frozen and maintained at temperatures necessary for the preservation of the product.

A. Kinds and Styles of Basic Vegetables

It is recommended that frozen mixed vegetables, other than small pieces of vegetables added as garnish, consist of the following kinds and styles of vegetables as basic vegetables:

1. Beans, green or wax: cut styles, predominantly of 1/2 inch to $1\frac{1}{2}$ inch cuts
2. Beans, lima: any single varietal type
3. Carrots: diced style, predominantly of 3/8 inch to 1/2 inch cubes
4. Corn, sweet: golden (or yellow) in whole kernel style
5. Peas: early type or sweet type

B. Recommended Proportions of Ingredients

It is recommended that frozen mixed vegetables consist of three, four, or five basic vegetables in the following proportions:

1. Three vegetables. A mixture of three basic vegetables in which any one vegetable is not more than 40 percent by weight of all the frozen mixed vegetables.

2. Four vegetables. A mixture of four basic vegetables in which none of the vegetables is less than 8 percent by weight nor more than 35 percent by weight of all the frozen mixed vegetables.
3. Five vegetables. A mixture of five basic vegetables in which none of the vegetables is less than 8 percent by weight nor more than 30 percent by weight of all the frozen mixed vegetables.

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Quality Control in Frozen Vegetables

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I. INTRODUCTION

Freezing is an effective mean of preservation that maintains the quality of foods almost to fresh product. Although freezing is one of the easiest and least time-consuming methods, it is not as economical as canning; but it retains more nutrients in the food if properly done. Most vegetables retain their natural color, flavor, and texture better when frozen than if other methods of food preservation are used. Natural enzymes in foods cause changes in the above parameters, and freezing delays this activity, though it does not stop it. Thus, to prevent further enzyme activity, vegetables need to be blanched in boiling water or steamed for a brief period of time before freezing. However, nutrient loss occurs during blanching, and these losses are greater than those from enzymatic activity if vegetables are not blanched. An alternative method is the addition of antioxidants, such as ascorbic acid. Freezing does not destroy spoilage organisms, such as bacteria, molds, and yeasts; it merely retards their growth temporarily. Once the food is thawed, microorganisms may continue to grow. On the other hand, the blanching process can destroy several microorganisms, especially the mesophiles. During the storage of frozen vegetables, moisture evaporation can render them dry and tough, with the development of off-flavors. To solve this problem, two options are available: provide high relative humidity throughout the storage period; and/or use moisture vapor-proof or resistant packaging.

Although freezing has the disadvantage of the initial investment for equipment for the food industry, the beneficial effects of the use of frozen vegetables in terms of their quality attributes will be higher. This chapter focuses on the physical, structural, nutritional, and sensorial changes during the freezing and frozen storage processes.

II. IMPORTANCE OF FROZEN VEGETABLES IN THE FOOD INDUSTRY

Among the "mild" or "new" technologies of minimal processing in foods, industrial freezing is undoubtedly the most satisfactory method of preserving quality during longer storage periods (1). Vegetables were found to be more palatable and have better color when frozen than when canned, while dehydrated vegetables were shown to be as good or better than the canned. In terms of energy use, cost, and product quality, freezing requires the shortest processing time. Although

more energy is required to process and store vegetables by freezing than by canning or dehydration, the overall cost, including packaging and cost of equipment, for preservation by freezing can be kept as low or lower than the cost for other methods of preservation.

The depletion of the ozone layer in the atmosphere caused by the use of chlorofluorocarbons is a leading concern for the global environment. This, together with high cost and high energy consumption, opens new challenges to the scientists and engineers of food freezing equipment, in terms of improved finished product quality, reduced processing costs, improved safety and environmental factors, and most importantly, consumer acceptance.

In order to achieve the desired freezing results, many factors are involved in the freezing process that determine final product quality, such as freezing methods, product ice crystallization, freezer burn, freezing rate, packaging, and moisture losses (2).

As nearly as Quick Frozen Foods International can determine, frozen food consumption in 13 European countries reached 11.1 million tons in the year 2000. Total retail sales of frozen foods in the U.S. reached more than $25 billion in 1999, up over one billion dollars from 1998 (USDA-NAAS Agricultural Statistics 1999). In 1999, manufacturers' food service sales of frozen foods in the U.S. totaled $40.6 billion. Thus the consumption of frozen vegetables has increased by 20% during the last 20 years (3).

III. PROCESSING OF FROZEN VEGETABLES

The freezing process is dependent on the freezing rate, the heat transfer coefficient, and the amount of heat removed from the food product. The freezing process time depends on the freezing rate, the amount of heat removed, the packaging and freezing methods used, the initial and final temperature desired, the thickness, and the food ingredients. The International Institute of Refrigeration (IIF) defines the freezing rate as the difference between the initial and final temperature of the product divided by the freezing time (4). The amount of heat to be removed and the cooling rate depend on the food structure and chemical composition. The freezing systems used affect ice crystal formation; large ice crystals induce product damage, which could be reduced with increased freezing rate. Several numerical mathematical models have been reported that consider assumptions including the irregular shape, the chemical composition, the heat transfer coefficient, and the type of freezing media used (5,6). Industries generally accept the target temperature of $-18^{\circ}C$ ($0^{\circ}F$) at the thermal center of the product for an efficient freezing process.

Several operations are needed during freezing that vary with the types of vegetables and the methods used, but general preparation procedures are summarized in Fig. 1, including postharvest preparation, blanching, freezing, and storage. Woodroof (7) reported general guidelines for harvesting, handling, and storing vegetables before commercial processing. To get an optimum quality after thawing, proper selection and control of raw material, cultivar, and maturity stage are very important factors. Thus vegetables should be harvested when they reach the peak of quality. During processing, vegetables should be handled promptly to avoid mechanical damage. During sorting and grading, insect-infected vegetables are removed, and during washing, dust, dirt, and insects are removed as well. In several cases, additional operations are needed, such as peeling, trimming, and cutting.

The most important step for enzyme inactivation is blanching. These enzymes cause the formation of off-flavors and discoloration during storage at freezing temperatures. An additional effect of blanching is the reduction of the number of microorganisms. There are several tests that can be used to assure that the blanching process has been adequately performed, the most

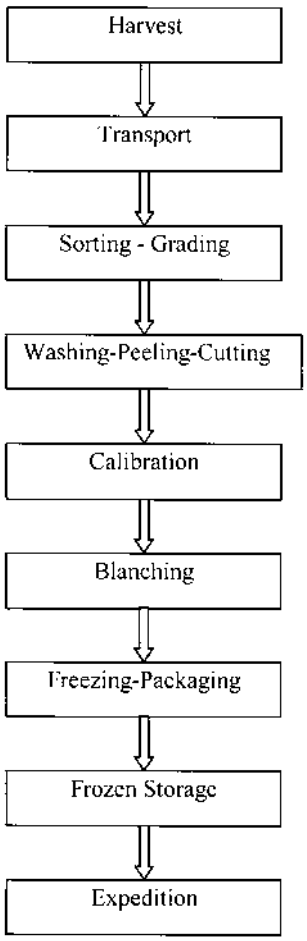

Figure 1 General flow diagram for processing of frozen vegetables.

commonly used being peroxidase, catalase, lipoxygenase, and polyphenoloxidase. A high correlation has been established between development of off-flavors during freezing storage and remaining peroxidase and lipoxygenase activities, suggesting the imperative use of blanching to inactivate these enzymes in frozen vegetables for a better final quality (8). However, there are some reports that several vegetables, such as tomatoes, green peppers, celery, and mushrooms, can be frozen for up to 12 months at $-18^{\circ}C$ without previous blanching and with no quality deterioration (9,10).

Classically, the peroxidase level activity has been used to monitor quality changes in frozen vegetables, since increases in peroxidase are thought to indicate changes in flavor, color, and texture in vegetables. Thus measurement of peroxidase is often performed prior to blanching as a reference for determining the effectiveness of the blanching process (11), for which a 95% loss of enzyme activity following blanching is considered adequate (9). Still, several studies have established that residual lipoxygenase activity was closely related to off-flavor of leguminous vegetables (12,13), while residual peroxidase activity has little effect on quality of frozen

vegetables (14,15). Increased peroxidase activity during frozen storage was found in peas blanched at 93–100°C for 1 min (16). Recently, it has been shown that although changes in total peroxidase activity may not predict flavor changes, the presence or absence of certain peroxidase isozymes may be useful in predicting off-flavor development in specific frozen corn genotypes (17).

There are a large number of published reports that reveal that the freezing rate is a key factor that preserves food products when physicochemical changes are studied. Quick freezing can be achieved by increasing temperature gradient between freezing media and food. Thus conventional mechanical freezing methods, such as forced air, are considered slower than liquefied gases such as nitrogen or carbon dioxide, which have low boiling points and freeze faster. These gases are commonly called "cryogenic gases," since their temperature range is cryogenic and the process is called cryogenic freezing. This type of freezing improves product quality and offers many advantages over mechanical freezing. It benefits include reduction in freezing time (extremely fast), reduction in moisture and flavor losses, reduction in ice crystal formation, minimum product cell damage, and high heat transfer. It is also a flexible and versatile system.

IV. PHYSICAL, STRUCTURAL, NUTRITIONAL, AND SENSORIAL CHANGES DURING FREEZING OF VEGETABLES

Processing operations destroy the cytoplasmatic structure, producing loss of turgor, weakness of cell wall, and some degree of cell separation. These changes have important effects on the texture of the vegetable, which is one of the most important quality factors of frozen vegetables from the consumer point of view. Quality frozen vegetables are directly correlated to pectin substances, firmness, texture, and histological structures.

The freezing temperature is the most critical factor affecting the cell structure in vegetables such as carrots (18). The blanched carrots reduced only 21% of their initial firmness, while in the raw samples this decrease was about 50%, the effect being due to the formation of a gel from the interaction between heat and pectic substances. In turn, a reduction in pectin extraction was observed (19). These results would confirm that damages occur in the middle lamella of the cells, the main damage being due to freezing rather than blanching. On the histological level, frozen raw samples showed physical changes, such as cell walls irregular in shape and separation among the cell layers, which were explained by the ice crystal effect. Contrarily, the cells of the blanched samples did not show tissue disruption.

As previously reported, freezing is an effective method of preservation, but comprehensive studies on physicochemical changes of foods during freezing and frozen storage have revealed that the freezing rate influences the quality of frozen and thawed vegetables. Thus cryogenic freezing could cause internal stress buildup leading to cracking or shattering that is critical and reversible in frozen materials (20). This mechanical damage is mainly due to both contraction and expansion of the volumetric changes associated with the water–ice transition (21). Physical properties, such as porosity and density, may also be affected by an ultrahigh freezing rate. Porosity indicates the amount of void space inside the vegetable, and a larger void space increases the possibility of internal stress. Density is usually proportional to the moisture content and inversely proportional to porosity; thus the greater the density, the higher the probabilities that stress will occur.

Water makes up over 90% of the weight of most produce and is held within the cell walls to give support, structure, and texture to the vegetable. Actually, the freezing of vegetables consists of freezing the water contained in the plant cell. When the water freezes, it expands, and the ice crystals cause the cell walls to rupture. Freezing as quickly as possible can control the structural

changes (cell wall disruption, internal stress, cracking, etc.). In rapid freezing, a large number of small ice crystal are formed, and less cell wall rupture can be expected by comparison with the formation of large ice crystals.

The size of the ice crystals affecting cell walls is related to the final quality after thawing. When a product is thawed, it is much softer than the raw product before frozen storage. The most typical example is tomato, which after being frozen and thawed turns liquid. The same can be concluded for celery and lettuce, which are not usually frozen. Textural changes due to freezing are not as apparent in products that are cooked before eating, since cooking also softens cell walls.

In frozen peppers, the maximum firmness was attributed to the activity of pectin-methylesterase (PME). Peppers blanched at 69°C showed increases in firmness, since PME was activated, generating free carboxylic acid groups that could cross-link with divalent cations. On the other hand, peppers blanched at 96°C showed inactivation of PME (22). Thus, for better texture attributes of this commodity, a decrease in temperature and an increase in time should be taken into account. In this sense, the use of calcium in combination with a low-temperature blanch is usually performed to maintain firmness during vegetable processing (23), through stimulation of the PME present in the cell walls by low-temperature blanching (24). The effects of this pretreatment on vegetables have been reported for canning (25), drying (26), and freezing (27).

The health benefits of vegetables are well recognized by nutritionists, but usually intakes are below recommendations. There are published reports linking fruit and vegetable intakes with a reduced risk of chronic diseases, such as cardiovascular disease and cancer (28). Among the nutrients, vitamins are essentials for human nutrition, and those acting as antioxidants deserve special attention. Vitamins C, Vitamin A, and its precursor β-carotene are considered the main agents responsible for the protective effects because of their antioxidant and antiradical properties. Vegetables are estimated to provide 30% of the vitamin C and 20% of the vitamin A (as carotenes). The expansion of the frozen food industry has meant that most food that can be frozen is available for consumption throughout the year. This is especially important for vegetables that are dense in the essential nutrients such as vitamins. Obviously, we must give consideration to the fact that the vitamin C content varies according to other factors such as cultivation, processing, and storage conditions. Since vitamin C has a high solubility in water and a high sensitivity to heat, its content gives a good indicator of the quality and freshness of the frozen product (29). Since vitamin C is vulnerable to chemical and enzymatic oxidation, it is an appropriate marker for monitoring quality change during transportation, processing, and storage (30). During the freezing process, water-soluble substances are lost, especially during blanching (31). Thus in broccoli half of the vitamin C was lost after a blanching time of 60 s (?) before freezing in a fluid bed tunnel (32). Similarly, in fiddlehead greens, losses of vitamin C ranged from 30 to 38% as a result of freezing (33), and losses were also attributed to the blanching process. However, losses of vitamin C during the canning process are much higher (47–57%), since vitamin loss is partly dependent upon heating time and temperature.

In a comparative study of the vitamin C content of fresh and frozen vegetables (peas, beans, broccoli, carrots, and spinach), the author concluded that the vitamin C level in the commercial quick-frozen product is equal to or better than that in the fresh produce market and much better than that in the supermarket stored at fresh or ambient temperature. Also, the loss of ascorbic acid from all these vegetables is most probably dominated by enzyme-induced oxidation. The variation in the rate of loss demonstrates the differing vulnerabilities of the different vegetables, such as surface area and mechanical damage, and their differing enzyme activities (30).

Carotenes are precursors of vitamin A, which is considered an essential nutrient for maintaining human health, but carotenes are susceptible to oxidation. The degradation of carotenes is associated with the development of off-flavors (34). Steam blanching is thought to result in little or no loss in β-carotene content (35). Similarly, the carotene retention was relatively

high in frozen fiddlehead, since provitamin compounds are not very water-soluble (33). In a comparative study of carotene retention in carrots, broccoli, and spinach, the mean carotene content of the three vegetables decreased with time after thawing, but no differences were found for extended thawing time (36). This author also concludes that frozen and thawed vegetables exposed to home environmental conditions for 4 hours before cooking may not lose much carotene, whereas dehydration of vegetables may adversely affect carotene content.

V. CHANGES DURING STORAGE OF FROZEN VEGETABLES

Most vegetables will maintain high quality for 12 to 18 months at $-18^{\circ}C$. However, it is well known that during frozen storage the number of ice crystals will be reduced, while their size will increase. These changes are affected by fluctuations in storage temperature, which in turn can cause the migration of water vapor from the product to the surface of the container. The increase of ice crystals during prolonged frozen storage induces drip loss. Also, physical and chemical changes can be expected, which were recently summarized (37). Since at frozen storage temperatures, no microorganism proliferation can be expected, the loss of quality is mainly due to physical, chemical, and sensorial changes of higher magnitude than those detected during the freezing process.

The main physical changes of vegetable products during frozen storage are due to recrystallization and sublimation phenomena related to the ice crystals' stabilization inside the product and on the outside surface. Both phenomena are thought to be controlled by temperature. The recrystallization rate decreases at low temperatures, with no ice crystal growth at lower temperatures than $-20^{\circ}C$. The ice sublimation occurs in unwrapped vegetable products during temperature fluctuations during frozen storage, which causes product dehydration and accelerates the oxidative changes on the product surface area (38).

With respect to chemical changes, these are a consequence of the residual enzymatic action that produces loss of nutrients and color, and the occurrence of off-flavors. In terms of loss of nutrients, only small changes in carbohydrates may occur during frozen storage, as biochemical processes are delayed at freezing temperatures, but a reduction in water-soluble carbohydrates may occur as a result of water loss during thawing. In several vegetables, such as fiddlehead greens (33) and sweet potatoes (39), the nutritional parameters did not change throughout frozen storage. Minerals (Ca, K, Mg, and P) remained unchanged during 10 months of frozen storage, while sugars (fructose, glucose, and sucrose) showed increases during 9 months of storage, mainly due to starch being converted to sugars by reactivation of the enzymes involved.

Several vegetables, such as spinach, contain high concentrations of galactolipids and phospholipids among their fat-soluble components, which are used as substrates for lipid-acyl hydrolases such as galactolipases and phospholipases. The highly active thermal stability of these enzymes should be taken into account and the enzymes used as indicator enzymes for determining the quality deterioration during frozen storage (40). In this vegetable, after 10 months of frozen storage 80% of the total folacin activity was retained with proper blanching and freezing processes (41).

The main factor determining the shelf life of frozen vegetables in prolonged storage is effective blanching, but several vegetables do not need blanching for optimum quality, as has been reported before. Unblanched vegetables, such as onions and leeks, were more acceptable after 15 months of storage than blanched samples (10), the lower quality being due mainly to loss of volatile oils during the blanching process.

In terms of the acceptability of vegetables, one of the most important quality factors is texture. Texture has even been associated as a criterion for the selection of raw materials. During

frozen storage of asparagus an increase of the maximum force during cutting is produced, mainly owing to increased fiber content that affects the fibrous attributes by a lignification process either enzymatically or otherwise (42). The enzymatic lignification has been attributed to residual peroxidase activity after blanching at the basal and medium zones of the asparagus, but not in the apical ones. During the freezing (with Freon-12 immersion) and frozen storage of peas, changes in texture properties have been reported. Thus freezing at a higher rate resulted in smaller ice crystals and less structural damage. In terms of chewiness, increased values during storage were observed due to the dehydration effects (43). Moisture loss by evaporation of water on the surface area of a product produces freezer burn, a grainy brownish spot where the tissues become dry and tough. This surface freeze-dried area is very likely to develop off flavors. Moisture-proof wrap is used to prevent freezer burn.

In a recent study of carrots (44), pronounced differences in textural quality were found between the freezing method and frozen storage. Thus decreasing the temperature from $-30^{\circ}C$ to $-70^{\circ}C$ resulted in increasing maximum firmness, with no differences after 1 and 5 months of frozen storage.

With respect to color, frozen vegetables show alterations in natural pigments, such as chlorophyll, anthocyanins, and carotenoids, or enzymatic browning. Chlorophylls *a* and *b* have been shown to be the main compounds responsible for the green color of vegetables (45). Degradation of chlorophylls has been studied because their bright green color is usually more pleasing to the consumer than the brownish color of pheophytin *a* and *b*, which is a chemical conversion (46). Since chlorophyll in green tissues may depend on the nature of its association with lipoproteins of the chloroplast, the lipid peroxidation, as a consequence of being frozen, will be increased by the lipoxygenase action (47). Thus chlorophylls *a* and *b* were slightly degraded (about 16%) in frozen spinach, but small amounts of pheophytins *a* and *b* were detected, because the spinach had been blanched.

Anthocyanins are hydrosoluble pigments responsible for the red color of some vegetables. Under several conditions, they may be destroyed as a consequence of polyphenol enzymatic oxidation. The final result of this oxidation is the occurrence of enzymatic browning in frozen vegetables such as cauliflower, potato, and mushroom. This reaction is catalyzed by the enzyme polyphenoloxidase in the presence of oxygen and the production of quinines, which in turn can oxidize other substrates like ascorbic acid and anthocyanins. The most convenient parameter for monitoring enzymatic browning is related to CIE Lab. L*, a*, and b* coordinates represent the color space, in which L* indicates lightness, and a* and b* are the chromaticity coordinates. These parameters are expressed as positive or negative values. In the color space, +a is the red direction and −a is the green direction. Similarly, +b is the yellow direction and −b is the blue direction. In this sense, the enzymatic browning in potatoes has been correlated with decreases in parameter b* (39).

The high or low acceptance of a specific frozen vegetable depends on its sensory attributes. Aroma and flavor together with color and texture are the most important. The lack of flavor and the absence of aroma are mainly due to the action of oxygen in the air on frozen product, producing rancid oxidative flavors. This can be solved with adequate wrapping material that does not permit air to pass into the vegetable, or by removing as much air as possible from the freezer bag or container before freezing.

VI. CONCLUSION

Freezing is a common process for long-term preservation of vegetables and is one of the best methods available in the food industry. Freezing retains the quality of vegetables near their fresh

state, but interest has grown concerning the quality and shelf life of frozen vegetables. Consumption of frozen vegetables has increased by 20% during the last 20 years. However, during frozen storage, physical, chemical, and nutritional changes usually occur. To minimize these effects, blanching has been used traditionally in vegetable processing to slow quality deterioration caused by enzyme activity. Some benefits of blanching prior to freezing are color stability, reduced vitamin losses, texture improvement, and removal of undesirable substances.

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18
Frozen Tomatoes

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I. INTRODUCTION

A. History

The tomato (*Lycopersicon esculentum*) is a member of the Solanaceae family. This family contains a number of plants important as human food, including potatoes, eggplant, and bell peppers. The name *Lycopersicon* derives from the Greek for wolf peach. The plant received its name from Anguillara and Marinello in 1561 (1) who mistakenly thought this name had already been given to the plant by Galen (2). Since Claudius Galen was referring to a plant growing in northern Africa in the second century A.D., 1400 years before the tomato arrived in that half of the world, he could hardly have been referring to the tomato. Another mistake was made when the genus was mistakenly spelled *Lycopersicum*. The misspelling appears to have been started by Hill (3) in 1773 and continued until it was pointed out by Druce (4) in 1914. This misspelling can still be seen in several places in the literature today. The first good description of the various tomato species, including the one commonly eaten today, was made by Miller in 1768 (5), hence texts frequently refer to the species as *L. esculentum* Mill (6).

Evidence points to the tomato originating in Central and South America. Although it is impossible to say for certain, from the large diversity of varieties grown in Mexico, its uses in native cooking, and the abundance of native names for the fruit, it appears that the original domestication took place in Mexico (2). The tomato was introduced into southern Europe soon after the discovery of the New World by Columbus. The Italian herbalist Pier Andrea Mattioli described a pomi d'oro (golden apple) plant bearing a golden fruit in 1544 (6). Ten years later, a second edition mentioned a variety of the plant bearing red fruit. The diagram is clearly the typical tomato we eat today (2). In Britain and the United States the plant was originally used for medicinal and decorative purposes before finally becoming common as a food item in the mid 18th century. In 1893, the U.S. Supreme Court settled the fruit vs. vegetable question by ruling that the tomato was legally a vegetable for reasons of commerce.

B. Biology

The tomato is a perennial plant industrially grown as an annual. Early selective breeding increased the size of the fruit, removed the ruffles, and decreased the seed content. The technique of back crossing varieties with desirable traits into existing varieties is widely used to increase pest and

disease resistance and improve color, viscosity, and solids content. Genetic engineering has been used to improve the species further. Breeders continue to breed for improved yield, color, soluble solids, and machine harvestability (7).

The portion of the tomato that is commonly eaten is the fruit, which is a berry. This fleshy berry consists of a skin over the outer wall and inner radial walls of pericarp containing the locular contents (Fig. 1). The skin is composed of a cuticle over the epidermis. The cuticle contains cuticular acids and waxes which make the fruit resistant to disease and insect attack, but they also make it difficult for processors to peel by steam or lye. Varieties have been bred to peel easily by the incorporation of the easy peel gene, but this is typically linked to worse insect and disease resistance. These varieties are also prone to cracking.

Just underneath the peel is attractive red flesh, rich in lycopene. If the fruit is overpeeled, this area is lost, exposing the less attractive yellowish vascular bundles. The interior locular cavities contain the seeds imbedded in a jellylike parenchyma. If these locular cavities are punctured, the interior will leak out, which is undesirable in whole peeled tomatoes.

C. Growing and Harvesting

The tomato thrives in a wide range of latitudes, soil types, temperatures, and methods of cultivation, though it does best in soil with good drainage (7). Plants may be started as seedlings and planted when they are 1 to 2 months old, or they may be directly seeded in the field (7). Both methods are in commercial practice. It normally takes 4 months from the emergence of the seedling to harvest. In suitable climactic conditions, the growing season for tomatoes can be 300 days a year.

Fruit set is based on the night temperature. The optimum temperature is 59–68°F (15–20°C), and it fails to set at 55°F (13°C) or below (8,9). Fruit set is not sensitive to day length and will occur under day lengths varying from 7 to 19 hours. When there are high levels of nitrogen in the soil, the plant will grow vigorously but not set fruit. The fruit requires 40 to 60 days from flowering to reach full ripeness (7).

The fruit of the tomato is climacteric. Unlike nonclimacteric fruit, the tomato produces ethylene when exposed to low concentrations of ethylene. In response to this gas, respiration increases and ripening occurs suddenly. For this reason, in years when the farmers need to force the field to ripen all at once, they spray their fields with a compound such as Ethrel that causes the tomatoes to produce ethylene.

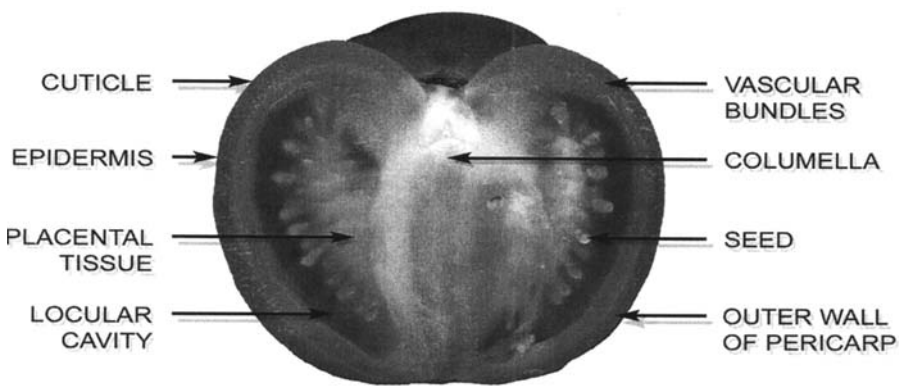

Figure 1 Cross section of a tomato.

Development of machine harvesting in the United States occurred in the 1950s and 1960s (7,10). Mechanical harvesters cut the vines and carry them into the machine. The fruit are shaken off the vines and the vines returned to the field. The fruit falls onto conveyor belts where they are manually sorted to remove green and rotten fruit. The rotten and green fruit are returned to the fields. The advent of mechanical harvesting required a focus on breeding the plants for mechanical harvesting. The two critical factors were that the vines be jointless and that all of the fruit ripen at the same time. With mechanical harvesting, the vines of the older varieties would break off at the joints, leaving a stem on the fruit. Since machine harvesting requires that the entire field be harvested at once, concentrated fruit set and ripening are critical. In the United States, all processed tomatoes are machine harvested.

Characteristics of the tomato fruit must also be suitable for mechanical harvesting. Besides ripening uniformly, they must be able to withstand handling by a mechanical harvester and bulk hauling. Processing tomatoes are usually smaller than for the fresh market, have a high solids content, and possess a firm texture. They are typically roma varieties, which are pear shaped.

D. Production Statistics

The tomato is an important product both for domestic and export markets. The largest producer of tomatoes in the world is China, followed by the United States, Italy, and Turkey (Table 1). In the United States, the largest tomato producing state is California, followed by Indiana, Ohio, and Michigan (Table 2). Approximately 85% of the crop by weight is used for processing, making it the second largest vegetable crop for processing, by dollar value in the United States. About 45% of the world supply of processed tomato products is from California alone.

In the United States, the yield per acre continues to increase every year owing to improvement in varieties and growing practices. Over the last 20 years in California, breeding has resulted in a 1.54%/year increase in yield, no change in soluble solids, and a 1.15%/year improvement in color (13). An additional 1.16%/year improvement in yield occurred due to improvements in growing practices. The lack of improvement in soluble solids is likely because of the tradeoff between improving solids and improving yield.

Table 1 2000 World Production Statistics for Tomatoes

Location	Area harvested (1000 ha)	Production (1000 metric ton)
World	3635	99,125
Asia	1842	42,461
Europe	710	21,914
North and Central America	331	16,921
Africa	591	11,424
South America	151	5918
Oceania	9	486
China	754	18,347
United States	195	13,255
Italy	130	7091
Turkey	158	6600
Egypt	180	5950
India	360	5450

Source: Adapted from Ref. 11.

Table 2 2000 U.S. Production Statistics of Tomatoes for Processing

State	Harvested area (acres)	Production (tons)
California	271,000	10,286,500
Indiana	6600	229,020
Ohio	5400	158,710
Michigan	2800	84,000
Pennsylvania	1400	42,560
Other	2400	57,450

Source: Adapted from Ref. 12.

E. Nutritional Value

The composition of the tomato is greatly affected by the variety, state of ripeness, year, climatic growing conditions, light, temperature, soil, fertilization, and irrigation. Tomato total solids vary from 5 to 10% (6) with 6% being average. Approximately half of the solids is reducing sugars, with slightly more fructose than glucose. Sucrose concentration is unimportant in tomatoes and rarely exceeds 0.1%. A quarter of the total solids consists of citric, malic, and dicarboxylic amino acids, lipids, and minerals. The remaining quarter, which can be separated as alcohol-insoluble solids, contains proteins, pectic substances, cellulose, and hemicellulose.

Tomatoes are mostly water (94%), a disadvantage when condensing the product to paste. They are a reasonably good source of vitamins C and A. In 1972 tomatoes provided 12.2% of the recommended daily allowance of vitamin C, only oranges and potatoes contributed more to the American diet (14). Tomatoes provided 9.5% of the vitamin A, second only to carrots. When major fruit and vegetable crops were ranked on the basis of their content of ten vitamins and minerals, the tomato occupied 16th place (7). However, when the amount that is consumed is taken into consideration, the tomato is placed first in its nutritional contribution to the American diet. This is because the tomato is a popular food, added to a wide variety of soup, meat, and pasta dishes.

II. PROCESSING STEPS: TOMATOES TO JUICE, PASTE, AND FROZEN SAUCE

The majority of processed tomatoes are made into juice, which is condensed into paste. The paste is remanufactured into a wide variety of sauce products. The majority of frozen tomato products are sauces that are part of frozen meat and pasta entrees.

After harvesting, tomatoes are transported to the processing plant as soon as possible. Once at the plant, they are processed immediately, and if this is not possible they are stored in the shade. Fruit quality deteriorates rapidly while waiting to be processed. To unload the tomatoes, the gondolas are filled with water from overhead nozzles. Gates along the sides or undersides of the gondolas are opened, allowing the tomatoes to flow out into water flumes.

A. Grading

The first step the tomatoes go through is to be graded to determine the price paid to the farmer. This is done at the processing facility or at a centralized station before going to the processing

facility. Individual companies may set their own grading standards, use the voluntary USDA grading standards, or use locally determined standards, such as those of the Processing Tomato Advisory Board in California. The farmer is paid based on the percentage of tomatoes in each category. Typically companies hire USDA graders or hold an annual grading school to train their own graders.

The USDA divides tomatoes for processing into categories A, B, C, and culls (15). Grading is done on the basis of color and percentage of defects. Color can be determined visually to determine the percentage of the surface that is red, or with an electronic colorimeter on a composite raw juice sample. Defects include worms, worm damage, freeze damage, stems, mechanical damage, anthracnose, mold, and decay. The allowable percentage of extraneous matter may also be specified. Extraneous matter includes stems, vines, dirt, stones, and trash.

The Processing Tomato Advisory Board inspects all tomatoes for processing in California. Their standards are similar to those of the USDA but more geared for the paste industry. They inspect fruit for color, soluble solids, and damage (16). A sample of raw tomatoes is comminuted for color and soluble solids. The minimum tomato color instrument reading is 39. Soluble solids are reported for informational purposes. A load of tomatoes may be rejected for any of the following reasons: $>2\%$ of fruit is affected by worm or insect damage, $>8\%$ is affected by mold, $>4\%$ is green, or $>3\%$ contains material other than tomatoes, such as extraneous material, dirt, and detached stems.

Proper sampling procedure is essential to grade the lot accurately. The Processing Tomato Advisory Board requires that each sample from a bin or bulk load contain 50 pounds of tomatoes. Approximately one-half of the number of bins in the sample must be located below the top layer of the load. For bulk loads, containing 30 tons or less, two samples must be taken from the load.

B. Washing

Washing is a critical control step in producing tomato products with a low microbial count. A thorough washing removes dirt, mold, insects, drosophila eggs, and other contaminants. The efficiency of the washing process will determine microbial counts in the juice or paste (17,18). Several methods can be used to increase the efficiency of the washing step. Agitation increases the efficiency of soil removal. The warmer the water spray or dip, up to 194°F (90°C), the lower the microbial count (19,20), though this is not typically done because of economic concerns. Lye or surfactants may be added to the water to improve the efficiency of dirt removal, although surfactants have been shown to promote infiltration of some bacteria into the tomato fruit by reducing the surface tension at the pores (21). The washing step also serves to cool the fruit. Since tomatoes are typically harvested on hot summer days, washing removes the field heat, slowing respiration and therefore quality loss.

Tomatoes are typically transported in a water flume to minimize damage to the fruit. Therefore tomato washing can be a separate step in a water tank, or built into the flume system. A water tank also serves to separate stones from the fruit, since the stones settle to the bottom. The final rinse step uses pressurized spray nozzles at the end of the soaking process. Flume water may be either recirculated or used in a counterflow system, so that the final rinse is with fresh water while the initial wash is done with used water. In either system, the first flume frequently inoculates rather than washes the tomatoes because all of the dirt in the truck is washed into the flume water (18). When the water is reused, high microbial counts on the fruit may result if careful controls are not kept.

Chlorine is frequently added to the water. Chlorine will not significantly reduce spores on the tomato itself because the residence time is too short. However, chlorine is effective at keeping

down the number of spores present in the flume water (18). When there is a large amount of organic material in the water, such as occurs in dirty water, chlorine is used up rapidly, so it must be continuously monitored.

During fluming to the next step, upright stakes may be placed at intervals within the flume. Vines and leaves that have made it this far in the process are caught on the stakes. Periodically workers remove the trapped vines.

C. Sorting

A series of sorters are used in a plant. The first sorter that is used, especially in small plants, is an inclined belt. The tomatoes are offloaded onto the belt. The round fruit rolls down the belt and into a water flume. The leaves, sticks, stones, and rotten tomatoes are carried up by the belt and dropped into a disposal bin.

Photoelectric color sorters are used in almost every plant to remove the green and pink tomatoes. These sorters work by allowing the tomatoes to fall between conveyor belts in front of the sensor. Unacceptable tomatoes are ejected by a pneumatic finger. A small percentage of green tomatoes in tomato juice does not adversely affect the quality. Green tomatoes bring down the pH but do not affect the color of the final product. In addition, less mature tomatoes result in a higher viscosity paste (22,23). Pink or breaker tomatoes are a problem, however, because they decrease the redness of the juice.

The final sorting step is done by human sorters, who are more sensitive than mechanical sorters. Employees remove extraneous materials and rotten tomatoes from sorting tables. Sorting conveyors should require the employees to reach no more than 20″ and move no more than 25′/min; the conveyors should consist of roller conveyors that turn the tomatoes as they travel, exposing all sides to the inspectors (24).

D. Break

The tomatoes are next put through a break system to be chopped. Some break systems operate under vacuum to minimize oxidation. In an industrial plant operating under vacuum, no degradation of ascorbic acid occurs during the break process (25). When vacuum is not used, the higher the break temperature, the greater the loss of ascorbic acid (26).

Tomatoes can be processed into juice by either a hot break or a cold break method. In the hot break method, tomatoes are chopped and heated rapidly to at least 180°F (82°C) to inactivate the pectolytic enzymes polygalacturonase (PG) and pectin methylesterase (PME). Inactivation of these enzymes helps to maintain the maximum viscosity. Most juice is made by the hot break method, since most juice is concentrated to paste, and high viscosity is important in tomato paste used to make other products. Most hot break processes occur at 200–210°F (93–99°C).

In the cold break process, tomatoes are chopped and then mildly heated to accelerate enzymatic activity and increase the yield. Pectolytic enzyme activity is at a maximum at 140–151°F (60–66°C). Cold break juice has less destruction of color and flavor but also has a lower viscosity because of the activity of the enzymes. This juice can be made into paste, but its lower viscosity is a special advantage in tomato juice and juice-based drinks. In practice, both hot and cold break paste can be purchased with excellent color and high viscosity.

E. Extraction

After the break system, the comminuted tomatoes are put through an extractor, pulper, or finisher to remove the seeds and skins. Extraction of the juice is done with either a screw type or a paddle

type extractor. Screw type extractors press the tomatoes between the screw and the screen. The screw is continually expanding along its length, forcing the tomato pulp through the screen. Very little air is incorporated into the juice, unlike in paddle type extractors, which beat the tomato against the screen, incorporating air. Air incorporation during extraction should be minimized because it oxidizes both lycopene and ascorbic acid. The screen size determines the finish, or particle size, which will affect the viscosity and texture.

F. Deaeration

Deaeration is frequently the next step to remove dissolved air incorporated during breaking or extraction. The juice is deaerated by pulling a vacuum as soon as possible because oxidation occurs rapidly at high temperatures. Deaeration also prevents foaming during concentration. If the product is not deaerated, substantial loss of vitamin C will occur.

G. Homogenization

The juice is homogenized to increase product viscosity and minimize serum separation. The homogenizer is similar to what is used for milk and other dairy products. The juice is forced through a narrow orifice at high pressure, shredding the suspended solids.

H. Concentration into Paste

The juice is next concentrated to paste. Concentration occurs in forced-circulation, multiple-effect vacuum evaporators. Typically three- or four-effect evaporators are used; most modern equipment now uses four effects. The temperature is raised as the juice goes to each successive effect. A typical range is 118 to 180°F (48 to 82°C). Vapor is collected from later effects and used to heat the product in previous effects, conserving energy. The reduced pressure lowers the temperature, minimizing color and flavor loss.

The paste is concentrated to a final solids content of at least 24% NTSS (natural tomato soluble solids) to meet the USDA definition of paste. Commercial paste is available in a range of solids contents, finishes, and Bostwick consistencies. Common commercial concentrations are 26 and 31% NTSS. Typical finishes include 0.027″ (0.69 mm), 0.033″(0.84 mm), 0.045″ (1.1 mm), 0.060″(1.5 mm), 0.078″ (2.0 mm) and 0.156″ (4.0 mm). The larger the screen size, the coarser the particles and the larger the finish. Bostwick may range from 2.5 to 8 cm (tested at 12% NTSS).

I. Aseptic Processing

The paste is heated in a tube-in-tube or scraped surface heat exchanger, held for a few minutes to pasteurize the product, then cooled and filled into sterile containers in an aseptic filler. A typical process might heat to 228°F (109°C) and then hold 2.25 minutes, or heat at 205°F (96°C) for 3 minutes. Aseptically processed products must be cooled before filling both to maintain high quality and because many aseptic packages will not withstand temperatures above 100°F (38°C). An aseptic bag-in-drum or bag-in-crate filler is used to fill the paste into previously steam sterilized bags. Paste is typically sold in 55 gallon drums or 300 gallon bag-in-boxes.

J. Remanufacturing into Sauce and Freezing

Manufacturers of convenience meals buy tomato paste and remanufacture it by mixing it with water, particulates, and spices to create the desired sauce. Some sauce is made directly from fresh

tomatoes during the tomato season, but this is less common. Sauce production from paste is more economical because it can be done during the off season using the equipment in tomato processing plants that would otherwise be unused. It is also cheaper to ship paste than sauce.

The sauce may be aseptically packaged and shipped to another plant, or immediately filled into the final container. Since the product will be frozen, it does not need to be retorted to make it shelf stable. Therefore, depending on the other ingredients, the product may not undergo any further heat processing. Once the sauce and other ingredients have been filled into the final container, the container is frozen on a spiral blast freezer at -30 to -40°F (-34 to -40°C).

K. Wastewater

Wastewater disposal is a critical issue in some locations, and it can put a tomato processor out of business owing to the high cost of disposal. One solution is to use flocculation to separate out the solids. The solids can then be disposed of as fertilizer on fields. The biological oxygen demand (BOD) of the remaining wastewater is low enough to permit economical disposal in the sewer system. Flocculation can be done with the addition of coagulants such as ferric chloride (27) or by pressurizing the sample, causing the water to absorb air. When the pressure is released, air bubbles are formed to attach to the solid waste, carrying it to the surface where it can be removed. Another solution is to pump wastewater, with or without the solids, directly into the fields to be used for irrigation.

III. PROCESSING: FROZEN SLICED TOMATOES

Currently, there are no frozen tomatoes available on the U.S. market. In Italy frozen tomatoes are successfully processed (28). Tomatoes are washed, sorted, blanched, peeled, sliced, diced, or left whole, inspected, and frozen on an IQF belt freezer. The whole peeled tomatoes are fluidized and quickly crust frozen in the first zone. The product is finish frozen on a second belt to 0°F (-18°C). A similar product was developed but not marketed in the United States. The tomatoes were sliced, blanched and cryogenically frozen. The company reported that the product remained firm, but it had to be stored below 0°F (-18°C) and was too expensive for the market.

IV. QUALITY AND HOW IT IS AFFECTED BY GROWING AND PROCESSING

A. Color and Lycopene

There are several methods for measuring color. The voluntary USDA grading standards for tomatoes to be processed use the Munsell Disk colorimeter (15). The Munsell Disk colorimeter consists of two spinning disks containing various percentages of red, yellow, black and gray. As the disks spin they visually combine to produce the same color as the tomato. USDA color comparators are plastic color standards which can be used to grade tomatoes visually. With fresh tomatoes, the Agtron colorimeter is common, especially for tomato juice and halves. The Agtron is an abridged spectrophotometer that measures the reflection at one to three wavelengths and reports the result as a color score. For processed tomato products, the Hunter colorimeter is common. The Hunter measures the L, a, and b values. The a and b values are put into a formula dependent on the machine, to correlate to color standards provided by UC Davis (29). The Agtron and Gardner can also be converted to these color scores. In the scientific literature, the L, a, b values are converted to hue angle (arc tangent b/a).

Consumers associate a red, dark-colored tomato product with good quality. The red color of tomatoes is created by the linear carotenoid lycopene. Lycopene is 80–90% of the carotenoids present. With the onset of ripening, the lycopene content increases (6,7). The final lycopene concentration in the tomato depends on both the variety and the growing conditions. Some tomato varieties have been bred to be very high in lycopene, resulting in a bright red color. During growth, both light level and temperature affect the lycopene content. The effect of light on lycopene content is debated. Some authors report that shading increases lycopene content (30), while others report mixed results (31). The effect of temperature is much more straightforward. At high temperatures, over 86°F (30°C), lycopene does not develop (30,32,33).

Lycopene does not have any vitamin activity, but it may act as an antioxidant when consumed (34). A review of epidemiological studies found that the evidence for tomato products was strongest for the prevention of prostate, lung, and stomach cancer, with the possible prevention of pancreas, colon and rectum, esophagus, oral cavity, breast, and cervix cancer (35). The consumption of fresh tomatoes, tomato sauce, and pizza has been found to be significantly related to a lower incidence of prostate cancer, with tomato sauce having the strongest correlation (36). Since anticancer correlations are typically stronger to processed tomatoes than fresh tomatoes, several studies have looked at the effect of processing on lycopene. Tomato juice and paste have more bioavailable (absorbed into the blood) lycopene than fresh tomatoes when both are consumed with corn oil (34,37). This may be because of thermally induced rupture of cell walls and weakening of lycopene–protein complexes releasing the lycopene, or improved extraction of lycopene into the lipophilic corn oil.

Color loss is accelerated by high temperature and exposure to oxygen during processing. The main cause of lycopene degradation is oxidation. Oxidation is complex and depends on many factors, including processing conditions, moisture, temperature, and the presence of pro- or antioxidants. Several processing steps are known to promote the oxidation of lycopene. During hot break, the hotter the break temperature, the greater the loss of color, even when operating under a vacuum (25). However in some varieties the break temperature affected color while in others it did not (38). The use of fine screens in juice extraction enhances oxidation because of the large surface area exposed to air and metal (39). Similarly, concentrating tomato juice to paste in the presence of oxygen degrades lycopene. It has been reported that heat concentration of tomato pulp can result in up to 57% loss of lycopene (40). However, other authors have reported that lycopene is very heat resistant and no changes occur during heat treatment (41). With current evaporators it is likely that very little destruction of lycopene occurs.

Processing also affects color owing to the formation of brown pigments. This is not necessarily detrimental, because a small amount of thermal damage resulting in a darker serum color increases the overall red appearance of tomato paste (42). Browning is caused by a number of reactions. Excessive heat treatment can cause browning owing to caramelization of the sugars. Amadori products, representing the onset of the Maillard reaction, occur during all stages of processing, including breaking, concentrating, and canning (43), although in the production of tomato paste the Maillard reaction is of minor importance (43). Degradation of ascorbic acid has been suggested to be the major cause of browning (44). Browning can be decreased by processing and storage at lower temperatures, by decreasing the pH to 2.5, and by the addition of sulfites (45).

B. Viscosity and Consistency

For liquid tomato products, viscosity is a very important quality parameter. It is second only to color as a measure of quality. Viscosity also has economic implications because the higher the viscosity of the tomato paste, the less paste needs to be added to reach the desired final product consistency. To the scientist, viscosity is determined by analytical rheometers, while consistency

is an empirical measurement. To the consumer they are synonyms. Depending on the method, either the viscosity or the consistency of the product can be measured. Tomato products are non-Newtonian, and so many methods measure consistency rather than viscosity. The standard method for determining the consistency of most tomato products is the Bostwick consistometer. The Bostwick value is how far the material at 20°C flows under its own weight along a flat trough in 30 seconds. Tomato concentrates are typically measured at 12% NTSS to remove the effect of solids. Theoretically, this can be modeled as a slump flow (46). The Bostwick measures the shear stress under a fixed shear rate. Efflux viscometers such as the Libby tube (for tomato juice) and the Canon-Fenske (for serum viscosity) measure shear rate under fixed shear stress.

The viscosity of tomato products is determined by the solids content, serum viscosity, and physical characteristics of the cell wall material. The solids content is affected by the cultivar but is primarily determined by the degree of concentration. The serum viscosity is largely determined by the pectin. Pectin is a structural cell wall polysaccharide. The primary component of pectin is polygalacturonic acid, a homopolymer of (1–4) alpha-D-galacturonic acid and rhamnogalacturonans. Some of the carboxyl groups are esterified with methyl alcohol. Pectin methyl esterase (PME) removes these ester groups. This leaves the pectin vulnerable to attack by polygalacturonase (PG), which cleaves between the galacturonic acid rings in the middle of the pectin chain, greatly reducing the viscosity. During the break process heat is used to inactivate pectolytic enzymes, but these enzymes are released during crushing and act very quickly. Genetic modification has been used to produce plants with either an antisense PME (47) or a PG (48) gene to inactivate the enzyme, producing juice with a significantly higher viscosity. The physical state of the cell wall fragments affects viscosity by determining how easily the particles slide past each other. Most tomato products are homogenized to create more linear particles, which increases the viscosity.

Conditions during processing, such as temperature, screen size, and blade speed, will affect the final viscosity. Hot break juice is typically of a higher viscosity than cold break juice owing to inactivation of the enzymes that degrade pectin. At very high break temperatures, such as 212°F (100°C), the structure collapses and the viscosity decreases again (25), though this effect is not always observed (49). The screen size and blade speed during extraction are also important factors. The effect of screen size is not a simple relationship. A higher viscosity is produced using a screen size of 1.0 mm than either 0.5 mm or 1.5 mm (50). Other studies have found no effect of finisher size on final viscosity (25). The faster the blade, the higher the viscosity. The higher the evaporation temperature, the greater the loss of viscosity (25).

C. Serum Separation

Serum separation can be a significant problem in liquid tomato products. Serum separation occurs when the solids begin to settle out of the solution, leaving the clear straw-colored serum as a layer on top of the product. Preventing serum separation requires that the insoluble particles remain in a stable suspension throughout the serum. Generally, the higher the viscosity, the less serum separation occurs.

Factors that affect the quantity and quality of the solids determine the degree of serum separation that occurs. The higher the temperature during the break process, the less serum separation occurs (25). Hot break juice has less serum separation than cold break. This may be due to greater retention of intact pectin in the hot break juice (49), though Robinson et al. (51) found that the total amount of pectin did not affect the degree of settling in tomato juice. The cellulose fiber may be more important in preventing serum separation than the pectin (51,52). Addition of pectinases degrades the pectin, increasing the dispersal of cellulose from the cell walls. The expansion of this cellulose minimizes serum separation (51).

Homogenization is commonly used to shred the cells, increasing the number of particles in solution and creating cells with ragged edges that reduce serum separation. The result is particles that will not efficiently pack and settle. Of these two effects, changing the shape of the particles is more important than their change in size (51). Evaporator temperature during concentration has little effect on serum separation (25).

D. Flavor

The flavor of tomatoes is determined by the variety used, its stage of ripeness, and the conditions of processing. Typically, varieties have not been bred for optimal flavor, though some work has focused on breeding tomatoes with improved flavor. Processing tomatoes are picked fully ripe, so the concern that tomatoes that are picked mature but unripe have less flavor is not important. Processing generally causes a loss of flavor. Processes are not optimized for best flavor retention, but practices that maximize color usually also maximize flavor retention. When flavor is evaluated, it is done by sensory evaluation. Gas chromatography is used to determine the exact volatiles present.

Flavor is made up of taste and odor. The sweet-sour taste of tomatoes is due to their sugar and organic acid content. The most important of these are citric acid and fructose (53). The sugar/acid ratio is frequently used to rate the taste of tomatoes, though Stevens et al. (53) recommend against it because tomatoes with a higher concentration of both sugars and acids taste better than those with low concentrations, for the same ratio. The free amino acids, salts, and their buffers also affect the character and intensity of the taste (54). The odor of tomatoes is created by the over 400 volatiles that have been identified in tomato fruit (54,55). No one single volatile is responsible for producing the characteristic tomato flavor. The volatiles that appear to be most important to fresh tomato flavor include *cis*-3-hexenal, 2-isobutylthiazole, beta ionone, hexenal, *trans*-2-hexenal, *cis*-3-hexenol, *trans*-2-trans-4-decadienal, 6-methyl-5-hepten-2-one, and 1-penten-3-one (54,55).

Processed tomato products have a distinctively different aroma from fresh tomato products. This is due to both the loss and the creation of volatiles. Heating drives away many of the volatiles. Oxidative decomposition of carotenoids causes the formation of terpenes and terpenelike compounds. The Maillard reaction produces volatile carbonyl and sulfur compounds.

Many of the volatiles responsible for the fresh tomato flavor are lost during processing, especially *cis*-3-hexenal and hexenal (56). *Cis*-3-hexenal, an important component of fresh tomato flavor, is rapidly transformed into the more stable *trans*-2-hexenal, so it is not present in heat processed products (57). The amount of 2-isobutylthiazole, responsible for a tomato leaf green aroma, diminishes during the manufacture of tomato puree and paste (58).

Other volatiles are created. The breakdown of sugars and carotenoids produces compounds responsible for the cooked odor. Dimethyl sulfide is a major contributor to the aroma of heated tomato products (54,56,59–60). Its contribution to the characteristic flavor of canned tomato juice is more than 50% (60). Linalool (59), dimethyl trisulfide, 1-octen-3-one (61), acetaldehyde, and geranylacetone (57) may also contribute to the cooked aroma. Pyrrolidone carboxylic acid, which is formed during heat treatment, has been ascribed to an off-flavor that occasionally appears (62). This compound, formed by cyclization of glutamine, arises as early as during the break process (43).

Heating causes degradation of some flavor volatiles as well as inactivating lipoxygenase and associated enzymes, which are responsible for producing some of the characteristic fresh tomato flavor (63). However, hot break has been found to produce a better flavor by some authors (38) and

a less fresh flavor by others (63). Within one study, the flavor of one variety may be rated better as cold break than hot break and another variety the reverse (26,38). This may in part be because some panelists prefer the flavor of heat treated tomato juice to fresh juice (60).

E. pH and Titratable Acidity

The pH of tomatoes has been reported to range from 3.9 to 4.9, or in standard cultivars, 4.0 to 4.7 (64). The critical issue with tomatoes is to ensure that they have a pH below 4.7, so that they can be processed as high-acid foods. The lower the pH, the greater the inhibition of *Bacillus coagulans* and the less likely flat sour spoilage is to occur (65). Within the range of mature, red ripe to overly mature tomatoes, the more mature the tomato, the higher the pH. Thus pH is more likely to be a concern at the end of the season. The USDA standards of identity allow organic acids to be added to lower the pH as needed during processing.

The acid content of tomatoes varies according to maturity, climatic conditions, and cultural method. The acid concentration is important because it affects the flavor and pH. Citric and malic are the most abundant acids. The malic acid contribution falls quickly as the fruit turns red, while the citric acid content is fairly stable (66). The average acidity of processing tomatoes is about 0.35% expressed as citric acid (55). The total acid content increases during ripening to the breaker stage and then decreases.

The relationship between total acidity and pH is not a simple inverse relationship. The phosphorous in the fruit acts as a buffer, regulating the pH. Of the environmental factors, the potassium content of the soil most strongly affects the total acid content of the fruit. The higher the potassium content, the greater the acidity.

Processing conditions further affect the pH and acidity of processed tomato products. During processing the pH decreases and the total acid content increases (67,68), though the citric acid content may increase (67) or decrease (68). Hot break juice has a lower titratable acidity (70) and a higher pH than cold break juice (26,49). The difference is caused by the pectolytic enzymes still present in the cold break juice breaking down the pectin (71).

F. Total Solids, Degrees Brix, NTSS, and Sugar Content

Tomato solids are important because they affect the yield and consistency of the finished product. Due to the time required to make total solids measurements, soluble solids are more frequently measured. Soluble solids are measured with a refractometer, which measures the refractive index of the solution. The refractive index is dependent on the concentration and the temperature of solutes in the solution, so many refractometers are temperature controlled. The majority of the soluble solids are sugars, so refractometers are calibrated directly in percentage sugar, or °Brix. NTSS or natural tomato soluble solids are the same as °Brix, minus any added salt.

The sugar content reaches a peak in tomatoes when the fruit is fully ripe (66). Light probably has a more profound effect on sugar concentration in tomatoes than any other environmental factor (6). The seasonal trends in the sugar content of glass house grown tomatoes have been found to follow roughly the pattern of solar radiation (69). Even the minor shading provided by foliage reduces the total sugar content by up to 13% (31).

During heat treatment, the reducing sugar content decreases due to caramelization, the Maillard reaction, and the formation of 5-hydroxymethyl furfural. The amount of sugar lost depends on the process. Studies have reported as much as a 19% loss in processed tomato juice (67) and a 5% loss during spray drying (72).

G. Enzymes

Pectin methylesterase and polygalacturonase break down the pectin chains, reducing the product viscosity as described in the section on viscosity. Lipoxygenase and associated enzymes cause lipid oxidation off-flavors during storage if the product is not adequately heat treated. Lipoxygenase and its associated enzymes are also responsible for the development of fresh tomato flavor during the cold break process.

V. QUALITY LOSS DURING FREEZING AND FROZEN STORAGE

Initial quality loss occurs during the freezing process. Liquid nitrogen frozen slices have a significantly better texture than slices frozen at −34°C (73). Addition of calcium chloride has been shown to improve hedonic ratings of frozen tomato slices in some cases (74) but not in others (73). However, these slices were still given lower hedonic ratings than fresh slices (73,74). The flavor of frozen slices was also found to be significantly worse than that of fresh slices (74).

Further quality loss occurs during storage. Most studies have focused on unblanched tomatoes. The enzymes remain active, resulting in significant losses in color, vitamin C, flavor, and texture. In unblanched dices at −4°F (−20°C), the loss of color and carotenoids was modeled as a linear decrease with time (75). The loss is accelerated by oxygen and light and can be decreased by the addition of spices with antioxidant properties (76). Color changes are observable by sensory evaluation after 6 months at −4°F (−20°C) or 12 months at −22°F (−30°C) (77). After a year of storage, 43% of vitamin C is lost at −4°F (−20°C) and 70% at −22°F (−30°C) (77). Hedonic ratings of color, texture, and flavor deteriorate significantly (57,77,78).

However, thawed, unblanched dices were still organoleptically acceptable for use on pizza after 12 months at −22°F (−30°C), or 9 months at −4°F (−20°C). They were still acceptable for use in vegetable salads after 12 months at −22°F (−30°C), or 6 months at −4°F (−20°C) (77).

Blanching appears to stop quality loss during storage. No difference in vitamin C, or hedonic ratings for color, appearance, texture, flavor, or taste, were seen in slices after 6 weeks at 0°F (−18°C) (78). In puree after 4 months at 0°F (−18°C), a 25% loss of vitamin C has been reported, but the flavor was still judged to be acceptable (79).

During the first three months of storage at −4°F (−20°C), there is a decrease in the number of microorganisms, including pathogens, on frozen tomato slices (80). However, the counts after 9 months of storage were still high enough to present a safety concern. Thus proper sanitation must be used during preparation, since little microbial death occurs during storage.

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Frozen French Fried Potatoes and Quality Assurance

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I. INTRODUCTION

This chapter describes the general process of manufacturing frozen French fried potatoes and some aspects of quality assurance of the products. The information has been derived from grading and inspection documents issued by the U.S. Department of Agriculture.

II. PRODUCTS COVERED

The principal products covered are the traditional French fries, potatoes cut into strips, partially deep fried, and frozen. The standard also may be applied to any potato product, regardless of shape or composition if it is similarly processed and frozen. This includes products fabricated primarily from mashed, crushed, cut, or shredded potatoes and which are preformed into units prior to frying and freezing. Because of the difficulty of keeping oils in suitable condition, deep frying has not been popular with home cooks. With the discovery and development of frozen French fries, home consumption has increased rapidly. Institutional use also is increasing yearly. Some believe that yearly production now far exceeds that of any other frozen vegetable.

A. Areas of Production

The white potato is the world's most important vegetable crop. It is grown to some extent in all agricultural areas in the United States. Certain types of potatoes, particularly those of low solids contents, are not always suitable for manufacturing. Therefore extensive production of frozen French fried potatoes is limited principally to those areas where the raw product is most suitable. They are in general the Idaho, eastern Oregon, and Washington areas, the San Joaquin Valley of California, and the state of Maine. There is also some sizeable production in New Jersey, eastern Pennsylvania, Michigan, and the Red River Valley of Minnesota.

Because of varietal differences and growing conditions, potatoes from these widely separated areas have their own characteristics, particularly with respect to flavor and mealiness. Very mealy French fries are produced principally from the Russett varieties in the Pacific Northwest. In other sections of the country, the solids of the raw product are generally lower and

the finished French fries have a slightly different flavor; they are less mealy than those from the Northwest region. These regional differences have given rise to claims of superiority of the product based principally on the degree of mealiness. This is partially a matter of personal preference. Good quality French fries are produced in all the leading producing areas.

B. Varieties

There are several dozen recognized market varieties of potatoes grown in the United States, and more are being developed each year. The Irish Cobbler is probably the most widely grown, and the Katahdin is grown in the greatest volume. Among the more popular varieties are the Russet Burbank (Idaho), Cobbler, Katahdin, White Rose, Green Mountain, Bliss, Triumph (red), Russett Rural, Kennebec, Norgold, and Pontiac. Various varieties of potatoes have their own cooking qualities. Some are more popular for one quality than for another, that is, bakers, boilers, and fryers. The characteristics of the various varieties are not distinct, and they are not always the same in all growing areas and all seasonal conditions. Therefore no one variety is used entirely for the production of frozen French fried potatoes.

C. Receiving

Frozen French fries are usually produced fairly close to the source of supply but occasionally the raw product may be drawn from any of the principal potato producing areas of the country. At time of harvest, most late varieties of potatoes have a total sugar content of less than 1 percent of total solids. Such potatoes are usually suitable for manufacturing into frozen French fries. After the potatoes are stored for a period of time at 40°F or less the starch content partially changes to sugar, and the potatoes, if used immediately out of storage, may be unsatisfactory because of the high sugar content. Sugar in excess of two to three percent (based on dry potato weight) may render the potato practically worthless for deep frying. Such potatoes subjected to high temperatures develop black or brown areas, spots, or streaks, owing to carmalizing and burning of the sugar.

They also may have a burnt or sweet taste. Most potatoes can be "conditioned" by storing them for a period of time, at least two weeks, at near 60 or 70°F. In conditioning, the potato starts to respire, a process that uses the sugar and converts a portion of it back to starch. If the potatoes have been subjected to excessive cold storage, that is, down to 32 to 34°F or lower, trouble in conditioning may be encountered, such as tissue breakdown leading to rotting.

D. Determining the Quality and Condition of Raw Potatoes for Frying Purposes

Processors try to evaluate and classify the quality of the raw product prior to purchase or processing. Two of the most important characteristics that indicate quality are specific gravity, closely associated with moisture content, and the degree to which starch has been converted to sugar. These will affect the texture and the color of the product. The size and shape of the potatoes is also important because of the cost of operations, the yield, the length of the units, and the number of slivers and irregular-shaped pieces. The presence of off-odors and off-flavors such as those caused by some insecticides is at times very serious.

No entirely satisfactory method seems to have been developed to predetermine the cooking quality of potatoes. Specific gravity tests, which to some extent indicate the degree of mealiness, are sometimes made. Picric acid color tests may also be made. These indicate to some extent the relative amount of sugars present. The objectionable flavor of benzine hexachloride—an insecticide—can be detected by boiling and mashing a sample of the potatoes.

Probably the most satisfactory method of determining the quality of the raw product is to subject a representative sample of the lot to a cooking test similar to the process that will be used in manufacture. The USDA, in cooperation with the State of Maine and certain potato processors, has developed a series of color photographs that show various degrees of darkening after a standard fry. Comparison of actual samples of cooked potato to the photographs provides a fairly accurate means of evaluating the quality of a load of potatoes for the purpose of making French fries. Some large users base their raw potato contracts on the fry colors shown in the USDA Color Standards for Frozen French Fried Potatoes.

III. MANUFACTURE

Each processor of frozen French fried potatoes has his own particular methods of manufacture. However, there are a number of things common to all processors. The following outline describes the principal steps in manufacture. These steps may vary with different manufacturers. The principles given here are basic.

After receiving potatoes or having withdrawn them from storage bins or "conditioning" cellars, frying and/or suitable chemical tests are made from representative samples of the lot to determine whether the potatoes are in condition to be processed.

A. Washing

If the potatoes are in a condition suitable for processing, they are washed and may be run through hot water to remove some of the dirt and to loosen the peel. The potatoes may then be sized prior to peeling. Some plants flume the potatoes from the place of storage to the peelers, thus accomplishing the preliminary washing in this manner.

B. Peeling

After excessive dirt is washed off, the potatoes are dropped into peeling machines. These may be steam, lye, abrasive, or roller type peelers. Steam and lye peelers give a quick cook that loosens the skin or peel but does not penetrate deeply into the potatoes. The peelings are then removed by passing the potatoes through rubber rollers and water sprays. In abrasive, roller type peelers the skin or peel is removed without the addition of heat.

C. Trimming

The potatoes after leaving the peeling machines are trimmed on wide moving belts. In the better plants, these belts are arranged in sections so that each potato is picked up by an operator, examined for defects, trimmed if necessary, and tossed over a barrier onto another section of the belt. This procedure is much more satisfactory than trying to stir the potatoes on a single belt, because many potatoes may miss any examination at all on the single belt. At this time the potatoes may also be sorted for size; the larger ones go to institutional lines, the smaller ones into the retail and by-product lines.

In some plants, electric eye sorters are installed after the slicing operation to eliminate blemished units, thus cutting down on the amount of hand sorting and trimming of the whole potatoes.

D. Slicing

After the potatoes are trimmed and sorted to size they go to the slicing machines. These slicers usually consist of two sets of knives, either rotary or fixed. One set of knives slices the potato to the desired thickness. The potato slices are then passed through another set of knives, which cut the slices to strips if desired. The size of the strips depends on the wishes of the management. It may vary from one quarter by one quarter inch to one half by one half inch in cross section. The usual size for retail sales is 3/8 by 3/8 inch. Poor slicing may be caused by small or irregular-shaped potatoes, by poor machinery, or by good machinery not properly used or adjusted. The knives may be straight or corrugated.

E. Sizing

In the process of cutting potatoes into strips, there is always a certain amount of slivers and otherwise irregularly shaped pieces. A certain number of these pieces are expected in this product and are allowed for in the tolerances contained in the grade standards. It is usually necessary, however, to pass the cut potatoes over some type of shaker screen to remove a portion of the small pieces and slivers. The amount of chip material removed depends to some extent on the wishes of the purchaser. Processors do not like to remove any more than they have to because of the loss in yield.

F. By-products

The excessive loss of potato material because of the peeling, trimming, and screening operations causes processors to consider by-products to utilize this material. Often this material is wasted; however, a large number of products, such as patties, puffs, and shreds, and diced and mashed potatoes, have been developed to utilize this material. Dehydrated flakes are also an important use. Where satisfactory use is made of screenings and sound throwouts, there is less tendency to keep this material in the frozen French fry pack.

G. Desugaring

Sugar in excessive amounts or irregular quantities of sugar between units may cause French fried potatoes to have dark or irregular color, poor texture, and/or unpleasant taste. Proper harvesting, good storage, and conditioning after storage helps in the control of the sugars. However, conditioning and storing potatoes is an expensive process and is avoided whenever possible. Reasonably satisfactory methods of rapid equalization of sugar content have been developed. The methods used vary between manufacturers. However, the basic principle is to run the sliced potatoes through a water bath leaching out a portion of the surface sugar and then replacing the sugar to the desired level by blanching in a sugar solution (partially cooking the product), so that upon frying the color between units will be uniform. This method, based on a patented process, evens the surface sugar content between units. The sugar content of the whole slice is not greatly affected.

H. Blanching

The sliced potatoes are usually run through a hot water blanch that partially cooks the product. This may or may not be a part of the desugaring process referred to previously. After blanching, the product may pass beneath heating units, under forced draft, which tends to remove most of the excessive moisture before the potato enters the fryer.

I. Frying

Frying of the potatoes is usually a continuous process. The potatoes enter the hot oil on or under a draper-chain type belt traveling a certain distance before being removed, or an undulating type belt moves the potatoes in and out of the oil; the oil flow moves the potatoes along from one end of the fryer to the other. Some manufacturers use a double fry. That is, after the first fry, at approximately 350 to 370 degrees Fahrenheit, the potatoes fall onto another belt and enter another fryer at about the same temperature. There are several reasons for this; the principal one being that there is more even coloring because of the stirring of the potatoes as they fall from one belt to another.

J. Fat or Oil

The term fat refers to a product that is plastic at room temperature such as lard or the usual vegetable shortenings. Oils are liquid at ordinary temperatures. The terms are here used to mean the same thing. Any animal or vegetable fat or oil that does not impart an unpleasant flavor to the French fries is suitable for the purpose. Different processors use different oils. Peanut oil, cottonseed oil, or mixtures of vegetable oils including some amount of soybean oil are used. Lard, which is hog fat, imparts a flavor to the French fries that is particularly desirable to some people. Soybean oil in large amounts may impart a flavor that is usually disliked. Hydrogenated lard is tasteless.

One of the biggest difficulties in proper frying is to maintain the fat or oil in good condition. Fats and oils deteriorate rapidly with the addition of water under high temperature, and also when in contact with bronze or brass fittings. When the frying oil deteriorates, it darkens in color and develops unpleasant odors that are imparted to the product. Dark bits of burnt carbon maybe deposited on the French fries, giving them an unpleasant appearance, Quality control people often use the amount of free fatty acid present in the oil as an indication of the degree of deterioration. A range in the area of 0.4 to 1.0 percent is regarded as normal.

Potatoes lose up to 30 to 40% of their weight, principally water, during frying. Water is removed from the oil by a partial vacuum created by the upward draft in the hood and attaching stack covering the frying vat. Condensation from the hood is carried away by troughs along the edge of the hood. The tendency to deteriorate may be checked by eliminating bronze or brass fittings, adjusting the size of the fryer to volume of potatoes, using oil that will stand the highest temperature in the system, and adding new oil from time to time.

In the better processing methods, the amount of oil used is very small, and it is usually heated by superheated steam in a heat exchanger rather than by direct flame. This keeps the oil in all parts of the system well below the scorching point. Usually the oil is filtered continually to remove charred materials and is thus kept clean.

K. Time and Temperature

There are many variants to be considered in determining the time and temperature of the fry. Potatoes of high specific gravity require less time to lose their excess moisture than those of low specific gravity. Different varieties of potatoes and potatoes in different conditions with respect to reducing sugars may require different cooks to attain a uniform degree of color. Certain markets seem to want potatoes fried much lighter in color than do other markets. French fries packed for institutional use, where an additional fry is to be given by the users, are usually fried to a much lighter color than are retail packs where the cooking is usually completed by the oven method. These light colored fries are usually designated as oil-blanched or par-fried.

Probably the most satisfactory means of arriving at the correct time and temperature for frying is to fry representative sample batches of each new load. If the samples come out too dark, either the time or the temperature, or both, of the cook may be reduced; if too light, they may be increased. In most plants, quality control people watch the color of the fries as they leave the fryer, both for overall color, and for uniformity of color, and recommend suitable adjustments of the process. These recommendations may be based on experience or on actual color plates or models that are provided as guides for the operators. The USDA color standards may be used for this purpose. Immediately after coming from the fryer heat may be applied to drive off excess surface oil. In many plants the potatoes are cooled quickly after the fry by a blast of air. This air blast may be designed to blow off the outer oil that clings to the hot potatoes.

L. Packaging

Packaging is usually accomplished by automatic machinery that places the proper weight of French fries into each package. The packages are usually weighed individually and adjusted for exact weight. This packaging operation may take place before freezing or, if belt freezing is used, after the potatoes emerge from the freezer. The resulting end product of the belt freezing method is easier to handle because the units separate easily, whereas the plate frozen product may emerge as one solid unit. Broken units are more common when the product is belt frozen.

IV. INSPECTION DURING PACKING OPERATIONS

The basic principles of in-plant inspection apply in general to inspection during manufacture. Processing operations as outlined above and as observed in the plant will suggest observations to be made and the best points to make them.

Good sanitation, particularly with respect to conveyors, belts, cutting machines, and machinery that comes in contact with cut potatoes is particularly important because yeasts, molds, and bacteria thrive in a potato-water medium and odors develop quickly. Also, there may be a buildup of oil or grease between fryer and packaging lines.

Samples checked for color at the discharge end of the fryers will indicate whether the potatoes are in proper condition for frying. Samples taken over the last shaker and just prior to packaging can be checked for defects (including defectives per pound). Cooking tests should be made as soon as practical after freezing in order to develop all the information necessary for the in-plant inspection report.

V. INSPECTING THE PRODUCT

A. Sample Unit Size

Any change in sample unit sizes from those specified in the standards changes the probability of the lot of passing or failing the intended grade. The size of the sample unit used is, therefore, very important. The sizes are

In the retail type, 16 ounces of product selected either from a production line or from one or more market packages.

In the institutional type, 32 ounces of product selected either from a production line or from one market package.

CAUTION: Make every effort to obtain a representative sample. French fries, particularly strip styles, tend to stratify themselves with vibration. Therefore try to take from the full depth on the belt or package rather than from the top. Often a sweep across the entire width of a belt would be better than from just one spot.

B. Initial Fry Color, Types, Styles, and Length Designations

These items provide a much needed standardized language for trading, since these terms—previously widely used—were subject to much individual interpretation. Accurate identification of the fry color, type, style, and length designation is very important. They should be reported on all certificates.

1. Fry Color

Color changes caused by frying require special consideration. Keep in mind the following definitions:

Fry color refers to the color change that occurs in the potato units solely because of the initial frying or the oil-blanch process.

Fry color of the individual units is ascertained by comparing them with the USDA Color Standards for Frozen French Fried Potatoes. The range of color includes the color space, up to but not including the next darkest color.

Fry color of the sample unit is the range of colors that occur in the frozen product before any additional heating.

Fry color designation of a sample unit is the fry color designation appropriate to the ranges specified in the Standards.

The USDA Color Standards referenced are a series of colors that depict changes that occur solely because of the frying process. They are numbers 0, 1, 2, 3, and 4.

These designations are amplified as follows:

USDA No. 0 in the color standards has no browning caused by frying. The background colors of all these illustrations is yellow. Background colors of potato strips are usually basically white. They may be creamy-white, yellow-white, or any other characteristic color. See Table 1.

Refry color means the actual color of a potato unit after heating—either deep frying or in an oven.

Refry color of the sample unit is the range of colors that are present after heating in preparation for grading.

Refry color designation is the color designation that may be given to the sample unit after heating. The appropriate criterion for this designation is given in Refry or (after heating) Color Range Guide in later discussion.

Table 1 USDA Color

USDA Color	Optional fry color designation	Application to a sample unit
No. 0	Extra light	A sample unit may be designated Extra light if almost all of the units have no fry color at the edges as in USDA No. 0.
No. 1	Light	A sample unit may be designated Light if most of the potato units are lighter than USDA Color No. 2.
No. 2	Medium light	A sample unit may be designated Medium light if most of the potato units are lighter than USDA Color No. 3 but may include Color No. 1.
No. 3	Medium	A sample unit may be designated Medium if most of the potato units are darker than USDA Color No. 2 and may further range in color as dark as Color No. 4.
No. 4	Dark	A sample unit may be designated Dark if most of the potato units are darker than USDA Color No. 3. This designation may contain units similar to No. 4, and darker. Sample units designated No. 4 Dark fry color are not allowed in Grade A.

2. Types

Many plants pack primarily for retail, and others primarily for the institutional market. Some pack an identical product for both types. For retail, however, the fry process usually has progressed to the extent that there is some color change and sufficient oil is retained that French fried potatoes of characteristic texture may be prepared by heating the product in an oven. For institutional use the units are usually processed very lightly, resulting in little color change and often not enough oil retention for proper preparation in an oven. This is often referred to as oilblanched or parfried.

The determination of type is based on intended use. You must make this determination on the information available to you.

Guidelines for this decision are as follows:

1. Small packages (5 pounds or less) which are labeled or marked as is customary or required for retail sales, and particularly those bearing official USDA marks, are considered to be of the retail type. Five-pound packages that are so marked, however, may be considered to be of the institutional type if declared by the applicant to be intended for such use.
2. Packages of any size that are not labeled or marked as is customary or required for retail sales and display are considered to be of the institutional type unless specifically declared to be retail by the applicant for inspection.
3. If the product is unpackaged, as on belts or in tote bins, or if the packaging does not indicate the intended use, it is considered to be retail type, and the retail type defective allowances apply. Such a lot, however, may be considered to be institutional type if so requested by the applicant.

3. Styles

a. Strips—This style should be designated as

Straight cut
Straight cut-shoestring
Crinkle cut

The cross-sectional dimensions of the strips are important to the buyer. Because of the nature of the product, these are not very uniform. Designate the cross sections, therefore, as "approximate" and to 1/8 inches—as approximately 5/8 × 5/8 inch, or 5/8 × 3/4 inch, etc. The cross-sectional dimension of crinkle cut strips are normally measured from "hill" to "valley.".

b. Slices, *Dices*, *Rissolé*, *Other*—See the chapter Frozen Vegetables and Product Description.

4. Length Designations (Applies Only to Strips)

Length in French fries is closely related to quality and value for many purposes. Extra long, for example, is usually considered a premium pack for institutional use. It is seldom packed for retail, since it presents difficulties in packaging in retail-size containers and often requires sizing of the uncut potatoes. Long is packed in both retail and institutional types and is often considered a premium pack for retail. Medium is the usual retail size.

With the exception of short lengths, which are specifically excluded from U.S. Grade A, the length of units is not considered to be a factor of quality under the U.S. standards. Short lengths may, however, be designated U.S. Grade A Short if the strips meet the other requirements of U.S. Grade A.

The lengths designated in the standards are intended to provide workable and much needed definitions for terms that are regularly used in trading.

Determining the length. The length designation may be determined readily by isolating the strips that are 3 inches in length or longer and those that are less than 2 inches in length. The percentages of 2 inches in length or longer and of 3 inches in length or longer can be readily calculated. Chips, slivers, pieces, and strips that are less than 1/2 inch in length are not considered in the total count.

See the USDA File Code 130-A-75 for the description and scale drawing of the Vegetable Strip Sizer, an effective device for sizing the strips.

The minimum equipment for inspecting frozen French fried potatoes is

1. Grading scale
2. Large flat trays
3. Ruler (size and length grading plate)
4. Percentage calculator
5. Authorized visual USDA Color Standards for Frozen French Fried Potatoes
6. Vegetable strip sizer
7. Oven of suitable type, or deep frying equipment

C. Preparation of the Sample

The factors of color and defects are partially evaluated before the product is heated. Often when a package is opened there is a film of frost on the units which masks the color, or if storage conditions have not been good there may be a crust of ice or a heavy coating of ice crystals. If there is any appreciable condition of frost, ice crystals, or icing in the sample, thaw until the

condition disappears to the extent that the color can be properly evaluated. Icing is usually not serious, but the thawing of the sample in the oven may add enough moisture to the potatoes that they are soggy when cooked and also cause an explosion when put into hot frying oil (see Texture).

The sample should be examined for color designation using the USDA Color Standards as a guide, as discussed under color.

VI. QUALITY EVALUATION

A. Grade Factors that Are Not Scored

1. Flavor

The flavor of French fried potatoes is affected by the conditions of the potatoes with respect to sugar or sunburn, by the condition of the fat or oil used, and, to a certain extent, by the variety of the potatoes, the type of soil, and climatic conditions; whether or not certain insecticides have been applied to the growing potatoes.

Good flavor is required in Grades A and A Short and at least reasonably good flavor in Grade B. Sweetness, bitterness, rancidity of oil, and pronounced scorched or caramelized flavor and odors are the usual reasons for lowering the evaluation of flavor from Good to only Reasonably good. Any definitely objectionable flavors or odors would be cause for lowering the grade of the product to Substandard. After the product has been heated in a suitable manner, taste it and smell it and classify its flavor as Good, Reasonably good, or Poor.

2. Color Designation of a Sample Unit

The exact color of good quality potatoes varies considerably because of varietal differences, physical differences, types of fat used, areas of production, and other causes. It also varies because of the amount of color change induced by the frying process. These values are important to buyers because certain markets and certain important customers have strong preferences as to the lightness or darkness of the brown coloring.

Two separate and distinct color determinations are required:

1. Classifying the fry color of the sample unit as to its value (that is, its lightness or darkness) in order to establish the proper fry color designations.
2. Evaluation and assigning the score points for color in compliance with the standards, giving consideration to color changes in the refried product.

Grade A, Good Color—27 to 30 points. This color is bright and typical of the product and meets the uniformity of fry color given for

No. 0—Extra Light
No. 1—Light
No. 2—Medium Light or
No. 3—Medium

and meets the uniformity of refry color given in the Re-Fry Color Range Guide.

Grade B, Reasonably Good Color—24 to 26 points (limiting rule). This color must be characteristic of French fried potatoes—not dull or off-color. It may exceed the fry color variation given for any of the USDA colors—including No. 4—dark. After heating, the variation in the refry color may exceed those indicated in the guide but may not seriously detract from the appearance of the product.

Substandard—0 to 23 points (limiting rule). Lots that darken quickly—before the interiors are cooked—or very irregular would fall into this classification.

B. Uniformity of Size and Symmetry

Uniformity of length of normal shaped strips is not considered under this factor. Consideration is given to the effect of any chips—as defined—on the appearance of the product and the percent by count of small pieces, slivers, and/or irregular pieces. In assigning score points be guided by the following:

Grade A

20 points—almost no chips, and/or (Strips) no more than 5 percent of small pieces, slivers, and/or irregular pieces (Other styles) almost perfect uniformity in size and shape of the units.

18 points—chips present but not to materially detract from appearance, and/or (Strips) more than 5 percent to 15 percent of small pieces, slivers, and/or irregular pieces. (Other styles) high degree of uniformity in the size and shape of the units.

19 points—by interpolation.

Grade B

17 points—chips present materially detract and/or (Strips) more than 15 percent to 20 percent small pieces, slivers, and/or irregular pieces (Other styles) reasonably uniform in size and shape.

16 points—chips present that approach serious appearance, and/or (Strips) more than 20 percent to 30 percent small pieces, slivers, and/or irregular pieces (Other styles) variation in the size and shape of the units detracting noticeably from the appearance of the product.

C. Defects

Defects are carefully defined in the standards as insignificant imperfections, minor defects, and major defects. Defectives are potato units affected with defects, as defined in the standards as minor defective or major defective. It is defectives rather than defects which are scored against.

1. Considerations

For each grade, three separate types of deficiencies are considered. While the principal consideration is major and minor defectives, three factors must be considered in assigning the scores for the sample units:

1. The total effect of all faults that might be present, whether specifically mentioned. This is the "overall clause." Among such are extraneous materials, insignificant imperfections, and carbon specks or defects (as defined), and obnoxious blemishes that are much worse in appearance than the usual major defects.
2. The effect of any carbon specks on the appearance of the product.
3. The allowances for minor and major defectives as specified in Tables 2 and 3 of the standards.

Table 2 Standards—All Styles Except Shoe Strings and Dices

RETAIL TYPE					
Grade	Point	Defective	Possible combinations of defectives		
A	20	Total	0–3	—	—
		Major	0	—	—
	19	Total	4–5	1–3	—
		Major	0	1	—
	18	Total	4–5	—	—
		Major	1	—	—
B	17	Total	6–9	6–9	2–5
		Major	0	1	2
	16	Total	6–9	—	—
		Major	2	—	—

INSTITUTIONAL TYPE						
Grade	Point	Defective	Possible combinations of defectives			
A	20	Total	0–6	1–4	—	—
		Major	0	1	—	—
	19	Total	7–18	5–18	2–12	3–8
		Major	0	1	2	3
	18	Total	13–18	9–18	4–18	—
		Major	2	3	4	—
B	17	Total	19–28	5–23	6–18	—
		Major	0–4	5	6	—
	16	Total	24–28	19–28	7–28	—
		Major	5	6	7–8	—

2. Defect Tables in the Standards

Defectives allowed in these tables are not averages. Sample units that fail the applicable requirement are allowable in the sample only as regular deviants.

3. Assigning the Score for Defects

1. Segregate the minor and major defectives in the sample unit and record them on the score sheet as (1) total (major and minor) and (2) major.
2. Assign a tentative score for defects as indicated by the following guide.
3. Adjust the score point if appropriate by giving consideration to the overall clause and the effect of any carbon specks present. This becomes the defect score for the sample unit.

Guide for assigning tentative score for defects—subject to adjustment for overall clause and for carbon specks.

D. Texture

Texture is evaluated within 3 minutes after heating the product as specified, and while it is well above room temperature.

Table 3 Standards—Shoestring, Strips, and Dices

RETAIL TYPE						
Grade	Point	Defective	Possible combinations of defectives			
A	20	Total	0–5	1–2	—	
		Major	0	1	—	
	19	Total	6–9	3–5	2–5	
		Major	0	1	2	
	18	Total	6–9	6–9	—	
		Major	2	1	—	
B	17	Total	10–18	3–15	4–8	
		Major	0–2	3	4	
	16	Total	16–18	9–18	5–18	
		Major	3	4	5	

INSTITUTIONAL TYPE						
Grade	Point	Defective	Possible combinations of defectives			
A	20	Total	0–10	1–8	—	—
		Major	0	1–2	—	—
	19	Total	11–28	9–28	3–21	5–18
		Major	0	1–2	3–4	5–6
	18	Total	22–28	19–28	7–28	—
		Major	3–4	5–6	7–8	—
B	17	Total	29–36	9–30	—	—
		Major	0–8	9–10	—	—
	16	Total	31–36	11–36	—	—
		Major	9–12	11–12	—	—

Groups are inclusive, i.e., $\frac{3-5}{1}$ means $\frac{3}{1}$, $\frac{4}{1}$, or $\frac{5}{1}\frac{\text{Total}}{\text{Major}}$.

E. Heating the Product

Oven method. The method of reheating specified in the standards is similar to that employed by the housewife. Crumpled foil is placed in the bottom of the pan in order to prevent excessive burning of the potatoes where they touch the metal pan. Fifteen minutes at 400 degrees is a minimum for most potatoes. The time depends on the size of the units, the sugar content, the type of oven (gas or electric), the number of samples in the oven, and how well it is ventilated. Trial runs are usually necessary to determine the proper time to cook any lot of potatoes in the available equipment. Potatoes are properly cooked when the interior of the largest units has lost the raw potato taste. This method should be used when it is obvious that the product is intended for home use and that cooking directions call for the oven method. Exceptions may be made when test runs have shown that the deep fat method (below) gives results comparable to the oven method on the particular potatoes.

Deep fat method. Frozen French fried potatoes prepared for institutional use usually have a lighter fry color than those prepared for the retail trade. This is because the institutions using these potatoes will give them a short fry in oil. This additional fry can be adjusted in time and temperature so that the finished French fries will have the desired color. This desired color may be

light or fairly dark depending upon the preference of the cooks. Also the directions on some retail packages provide for an additional cook in hot oil rather than an oven cook. For this reason, provision is made in the United States standards for heating the product by any other method that will give comparable results.

Deep fat frying is probably preferred for inspection use because of the speed with which the samples can be run. It should always be used where the product is light in color and/or obviously intended for institutional use. Where large numbers of samples are to be inspected, a deep fat fryer of the type marketed for household use and provided with an automatic heat control is very useful. If only an occasional sample is to be inspected, equally good results may be obtained by using a small stew pan with a wire dipper. With this equipment it is necessary to have an emersion thermometer capable of registering up to 600 degrees Fahrenheit. Also, new automatic frying pans can be obtained with heat control units.

Heat at least 100 units to determine the score for character. The temperature of the oil is very important. The temperature must be high during the entire refry time or the results will be in error. 100 units in a very large tank such as may be available for in-plant inspection would not lower the temperature significantly. With a quart or pint of oil only a few units can be fried at a time without lowering the oil temperature. Good texture varies somewhat with the varieties used and the area of production. It may vary from a somewhat cheeselike, very fine grained texture to a coarse-grained and almost powdery texture.

Usual variations from acceptable texture are:

Sogginess. As the name implies, this refers to a wet pasty or mushy condition loaded with either water or oil. It may be a basic characteristic of the potatoes, or it may be induced by frying at too low a temperature. Often only a portion of the potato becomes soggy. Both the amount of the unit affected and the degree of sogginess must be considered in estimating the effect on texture. Score the unit only if 50% of its length (or less if very objectionable) is so affected.

Hardness. Interior portions that are very firm, sometimes oily to the touch, and raw in taste even if well cooked. Often, as with sogginess, only a portion of a strip or slice is hard. Score such units only if 50% (or less if very objectionable) of its length is so affected.

Pull away. Interior portion of a strip that has withdrawn from the outer shell, voiding 1/3 of the cross-sectional area of a regular strip or 2/3 of the cross section of a shoestring.

Crisp outer surface. Really crisp outer surfaces is a texture fault in any grade. A slight crispness is expected in Grade A and the surfaces may be slightly hard or slightly tough in Grade B. Keep in mind that excessive cooking will increase the crispness of the outer surfaces.

Sugary ends. A unit that has a dark and often soft rubbery end, caused by excess sugar.

Excessive oiliness. For reasons that are not always explainable, an unusual amount of oil is sometimes retained by the fries. It is very objectionable to buyers as it affects the texture adversely. Excessive oiliness can often be detected by the feel of the units prior to the heating. If excessive oiliness does not disappear with normal preparation, lower the texture score to reflect this condition.

F. Score Points

The exact score points to assign requires careful preparation of the sample. Consider all the factors affecting texture and assign scores as indicated in the following guide:

Scoring procedure: heat 100 strips to determine the Texture score. The number of points deducted from a possible 30 points will depend on the overall excellence of the sample. Consideration must also be given for those units in a sample that have a soggy or hard texture, or show pull away, or have excessively oily outer surfaces. Sugary ends not serious enough to be

considered defects would fall into this category. The sample shall be practically free of such units to score in the Grade A range. Percentages ranging from 0% to 10% by count, depending on the seriousness of the defective units, are acceptable in this grade.

Prepared French fried potatoes that are scored 24 to 26 points for texture must be reasonably free from soggy or hard texture, pull away, or sugary ends, or those that do not have a crisp outer surface.

Score 26 points if there are 11 to 15% by count of these scorable units or if the units with slightly soggy or hard interior portions, or soft or slightly hard exterior surfaces, materially affect the overall appearance or eating quality of the product.

Score 25 points if there are 16 to 20% by count of the scoreable units and 24 points if there are 21 to 25% by count.

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Frozen Peas: Standard and Grade

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In the United States, two federal agencies have the responsibility to ensure that the canned vegetables in the market are safe and do not pose any economic fraud. The U.S. Food and Drug Administration (USFDA or FDA) issues regulations to achieve both goals. The U.S. Department of Agriculture (USDA) issues voluntary guide lines, in addition to achieving the same goals, aiming at facilitating commerce. The information in this chapter has been modified from such regulations and guidelines.

I. STANDARDIZED FROZEN PEAS: FDA REQUIREMENTS

Appendix B of this volume reproduces the USFDA requirements for standardized frozen peas.

II. FROZEN FIELD PEAS AND FROZEN BLACK-EYED PEAS: USDA STANDARDS FOR GRADES AND GRADING METHODS

While the FDA establishes the requirements for standardized frozen peas to assure the safety of the product and to avoid economic fraud, the USDA develops grade standards to supplement the goals of the FDA, that is, to facilitate commerce between the sellers and buyers of frozen peas.

Voluntary U.S. grade standards are issued under the authority of the Agricultural Marketing Act of 1946, which provides for the development of official U.S. grades to designate different levels of quality. These grade standards are available for use by producers, suppliers, buyers, and consumers. As in the case of other standards for grades of processed fruits and vegetables, these standards are designed to facilitate orderly marketing by providing a convenient basis for buying and selling, for establishing quality control programs, and for determining loan values.

The standards also serve as a basis for the inspection and grading of commodities by the Federal Inspection Service, the only agency authorized to approve the designation of U.S. grades as referenced in the standards, as provided under the Agricultural Marketing Act of 1946. This service, available as on-line (in-plant) or lot inspection and grading of all processed fruit and vegetable products, is offered to interested parties, upon application, on a fee-for-service basis.

The verification of some specific recommendations, requirements, or tolerances contained in the standards can be accomplished only by the use of on-line inspection procedures. In all instances, a grade can be assigned based on final product factors or characteristics.

In addition to the U.S. grade standards, grading manuals or instructions for inspection of several processed fruits and vegetables are available upon request for a nominal fee. These manuals or instructions contain detailed interpretations of the grade standards and provide step-by-step procedures for grading the product.

Grade standards are issued by the Department after careful consideration of all data and views submitted, and the Department welcomes suggestions that might aid in improving the standards in future revisions.

This chapter presents the USDA voluntary grade standards for frozen field peas and frozen black-eyed peas. The coverage is as follows:

III. 7 CFR 52.1661 PRODUCT DESCRIPTION

Frozen field peas and frozen black-eyed peas, called frozen peas in these standards, mean the frozen product prepared from clean, sound, fresh seed of proper maturity of the field pea plant (*Vigna sinensis*), by shelling, sorting, washing, blanching, and properly draining. The product is frozen and maintained at temperatures necessary for preservation. Frozen peas may contain succulent, unshelled pods (snaps) of the field pea plant or small sieve round type succulent pods of the green bean plant as an optional ingredient used as a garnish.

IV. 7 CFR 52.1662. STYLES

1. Frozen peas
2. Frozen peas with snaps

V. 7 CFR 52.1663. TYPES

A. Single Type

Frozen peas that have distinct similarities of color and shape for the type are not considered "mixed." Single types include, but are not limited to, the following:

1. Black-eyed peas or other similar varietal types, such as Purple-hull peas, that have a light colored skin, a definite eye (contrasting color around the hilum), and are bean shaped.
2. Crowder peas of various groups, such as Brown Crowder, that are nearly round in shape and have blunt or square ends.
3. Cream peas of various groups, including White Acre, that have a solid cream-colored skin and are generally bean shaped.
4. Field peas means any varietal group or type of the field pea plant that has similar color and shape characteristics and includes black-eye peas, Crowder peas, and Cream peas.

B. Mixed Type

Frozen peas that are a mixture of two or more distinct single varietal groups or are not distinguishable as a single varietal group shall be considered to be of the mixed type.

VI. 7 CFR 52.1664. DEFINITIONS OF TERMS

A. Acceptable Quality Level (AQL)

The maximum percent of defective units or the maximum number of defects per hundred units of product that, for the purpose of acceptance sampling, can be considered satisfactory as a process average.

B. Appearance

The overall appearance of a sample unit refers to its brightness and uniformity. The color of snaps in the "frozen peas with snaps" style is considered under the overall appearance.

1. Good Appearance

The sample unit has a bright and uniform overall appearance.

2. Reasonably Good Appearance

The sample unit has an overall appearance that may be dull.

C. Blemished

Blemished means discolored, spotted, or damaged by any means to the extent that the appearance or eating quality is materially affected.

D. Broken

Broken means that the skin or portions of the skin, the cotyledon or portions of the cotyledon, have become separated from the unit. Broken is not applicable to snaps in the style of frozen peas with snaps.

E. Character

Character refers to the tenderness of the frozen peas, including snaps.

1. Good Character

The units are tender and are practically uniform in texture and tenderness.

2. Reasonably Good Character

The units are reasonably tender and may be variable in texture and tenderness; and the cotyledons may be mealy or firm but not hard.

F. Color Defective

A unit that varies markedly from the color that is normally expected for the variety and grade.

G. Defect

Any nonconformance with a specified requirement.

H. Dissimilar Varieties

In single types only, peas that are markedly different varietal colors and/or shapes. "Dissimilar varieties" is not applicable to snaps in the style of frozen peas with snaps.

I. Harmless Extraneous Vegetable Material

1. In the Style of Frozen Peas

a. Class 1. Hulls or pieces of unshelled pods, leaves, small tender stems, or other similar vegetable material.

b. Class 2. Coarse, fibrous units of vegetable material that are harmless.

2. In the Style of Frozen Peas with Snaps

a. Class 1. Leaves, small tender stems, or other similar vegetable material, except snaps.

b. Class 2. Coarse, fibrous units of vegetable material that are harmless.

J. Flavor and Odor

1. Good Flavor and Odor

The product, after cooking, has a good, characteristic normal flavor and odor and is free from objectionable flavors and objectionable odors of any kind.

2. Reasonably Good Flavor and Odor

The product, after cooking, may be lacking in good flavor but is free from objectionable flavors and objectionable odors of any kind.

K. Grit

Sand, silt, or other earthy materials.

L. Sample

The number of sample units to be used for inspection of a lot.

M. Sample Unit

The amount of product specified to be used for inspection. It may be

1. The entire contents of a container
2. A portion of the contents of a container

3. A combination of the contents of two or more containers
4. A portion of unpacked product

N. Shriveled

A unit that is seriously wrinkled in appearance, including snaps.

O. Snap

A succulent, unshelled pod of the field pea or black-eyed pea plant or small sieve round type succulent pods of the green bean plant that should be able to pass through the openings of a No. 3 sieve.

P. Unit

Any individual frozen pea, or any individual succulent, unshelled pod.

VII. INSPECTIONAL CONSIDERATIONS WHEN USING THE DEFINITIONS

The USDA has provided some explanation for the above terms during the inspection of a processing establishment.

A. Overall Appearance

Judge the prerequisite quality factor of overall appearance on the basis of brightness and dullness. Uniformity of color is not required. Evaluate the color of snaps, in the style of frozen peas with snaps, under the prerequisite factor of overall appearance. Consider off-color snaps as to their effect on the overall appearance of the sample unit. Snaps should be green and succulent pods. Consider any snaps that possess colors that indicate advanced maturity of pods under the factor overall appearance.

B. Blemished

Green units of field shelled peas (mechanically harvested) often oxidize and turn brown if held too long before processing. When the units are noticeably discolored, classify as blemished.

Cowpea curculio damage to field peas may occur as visible holes eaten into the cotyledons or discoloration, commonly called weevil sting. Damage is either insignificant or a defect that is counted. It depends on the extent to which the damage is noticeable. Generally, classify units affected by larva holes or dark-colored stings as blemished. Slight discoloration is insignificant. Sometimes Crowder peas develop an objectionable condition during periods of excessive rainfall at harvest. The peas take on an extreme rusty-brown color. Classify this objectionable discoloration as blemished.

C. Broken

Mechanical harvesting increases loose skins and broken cotyledons. Some varietal types of field peas, especially cream peas, are more subject to mechanical damage than other varietal types.

Sprouted peas often occur in the sample unit. If the pea is damaged, noticeably, by sprouting, it and the sprout are classified as broken. Include detached sprouts (loose sprouts) with other broken material in the sample unit and weigh.

Determine broken peas on a weight basis. After making several weighings of broken peas, use estimation to judge the amount of broken peas in the sample unit. If the sample unit is borderline, actual weight is advised.

D. General Character

General character is a prerequisite quality factor. Use it as a "stopper" if a sample unit meets all other quality factors but is obviously processed from peas that are too mature for good quality. Character is not necessarily related to the number of color attributes. Some green peas are hard after cooking 40 minutes. Other sample units with few "green" peas are tender.

Peas. Mechanically harvested field peas normally contain some "seed-dry" peas. Allow for occasional seed-dry peas to avoid being overly critical. In "good character" any seed-dry peas should blend well with the overall palatability of the cooked sample unit. When excessive seed-dry peas are present in the sample unit, its character is grade B, or substandard, depending on the quantity and tenderness of the firm and hard peas.

Snaps. Immature, succulent pods are required as the garnish for frozen peas with snaps. Character is applicable to snaps. However, snaps do not have the same tenderness as pods of other legume plants, such as green beans. Make allowances for the natural characteristics of the field pea pods. Cooking procedure. It is not intended that each sample unit need be cooked for determination of character. Individual judgment should determine the number of sample units to cook. However, cook enough sample units to get a good cross section of character.

E. Harmless Extraneous Vegetable Material (HEVM)

General. Mechanically harvested peas contain large amounts of HEVM, principally pod and stem material. Shakers, air blasts, and water flotation equipment are used to remove most of this material. Hand-picking on the sorting belt is used for final HEVM cleanup. Without hand-picking, or sorting, the product will rarely make grade.

Insignificant HEVM. Consider small, tender, units of the placental part of the pod (connects the pea to the pod) insignificant.

HEVM that is counted. Each individual piece is one defect. Do not reassemble pieces to approximate one piece of pod or pod material.

Unstemmed snaps. In frozen peas with snaps, count each piece of unstemmed snap material as one class 1 HEVM defect. In frozen peas, count each unstemmed snap only once. The stem and pod are related defects and are not counted as two separate defects.

Frozen peas with snaps. If the sample fails the criteria for the style of frozen peas with snaps, don't recount pieces of pod material as HEVM. Consider the sample as failing the requirements for style only.

Hard, woody material. Count hard, woody material as harmful. Beware of handling objectional weed material that is not HEVM, such as foxtail seed heads.

Large units of HEVM. If an otherwise class 1 piece of HEVM is extremely objectionable because of its large size, count the unit as class 2 HEVM.

Other succulent vegetable material. Count other succulent vegetable material that detracts from the overall appearance of the sample unit, such as squash, carrots, or corn, as class 1 HEVM. In the absence of other class 1 HEVM, more of the alien vegetables are permitted. In the presence of other class 1 HEVM, less of the alien vegetables are permitted.

F. Shriveled

Field shelled peas lose moisture rapidly. The peas shrink in size. Once the peas are cleaned and placed in holding tanks, filled with water, they absorb moisture and swell to their original size. Do not count peas with slightly wrinkled skin as shriveled.

G. Snaps

Consider two or more parts of a split pod as one snap in counting snaps for determination of style. Reassemble the pods to their approximate original shape, or the shape of the predominant sized snap in the sample unit. Do not use this procedure for HEVM.

VIII. 7 CFR 52.1665. SAMPLE UNIT SIZE

Compliance with requirements for all factors of quality is based on the following sample unit sizes:

1. White Acre—5 ounces (141.75 grams)
2. All other types—10 ounces (283.5 grams)

IX. 7 CFR 52.1666. GRADES

A. U.S. Grade A Is the Quality of Frozen Peas That

1. Meets the Following Prerequisites

1. Has a good appearance
2. Has a good flavor and odor
3. Is practically free from grit
4. Has a good character
5. Weight of broken peas does not exceed 0.25 ounce (7.1 grams) for "White Acre" peas and does not exceed 0.5 ounce (14.2 grams) for all other types

2. Is within the Limits For Defects as Classified in Table 1 and Specified in Table 2

B. U.S. Grade B is the Quality of Frozen Peas That

1. Meets the Following Prerequisites:

1. Has a reasonably good appearance
2. Has a reasonably good flavor and odor
3. Is practically free from grit
4. Has a reasonably good character
5. Weight of broken peas does not exceed 0.5 ounce (14.2 grams) for "White Acre" peas and 1 ounce (28.35 grams) for all other types

Table 1 AQL's and Tolerances (Tol.) for Defects in Frozen Peas (Except "White Acre") Based on 700 Units of Product for 13 Sample Units, 700 × 13 = 9100 Units

Sample units × sample unit size			1 × 700	3 × 700	6 × 700	13 × 700	21 × 700	29 × 700
Units of product			700	2100	4200	9100	14,700	20,300
Defects	AQL	TOL						
						ACCEPTANCE		
GRADE A						NUMBERS		
Blemished	4.3	4.6	39	106	202	424	674	922
EVM (minor)	0.575	0.7	7	18	32	64	99	134
EVM (major)	0.218	0.3	3	8	14	27	41	55
Dissimilar varieties and shriveled units	3.7	4.0	34	92	176	367	582	796
Color defective[a]	9.9	10.4	83	231	450	950	1518	2083
Color defective[b]	16.4	17.0	131	372	728	1,550	2484	3416
						ACCEPTANCE		
GRADE B						NUMBERS		
Blemished	6.6	7.0	57	158	304	641	1022	1400
EVM (minor)	1.12	1.3	12	31	58	118	186	252
EVM (major)	0.486	0.6	6	15	28	55	85	115
Dissimilar varieties and shrivelled units	5.0	5.4	45	122	234	490	780	1068

[a]For black-eyed peas, cream peas, field peas, and mixed types only.
[b]For crowder peas only.

Table 2 AQL's and Tolerances (Tol.) for Defects in "White Acre" Frozen Peas Based on 1400 Units of Product for 13 Sample Units, 1400 × 13 = 18200 Units

Sample units × sample unit size			1 × 1400	3 × 1400	6 × 1400	13 × 1400	21 × 1400	29 × 1400
Units of product			1400	4200	8400	18,200	29,400	40,600
Defects	AQL	TOL						
						ACCEPTANCE		
GRADE A						NUMBERS		
Blemished	2.13	2.3	39	105	201	4200	667	913
EVM (minor)	0.297	0.36	7	18	33	66	102	138
EVM (major)	0.1	0.14	3	7	13	25	38	51
Dissimilar varieties and shriveled units	1.84	2.0	34	92	175	365	579	792
Color defective	4.9	5.2	82	229	445	941	1503	2063
GRADE B						ACCEPTANCE		
						NUMBERS		
Blemished	3.3	3.5	57	158	304	641	1022	1400
EVM (minor)	0.548	0.64	12	31	57	116	182	247
EVM (major)	0.233	0.29	6	15	27	53	82	110
Dissimilar varieties and Shriveled units	2.5	2.7	45	122	234	490	780	1068

2. **Is within the Limits For Defects as Classified in Table 1 and Specified in Table 2**

C. Substandard is the Quality of Frozen Peas That Fail to Meet the Requirements For U.S. Grade B

X. 7 CFR 52.1667. FACTORS OF QUALITY

A. The Grade of a Sample of Frozen Peas Is Based on Compliance with the Prerequisites Specified in 7 CFR 52.1666 and with Limits for the Following Quality Factors

1. Dissimilar varieties and shriveled units
2. Harmless extraneous vegetable material
3. Blemished units
4. Color defectives

XI. 7 CFR 52.1668. CLASSIFICATION OF DEFECTS

See Tables 1 and 2.

XII. 7 CFR 52.1669. SAMPLE SIZE

The sample size used to determine whether the requirements of these standards are met shall be as specified in the sampling plans and procedures in the Regulations Governing Inspection and Certification of Processed Fruits and Vegetables, Processed Products Thereof, and Certain Other Processed Products (7 CFR 52.1 through 52.83).

XIII. 7 CFR 52.1670. ACCEPTANCE CRITERIA

A. Quality Factors

A lot of frozen field peas and black-eyed peas is considered as meeting the requirements for quality if

1. The prerequisites specified in 7 CFR 52.1666 are met.
2. The Acceptance Numbers in Table 1 or 2 in 7 CFR 52.1667, as applicable, are not exceeded.

B. Single Sample Unit

Each unofficial sample unit submitted for quality evaluation will be treated individually and is considered as meeting requirements for quality and style if

1. The prerequisites specified in 7 CFR 52.1666 are met.
2. The Acceptable Quality Levels (AQL's) in Tables 1 and 2 in 7 CFR 52.1667, as applicable, are not exceeded.

21
Dehydrated Vegetables: Principles and Systems

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I. INTRODUCTION

Dehydration is perhaps one of the most effective means to extend the shelf life of perishable foods. The main purpose of dehydration in preserving foods is to remove moisture so that the water activity of the dehydrated product is low enough (e.g., $a_w < 0.6$) to stop spoilage and the growth of pathogenic microorganisms and to reduce other deterioration reactions. Dehydration is also used in combination with other hurdles, such as low pH and preservatives, to extend the shelf life of foods. Dehydration significantly reduces the costs of transportation and storage, because of the significantly reduced weight and volume of the dehydrated products and because the products do not require refrigeration. In addition, dehydration is an effective method to prepare convenient food ingredients for use in products such as dry soup mixes, frozen entrees, baby foods, and dairy products, or directly as seasoning blends (1).

Sun drying has been used since ancient times to produce dehydrated foods. This method is inexpensive, but it relies on good weather and requires long drying times. Modern drying methods have been developed to shorten drying times, improve product quality, and allow for better process control. These methods vary from relatively expensive freeze-drying, which is suited for heat-sensitive and high-value products, to hot air tunnel drying, designed for the mass production of less expensive products. Today there are many options among which to choose when designing a commercial dehydration process for vegetables. Appropriate selection among these processes depends upon desired attributes of the end products, convenient forms of energy supply at the processing site, types of raw materials used for drying, and capital and operational costs of these drying systems, among other considerations.

In spite of the different physical processes used in various drying methods, the underlying principles are very similar, with few exceptions. This chapter presents basic principles that govern most drying methods and the resulting quality of dehydrated products. It also provides a general description of most commonly used drying methods for dehydration of vegetables. In this chapter "dehydration" and "drying" are used interchangeably to describe processes that remove most moisture from food products.

II. DRYING FUNDAMENTALS

This section presents the major factors considered in the design and operation of a drying process: (a) properties of heated air in the drying processes; (b) properties of moisture in foods associated with different drying processes and their effect on the shelf life of dried products; (c) heat and mass transfer characteristics in foods during heated air drying processes.

A. Properties of Air–Water Vapor Mixture in Drying

Heated air is used as the source of sensible heat (that raises product temperature) and latent heat (that is used in water evaporation in foods) in many drying systems, including spray dryers and tunnel dryers. Heated air also serves as the carrier of the evaporated moisture in most drying systems, e.g., spray, tunnel, and drum dryers.

The approximate composition of dry air by volume is nitrogen, 78.084%; oxygen, 20.9476%; argon, 0.934%; carbon dioxide, 0.0314%; and the remainder consists of neon, helium, methane, sulfur dioxide, hydrogen, and other minor components such as krypton, xenon, and ozone (2). The weighed average molecular weight for dry air is 28.9645. Moist air experienced in our daily life and in drying processes is a binary mixture of dry air and water vapor. During drying operations, temperature and the amount of water vapor in the air change sharply owing to heat and moisture transfer between the air and the foods. The properties of the air–water vapor mixture in those systems, to a large extent, determine the drying efficiency and process control. It is, therefore, desirable to understand the fundamental characteristics of the air–water vapor mixture or moist air related to hot air drying processes. Psychrometry is the study of the properties of moist air at different temperatures and saturation levels. A detailed treatment of this subject can be found elsewhere (2–4). We will introduce here only briefly the most important properties of moist air relevant to drying processes.

1. Definitions

The total pressure of moist air, P (Pa), is the sum of the partial pressure of dry air, P_a (Pa), and the partial pressure of water vapor, P_w (Pa):

$$P = P_a + P_w \tag{1}$$

where $P_a = n_a RT/V$, $P_w = n_w RT/V$, n_a is the number of moles of dry air, and n_w is the number of moles of water vapor. R is the universal gas constant [8.314 J/(mole K)], T is the absolute temperature (K), and V is the total mixture volume (m^3).

The maximum partial pressure of water vapor (designated as P_{ws}) at a given temperature corresponds to the condition where the air is saturated with water vapor. The maximum amount of water vapor in moist air increases with temperature.

The humidity ratio (or specific humidity) H is defined as the ratio of the mass of water vapor, m_w, to the mass of dry air, m_a:

$$H = \frac{m_w}{m_a} = \frac{MW_w}{MW_a}\frac{P_w}{P - P_w} = 0.622\frac{P_w}{P - P_w} \tag{2}$$

where MW_w is the molecular weight of water (18.01534) and MW_a is the molecular weight of dry air (=28.9645). At saturation,

$$H_s = \frac{m_{ws}}{m_a} = 0.622\frac{P_{ws}}{P - P_{ws}} \tag{3}$$

The relative humidity RH is defined as the ratio of the partial pressure of water vapor in moist air, P_w, and the partial pressure of saturated water vapor, P_{ws}, at a given temperature:

$$RH(\%) = \frac{P_w}{P_{ws}} \times 100\% \tag{4}$$

From this definition, $RH = 100\%$ when the air is saturated with water vapor at a given temperature. This moist air cannot take on further moisture.

The wet-bulb temperature T_{wb} (°C) is the dynamic equilibrium temperature attained by a water surface when the rate of heat transfer to the surface by moving air equals the latent heat of water evaporation at this surface. The wet-bulb temperature of moist air is often measured with a temperature sensor with a wet wig wrapping around the sensing tip and with adequate airflow over the tip. The dry-bulb temperature is the temperature measured by a temperature sensor.

The dew point temperature of a moist air is the temperature at which water vapor starts to condense when this air is gradually cooled from its original temperature.

Other properties of moist air include specific volume (m^3/kg dry air) and enthalpy (relative energy content in J/kg dry air).

2. Use of a Psychrometric Chart in Evaluating Drying Processes

The relationships among several important properties of moist air are provided graphically by psychrometric charts (Fig. 1) (5). A point in the chart represents the state of the moist air. If any two properties for the air are given, the other properties can be readily determined (Figs. 1, 2). A psychrometric chart is useful in the design and evaluation of a heated air drying process.

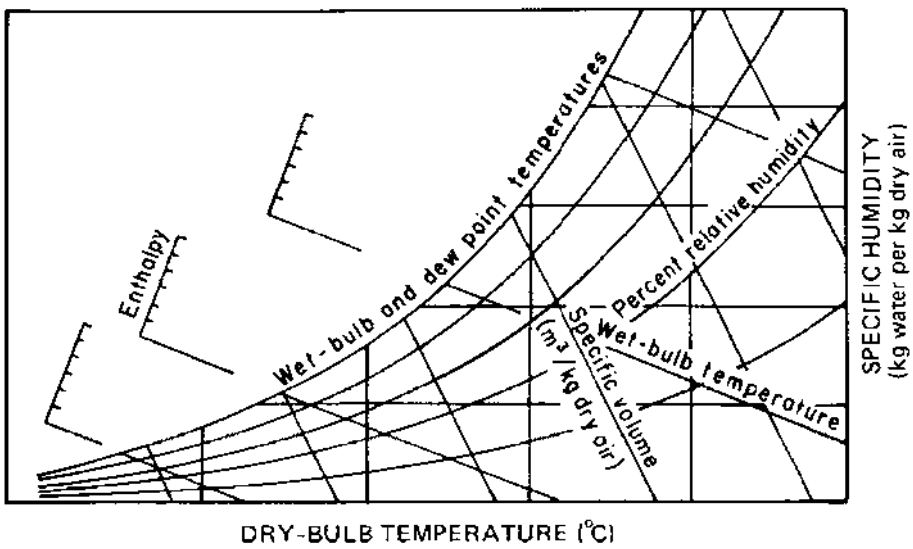


Figure 1 A skeleton psychrometric chart. (From Ref. 5.)

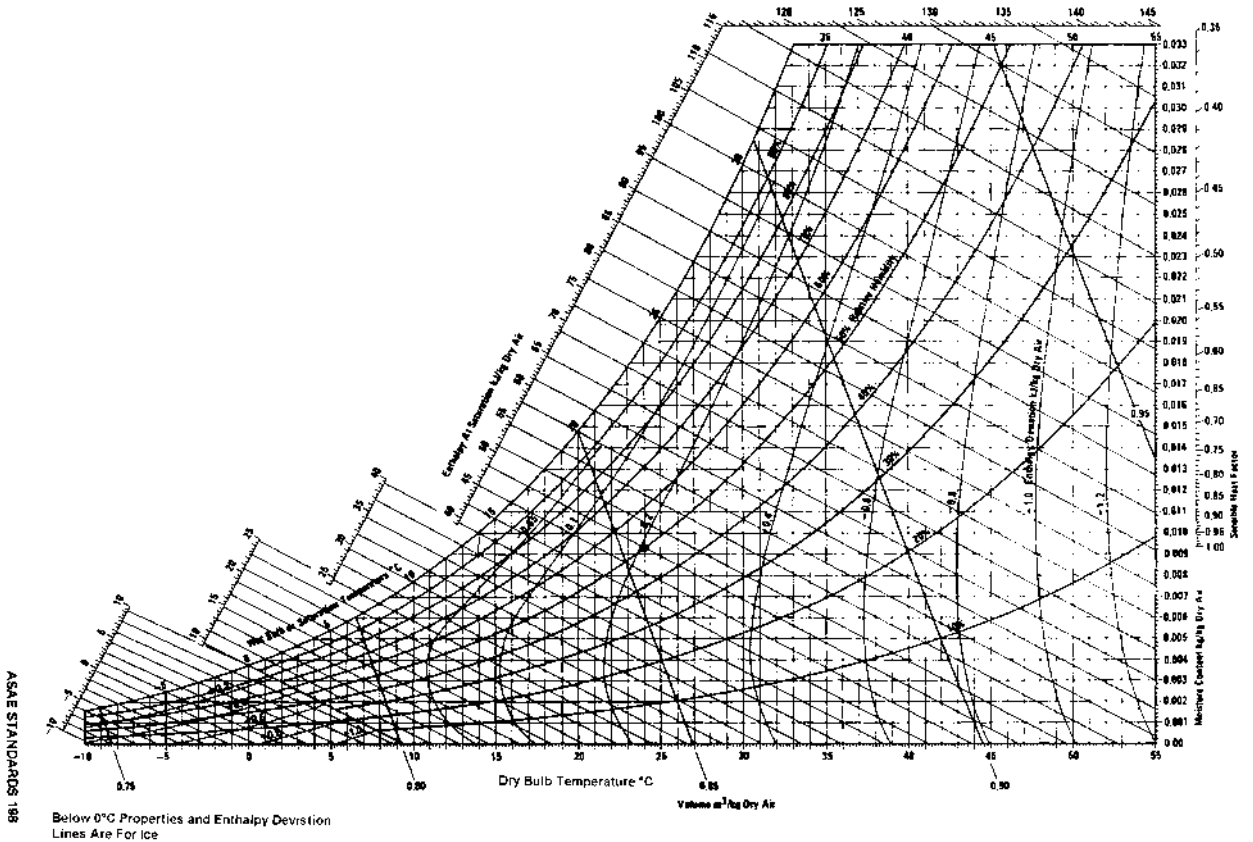


Figure 2 Psychrometric chart at one atmospheric pressure. (From Ref. 6.)

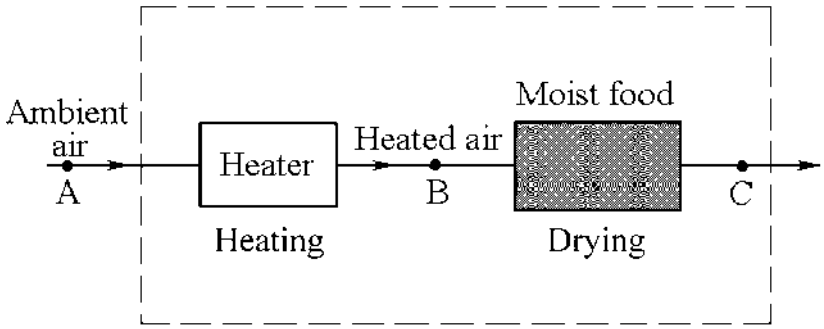


Figure 3 A schematic diagram of a hot air dryer.

A schematic presentation of a generic heated air dryer is presented in Fig. 3. In general, an ambient air is heated before being brought into contact with foods to remove moisture. The change of the air properties in this drying system can be studied with the help of a phycrometric chart in two steps: heating and drying.

Heating: when the air (i.e., at point A in Figs. 3, 4) passes through the heater, no moisture is lost or gained, and the specific humidity stays constant. Therefore a heating (and cooling) process is represented by a content humidity line. As a result of the heating, the dry-bulb temperature of the air increases, and the point representing the condition of the air moves along the constant humidity line to the right of the chart (i.e., indicated by point B in Fig. 4). As a result, the temperature and energy content (enthalpy) of the air are increased and the relative humidity is reduced.

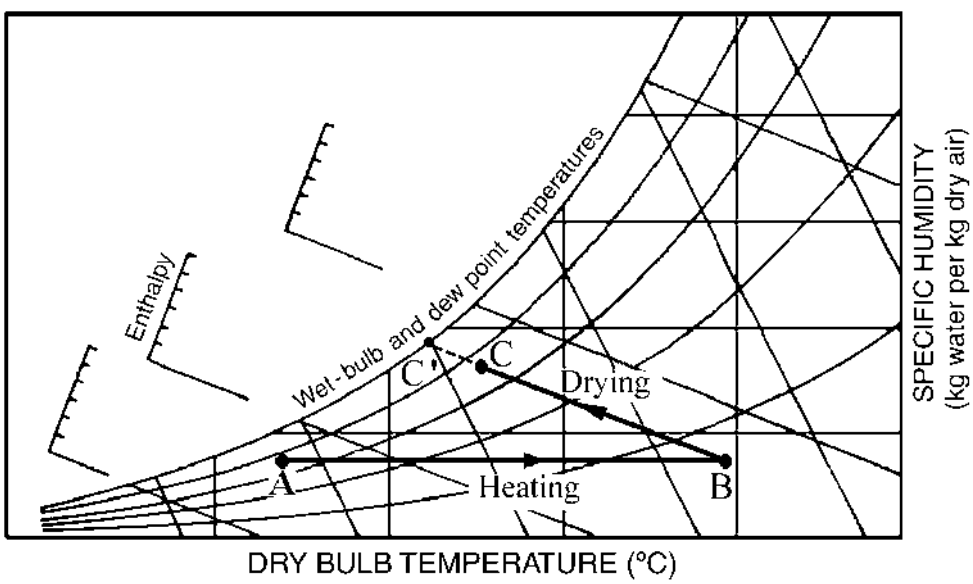


Figure 4 Heating and drying processes presented in a psychrometric chart. (From Ref. 5.)

Drying: After leaving the heater, the air passes through a bed of moist foods (e.g., in a tunnel dryer) or is mixed with moist food particles (e.g., in a spray dryer) (Fig. 3). The air gives up sensible heat (therefore decreasing the dry-bulb temperature) that is used to evaporate water in foods. The point representing the condition of the moist air in this process follows an adiabatic saturation line (from B to C in Fig. 4). That is, the energy content of the moist air is constant, while the sensible heat is exchanged for the latent heat of evaporated water. Both the relative humidity and the humidity ratio of the air increase. If the amount of air is inadequate, or the drying bed is too deep, the air may become saturated with water vapor and the point C moves to C′ in Fig. 4. Any drop of temperature beyond the saturation point causes condensation.

During the drying of moist food, evaporation of water at the surface of the food maintains the product temperature at approximately the web-bulb temperature of the heated air, until most of the free water is removed. In spray drying, for example, the heated air enters the dryer at 150–300°C, but evaporative cooling maintains the product temperature at 40–50°C when the food droplets are high in free water (7). This helps reduce thermal degradation.

The process lines presented in Fig. 4 can be used to determine the minimum airflow rate needed to prevent condensation, to select the size of the heater, and to estimate product temperature, air temperature, and relative humidity during drying with heated air.

B. Equilibrium Moisture Content

1. Definitions

The moisture content indicates the total amount of water in a food. The value of the moisture content as a percentage is often expressed on one of two bases: wet basis (wb) and dry basis (db).

The moisture content on a wet basis is defined as

$$MC_{\text{wb}}(\%) = \frac{\text{mass of water}}{\text{total mass of food}} \times 100\% = \frac{\text{mass of water}}{\text{mass of dry solids} + \text{mass of water}} \times 100\% \tag{5}$$

The moisture content on a wet basis is often used in the food industry because it represents the percentage of water in a moist food ($0 \leq MC_{\text{wb}} \leq 100\%$), and its meaning is easy to appreciate.

The moisture content on a dry basis is defined as

$$MC_{\text{db}}(\%) = \frac{\text{mass of water}}{\text{mass of dry solids}} \times 100\% \tag{6}$$

In moist products, such as fresh vegetables, the mass of water can be 3 to 5 times the mass of dry solids, and MC_{db}, therefore, varies between 300 to 500%. Moisture content on a dry basis is often used in the drying engineering literature, because the mass of dry matter in foods remains constant throughout a drying process. The derivation of MC_{db} directly leads to an important property in evaluating a drying system—the drying rate.

The moisture contents on a wet basis and on a dry basis can be converted to each other by

$$MC_{\text{db}}(\%) = \frac{MC_{\text{wb}}(\%)}{1 - MC_{\text{wb}}(\%)/100} \tag{7}$$

$$MC_{\text{wb}}(\%) = \frac{MC_{\text{db}}(\%)}{1 + MC_{\text{db}}(\%)/100} \tag{8}$$

The equilibrium moisture content of a food represents the ultimate moisture content that this product will reach when it is fully exposed to air of fixed temperature and relative humidity for an extended period of time under an ideal condition in which no chemical or microbiological action takes place. At this moisture content, a thermodynamic equilibrium is established between the air and the food, and the partial vapor pressure (more strictly, chemical potential) of water vapor in the air equals the partial pressure of the moisture in the foods. A food has a higher equilibrium moisture content when exposed to air of higher relative humidity at a given temperature.

A curve representing the relationship between equilibrium moisture content and relative humidity of the air is commonly referred to as an isotherm (Fig. 5) (8). In general, the equilibrium moisture content of a food decreases with increasing temperature (Fig. 5).

2. Effect of Equilibrium Moisture Content on Drying Rates

The equilibrium moisture content determines the moisture content that a food can finally reach for a given dry air condition. It is also an important factor that determines the rate of drying (Fig. 6). The larger the differences between the moisture content of the food and the equilibrium moisture content, the greater the drying rate (the slope of the curves in Fig. 6). When the moisture content of the food approaches the equilibrium moisture content, little or no drying takes place (Fig. 6). This is one of the reasons why heated air with much reduced relative humidity (e.g., represented by point B in Fig. 4) and low corresponding food equilibrium moisture content is used to speed

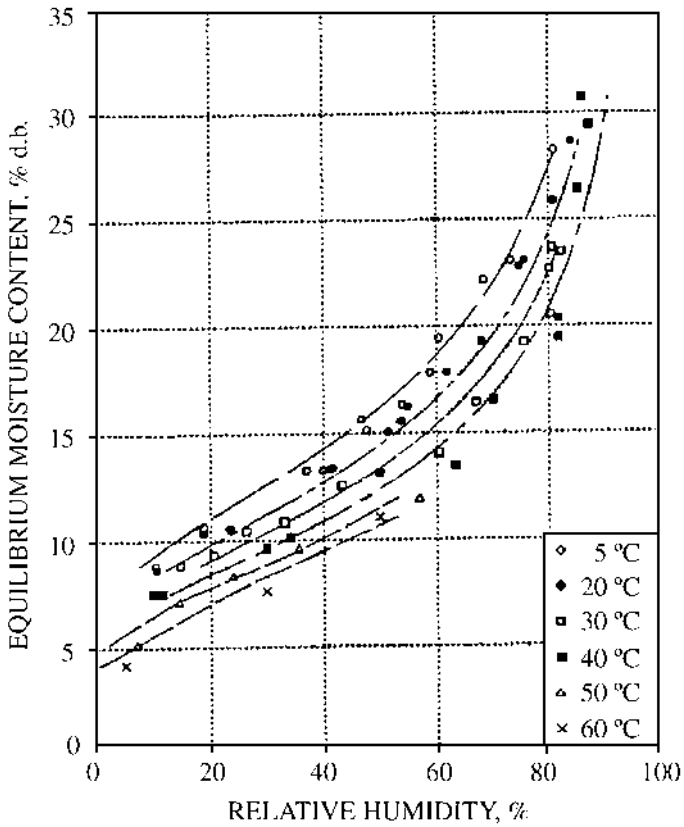


Figure 5 A desorption isotherm for lentils at six different temperatures. (From Ref. 8.)

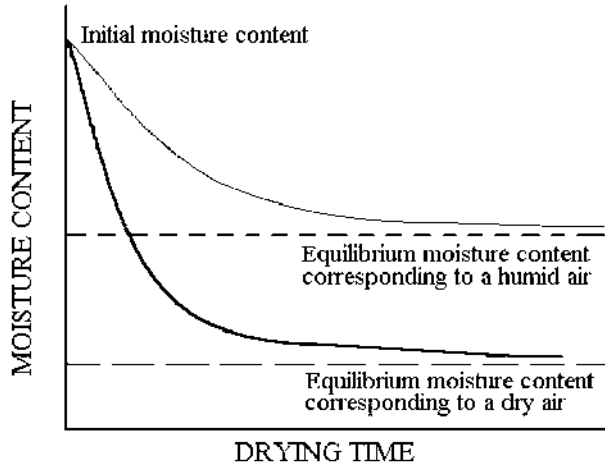


Figure 6 Drying curves of the same food as influenced by two equilibrium moisture contents.

up drying processes and to obtain low moisture dehydrated foods. As will be discussed later, increasing temperature also sharply increases moisture diffusivity within foods (often following an Arrhenius relationship), which in turn helps increase drying rates and reduce drying times.

3. Measurement of Equilibrium Moisture Content

The equilibrium moisture content of a food is often determined in experiments by placing food samples for long periods of time in a closed environment of a stable temperature and relative humidity. A large range of stable relative humidities can be provided in the head space of selected saturated salt solutions in enclosures over a large temperature range (9). Moist food samples can be used for those tests in which the samples lose moisture (desorption) to reach the equilibrium moisture contents. Or conversely, dehydrated samples can be used so that the samples gain moisture (adsorption) to reach the equilibrium moisture contents. For many foods, the equilibrium moisture content of the food attained through desorption is lower than that attained through adsorption for a given relative humidity. This phenomenon is referred to as hysteresis (Fig. 7). The extent of the difference depends upon food composition. For dehydration, we are often concerned with desorption isotherms of foods.

Experimental results on equilibrium contents of many vegetables, e.g., celery, horseradish, tomato, and sunflower, have been reported in the literature, and empirical and semiempirical equations were also developed to describe isotherm relationships. Detailed reviews on the subject of isotherms and hysteresis can be found elsewhere (10–13), and a comprehensive collection of experimental data for agricultural produce is provided in ASAE Standard D245.5 (13).

C. Water Activity

1. Definition

One of the most important purposes of dehydration is to discourage the growth of microorganisms and other deteriorative biochemical reactions by removing excess water. In moist foods, however, not all the water is available for those reactions, because some is tightly bound to food solids. Water activity, a_w, is an effective measure of the availability of water in a food system. It is defined

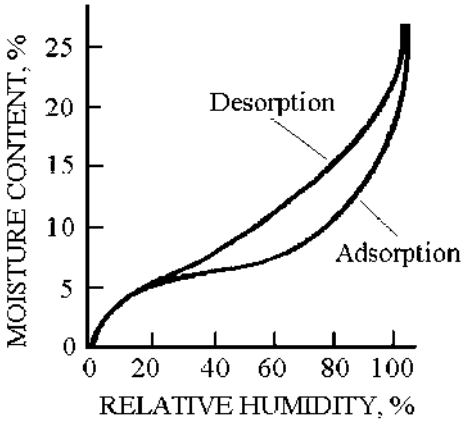


Figure 7 Hysteresis shown by the difference between the isotherm of a food for desorption and for adsorption.

as the ratio of the vapor pressure in food and the saturated vapor pressure of water at the same temperature:

$$a_w = \frac{P_w}{P_{ws}} \tag{9}$$

Equation 9 resembles Eq. 4 for relative humidity, except that water activity is expressed in decimal values between 0 and 1, whereas relative humidity is expressed in percentage. In fact, the water activity of a food equals the relative humidity (*RH* divided by 100) of the air in equilibrium with the product. This relative humidity is commonly referred to as the equilibrium relative humidity of a food at a given temperature. Thus an isotherm describing the relationship between food moisture content and relative humidity at an equilibrium state also describes the relationship between food moisture content and its water activity. As shown in Fig. 5, for a given moisture content, the higher the temperature, the greater the water activity.

Water molecules have a strong affiliation to polar sites of food molecules, such as the hydroxyl groups of polysaccharides, carbonyl, and amino groups of proteins, as a result of hydrogen bonding. The amount of bound water and the degree of association between the bound water and the solid matter thus depends upon food composition. In general, foods high in protein, starch, and high-molecular-weight polymers have lower water activities than those high in fat, soluble solids, and sugars at the same moisture content. Water activities of selected vegetables and root crops are listed in Table 1.

2. Effect of Water Activity on Microbial Safety and Biochemical Reactions

Free water and some of the loosely bound water in foods serve as solvents or reactants, increasing the mobility of reactants/nutrients in biochemical reactions, and helping maintain enzyme conformation. Reducing water activity through dehydration hinders enzymatic activity, hydrolytic reactions, nonenzymatic browning, and lipid oxidation (Fig. 8). Most importantly, reducing water activity prevents microbial growth in foods during storage. Bacteria growth is mostly inhibited at $a_w < 0.9$, yeast at $a_w < 0.8$, and molds at $a_w < 0.7$. Almost all microbial activities are inhibited below $a_w = 0.6$. Therefore target water activities for dehydrated products are below 0.6. The moisture content of the foods corresponding to $a_w = 0.6$ can be determined from isotherms. For example, from Fig. 5 the moisture content, *MC*, of lentil corresponding to $a_w = 0.6$ (or

Table 1 Water Activities of Selected Vegetables, Nuts, and Root Crops

Product	Moisture content % (db)	a_w	Temperature (°C)
Almonds	10	0.38	30
	15	0.73	
	20	0.88	
Celery	10	0.43	25
	15	0.59	
	20	0.67	
Cocoa	5	0.1	25
	10	0.34	
	15	0.60	
	20	0.77	
Horseradish	10	0.56	24
	15	0.65	
	20	0.74	
Onion	10	0.40	27
	20	0.62	
	30	0.74	
Potato	5	0.12	36
	10	0.47	
	15	0.69	
Potato starch	15	0.39	30
	20	0.69	
	23	0.81	
Sugarbeet root	10	0.46	20
	15	0.57	
	20	0.66	
Tapioca	5	0.14	25
	10	0.33	
	15	0.60	
Tomato	10	0.44	27
	20	0.61	
	30	0.69	

Source: Adapted from Ref. (10).

equilibrium relative humidity = 60%) at 20°C is 17% on a dry basis (db) and 14.5% on a wet basis (wb). Therefore to avoid spoilage during lengthy storage at room temperature, lentils should be dried to less than 14.5% moisture content (wb).

It is should be noted that dehydrated foods with very low water activities are susceptible to lipid oxidation owing to the action of free radicals (Fig. 8) (14,15). Lipid-containing dehydrated food products at low water activities are therefore often stored in good oxygen barrier packages (vacuum packaged, flushed with N_2, or packaged with O_2 scavengers) to reduce the development of off-flavors due to lipid oxidation.

3. Measurement of Water Activity

Water activity meters are available from commercial suppliers. In water activity measurement, a food sample (usually in a powder form to reduce measurement times) is placed in a small enclosed sample chamber and brought to an equilibrium state by internal air circulation. The relative

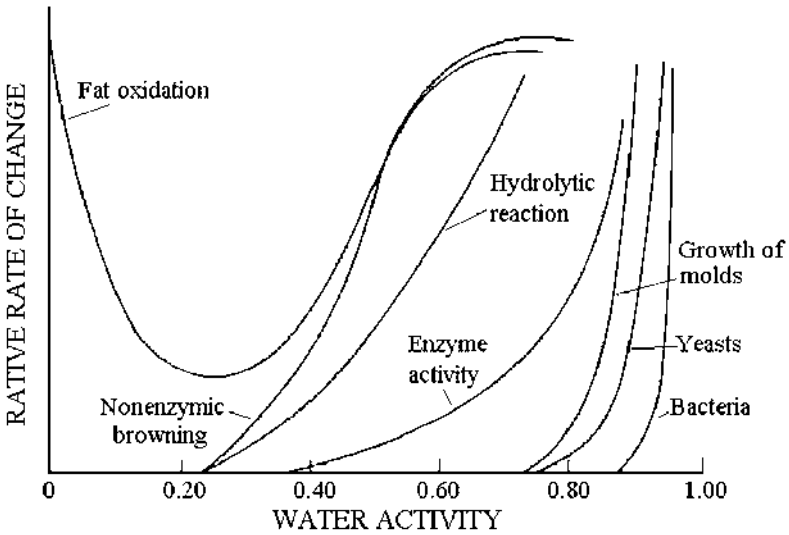


Figure 8 Influence of water activity on chemical and microbiological changes in foods.(From Ref. 14.)

humidity of the headspace is measured and reported as the water activity of the food at the indicated temperature. The most accurate commercial water activity meters, such as the AquaLab water activity meter in Fig. 9, use a chilled-mirror dew point temperature sensor and an accurate dry-bulb temperature sensor to determine the relative humidity of the headspace via a pre-programmed psychrometric relationship. These meters can give an accuracy of ± 0.003 over an a_w range of 0.03 to 1.0 (16). The measurement time for a sample is typically less than 5 minutes.

Figure 9 AQUA LAB water activity meter. (Courtesy of Decagon Devices, Pullman, WA.)

Figure 10 Handheld water activity meter. (Courtesy of Decagon Devices, Pullman, WA.)

Inexpensive handheld water activity meters that use less accurate relative humidity sensors are also available commercially for quick quality assurance examination for dehydrated products (Fig. 10).

D. Heat and Mass Transfer in Drying

1. Experimental Drying Curves

During drying with heated air of constant temperature and relative humidity, the moisture content of a product changes with drying time until it reaches the equilibrium moisture content of the food. A typical experimental drying curve, showing the change of moisture content with time, is presented in Fig. 11A. The associated rate of moisture change (time derivation of the drying curve) vs. time and vs. moisture content is shown in Figs. 11B and 11C, respectively. A typical product temperature curve is shown in Fig. 11D. These curves demonstrate that a drying process can be divided into several periods: heating, constant rate, and falling rate drying periods.

a. Heating and Constant Drying Rate Periods At the start of a drying process, a large portion of the thermal energy transferred to the product from the air is used to raise product temperature until it reaches the wet bulb temperature of the drying air, provided that the air movement over the product surface is adequate (Fig. 11D). The drying rates increase as product temperature rises (between point A and B in Fig. 11B). After reaching point B, the thermal energy from the heated air is used almost exclusively to evaporate free moisture in foods. The drying is rapid (B–C in Fig. 11A), and the drying rate is constant (B–C in Fig. 11B). The predominant factor that controls the drying rate in the constant drying rate period is the heat transfer from the air to the product, which can be increased to a certain extent by increasing airflow. The length of the constant rate drying period and the moisture content corresponding to point C in Figs. 11A,B are not intrinsic characteristics of the material being dried. They depend upon the conditions of the drying air (i.e., air temperature, relative humidity, and flow rate) and the raw materials (i.e., initial moisture content, size, shape, and structures). Many drying processes may not have a distinctive constant drying rate period.

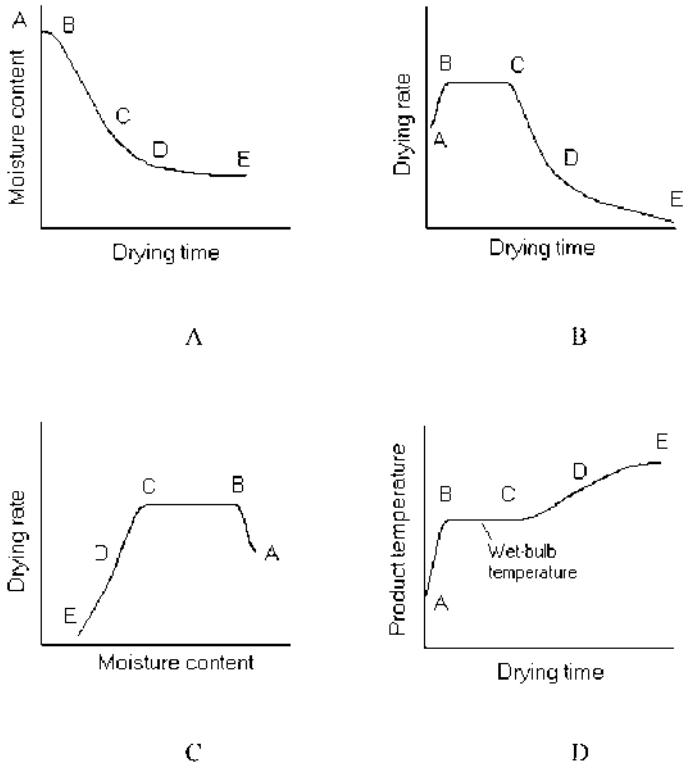


Figure 11 Drying curve (A), corresponding drying rate vs. drying time (B), drying rate vs. moisture content (C), and product temperature vs. drying time (D).

b. Falling Rate Drying Periods After removing surface and easily accessible free water, the drying rate is significantly reduced (C–E in Fig. 11A), and product temperature increases above the wet-bulb temperature to approach the dry-bulb temperature of the air (C–E in Fig. 11D). The migration of moisture within the product gradually dominates the drying process. Moisture migration decreases sharply with reducing moisture content (17). The drying process, therefore, goes through so-called falling rate periods (starting from point C in Fig. 11A,B,C). As drying progresses, the heat transfer is further hindered by the dried (and often porous) surface portion of the product. Moisture evaporation and migration become more difficult as a larger portion of the remaining water is bound water. A hygroscopic material may go through more than one falling rate drying period.

c. Effect of Different Drying Rates on Drying Process Heated air drying in the constant rate drying periods is energy efficient and takes relatively short times to complete. But in commercial drying operations, the major part of the total drying time is used in the falling rate periods to remove final moisture and to bring the product to its desired water activity (normally $a_w < 0.6$). Heated air drying methods are inefficient in energy use and can be very time-consuming in the falling rate periods. Because the drying process is determined by internal moisture migration, changing airflow velocity over the product beyond a certain limit can do little to increase drying rates. Using a low relative humidity air, can increase the moisture gradient from the interior to the surface and reduce drying times. An even more effective means to reduce drying time during the falling rate drying periods is to use air at a high temperature. High product temperature sharply increases the moisture diffusion coefficient (17). Using a high air temperature

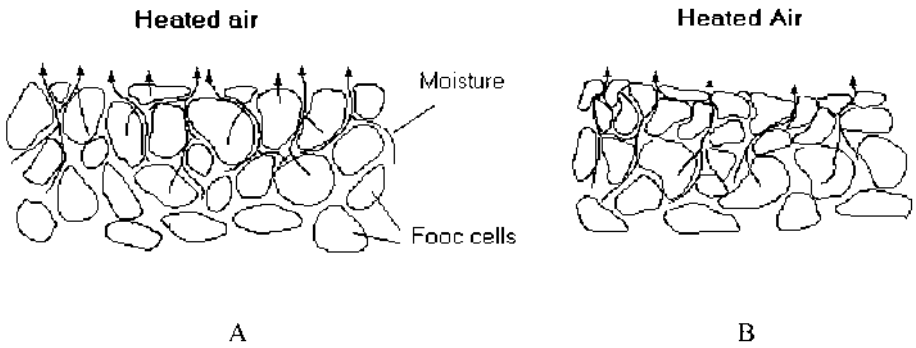


Figure 12 Movement of moisture in vegetables at an initial drying stage (A). Case hardening hinders moisture migration (B).

also results in a high heat transfer to the product interior, where moisture evaporation takes place after the product surface is dried. High-temperature drying, however, may cause undesirable quality changes.

Case-hardening is a phenomenon commonly observed in heated air drying of food materials and is closely associated with drying rates. This phenomenon is illustrated in Fig. 12. In the initial stage of drying, moisture evaporates rapidly at the product surface, creating a moisture gradient that drives interior moisture to move to the product surface (Fig. 12A). However, a too rapid drying may deplete the surface moisture at a rate far exceeding the supply of moisture from the food interior. The plant cells at the product surface wither, creating a dry and hard skin that significantly hinders moisture transfer in further drying (Fig. 12B). Significant case-hardening may also result in the development of mechanical stresses (e.g., tensile stresses at the surface and compression stresses at the interior) in foods, which may cause cracking and reduce product quality. Often, a tempering period between two or three drying stages helps reduce total drying times, improve product quality, and increase energy efficiency.

2. Predictive Models for Drying Times

In hot air drying, the only source of thermal energy used for raising product temperature and for water evaporation is the heated air. Therefore convective heating is the predominant means for the heat transfer. The rate of heat transfer, Q (kW/kg), can be calculated by

$$Q = Ah(T_{\text{air}} - T_{\text{food}}) \tag{10}$$

where h (kW/m^{2}K) is surface heat transfer coefficient, A is total product surface area (m^2/kg dry matter), and T_{air} and T_{food} (°C) are air and the product surface temperatures, respectively.

a. Constant Rate Drying Periods In the constant drying rate period, the thermal energy from the heated air is exclusively used for water evaporation. That is,

$$Q = -\lambda M_{\text{d}} \frac{dMC_{\text{db}}}{dt} \tag{11}$$

where λ is the latent heat of water vaporization (kJ/kg), M_{d} is dry matter (kg), and t is time (s). Combining Eqs. (10) and (11) yields

$$-\lambda M_{\text{d}} \frac{dMC_{\text{db}}}{dt} = Ah(T_{\text{air}} - T_{\text{food}}) \tag{12}$$

The drying rate can, therefore, be calculated from

$$-\frac{dMC_{db}}{dt} = \frac{Ah(T_{air} - T_{food})}{\lambda M_d} \tag{13}$$

Integrating the above equation gives the drying time for the constant drying rate period:

$$t = \frac{MC_{db1} - MC_{db2}}{Ah(T_{air} - T_{food})} \lambda M_d \tag{14}$$

where t represents the time needed to bring moisture content from MC_{db1} to MC_{db2} in the constant drying period.

As shown in Eq. 14, drying time in the constant drying rate period decreases with increasing temperature difference, $T_{air} - T_{food}$, with increasing product surface area, A, and with surface heat transfer coefficient, h. Food surface temperature T_{food} in the constant drying rate period is approximately the wet-bulb temperature of the drying air. The value of h in Eq. 14 increases with air velocity, and correlations to estimate h values for different drying beds and types of particles are summarized in Crapiste and Rotstein (18).

b. Falling Rate Periods The limiting factor for drying in the falling rate periods is the slow moisture movement within food products. It is difficult to develop an accurate mathematical expression to describe a particular drying process during these periods, because many mechanisms may contribute to the moisture migration (i.e., capillary forces, pressure gradients, moisture concentration gradients) (19). It has been, however, a general practice among researchers and engineers to approximate the drying of biological materials in the falling rate periods using a lumped diffusion equation (20):

$$\frac{\partial M}{\partial t} = \nabla(D_{eff} \nabla M) \tag{15}$$

where $M(x, y, z)$ is local moisture concentration and D_{eff} the effective moisture diffusivity (m^2/s). In theory, it is difficult to obtain a close-form solution for the above equation, because D_{eff} is dependent on local moisture content in a nonlinear manner (21). One needs to resort to numerical methods with the aid of computers to provide an approximation of the drying process. But the success of numerical methods relies on accurate information about related physical properties including porosity and moisture diffusivity which are moisture and temperature dependent. Those properties are not readily available in the literature and are difficult to measure. As a result, simplified expressions for diffusion in simple geometries have been used to approximate drying behavior, with an assumed constant moisture diffusivity estimated from thin-layer drying tests. An example of this expression for sliced foods is given in Tang and Sokhansanj (21):

$$\frac{\partial MC_{db}}{\partial t} = \frac{\pi D_{eff}}{4a^2}(MC_{db} - MC_{dbe}) \tag{16}$$

where a is half thickness of the sliced foods, MC_{db} is the average moisture content, and MC_{dbe} represents equilibrium moisture content corresponding to the drying air. It is evident from Eq. 16 that the larger the difference between moisture content of the product MC_{db} and the equilibrium moisture content MC_{dbe}, the larger the drying rate.

The value of D_{eff} of biological materials increases sharply with increasing product temperature, following an Arrhenius type relationship (18,20,21):

$$D_{eff} = D(M)e^{-E_A/RT} \tag{17}$$

where E_A is activation energy, R is the gas constant, and T is absolute temperature. Thus increasing air temperature in the falling rate periods can increase drying rates by increasing moisture diffusivity in foods and by reducing the equilibrium moisture content of the product.

Other simple forms of thin-layer model have been used to describe drying in the falling rate periods. Those models were developed mostly for grain drying but should be readily used for other biomaterials, including vegetables. Reviews of those thin-layer models is presented in Parry (22) and Sokhansanji and Cenkowski (23), and their uses in deep-bed drying presented in Parry (22).

In spite of extensive published research on drying technologies, it is still impossible to predict accurately the performance of a commercial drying system based only on theory and fundamental equations because of the complicated nature of heat and mass transfer in biological materials during drying processes and the difficulty in determining related transport properties that depend upon moisture content and temperature. The fundamental knowledge on drying only serves as a general guide. Today's engineers still rely heavily on experience and pilot-scale testing to determine the best drying strategy for a particular product in the selection and operation of drying systems.

III. DRYING SYSTEMS

Various drying systems/methods have been developed to remove water from moist solid or liquid foods. Regardless of the difference in design, all drying systems consist of at least three main components: (a) a source of thermal energy to enable phase change during the removal of moisture, (b) a means to move foods; (c) a means to carry away evaporated moisture. Since drying requires a large amount of energy for the phase change of water (from liquid to vapor or from ice to vapor), drying is perhaps the most energy intensive unit operation in the food industry. Energy efficiency is, therefore, one of the major considerations in the design of a drying system. In addition, biomaterials are heat sensitive. Uniformity in drying and thermal degradation of food materials are, perhaps, the most important factors in drying system design for high-value products. Other considerations include capital and operation costs, throughput, space requirement, and ease of sanitation. In this section, we briefly describe the most commonly used drying systems for drying vegetables in commercial operations.

A. Solar (Open-Air) Drying

This is probably the oldest industrial process currently being used. It certainly dates back to antiquity and has been used with many different products including fruit, meat, fish, and plants (26). However, this process has several drawbacks that limit its use for large-scale production. The drawbacks include the requirement for large areas of space and for high labor inputs, difficulty in controlling the rate of drying, insect infestation, microbial contamination, and difficulty in controlling product quality.

B. Heated Air Drying

1. Tray or Cabinet Dryers

A tray or cabinet dryer consists of perforated trays fitted in an insulated cabinet (Fig. 13). Hot air is circulated through thin layers (2–6 cm deep) of products. The air can be directly heated by a gas burner or an electric heater, or indirectly by steam coil heat exchangers. Baffles are used to ensure

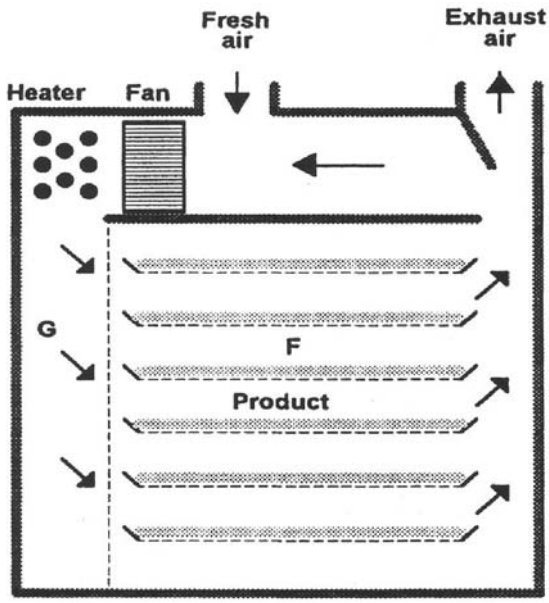


Figure 13 Schematic diagram of a cabinet tray dyer. G: heated air; F: food products. (From Ref. 18.)

desired air circulation. In tray dryers, crossflow (air flows across thin layer foods, as compared to parallel flow in which air flows over and under thin layers of foods) is desired to ensure uniform product quality and maximum drying capacity. A controlled amount of fresh air is added, and hot air is exhausted to remove evaporated moisture and maintain a relatively low relative humidity in the cabinet. Cabinet dryers are simple to build and are very flexible. They are used in small operations (100–2000 kg dried food per day), or in pilot-scale testing to determine parameters for continuous belt or tunnel drying processes (24).

2. Tunnel Dryers

Tunnel dryers are widely used for dehydration of vegetables and fruits. Tunnel dryers are similar to cabinet dryers except that trays are placed on mobile shelves that move along in tunnels (Fig. 14). The operation is semicontinuous, in that fresh produce is added at one end of the tunnel and the dried products removed from the other end at predetermined intervals. The material flow can be in the same direction as the heated air (concurrent flow) or in the opposite direction (counterflow). The throughput of the dryer depends upon the number of trays, the size of the tunnel, and the air temperature and flow rates, among many other factors.

Drying with tunnel and cabinet dryers of all types is a slow process and requires lower operating temperatures to prevent scorching.

3. Conveyor (or Belt) Dryers

Continuous conveyor dryers are particularly suited for cut vegetable (24). In operation, wet materials are conveyed on perforated metal or plastic belts. Hot air is directed through the belt to provide maximum exposure of foods to the air. A dryer may consist of several sections in series (Fig. 15a,b,c). Air temperature, air circulation speed and direction, and the moving belt speed in each section are controlled independently. Exhaust is also controlled in each section to maximize drying rate and to optimize energy efficiency. To take advantage of high energy efficiency drying in the constant drying rate periods and to overcome the difficulty of low drying rates during the

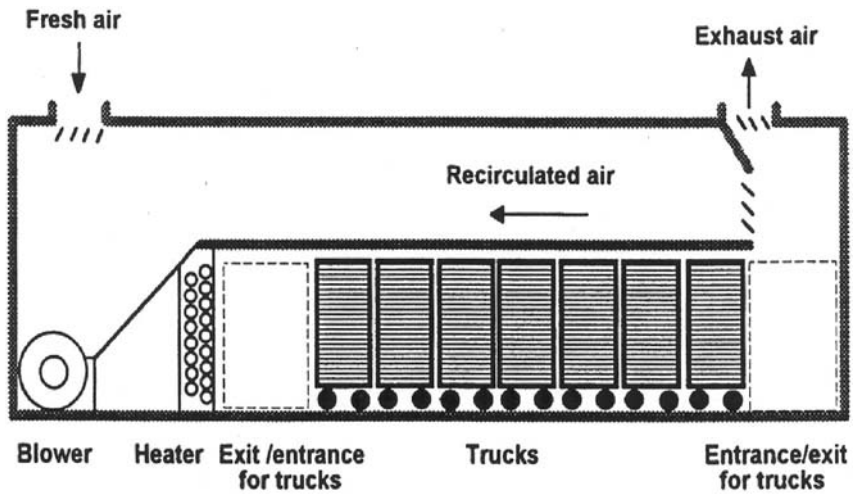


Figure 14 Schematic diagram of a tunnel dryer. (From Ref. 18.)

falling rate periods, wet products are often laid in a thin layer (e.g., 5–6 cm thick) on a fast moving belt in the first one or two sections; intermediate moist products from those sections are moved over slower moving belts and dried in thicker layers (e.g., 15–20 cm deep). Transferring between belts allows reorientation and mixing of product, the breakup of agglomerated product, and improvement of drying uniformity. Both upward and downward airflow are used in the first sections of drying to minimize stratification of moisture within the product layer (bed) and to avoid compacting of the bed due to air pressure. Downward flow is used in the finished drying section to avoid possible lifting of the dried particles. Products can be dried from 80 to 90% moisture content (wet basis) to below 5% in a single drier, or to about 20% and then finish dried in a separate dryer (e.g., a bin or tunnel dryer). Conveyor belt dryers are relatively expensive compared to cabinet or tunnel dryers, but they provide higher throughputs and more consistent product quality. Continuous vegetable dehydrators are commonly sized for feed rates into the dryer ranging from 2 metric tons per hour to more than 7 metric tons per hour. After dehydration, the yield will depend on the initial and final moisture contents of the products, which can range from 300 to 1800 kg/h or more. Equipment of this capacity can easily reach 200 ft (61 m) long.

Multistage dehydrators offer several advantages to the process. First and foremost is the ability to adapt the operating parameters (residence time, airflow, temperature, and humidity) to follow the drying curve. In this way, production can be maximized while optimizing the energy efficiency of the process. Additional advantages worthy of mention include first-in, first-out, complete access to the inside, sanitary construction, and consistent, reliable production, day in and day out. This equipment is often used 24 h per day, 7 days per week, year round, with brief stoppages for cleaning as required.

Airflow patterns within the dryer are designed around the product being processed. They range from less than 10,000 cfm to more than 40,000 cfm. The exhaust is determined by the evaporative load and is normally a fraction of the total recirculated air volume.

C. Drum Drying

Drum drying is one of the most energy-efficient drying methods and is particularly effective for drying high viscous liquid or pureed foods, such as baby foods, pureed vegetable, mashed

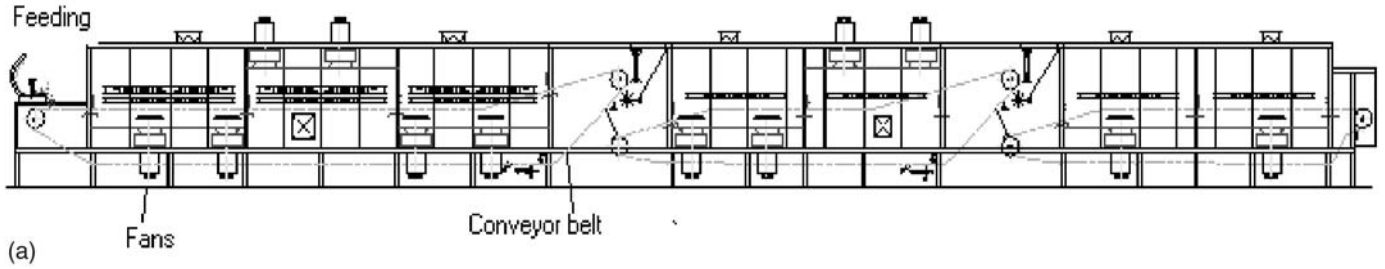
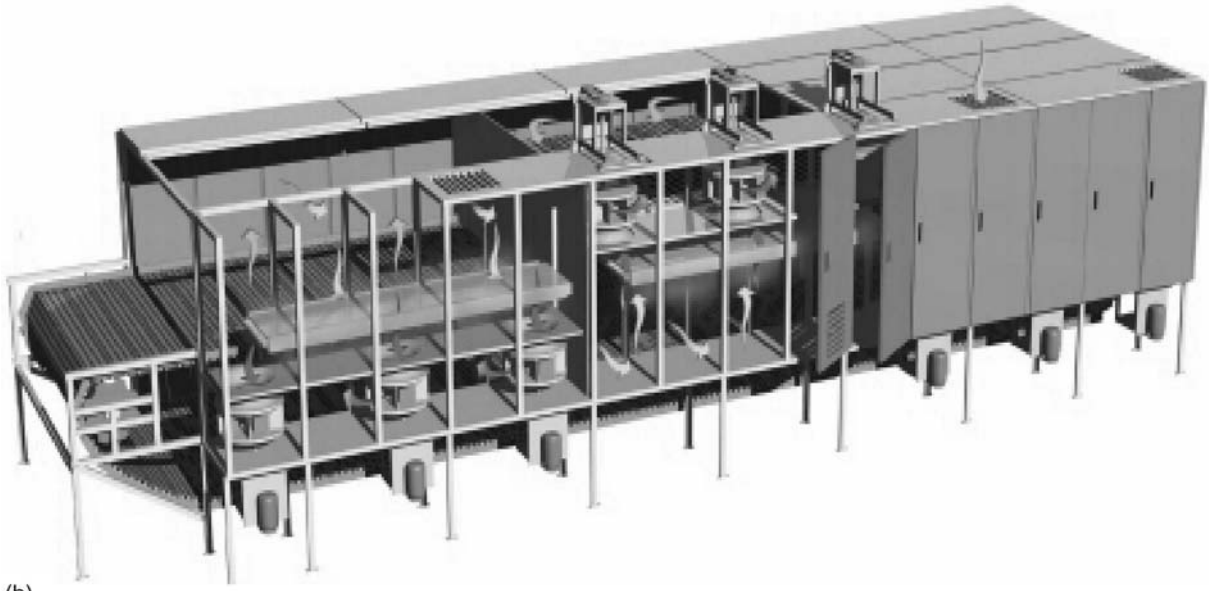


Figure 15a Schematics of a multistage conveyor dryer for vegetables. (Courtesy of the National Drying Machinery Company, Philadelphia, PA.)



(b)

Figure 15b A section of a multistage conveyor dryer, showing direction of air flow. (Courtesy of the National Drying Machinery Company, Philadelphia, PA.)

(c)

Figure 15c The feeding end of a conveyor dryer. (Courtesy of the National Drying Machinery Company, Philadelphia, PA.)

potatoes, cooked starch, and spent yeast (27). In this drying operation, liquid or pureed food is applied as a thin layer onto the outer surface of revolving drums that are internally heated by steam. After about three-quarters of a revolution from the point of feeding, the product is dried and removed with a static scraper. The dried product is then ground into flakes or powder.

Typical structures of single and double drum dryers are shown in Fig. 16. The dryer consists of one or two horizontally mounted hollow cylinder(s) made of high grade cast iron or stainless steel, a supporting frame, a product feeding system, a scraper, and auxiliaries. Typical drums range from 0.5 to 6 m in diameter and from 1 to 6 m in length. In operation, steam at temperatures up to 200°C heats the inner surface of the drum. The moist material is uniformly applied in a thin layer (0.5 to 2 mm) onto the outer drum surface. Most of the moisture is removed at water boiling

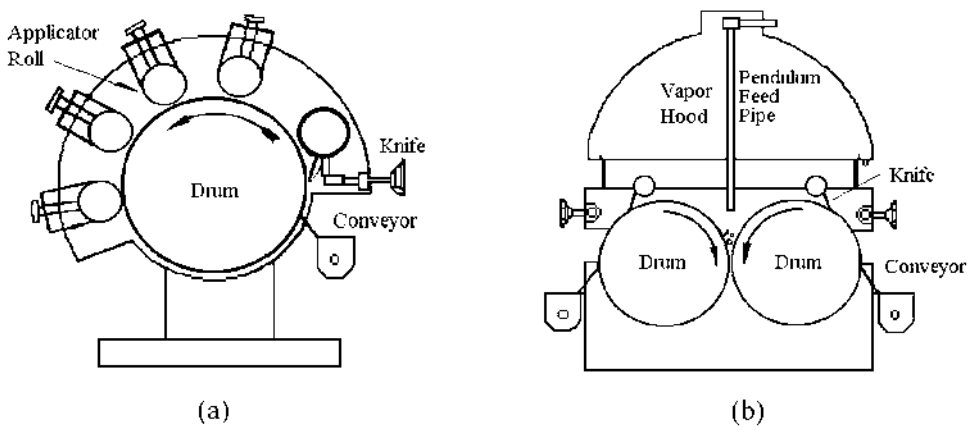


Figure 16 (a) Single drum dryer and (b) double drum dryer.

temperature. The residence time of the product on the drum ranges from a few seconds to dozens of seconds to reach final moisture contents often less than 5% (wet basis). The energy consumption in a typical drum dryer ranges between 1.2 and 1.5 kg steam per kg of evaporated water, corresponding to energy efficiencies of about 70–90%. Under ideal conditions, the maximum evaporation capacity of a drum dryer can be as high as 80 kg H_2O/hm^2. A drum dryer can produce product at a rate between 5 to 50 kg/hm^2, depending upon the type of foods, the initial and final moisture content, and other operation conditions.

In drum drying operations, consistency of the product layer on the drum will directly affect the quality of the dried product, the control of the system, as well as the throughput of the dryer. Therefore the selection of the feeding method is very important. The method of applying product onto the drum surface differs, depending on the drying drum arrangement, as well as the solid concentration, viscosity, and wetting ability of the product. Industrial drum dryers use five basic feeding methods, namely, roll feeding, nip feeding, dipping, spraying, and splashing. Usually the selection of the proper feeding method relies on previous experience and/or on conducting drying tests of the product on a pilot unit.

Care must be taken to ensure that the product that is to be dried adheres well to the drying surface; thus, in some cases, it may be necessary to modify the liquid product by the addition of other substances to change its surface tension or viscosity. Temperature and concentration should both be controlled during drum drying. Drum dryers have high drying rates and high energy efficiencies. This technique has been used extensively in the past, but its use for food processing is decreasing as other methods of drying, in particular spray drying, that cause less heat damage become available. Drum drying is most effective for slurries or liquid foods that are too thick or contain particles too large for spray drying.

Figure 17 shows an example of product and drum surface temperature changes during drum drying. It is evident that the product temperature in drum drying is very high, which may cause severe heat damage to the product. For materials sensitive to heat damage, a vacuum drum dryer may be used to reduce drying temperature. A vacuum drum dryer is similar to other drum dryers except that the drums are enclosed in a vacuum chamber. In continuous vacuum drum dryers,

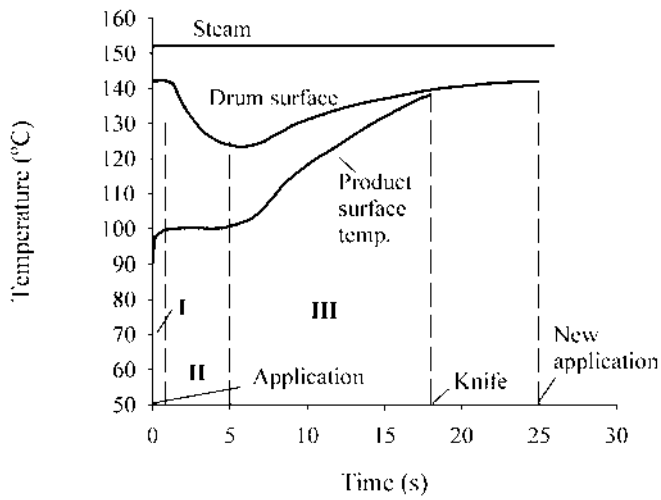


Figure 17 Product and drum surface temperatures during one revolution of drum drying in three different drying periods. (From Ref. 27.)

receivers and air locks are designed to provide appropriate seal. Equipment and operation of vacuum drum dryers are relatively expensive, which limits vacuum drum drying to only high-value products or products that cannot be produced more economically by other means.

D. Spray Drying

Spray drying is used to remove the water from a free flowing liquid mixture, thus transforming it into a powdered product (7). Figure 18 shows an example of a spray drying system. In operation, a liquid food is first preheated to reduce viscosity and enhance drying economics. It is then pumped through either a nozzle or a rotary atomizer to form small droplets (10–200 μm in diameter) with large surface areas. The droplets are sprayed into a drying chamber and mixed with hot drying air at temperatures between 150 and 200°C. Dried products are then separated from the hot air in cyclones and/or filter bags.

In spray drying, moisture evaporates rapidly, and most drying takes place in the constant drying rate period due to the large surface-to-volume ratio of the small droplets. As a result, the droplets remain at the wet-bulb temperature (40–50°C) of the heated air, until the end of the drying period, when most moisture has been removed. Although the product exits the drying chamber at about 90–100°C, the very short residence time (1–20 s) helps reduce heat damage.

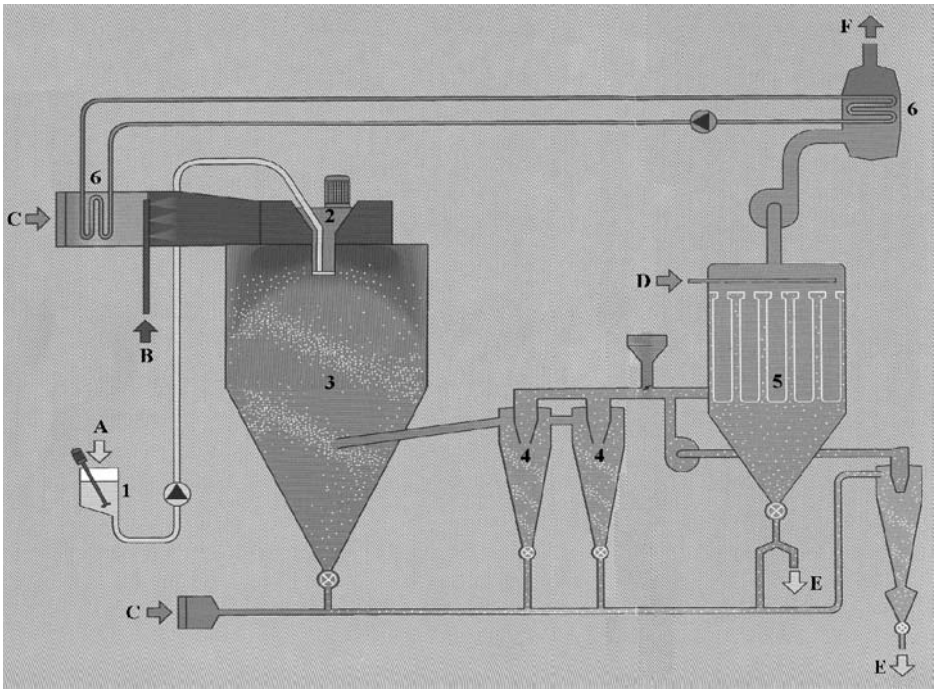


Figure 18 Schematic diagram of a spray drying system. (Courtesy of APV Crepaco, Inc., Dryer Division, Attleboro Falls, MA.) A: product inlet; B: natural gas; C: air inlet; D: compressed air; E: products; F: air outlet. 1: feed tank; 2: atomizer; 3: spray drying chamber; 4: cyclones; 5: bag filter; 6: liquid coupled heat exchanger to increase energy efficiency.

The products coming directly from a spray dryer are in the form of spherical particles of a fairly uniform size, often in the shape of hollow beads. The dried product, e.g., coffee powder, is often agglomerated to facilitate its rapid dispersion in water. Spray drying can be combined with a fluidized-bed dryer (28), which will convert the liquid directly into an agglomerated product.

Spray drying is often used in the food industry to dry liquid foods of relatively low viscosity, e.g., liquid milk, coffee or tea extract, vegetable juices, etc. To save energy, some liquid foods are concentrated in multieffect evaporators before being spray dried. Spray dryers are available from commercial equipment suppliers in various sizes, from pilot-scale testing units to large-scale equipment capable of producing 80,000 kg of dried product per day (7). A large disadvantage with this process is the size of the equipment required to achieve the drying. Furthermore, not all materials can be spray dried. For instance, very oily materials might require special preparation to remove excessive levels of fat before atomization. High sugar content juices require a carrier, such as maltodextrine, to prevent high temperature products from forming a thermoplastic mass on the drying chamber walls.

E. Fluidized-Bed Drying

Fluidized-bed dryers were first commercialized on a large scale by US petroleum companies during World War II. The technique of fluidized-bed drying was initially used for the catalytic cracking of crude petroleum. The chemical industry soon realized that it could be a very versatile technique and adapted it for many unit operations. This technique can produce particles of uniform size and can maintain constant product temperature. By setting the operating conditions within narrow limits, scaleup from laboratory-to commercial-sized units can be readily accomplished.

The technique involves levitating particulate solids in an upward-flowing gas stream, usually of hot air. Fluidization mobilizes the solid particulates, thus creating intimate contact between the dry, hot carrier gas and the solids. Drying occurs by convection. At the proper gas flow rate, the solids will behave as if they were a liquid, thus ensuring more intimate contact between the solids and the carrier gas, and increasing the drying rate. Fluidization is dependent on the characteristics of the particles: size distribution, density, shape, and viscosity. The properties of the carrier gas that contribute to fluidization include density and viscosity.

A typical commercial fluidized-bed dryer has a reaction chamber that is fixed in place and usually cylindrical in shape. The hot gas is introduced into the bottom of the preloaded bed and exits at the top. The flat bed has been modified by the addition of a vibratory mechanism to increase the contact of the product with the hot gas even further. Fluidized-bed drying is usually carried out as a batch process and requires relatively small, uniform, and discrete particles that can be readily fluidized. Thus small vegetable pieces such as whole peas or diced/sliced vegetables are well suited for this process, whereas powders would be inappropriate, as they would clog up the cyclone. Fluidized beds are extensively used in dairy processing in combination with spray drying to produce agglomerated milk powder and dried whey.

F. Freeze-Drying

Freeze-drying, or lyophilization, utilizes the principle that under high vacuum (<4.58 torr, or 0.61 kPa), frozen water in food changes into vapor without going through a liquid phase (29). This phenomenon is known as sublimation and is responsible for giving freeze dried foods characteristics that are unique among dried food products. In operation, prefrozen food pieces placed on trays are brought into an airtight drying chamber, as shown in a typical tunnel freezer in Fig. 19. A vacuum is drawn to reduce the chamber pressure to between 0.1 and 2.0 torr (24).

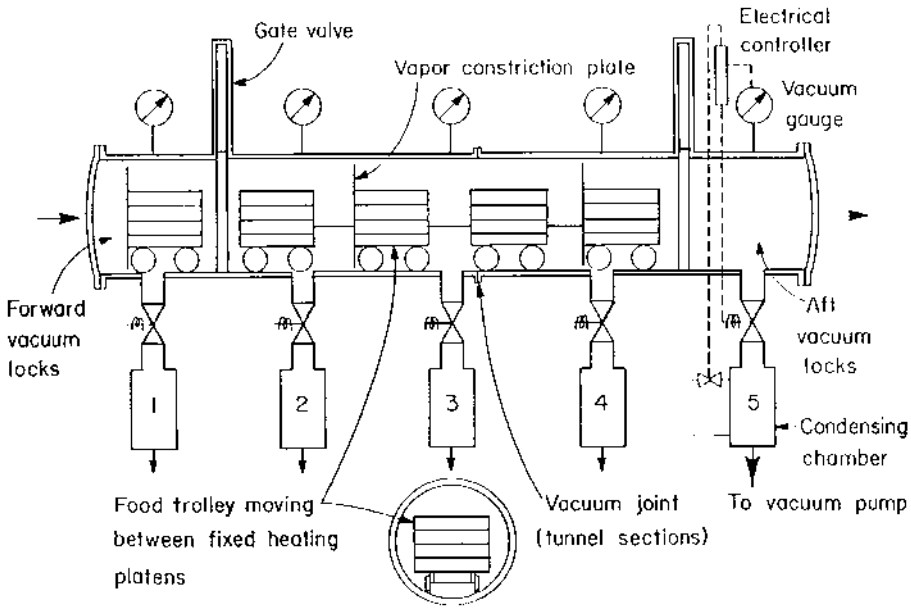


Figure 19 Schematic diagram of a tunnel freeze-dryer. (From Ref. 29.)

A controlled amount of thermal energy is applied to the foods either via heating plates in close contact with the bottoms of the food trays and/or by radiant heaters over the food trays. The thermal energy is transferred to a sublimation front at which ice changes into vapor. Water vapor is then removed from the product onto condensing plates or coils that are at a low temperature (typically -35 to $-50^{\circ}C$). This low temperature changes the water vapor back to ice. The ice is then subsequently removed by melting. Because foods remain at a low temperature during a freeze-drying process, a consistently high retention of flavors and nutrients is achieved. There is little or no loss in sensory qualities of the product. Because the removal of ice crystals leaves a porous structure, the product tends to rehydrate rapidly. Since product shrinkage and deformation is minimal, freeze-drying is often used where the appearance of the finished product is important.

Both batch and continuous dryers are used commercially. Continuous dryers are significantly more complex and tend to be used in facilities processing only a single item. Drying rates vary greatly by product but are generally in the range of 0.5 to $1.2\,kg/h\,m^2$ (or 0.1 to $0.25\,lb/h\,ft^2$) of drying shelf. Corn, peas, broccoli, green beans, cauliflower, peppers, and potatoes are among the many vegetables currently freeze dried. Many fruits, meats, dairy products, and entrees are also freeze-dried.

Freeze-drying is, however, a very lengthy (10 to 40 h, depending upon food particle size, bed depth, and drying conditions) and expensive process. Four potential rate-limiting factors have been identified: the external transfer of heat to the outer surface of the material from the heat source, the internal transfer of heat within the material, the external mass transfer of water vapor from the surface, and the internal mass transfer within the material. During the drying cycle, as the sublimation front recedes from the heating source, the thickness of the dried layer increases, thus slowing down the sublimation rate. The long processing time requires additional energy to run the compressor and refrigeration units, which makes the process expensive for commercial use. In general a freeze-dried product is much more expensive than the hot air dried counterpart. As a result, freeze-drying is mostly used for products that can be sold at a premium or that can

withstand only a small amount of sensory deterioration, or to impart certain desired characteristics, e.g., hydration ability. Because of the porous and often open structures of freeze-dried products, oxidative reactions take place very rapidly. Freeze-dried products require packaging materials with good oxidation barriers for storage.

IV. OTHER DRYING METHODS

A. Explosive Puffing

Explosive puffing (30–32) is designed to give small particles a porous structure. By using a combination of high temperature and high pressure, and a sudden release of the pressure (explosion) to flush out the superheated water in the product, a good rehydratability can be obtained. However, the high heat can degrade the food quality, and the explosion might compromise product integrity.

B. Osmotic Dehydration

Osmotic dehydration (33–37) is designed for solute-infused products. This process involves soaking products with a large water content in concentrated sugar or salt solutions. This promotes countercurrent mass transfer of both water and solutes between the product and the solution (37). Many sugar-infused blueberries, cranberries, cherries, and so on are produced this way. The increase in solids due to infusion results in a substantial increase in yield.

Conveyor drying of air dried sugar-infused fruits is a common approach used in industrial practice, with consideration given to special handling requirements and more careful attention to temperatures.

A potential problem with osmotic drying is the large amount of residual fluid that must be disposed of after the process is complete. This fluid can be recycled, as suggested by Bolin et al. (35), or further processed into such products as puree, juice, jelly, jam, and fruit leathers, or used as a flavoring agent.

By combining osmotic drying with vacuum drying, a high-quality intermediate-moisture food can be produced. A modified osmotic dehydration process was developed (38–40) to air dry food particles to 20–50% of their original weight (i.e., process stopped before heat damage causes significant quality deterioration), and then mix them with precalculated solutes for further concentration of solids in food via infusion. By using this method, foods can be rendered shelf stable with minimum waste. Furthermore, the solutes bind the residual water in foods and prevent it from migrating into big ice crystals during freezing storage and so provide a free flow of product even at subzero temperature. The product can be compressed and rehydrated readily without compromising either the integrity or the quality of foods (Fig. 20). A military ration prototype was developed by compressing a mixture of air dried osmotically infused vegetables, intermediate moisture meats, instant rice (or pasta, beans, or wheat), and spices to form a compressed meal (Fig. 21). The meal, with its light weight, low volume, and convenient preparation (i.e., by adding boiling water for 5 minutes to reconstitute), provides soldiers with a high-quality entrée with a well-balanced meal (41).

C. Microwave Drying and Radio Frequency Drying

Microwave drying uses the electromagnetic radiation in the microwave frequency range (300–3,000 MHz) as a form of energy to dry food products. Microwave drying systems take advantage

Figure 20 Air dried, solvent-infused carrot.

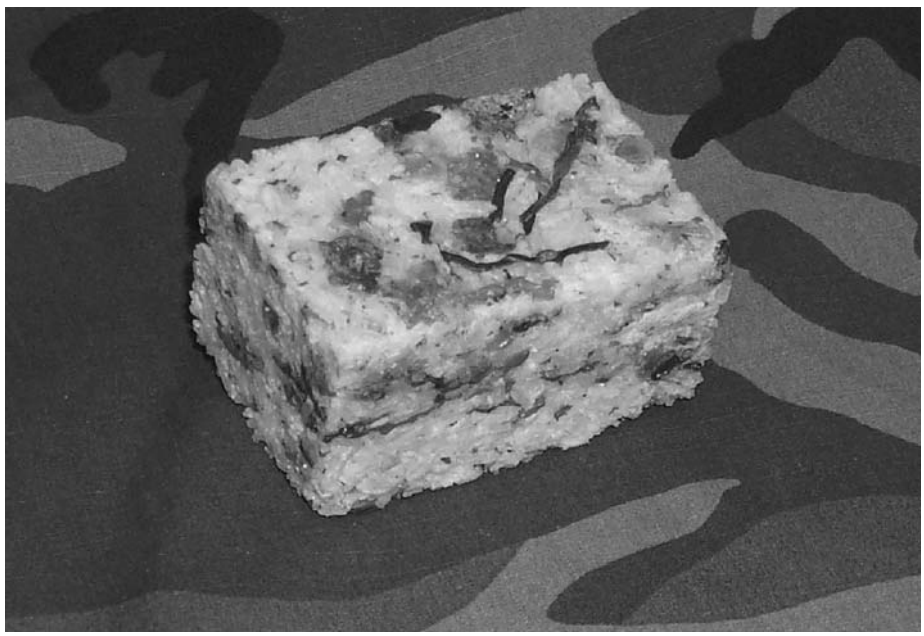


Figure 21 A prototype: compressed, dehydrated meal for a military ration.

of the fact that microwaves directly interact with polar molecules, especially water, in moist foods to generate heat for moisture evaporation. Recent research has demonstrated that microwave heating in combination with a fluidized bed can be very effective in increasing drying rates of particulate products during the falling rate periods while maintaining a relatively low product temperature to retain product quality (19,42,43). Microwave drying is currently used commercially to finish dry pasta products. Electromagnetic energy in the radio frequency range 1–100 MHz has also been extensively used to finish dry crackers and cookies as well as some cereal products.

D. Microwave-Augmented Freeze Drying

Conventional freeze-drying can be speeded up by using a volumetric heating mode, such as microwaves (44,45). By using microwave energy to augment the conduction heating of freeze-drying, drying rates can be increased by as much as an order of magnitude. Figure 22 shows a schematic diagram of microwave-augmented freeze-drying equipment. This dryer is basically a conventional freeze dryer that has the added capability of allowing microwaves to be introduced within the drying chamber.

The initial capital costs of this equipment are greater than those of conventional freeze-drying equipment, but the costs are offset by an increased drying rate, which allows more efficient use of the equipment.

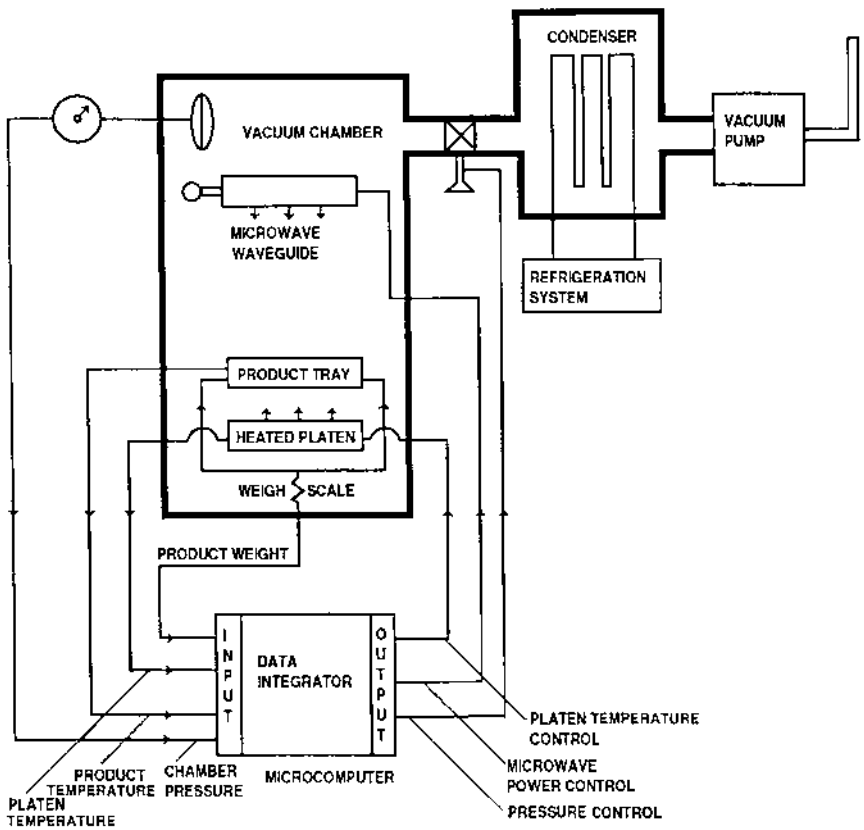


Figure 22 Schematic diagram of a microwave-augmented freeze-dryer.

As with any microwave processing procedure, a major drawback is the nonuniformity of the energy within the chamber. However, this problem can be partially offset by the use of well-designed microwave applicators and a rotating tray. It has also been reported that large-scale commercial drying cavities tend to lessen this nonuniformity. However, there are limits to the energy level that can be used. We have found that arcing occurred when the average power in a $0.34\,m^3$ cavity was increased much above $1.5\,kW/m^3$, but as most of the increased drying rate occurred at $1.5\,kW/m^3$, this is not really a serious limitation.

A large variety of food products can be dried using this method to great advantage. We have successfully dried vegetables with essentially no fat, fruit with high sugar content, and ground meat with high fat content. In all cases the drying time was reduced to between one third and one half the time required without the use of the microwaves.

E. Centrifugal Fluidized-Bed Drying

The centrifugal fluidized-bed dryer works on the same principle as the conventional fluidized-bed dryer except that a rotating chamber is used (46,47). A schematic diagram of a centrifugal fluidized-bed dryer is shown in Fig. 23. The product to be dried is loaded into the chamber, which is then closed. Hot air is introduced into the bottom of the chamber, which is rotated at relatively high speed. The rotational speed and the flow rate of the air must be balanced to ensure that fluidization is achieved. If fluidization does not occur, the particles will tend to adhere to the walls of the chamber when it is rotating. Some drying will still occur, but the process will not be as efficient. The same restrictions regarding the particle size and shape as with the nonrotating fluidized-bed dryer apply here. By using the centrifugal force to counter the increasing air flow, thus assuring fluidization, the drying rate is significantly increased.

There are other variations of fluidized-bed dryers. In a spouted-bed dryer (26), the heated gas enters the chamber at the center of a conical base as a jet. The particles are rapidly dispersed in the gas, and the drying occurs in an operation that is similar to flash drying (a process that uses extremely-high-temperature heating, sometimes up to several thousand degrees, for very short time periods to remove moisture). This works well with larger pieces that can be dried in the fluidized-bed dryer.

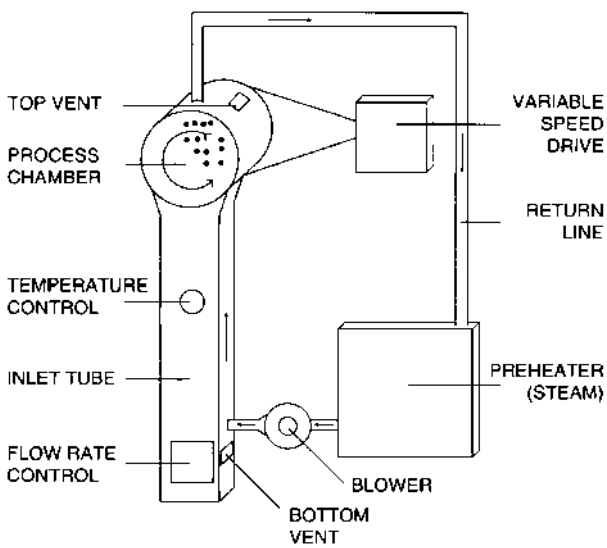


Figure 23 Schematic diagram of a centrifugal fluidized-bed dryer.

Another variation is the spin flash dryer (26). This method can be used with pasty mixtures, which do not readily disperse in the conventional fluidized-bed dryer. An agitator rotates continuously in the bottom of the dryer chamber during the entire drying process. This agitation tends to break up and disperse the paste.

F. Ball Drying

A schematic diagram of a typical commercial ball drying system is shown in Fig. 24. The material to be dried is added to the top of the drying chamber through a screw conveyor. The conveyor assures a constant rate of product addition, but it can be bypassed and the material added directly to the drying chamber. Heated air is also added continuously to the chamber. The material within the drying chamber comes into direct contact with heated balls made from ceramic or other heat-conductive material. Drying occurs primarily by conduction. The large screw within the chamber rotates during the entire drying process, and the speed of rotation governs the dwell time of the product within the chamber. When the product arrives at the bottom of the chamber, it is separated from the balls and collected. Except for temperature, the most important variable to control is that of rotational speed (47).

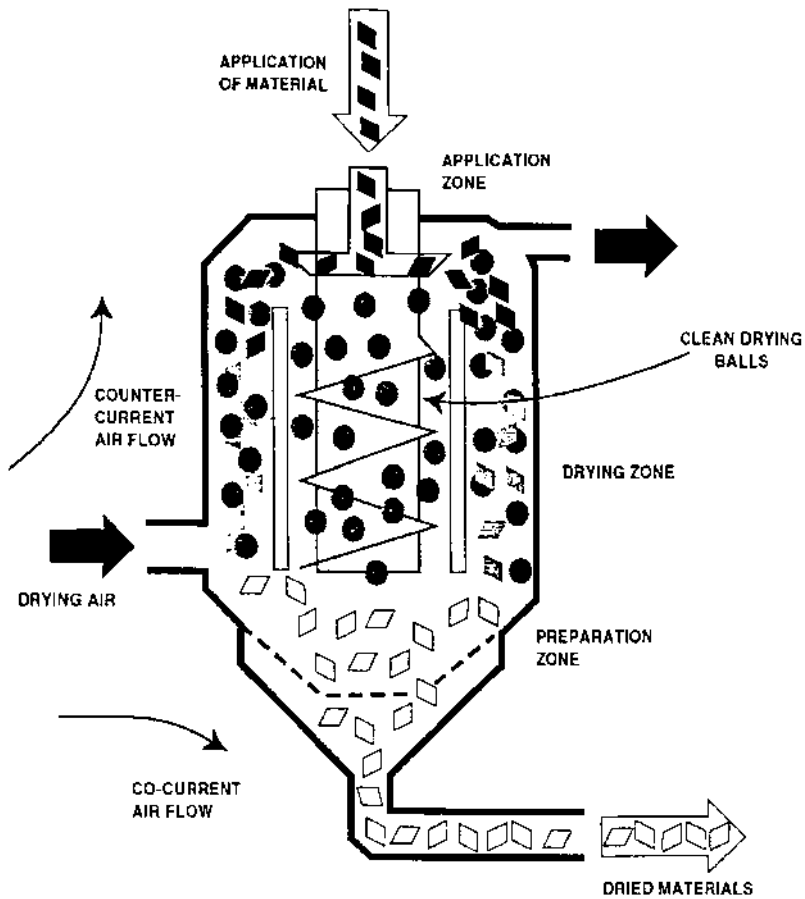


Figure 24 Schematic diagram of a ball dryer.

Relatively small particles such as vegetable pieces must be used. If the material has an excessive sugar content, as is the case with fruit in syrup, the material tends to stick to the drying balls and cannot be separated. The ball drying process can be run at somewhat lower temperatures (70°C) than all the other techniques described except for freeze-drying. However, sanitation can be a concern at low temperatures because of the extended length of the drying process.

G. Ultrasonic Drying of Liquids

It has been reported that ultrasonic energy can be used to remove liquid water from solutions in food particles (48). To use this process, the liquid is atomized to produce small-diameter droplets, first by a nozzle and then by further cavitation using ultrasonic energy within a drying chamber. The particles are then subjected to heating to remove the water, and the dried residue is collected. An example of an experimental ultrasonic dryer is shown in Fig. 25. The technique can greatly increase the evaporation rate of the water (with drying sometimes occurring in seconds). Babin

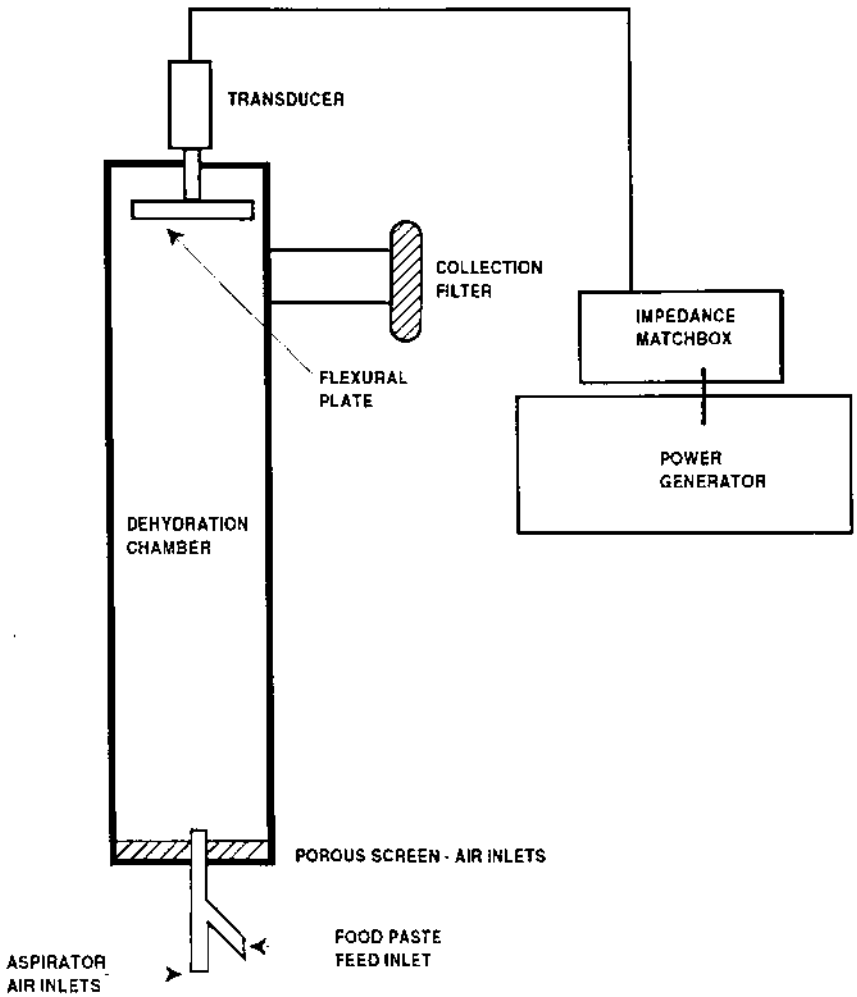


Figure 25 Schematic diagram of an experimental ultrasonic dryer.

et al. (49) and Taylor and Hansen (50) developed special equipment that demonstrated that water could be effectively removed from dilute solutions of nonfatty products, thus suggesting that ultrasonic drying may be used as an alternative to spray drying. The procedure works best with low-fat solutions, because oily and fatty foods do not dry effectively in an aerosol. The first commercial-scale sonic-assisted drying plant was started in 1987 (51) in California to dry various products, including cheese and milk powders, citrus products, and vegetables (e.g., onions and garlic).

H. Refractance Window™ Drying Method

The Refractance Window™ drying system is a novel drying method developed by MCD Technologies, Inc. (Tacoma, WA). It utilizes circulating water at 95–97°C as a means to carry thermal energy to materials to be dehydrated. Pureed products are spread on a transparent plastic conveyer belt that moves over circulating water in a shallow trough. The unused heat in the circulating water is recycled (Fig. 26a,b). The dried products are then moved over a cold water trough to enable easy separation of the product from the belt by the scraper device. Products on the moving belt dry rapidly. The residence time of the product on the drying belt is typically 3–5 min, contrary to the lengthy times required for tray, tunnel, and freeze dryers. Refractance Window™ drying is similar to drum drying in that the product is dried in a thin layer on a heated surface, except that the heated surface is at much lower temperature (70–85°C vs. 120–150°C). It is effective in drying pureed vegetables, algae, fruits, and liquid eggs. In particular, it can be used to dry pureed fruits with high sugar contents with no need of a carrier (such as maltodextrin). The energy efficiency of an RW system can be as high as 70%, and the system can result in over 6 log reduction of vegetative bacterial cells.

Abonyi et al. (53) evaluated the quality retention characteristics of strawberry and carrot purees dried using the RW drying method against the freeze-drying, drum drying, and spray drying methods. Ascorbic acid retention in strawberry purees dried with the RW system was comparable to freeze-dried products (Table 2). Total α- and β-carotene retention in carrot purees after RW drying were comparable with freeze-dried samples and much higher than seen in drum dried products (Table 3). Images of dried carrots and strawberry purees are shown in Fig. 27.

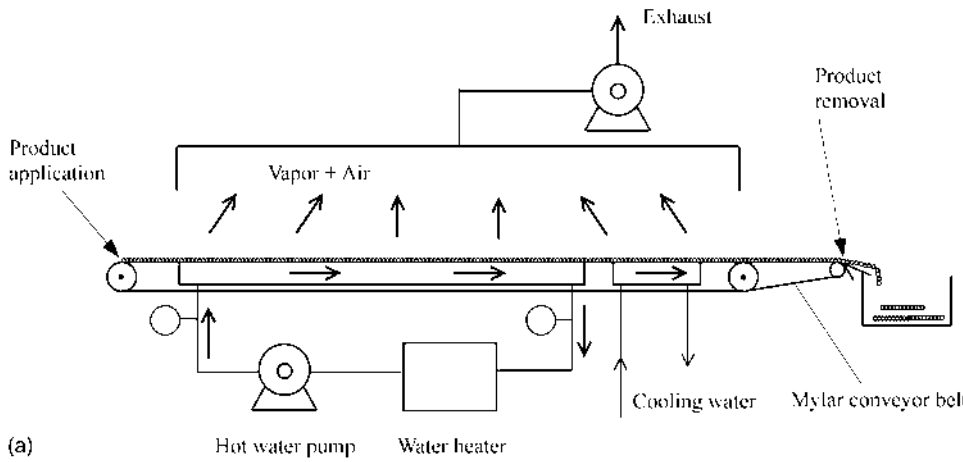


Figure 26a Schematic of a Refractance Window™ system.

(b)

Figure 26b An industrial scale Refractance Window Dryer. (Courtesy of MCD Technologies, Tacoma, WA.)

Research is still being carried out at Washington State University and MCD Technologies to improve the consistency of drying performance and expand the application of this drying technology to different products.

I. Selection of New Drying Systems

We have discussed a number of novel drying techniques that can be used as alternatives to the better-known methods for moisture reduction in foods (see Table 4 for a summary of these techniques). Before a particular process is selected, consideration should be given to many factors,

Table 2 Comparison of Vitamin C Content of Refractance Window and Freeze-Dried Strawberry Purees Without Carrier

Treatment	AA mg/g solid	AA loss (%)	MCwb (%)
Fresh puree	1.80 ± 0.01^{a}	—	93.6 ± 0.2
RW dried	1.69 ± 0.03^{b}	6.0 ± 1.3^{b}	9.90 ± 0.6
Freeze-dried	1.68 ± 0.04^{b}	6.4 ± 1.6^{b}	12.1 ± 0.5

RW, Refractance Window.
AA, ascorbic acid.
MCwb, moisture content on a wet basis, average of four replicates.
[a,b]Different letters in the same column indicate a significant difference ($p \leq 0.05$).
Source: Ref. (53).

Table 3 Carotene Losses in Carrots Among Control and Samples Dried by Drum, Freeze, and Refractance Window Drying Methods to 10–12%

	Total carotene		Alpha carotene		Beta carotene	
Sample	g/g solid	Loss (%)	g/g solid	Loss (%)	g/g solid	Loss (%)
Control	1.77 ± 0.09[†,a]	—	0.85 ± 0.04[a]	—	0.92 ± 0.05[a]	—
Drum dried	0.78 ± 0.18[b]	56.0	0.38 ± 0.09[b]	55.0	0.39 ± 0.08[b]	57.1
RW dried	1.62 ± 0.33[a]	8.7	0.79 ± 0.16[a]	7.4	0.83 ± 0.17[a]	9.9
Freeze-dried	1.70 ± 0.06[a]	4.0	0.83 ± 0.03[a]	2.4	0.87 ± 0.03[a]	5.4

RW, Refractance Window.
[†]Average of three replicates.
[a,b]Different letters in the same column indicate a significant difference ($p \leq 0.05$).
Source: Ref. (53).

including the type of product to be dried, the finished product desired, the product's susceptibility to heat damage, and the cost of processing. Each drying method may be particularly suited for a specific group of products. There is no one best technique for all products. Energy is also a major consideration in selecting a drying method, because a large amount of thermal energy is required for moisture evaporation, and energy efficiency varies among different type of dryers. As a reference, Table 5 shows variations in space requirements and energy efficiencies for selected and well-known drying systems.

In the future, it is probable that more novel drying techniques will be developed and become available for specialized purposes. Furthermore, current techniques will also probably be further refined to make them more economical and energy efficient and will also be explored for use with other food products.

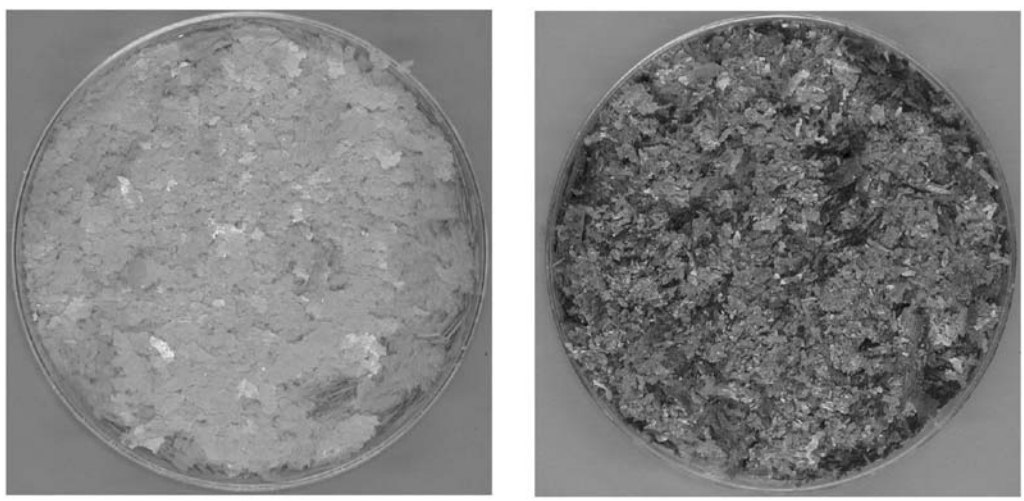


Figure 27 Products dried with Refractance Window systems. (A) Carrot dried from purees; (B) strawberries dried from purees.

Table 4 Summary of Novel and Conventional Drying Techniques for Food

Technique	Suitability/ current usage	Advantages	Disadvantages
Microwave drying and radio frequency drying	High value-added products, pasta, cookies	Good for finishing drying, low temperature, batch or continuous operation, good quality	May be expensive
Microwave-augmented freeze-drying	High value-added products	Low temperature, rapid, good quality	Expensive
Centrifugal fluidized-bed drying	Small particles, vegetable pieces, powders	Rapid, easy to control	Loss of product integrity, noisy
Ball drying	Small particles, vegetable pieces	Relatively low temperature, rapid, continuous	Loss of product integrity, difficult to control
Ultrasonic drying	Liquids	Rapid	Requires low-fat solutions
Solar (open-air) drying	Fruit, meat, fish, plants	Simple, low cost	Large space required, labor-intensive, difficult to control, slow
Smoking	Meat, fish	Added flavors	Difficult to control, slow
Cabinet tray dryer or tunnel dryer	Fruit, vegetables, meat and fish	Batch or semicontinuous (for tunnel dryer), flexible	Relatively small throughputs, poor control of quality
Conveyor dryer	Diced vegetables and fruit	Continuous, large throughputs, consistent quality	Large floor space required; some thermal degradation when using high temperature to shorten process time
Drum drying	Liquids, pureed fruit and vegetable	Continuous, high energy efficiency	May require modification of liquid to allow good adhesion to the drum wall
Spray drying	Liquids, instant tea, coffee	Spherical product	Some quality loss
Fluidized-bed drying	Small uniform particles, small vegetable	Usually batch operation, uniform drying, rapid	Restriction on particle size

(*continued*)

Table 4 Continued.

Technique	Suitability/ current usage	Advantages	Disadvantages
Freeze-drying	High value products, fruit pieces, instant coffee, vegetables, dairy products, meats	Can be used in continuous operation, no restriction on particle size, excellent retention of product sensory, physical, and nutritive characteristics	Slow, expensive, fragile product, need good package material to prevent oxidation
Explosive puffing	Gives small particles, honeycomb structure	Good rehydratability, rapid	High heat, loss of product integrity
Osmotic drying	Sugar-infused fruit	High quality	Multiple-step process
Refractance Window	Pureed products	High quality	Continuous, still in perfection stage

Table 5 Capacity and Energy Consumption for Selected Dryers

Dryer	Typical evaporation capacity (kg H_2O) (h^{-1})	Typical energy consumption (kJ/kg H_2O removed)	Energy efficiency (%)
Tunnel	—	5500–6000	38–42[a]
Conveyor	—	4000–6000	38–58
Fluidized-bed	—	4000–6000	38–58
Spray	$1–30\,m^{-3}$	4500–11,500	20–51
Drum	$6–20\,m^{-2}$	32–6500	35–72

[a]Based on latent heat of vaporization for water of 2300 kJ/kg H_2O.
Source: Adapted from Ref. (54).

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22

Dehydrated Oriental Mushrooms, Leafy Vegetables, and Food Preparation Herbs and Condiments

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I. BASIC PRINCIPLES AND TECHNOLOGY FOR VEGETABLE DEHYDRATION (1–4)

Fresh vegetables contain large amounts of water, usually above 90% and in the free form; thus they are subject to microbial deterioration. At the same time, fresh vegetables occupy large volumes with tender tissues, posing difficulty in storage and transportation. By reducing their water content and subsequently their water activity, and increasing their soluble solids contents, we can inhibit microbial activities, lower enzymatic activities, and increase the storage stability of vegetables. This process method is called dehydration. Dehydration of vegetables has a long history that shows various kinds of products that are nutritious, easy to store and transport, and convenient to consume. Typical dehydrated vegetables in China include black fungus (wood ear), dried chili pepper, lily flower (jinjianchai), and bamboo sprout slices (yulanpien).

Dehydration is a water evaporation process. First, surface water on the raw material is evaporated. This is called "external diffusion." The larger the surface area, the faster the air circulation, and the faster the water evaporation. Water at higher concentration in the interior of the raw material moves to the surface with lower water concentration. This transition phenomenon is called "internal diffusion." The rates of external diffusion and internal diffusion must be coordinated. If the rate of external diffusion for water is far greater than the rate of internal diffusion for water, the water in the interior cannot move fast enough to the surface thus causing the surface to be overdehydrated with the formation of case hardening, affecting the dehydration. When the water concentration in the interior is too high, its water vapor pressure will be too high. This causes cracking of the more tender tissues and thus the cracking of the surface with leaching of the soluble substances from the interior, affecting negatively the appearance and quality of the final product.

There are many methods of dehydration. Based on the heat source or the utilization of energy, and the various treatments, they can be grouped into mechanical dehydration and natural drying.

A. Mechanical Dehydration

1. Drying in Artificial Dehydrators

This method utilizes fuels (such as coal, charcoal, wood, oil, gasoline, and natural gases) to generate heat in order to achieve the purpose of dehydration. This is a common process. The equipment varies, with the simpler kiln and hot chambers, and the various more complicated dehydrators. The tunnel-type dehydrator is fairly common in the production of dehydrated vegetables.

Tunnel-type dehydrators have either one or two long narrow tunnels as a heating room. Inside the tunnels, there are rails. Raw materials are loaded on trays in carts and exposed to the hot air for interaction. The carts move from one end to the other end of the tunnel. Part of the exhaust gas is vented out and the rest recycled into the heating tunnel. Based on the direction of the air movement and the direction of the loaded carts, dehydrators can be cocurrent, countercurrent, and combined type.

For cocurrent dehydrators, the loaded cart will move in the same direction as the hot air. At the beginning of the dehydration, raw materials are exposed to high-temperature air with low relative humidity. Water evaporates rapidly. As the carts move forward, the lower is the temperature and higher the relative humidity. In general, the initial temperature is 80–85°C, and the ending temperature is 55–60°C. The higher initial temperature inhibits enzymatic activities better.

For countercurrent dehydrators, carts loaded with raw materials move in opposite directions against the hot air. At the initial stage of dehydration, raw materials are exposed to lower temperature and higher relative humidity, and the dehydration is completed at high temperature and low relative humidity. In general, the entrance temperature is 40–50°C, and the ending exit temperature is 65–85°C. This process is more suitable for fruits with high sugar content and viscous juice (cytoplasm).

For combined type dehydrators, the dehydration is a two-stage process: one is cocurrent, and the other is countercurrent, i.e., hot air comes in from both ends of the tunnel, and the exhaust vent is in the middle. This process first exposes the raw materials by way of cocurrent while water is rapidly evaporated under higher temperature air. In the intermediate stage, temperature is lower, and relative humidity is higher and evaporation slower, avoiding case hardening. At the final stage, raw materials are exposed to higher temperature and lower relative humidity to ensure that the product will meet the dehydration level.

Besides these there are drum dryers and belt-type dryers. The former are composed of one or two drums. The drums are both heating and cooling media. Raw materials are dried on the drum. In the latter type, the raw materials are spread on the belt, and the belt moves forward exposing the raw materials to the heating medium.

2. Freeze-Drying

Freeze-drying is also called freeze sublimation dehydration or lypholization. Raw materials are frozen to temperatures below the freezing point, and the water is converted to ice. Under a high vacuum condition, ice is converted (sublimed) to water vapor and removed, thus drying the materials. Freeze-drying preserves the original flavor of the raw material with minimal heat damage. However, the product cost is high, and it is only suitable for products with very high quality standards such as functional foods and pharmaceuticals.

3. Microwave Dehydration

Microwave dehydration utilizes high-frequency alternating current at microwave frequencies of 300 MHz to 300 kMHz and wavelengths of 1 mm to 1 m. Microwave dehydration has the advantages of rapid drying rate, short dehydration time, homogenous heating, and high heat efficiency.

4. Far Infrared Dehydration

Far infrared rays are infrared rays with wavelength of 5–1000 μm. The far infrared rays are absorbed by the raw materials and directly converted to heat energy, thus achieving the heated dehydration effect. During dehydration, every layer of the material receives the same heat treatment. This process has the advantages of rapid dehydration, high production efficiency, energy efficiency, small-scale facilities, low capital investment need, and good quality of dehydration.

5. Vacuum Dehydration

Vacuum dehydration utilizes the principle that water evaporates through boiling under low pressure (vacuum). Water in a vegetable is mechanically removed from its tissues, thus achieving the dehydration effect. This process protects heat-sensitive materials and avoids the loss of volatiles. However, it requires more energy.

6. Spray Drying

Liquid or pasty material is usually spray dried. The basic principle is to heat up the liquid with hot air and then spray it into small droplets through the high-speed rotation of nozzles. The droplets are exposed to high temperatures for a short time to achieve the dehydration effect. The dried product is collected in the cyclonic separator.

B. Natural Drying

Natural drying utilizes the natural elements in the environment (such as the sun and hot winds) to dry the vegetables. Exposing the raw materials directly to the sun is called sun (solar) drying. Drying in the shade or in well-ventilated rooms is called natural drying or airing. It is characterized by simple facilities and low production costs, but it is limited by weather and location.

C. Dehydration Technology

Mechanical dehydration technology includes the following steps: selection of raw materials → trimming and washing → peeling and cutting (size reduction) → rinsing → blanching and cooling → color protection → dehydration → moisture equilibrium and softening → grading and packaging.

1. Selection of Raw Materials

Raw materials designated for dehydration must be fresh, bright-colored with well-developed and firm tissues, and minimal fibers and trimmings. They must be of suitable shape, size, homogenous maturity, and not deteriorated or severely damaged.

2. Trimming and Washing

Trimming removes the inedible portions such as peels, rinds, roots, leaves, and off-graded parts. Washing removes soil, foreign matter, agricultural chemicals, and microbiologically contaminated tissues, thus meeting the basic requirements for dehydration.

3. Peeling

For root-type vegetables, the peels have to be removed. This not only facilitates water evaporation and benefits dehydration, it also increases the eating quality of the final product. Peeling can be accomplished by hand, mechanical devices, heat, and chemicals.

4. Cutting and Rinsing

Based on product requirements, raw materials can be cut into definite shape and size to facilitate dehydration. In general, vegetables are cut into slices, strips, dices, and shreds, either mechanically or by hand. For some vegetables such as scallions and garlic, cutting has to be accompanied by continuous rinsing to remove the colloidal liquid (cytoplasm) due to cutting to facilitate dehydration and provide products with good color and appearance.

5. Blanching and Cooling

Blanching is briefly to treat the raw materials with heat to inhibit enzymatic activities, prevent discoloration and browning, reduce microbial contamination, and soften the tissues to facilitate dehydration. In general, blanching can be conducted in steam or boiling water. Blanching time depends on kinds of raw material, shape, size, tissue, and tenderness, and varies accordingly; it is usually 2–5 minutes, or even several seconds. In order to protect the original bright color, for some vegetables such as snow pea pods, broccoli, and carrots, the addition of a small amount of food-grade sodium bicarbonate or citric acid may be necessary.

Rapid cooling right after blanching prevents over-softening, which might cause shape change and loss of elasticity and brightness.

6. Color Protection

For vegetable products that change color easily, the addition of harmless color protectants such as sodium bicarbonate or citric acid (in the blanching water) may be permitted. The residual liquid on the vegetable must be removed by centrifuge.

7. Dehydration

In general, a tunnel-type dehydrator is used to conduct the dehydration. The procedures are as follows:

1. Loading the trays. Raw materials ready for dehydration are loaded evenly onto drying innocuous trays. They are usually cuboid, with dimensions of $1.0 \times 1.0 \times 0.48$ m, with square pore of 6×6 mm. Each tray can hold 2.0 to 5.0 kg, depending on kind of vegetable.
2. Loading carts. Loaded trays are loaded into drying carts. Each cart can hold 18–20 layers with 36–40 trays.
3. Drying. Carts with vegetables are carried by belt into the tunnel for dehydration. New carts are put into the tunnel periodically, replacing another cart loaded with dehydrated vegetables. This process is continuous to maximize efficiency. Each tunnel usually holds 8 or 9 carts, at temperatures of about 60°C, but not above 65°C. In general, it takes 6–8 h to complete the dehydration; the exact dehydration time depends on the required moisture content of the final

product. Too high a temperature induces expansion of the cytoplasm and eventually the loss of contents, case hardening, and browning. Vegetables with high sugar content and volatiles should be dehydrated at a lower temperature.

8. Moisture Equilibrium

Because there are different cultivars (varieties), different shapes and sizes, and various thicknesses, when loading the trays, it is not uncommon that there are slight differences in the moisture content of the final product coming out of the tunnel. Therefore dehydrated products, after brief cooling, should be packed in air-tight drums or plastic bags in containers for 1 or 2 nights to allow for moisture equilibrium before conducting the next step.

9. Grading

Grading is to remove the broken pieces and foreign matter, and also the off-grade products. Grading has to be rapid to avoid reabsorption of moisture. Graded products have to be followed by quality and moisture examination. Off-grade products will need reconditioning (additional dehydration).

10. Compression

Dehydrated vegetables exist in loose form with considerable volume, and are not good for packaging and transportation. Therefore some dehydrated vegetables have to be compressed. Requirements for compression are 60–65°C, suitably controlled moisture content, and 20–80 kg·f/cm^2 pressure.

11. Packaging

Dehydrated vegetables are packed in moisture-proof aluminum-impregnated plastic bags and subsequently in plastic bags and corrugated boxes. For products easily oxidized, laminated plastic bags and aluminum-impregnated plastic bags are needed. Each box weighs 20 or 25 kg.

12. Storage

Packaged products should be stored in warehouses at about 10°C. The warehouse should be dry, cool, and free of offensive odors and pests. The stored products have to be examined periodically for moisture content and insect damage.

II. SOME DEHYDRATED VEGETABLES (3–7)

A. Onion (*Allium cepa* L.)

The onion belongs to the Liliaceae family and originates in southwestern Asia. It is nutritious and well liked by consumers. Table 1 shows selected nutrients of the onion. Besides, it contains compounds characteristic of its flavor such as thiol, dimethyldisulfide, diallylsulfide, disulfides, and thiosulfate, as well as small amounts of citric acid, *o*-hydrocinnamaldehyde, caffeic acid, asafetidic acid, protocatechuric acid, polysaccharide A, polysaccharide B, quercetin 3,4′-diglycoside, thymine, and several amino acids. Medical reports have shown that onion can lower blood lipids and prevent hardening of the arteries. It contains selenium that can induce the human body to release large amounts of glutathione. When the concentration of this compound increases,

Table 1 Selected Nutrients in Onion

Nutrient	Content (per 100 g edible portion)
Protein	1.8 g
Carbohydrates	8.0 g
Crude fiber	1.1 g
Calcium	40.0 mg
Phosphorus	50.0 mg
Iron	1.8 mg
Thiamin (Vitamin B_1)	0.3 mg
Riboflavin (Vitamin B_2)	0.02 mg
Niacin	0.2 mg
Ascorbic acid (Vitamin C)	8.0 mg

the occurrence of cancer is greatly lowered. Besides, onion flavonoids have antidiabetic, antiaging, and bacterial-inhibition effects. Onion can be processed into dehydrated onion and onion powder and other products.

Dehydrated onion. Select large, white-colored, well-developed, and damage-free mature onions. Wash with sanitary water and drip dry. Cut off both top and bottom ends. Remove the outer layers. Slice the onion into pieces 3–5 mm thick. Spread the onion slices onto the drying trays and subsequently load the carts. Onion slices in the loaded carts are dehydrated at the controlled temperature of 93°C for 1–1.5 h. The temperature is then lowered to 53°C. When the moisture content reaches 6–7%, the temperature is again lowered to 45°C until the moisture content reaches 3.5%. Dehydrated onion slices are taken out from the dehydrator and cooled at ambient temperature before packaging.

B. Tomato (*Lycopersicum esculenta* L.)

The tomato originates in South America. It is one of the most-liked vegetables in the world. It is rich in B-vitamins, ascorbic acid (vitamin C), and carotene (see Table 2). It is one of the best vegetables for patients with hardened arteries. In the human body, vitamin C blocks the reaction between amine or acid amide and nitrite, thus inhibiting the formation of carcinogenic

Table 2 Selected Nutrients in Tomato

Nutrient	Content (per 100 g edible portion)
Ash	0.4 g
Calcium	8.0 mg
Phosphorus	37.0 mg
Iron	0.4 mg
Thiamin (Vitamin B_1)	0.03 mg
Riboflavin (Vitamin B_2)	0.02 mg
Niacin	0.6 mg
Carotene	0.31 mg
Ascorbic acid (Vitamin C)	1.0 mg

nitrosamines. Therefore regular consumption of the tomato helps prevent cancer. Besides, it contains citric acid, malic acid, and other organic acids as well as adenine, trigonelline, choline, lycopene, and small amounts of tomatine. Lycopene has a curing effect for patients with prostate diseases. Tyrosine has an inhibition effect on several pathogenic fungi and bacteria; it is also effective in some inflammatory cases and thus has a curing effect on intestinal diarrhea. Besides, the tomato contains substance(s) that can inhibit tyrosinase enzymatic activity, causing the reduction or disappearance of pigments in the skin and in the organs, keeping the skin clean.

a. Dehydrated Tomato Select fresh tomatoes that are slightly underripened, well developed, and contain high solid contents. Remove the insect-damaged fruit and wash the tomatoes. Cut them horizontally and rinse off the juice and seeds adhered to the slices. For sun drying, spread the tomato slices single-layered on mats and dry under the sun. Turn over the slices periodically until they are dried. For mechanical dehydration, tomato slices are spread on drying trays and loaded into the carts before they are subject to dehydration in a dehydrator. The dehydration temperature should be controlled at 60 to 65°C. The dehydration can be completed in 30 h.

b. Tomato Powder Select fresh tomatoes that are fully ripe, bright-colored, and well developed and have high solid contents. Remove deteriorated and insect-damaged fruit. Wash them with sanitary water and remove the stem core. Blanch them in boiling water for 2 min and pulp them. After pulping, screen off the skin, seeds, and fibers. The juice is then concentrated under vacuum to 18°Brix. After concentration, the juice is homogenized at a pressure of 150–200 kg/cm^2. Salt at 1–2% may be added to enhance the flavor. Addition of 0.03% sodium bisulfite can protect the vitamin C. Homogenized tomato juice should be kept at 65°C. When the temperature of the dehydration chamber of the spray dryer reaches 85°C, spraying can be initiated. The temperature of the hot air at the inlet of the dehydration chamber should be at least 160°C, and the temperature of the dehydration chamber should be maintained at 80–85°C. Spray dried tomato powder is then collected through the collector chamber. Tomato powder should be packed airtight.

C. Carrot (*Daucus cart* L. var. *sativa* DC.)

The carrot originates from Europe and Central Asia. It is nutritious (see Table 3). The proteins in carrot contain five of the essential amino acids for humans. Carrot contains calcium and phosphorus, which are essential for bone development. Copper and iron are essential in the synthesis of heme. Fluorine can induce the anticavity ability of tooth enamel. Magnesium, manganese, and cobalt are components of enzymes and proteins. Crude fiber can induce gastrointestinal movement. In addition, carrot contains caffeic acid, chlorogenic acid, gallic acid, and other organic acids and volatiles such as α-pipene, camphene, laurine, α-phellandrene, and bisabolene. Carrot is rich in carotene, which is converted by carotenase to vitamin A in the liver and intestinal inner surface. Recent medical reports show that carrot contains a substance that can lower blood sugar. Regular consumption of carrots help brighten the eyes, strengthen the stomach, eliminate congestion, and prevent eye disease, colds, gastrointestinal diseases, skin disease, and cancer.

a. Carrot Powder Select carrots that are free from insect damage and deterioration. Discard the off-grades. Wash the sound ones clean. Dip the carrots in 8–12% sodium hydroxide solution to peel off the skin. The temperature of the lye solution should be 95°C or above, and the soaking time not more than 3 min. Rinse the lye treated carrots three or four times in running water to remove the residual lye and at the same time cool the carrots. Trim and crush the carrots. Soften them either in steam or in boiling water. For boiling water softening, carrots and water (ratio 1 : 1) are put into a steam kettle. Add enough citric acid to adjust the pH value to 5.5. Boil

Table 3 Selected Nutrients in Carrot

Nututrient	Contents (per 100 g edible portion) Yellow carrot	Red carrot
Water	89.6 g	89.3 g
Protein	0.6 g	0.6 g
Fat	0.3 g	0.3 g
Carbohydrates	7.6 g	8.3 g
Calories	35.0 kcal	38.0 kcal
Crude fiber	0.7 g	0.8 g
Ash	0.8 g	0.7 g
Calcium	32.0 mg	19.0 mg
Phosphorus	30.0 mg	29.0 mg
Iron	0.6 mg	0.7 mg
Carotene	3.62 mg	1.35 mg
Thiamin (Vitamin B_1)	0.02 mg	0.04 mg
Riboflavin (Vitamin B_2)	0.05 mg	0.04 mg
Niacin	0.3 mg	0.4 mg
Ascorbic acid (Vitamin C)	13.0 mg	12.0 mg

for 20–30 min. Softening in steam can be conducted either under ambient or pressurized conditions. Pulp the softened carrot using a blade type pulper with screen openings of 0.4–1.5 mm. The carrots should be pulped two or three times when the carrots are still hot to obtain puree that is smooth and without separation. Drum dry the puree with a drum surface temperature of 120–140°C. An amount of puree should be put on the drum to complete the drying in one rotation. The dried carrot is then scraped off from the drum using a special blade; at the same time, the dried carrot is cooled. It is sieved through a No. 80–100 sieve before packaging.

D. Spinach (*Spinacia olercea* L.)

Spinach belongs to the Chenopodiaceae family. It is either an annual or a biannual plant. Selected nutrients in spinach are listed in Table 4. Spinach is rich in zinc, folic acids, amino acids, carotenoids, spinasterol, cholesterol, marigold, and spinacin. Spinach is said to be good for the

Table 4 Selected Nutrients in Spinach (per 100 g edible portion)

Component	Content	Component	Content
Moisture	91.8 g	Phosphorus	53.0 mg
Protein	2.4 g	Iron	1.8 mg
Fat	0.5 g	β-carotene	3.87 mg
Carbohydrates	3.1 g	Thiamin	0.04 mg
Crude fibers	0.7 g	Riboflavin	0.13 mg
Ash	1.5 g	Nicotinic acid	0.6 mg
Calories	27.0 kcal	Ascorbic acid	39.0 mg
Calcium	72.0 mg		

blood. It is generally believed that this is related to the iron content in spinach. However, others believe that the iron in spinach is not that easily absorbed by the human body, and the blood enriching property is related to carotenoids and vitamin C. Besides, spinach contains cyanocolbalamin. Deficiency in this factor can cause macrocythemia and lowering of leukocytes. Spinach can excrete a stimulant that is helpful to the gastrointestinal tract and excretion ability of the pancreas, thus enhancing the food absorption and digestive functions. In addition, the fibers in spinach are smoother than the other vegetables and can be easily excreted during the intestinal movement, carrying out the waste and toxic substances.

a. Dehydrated Spinach Select large-leafed spinach as the raw material. Trim off the roots and the older leaves. Wash thoroughly before loading onto trays and subsequently the carts for dehydration. The temperature should be maintained at 80°C. The dehydration time is about 4 h. The moisture content of dehydrated spinach should be below 6.5%.

E. Other Dehydrated Vegetables

There are many kinds of vegetables. Besides those described above, green pepper, black-eyed beans (cowpeas), and cabbage are also important. They provide nutrients and occupy important positions in daily life.

a. Dehydrated Green Pepper Select large green peppers with thick and tender rinds harvested in the summer. Cut longitudinally into halves and remove the seeds. Dip the halves into 90–100°C hot 5% lye solution for 3–4 min. Remove and cool with water before thorough washing and drip dry. The treated pepper halves can be dried in a dehydrator at 60–70°C.

b. Dehydrated Black-Eyed Beans with Pods Select black-eyed beans with pods that are tender, long, uniform, well developed, and insect-free. After washing, put the beans in boiling water and hold until boiling. Remove and drip dry. Spread the beans on mats and sun-dry until they are 80% dry. Load these intermediately dried beans into a steamer for additional processing, until the beans are soft and moist. Remove and spread the beans on mats and sun-dry again until completely dried. Soften the dried bean for 1–2 days before packaging.

c. Dehydrated Cabbage Select cabbages that are big and of good quality with soluble solids not less than 4°Brix. Remove the outer layers of the head cabbage and shred the cabbage. Boil the shredded cabbage in water (0.2% sodium bisulfite added) for 3 min. Remove and drip dry before loading onto the dry trays for the dehydrator. The temperature at the later stage of dehydration should be 55–60°C. Dehydration time is about 9 h.

III. EDIBLE MUSHROOMS AND FUNGI (8–17)

Edible mushrooms provide characteristic flavor and are nutritious. They can modify the food composition and balance the nutrients, and also elevate the utilization rate of proteins. In general, the protein content of fresh edible mushrooms is twice that of vegetables, and four times that of oranges. Among the common 20 kinds or more of amino acids, edible mushrooms contain 17 or 18 and provide almost all the eight essential amino acids needed for the human body. Edible mushrooms do not contain starch; they are low in lipids (about 2–8% of dry weight), so they are ideal for diabetics. They are called the "safe food." Edible mushrooms contain several vitamins and are high in mineral contents. The thiamin, riboflavin, and nicotinic acid contents are higher than meats. The vitamin B_{12} content is higher than cheese and fish. Many mushrooms contain ergosterol, which is absent in most vegetables. Ergosterol is the precursor for vitamin D_2; deficiency in this vitamin affects calcium absorption. The mineral contents in edible mushrooms are generally twice those of vegetables and higher than beef and lamb.

Edible mushrooms have high pharmaceutical values. Recent studies confirm that edible mushrooms contain special components such as fungal polysaccharides and glucoproteins that possess biological activities. They can induce the synthesis of interferons, strengthen immune systems, and elevate an organ's anticarcinogenic ability. Edible mushrooms become the main sources for screening anticarcinogenic compounds. They can maintain and lower cholesterol levels in humans. This is more evident with the consumption of animal fat.

Edible mushrooms contain over 90% water. They continue to grow after harvest. In general, they are not suitable for long-term storage. Besides those targeted for fresh consumption or export, they should be processed. Dehydration is a common processing method for edible mushrooms. The moisture requirement for dehydrated mushrooms is 12% or less. Edible mushrooms can be sun-dried, mechanically dehydrated, or naturally evaporated to dryness; or a combination of one or more of these dehydration methods is used.

A. Straw Mushroom (*Volvariela voluacea* Sing.)

The straw mushroom grows in areas with high temperature and a considerable amount of rainfall in the tropics and subtropics. It is a fungus grown on humus. Besides being used for fresh consumption, the straw mushroom can be processed into dehydrated straw mushrooms with even stronger flavor and easier packaging, transportation, and storage. Or it can be processed into canned straw mushrooms or into powder or used in soy sauce manufacturing. It ranks third in volume in world mushroom production. The straw mushroom has a tender texture and a better flavor, and it is nutritious. According to analysis, the straw mushroom contains 158.44 mg per 100 g wet weight vitamin C. Dehydrated straw mushroom contains per 100 g dry matter: crude protein, 33.77 g; lipid, 3.62 g; nitrogen-free extract, 30.51 g; crude fiber, 18.40 g; and ash, 13.30 g.

Regular consumption of the straw mushroom is beneficial to the human body. It is generally recognized that consumption of food rich in vitamins can enhance the regular metabolism, elevate the resistance to epidemic diseases, increase the healing rate to wounds, and can prevent the occurrence of scurvy. The straw mushroom contains an unusual protein that has an anticarcinogenic effect. The nonnitrogen extracts and purine bases can inhibit the growth of cancer cells.

In the dehydration of straw mushrooms, first clean up the unuseful matter in the bottom part of the straw mushroom. Cut longitudinally into halves. Spread them on drying trays and subject them to dehydration. The initial dehydration temperature is 40°C, followed by regular turnover and change of positions of trays. With the decrease in moisture content, the dehydration temperature is gradually raised to 60°C with moisture content of the straw mushroom lowered to 12% or less and then packing.

B. Shiitake (Black) Mushroom [*Lentinus edodes* (Berk) Sing.]

The shiitake (black) mushroom is widespread in China, Japan, Korea, and Vietnam. It is nutritious. Dehydrated shiitake mushroom contains per 100 g dry matter: crude protein, 17.5 g; lipid, 8.0 g; carbohydrates (including fiber), 67.5 g; ash, 7.0 g. It occupies an important position in the health food area. The shiitake mushroom contains 18 kinds of the common amino acids, 27.2% being glutamic acid, among the highest in edible mushrooms. It contains ergosterol, which is not common in vegetables; the content can be up to 128 I.U. (20 times more than soybean, and 8 times that of seaweed.) Thus consumption of the shiitake mushroom enhances calcium absorption and prevents rickets in children and bone softening in pregnant women, women giving birth, and people with limited exposure to sunlight. It also has anticarcinogenic properties, prevents cirrhosis (hardening) of the liver, removes poisons in blood, and lowers blood cholesterol.

A small percentage of shiitake mushrooms are consumed fresh, while the majority enters the processing market. In the production (dehydration) process of shiitake mushroom, the initial dehydration temperature is generally 40°C, with the venting windows completely opening. After two hours, the dehydration temperature is increased 2°C per hour with gradual closing of the venting windows. The final dehydration temperature is 60–65°C, with venting windows closed completely and holding for one hour.

C. Oyster Mushroom [*Pleurotus ostreatus* (Jacq. ex. Fx.) Quel.]

Oyster mushroom is the general term used to include all the pleurotus edible mushrooms. There are more than 30 varieties. It is a large and rapid growing edible mushroom among the more than 360 edible mushrooms discovered in China. The oyster mushroom contains per 100 g dry matter: crude protein, 19.46 g; lipids, 3.84 g; nonnitrogen extract, 65.6 g; crude fiber, 6.15 g; and ash, 4.94 g. Recent studies show that the oyster mushroom contains biologically active compounds such as pleurotus ostreatusin and acidic polysaccharides that are beneficial to health maintenance and disease prevention.

In the dehydration of the oyster mushroom, preheat the hot room to 40°C with all moisture removed before putting the mushroom into the chamber. Hold for 2 hours and increase the dehydration temperature to 50°C. Five hours later, increase the temperature to 60°C and hold for 2 hours. Lower the temperature slowly, avoiding the "burning" of the mushroom.

D. Bearded Tooth (Houtou) Mushroom [*Hericium erinacous* (Bull et Fr.) Pers.]

The bearded tooth (Houtou) mushroom is the fruit of the fungus. The main production area is China. The bearded tooth mushroom is nutritious with umami-type flavor. It is not only a precious food item but also has medicinal functions. The bearded tooth mushroom contains polysaccharides with the highest anticarcinogenic effect among all the mushrooms. It has a definite curing effect to stomach and duodenum ulcers, as well as cancers in the digestive system without side effects. Bearded mushroom contain per 100 g dry matter: moisture, 10.2 g; protein, 26.3 g; lipid, 4.2 g, carbohydrates, 44.9 g; calories, 1352 Kcal; fibers, 6.4 mg; calcium, 2 mg; phosphorus, 356 mg; iron, 18.0 mg; thiamin (vitamin B_1), 0.69 mg; and riboflavin, 1.89 mg. Of all the nutrients in bearded tooth mushroom, the contents of lipid, phosphorus, thiamin, and riboflavin are higher than other mushrooms. Bearded tooth mushroom contains 16 kinds of the common amino acids, with seven of the essential ones.

In the dehydration of bearded tooth mushrooms, fresh mushrooms are naturally dried for 1 or 2 days followed by size grading and mechanical dehydration. The temperature of dehydration starts at 40°C and is gradually raised to 60°C until the completion of dehydration. The moisture content of dried bearded tooth mushroom should be maintained at 10–13%. It is important that the "bearded tooth" of the mushroom stay intact for the dehydrated product.

E. Fuling Fungus [*Poria cocos* (Fr.) Walf.]

Fuling fungus is produced mainly in Hunan, China. It is distributed in China, Japan, and North America. China is the leading producing country for Fuling fungus, which is extensively marketed in southeastern Asia and various places in the world. Fuling fungus is a delicious and high-priced food. It has also medicinal functions and is widely used in herbal medicine. It has been used for at least 3000 years in traditional Chinese medicine. According to the *Shen nong bai chao*, it is classified as a perfect herb.

Table 5 Chemical Composition of Fuling Fungus

	Content (g/100 g)					
Sample #	Moisture	Protein	Carbohydrates	Lipid	Crude fiber	Ash
1	12.92	0.79	79.88	0.35	5.77	0.24
2	9.16	6.68	84.2	—	2.84	6.168

Recent studies show that the main components of Fuling fungus are the Fuling polysaccharide, protein, fuling acid, ergosterol, choline, and lecithin. Table 5 lists the selected nutrients in Fuling fungus. According to the traditional Chinese medicine classification, Fuling fungus is neutral in nature and light tasting, and can enter the heart, lung, spleen, and kidney meridians. The main curing functions include excretion of dampness, swelling of skin, strengthening the spleen, enhancing the excretion of liquids, and calming the spirit (mind). It can also cure excessive (coughing) mucus, swelling due to excessive water, difficulty in urination, diarrhea, frightening and dizziness, an unstable mind, and frightened insomnia.

Fuling fungus is harvested at maturity without delay; its volume is reduced by evaporating its moisture naturally. This process is usually called "sweating." In general, the cleaned and washed Fuling fungus is left in a dry and ventilated room to allow natural evaporation until the surface is wrinkled and turned brown. The Fuling fungus is then left in a shaded and cool area until complete dryness. After dehydration, Fuling fungus is usually ground to a powder for utilization.

F. Wood Ear or Black Fungus [*Auricularia auricula* (L. ex Hook) Undew] and White Fungus (*Tremella fuciforms* Berk)

Wood ear (black) fungus and white fungus are well-known edible fungi. The resources for wood ear fungus are most abundant in China. Wood ear fungus contains per 100 g dry matter the following selected nutrients: water, 10.4 g; protein, 10.5 g; carbohydrates, 69.5 g; lipid, 1.2 g; crude fiber, 4.2 g; ash, 4.2 g; free amino acids, 7.9 g. It is fairly abundant in protein, carbohydrates, vitamins, and minerals, but low in lipid. Wood ear fungus is rich in hydrocolloids. Recent reports show that the main components in the wood ear hydrocolloid are polysaccharides, glucuronic acid, mannose, and small amounts of glucose and fructose. They have significant inhibition effect on cancers in mice. In traditional Chinese medicine, it is generally believed wood ear fungus has the following functions: strengthen the "essence," tone the kidney, moisten the lung, increase saliva secretion, stop coughing, lower the *huo*, lubricate the intestine, tonify the *Qi* or *chi*, benefit the spleen and stomach, strengthen the heart, strengthen the brain, beautify the complexion, tenderize the skin, lower blood pressure, lengthen the life span, and enhance longevity.

Wood ear fungus is generally dehydrated for long-term storage. The processes include selection, dehydration, grading, and packaging. After dehydration, the moisture is lowered to about 13%. The success of dehydration depends on dehydration steps with lower initial temperature and higher final temperature. The initial dehydration temperature is controlled at 10–15°C and gradually rises to about 30°C.

White fungus is mainly produced in Fujian Province, China. In traditional Chinese medicine, white fungus is believed to have the following functions: sweet and light taste, neutrality in nature, enrich the *yin*, moisten the lung, support the stomach, increase saliva secretion, enrich the kidney, benefit the "spirit," and strengthen the heart and the brain. White

fungus is known to be a precious herb and has the same reputation as ginseng, pilose antler, and swallow saliva. White fungus has the following nutrients (per 100 g dry matter): carbohydrates, 61.8 g; protein, 7.3 g; lipid, 0.7 g; crude fiber, 12.8 g; and ash 4.4 g. Dehydration procedure for white fungus is the same as for wood ear fungus.

G. Lucid Ganoderma or Lingzhi [*Ganoderma lucidum* (Leyss, ex Fx)]

Lucid ganoderma is not only a valuable herb but also an exquisite food. Lucid ganoderma performs numerous biological activities, and many of its compounds have been already isolated. The polysaccharides in lucid ganoderma have the ability to stimulate the hidden host's immunity reaction; inhibit a transferred tumor's biological activity; increase a muscle's durability to oxygen deficiency; eliminate free radicals; resist radiation; increase the ability to synthesize DNA, RNA, and protein in liver, bone marrow, and blood, and consequently extend life span. The main components in Lingzhi or lucid ganoderma are ganodermic acid and triterpenoids, and they are responsible for the bitter taste of lucid ganoderma. This group of compounds strengths the stomach, inhibits the release of histamine, and has pain-releasing and calming effects. They also have detoxification, liver protection, and cancer killing effects. Adenosine, mannitol, and ergosterin also regulate the synthesis or decomposition of neutral fats in fatty cells. The other functional components such as lucid alkaloids can significantly increase the blood flowing volume in an anesthetized dog and lower the resistance of a coronary artery and the oxygen consumption of the heart muscle. The spores in lucid ganoderma contain ester(s) that can lower blood cholesterol content.

After harvesting the brightly colored lucid ganoderma, the stem end with adhering root and other foreign matter is trimmed off from the fresh soft mushroom. The mushroom has to be spread out for natural drying. They can also be mechanically dehydrated at 40–50°C with good ventilation to avoid rotting due to excessive heat generated. Lucid ganoderma can also be sliced before dehydration.

H. Enoki (Winter or Golden) Mushroom [*Flammulina velutipes* (Curt ex Fx) Sing.]

The enoki mushroom has beautiful appearance and umami-type flavor. It is well known as a mushroom for herb, food, and "look and enjoy." Regular consumption can prevent liver and gastrointestinal tract diseases. The lysine and arginine contents in the winter mushroom are higher than those in other mushrooms, and they are beneficial to the development of intelligence and health in young adults or adolescents. It is also called "intelligence increasing mushroom" in some countries. Winter mushroom contains the following selected nutrients per 100 g of dry matter: protein, 16.2 g; fat, 1.8 g; carbohydrates, 60.2 g; crude fiber, 7.4 g; ash, 3.6 g; calcium, 76 mg; phosphorus, 280 mg; iron, 8.9 mg; thiamin (vitamin B_1), 0.16 mg; riboflavin (vitamin B_2); and niacin, 23.4 mg. Besides, winter mushrooms contain flammulin, which is an effective anticarcinogen.

In the dehydration of enoki mushrooms, select long stemmed and tender mushrooms with the umbrella closed. Remove the growing medium and foreign matter adhered to the mushroom's stem. Steam the mushrooms for 10 minutes. Remove and spread them on trays for dehydration in a dehydrator. Dehydrated winter mushrooms are tied into small bundles and packed in plastic bags. The dried product has to be reconstituted before consumption.

I. Edible Boletus (*Boletus edulis* Bul. ex Fx)

The edible boletus is known all over the world as an edible mushroom. Cultivation of this mushroom is still unsuccessful, so the supply for this wild mushroom does not meet the demand of consumers. This mushroom is most suitable to dehydration. The initial dehydration temperature is 35°C with an increase of 5°C every hour. When the temperature reaches 60°C, hold for 1 hour and then lower the temperature gradually to 50°C. Ventilate immediately and continue the dehydration until the moisture content of the product reaches 12% or lower.

IV. SPICES AS FOOD AND MEDICINE (19–26)

There are about 500 species of spices in China. Many of them are used as seasonings in food preparation and as medicine, such as clove, cinnamon, anise, star anise, and orange (citrus) peels. They serve as important ingredients in the food industry, from meat and seafood processing to the preparation of various convenience foods. In foods, spices may be used individually or in formulations of more than ten different spices in order to provide their characteristic odors and tastes. At the same time, these spices can be used as herbs with health maintenance and curing functions. In addition, many spices are natural antioxidants.

There are different ways to utilize spices. Some are used directly as raw materials such as huajiao (Chinese prickly ash, Zanthoxylum bungeanum Maxim), cinnamon, star anise, and cloves. Some are processed into powders, such as pepper and huajiao. At this time, with the fast development of science and technology, flavor formulations are varied with newer forms such as encapsulation, adhesive type, and emulsions.

In food preparation, it is common to use seasoning formulations with natural spices in the original form or in powders. The use of natural-flavored seasonings can provide foods with more complete natural flavors. For seasonings having combinations of special flavor and spicy hot sensations, there is a balance of flavor and sensation, causing the consumption of food with these natural flavorings a tasty and enjoyable occasion. These are the advantages of natural seasonings. The disadvantages are that there are more opportunities for microbial growth and contamination with foreign matter, affecting their quality standard and storage stability.

A. Cinnamon (*Cinnamonum cassia* Prel.)

Cinnamon belongs to the Lauracea family. It is the dehydrated bark of the cinnamon plant. It is one of the most common spices used in the world and reasonably priced. Cinnamon contains 1–2% volatile cinnamon oil, and tannins, exudates, and resins. The composition of cinnamon oil is 75–90% cinnamal with small amounts of cinnamyl acetate and cinnamyl propinate. According to traditional Chinese medicine, cinnamon warmly tonifies *yang*, and can eliminate coldness and relieve pain. According to *New Scientist* magazine in 2000, U.S. researchers discovered, in their studies on the effects of cinnamon on fat cells, the component of the most biologically active compound, methylhydroxychalcone polymer (38). This compound can increase the glucose metabolic rate by 20 times. If this compound in future studies provides the same effect, there may be available a natural compound for treating diabetes. Also, in 1999, researchers at Kansas State University in the U.S. discovered that cinnamon has a bactericidal effect on coliforms (39). The study was conducted with apple juice. 3% cinnamon was added to apple juice. 99.5% of the coliforms were killed in the juice–cinnamon mixture after incubation for 3 days at ambient temperature.

With advances in science, cinnamon is increasingly applied in various products. Recent reports show that the annual production of cinnamon is 2000 to 2500 tons. The projected world

demand for cinnamon is 6000 tons, 300 tons, and 200 tons for medical use, the food industry, and other light chemical industries, respectively. An estimate for annual world demand is about 5300 to 5500 tons. Cinnamon occupies more than 25% of the world spice trade.

Cinnamon plants have to be 10 years old before they can be harvested for their bark for processing. The quality is best in July and August. Bark harvested in February and March is of lower quality. They are usually sun-dried.

B. Star Anise (*Illicium vernum* Hook.f)

Star anise is the fruit of the star anise plant of the Magnoliacea family. It is grown in loose soil of shaded damp slopes. It is widely distributed in Fujian, Guangdong, Guangxi, and Yunnan Provinces of China. The chemical composition of star anise includes 5% volatile oil (anisic oil) and 22% fat, as well as protein and resins. The main component of star anise oil is anisole, about 80–90%. Besides, it contains small amounts of methyl chavicol, anisylaldehyde, anisylacetone, pinene, phellandrene, citrophen, 1,8-cineol, safrole, 3,3-dimethylpropenyl-*p*-propenylphenylester. The alcohol extract of star anise has, in vitro, inhibitory effects on gram-positive bacteria (such as Streptococcus, Pneumonas, and diphtherial bacilli) and is similar to penicillin potassium salt solution at 20 unit/mL. Inhibitory effects on fungi is greater than 1% benzoic acid and salicylic acid. The production of star anise and star anise oil in China is 50% and 80%, respectively, of the world trade.

There are mainly four methods of production for star anise: sun-drying, blanching and sun-drying, mechanical dehydration, and dehydrator drying. For sun-drying, freshly harvested star anise fruit are dried in piles in the drying field, with regular turning until completely dried. For blanching and sun-drying, star anise fruits are blanched in 90–100°C water for 4–6 min with occasional stirring. When the color of the green fruit turns light yellow, remove from the blanching water. Blanched star anise are spread on the drying field and sun-dried. For mechanical dehydration, heat up the dehydrator to 90–100°C and put in the freshly harvested star anise fruits. Adjust the temperature to 50–60°C and maintain the temperature for 7–8 h to complete the dehydration. For dehydrator drying, the fresh star anise fruits are put into the boiler-generated steam baking chambers at 45–55°C. The process can be completed in 24 h.

C. Fennel (*Foeniculum vulgare* Mill.)

Fennel is the fruit of fennel plants belonging to the Umbelliferae family. It is widely grown in China. Anise contains 3–6% volatile oil, the main components being anisole (50–60%) and anisone (18–20%). Besides, it contains pinene, phellandrene, camphene, diamylene, anisalaldehyde, anisic acid, and ciso-anisole. In addition, anise contains about 18% fat, the fatty acid composition being apic acid (60%), oleic acid (22%), linoleic acid (14%), and palmitic acid (4%). It also contains alcohol >18°C, wax composed of palmitic acid, arachidonic acid, and behenic acid, as well as sitosterol, and 7-hydroxy coumarin.

Besides the components listed above, fennel contains ascorbic acid, carotene, vitamin B_1, vitamin B_2, folic acid, niacin, vitamin E, bioflavonoid (vitamin P), large amounts of potassium, iron, calcium, and phosphorus salts, as well as phytobacteriocides. In the brining (pickling) of Chinese cabbage, mushroom, or other vegetable, the addition of anise can serve as a preservative seasoning. Recent studies show that anise juice can lower eye (ocular) pressure, lower gastrointestinal cramps, increase the excretion of bile acid, enhance the bacteriocidal effect, decrease fermentation and putrefaction in the intestinal tracts, and reduce gases in the intestinal tracts.

Fennel can be sun-dried, mechanically dried, or bake dried. Dried fennel should be stored in a dry and ventilated environment.

D. Huajiao (*Zanthoxylum bungeanum* Maxim.)

Huajiao is the rind of the huajiao plant which belongs to the Rutaceae family. The volatile oil content in huajiao fruit varies from 0.7% (produced in Guizhou Province), to 2–4% (produced in Gansu Province), to 4–9% (produced in Guangdong Province). The volatile oil contains geranic alcohol, citralene, cuminic alcohol, and sterol as well as unsaturated and organic acids. Good quality huajiao should be bright red, strongly odorous, with a long-lasting numby (tingling) hot taste. Szechuan Province in China is located in a shady humid area, with mountainous surroundings. Huajiao has the ability to eliminate the cold and dampness (traditional Chinese medicine terminology) and is liked considerably by the people there.

Huajiao can be sun-dried, mechanically dehydrated, or bake dried. After harvesting, the Huajiao fruits should be spread out to dry immediately to avoid deterioration owing to the respiration heat generated. Upon dehydration, the rind will crack. The dehydrated rind can be recovered after sieving out the seeds. Haujiao rind can also be dried by stir-frying. The cleaned rind is stir-fried at low to medium heat until the rind is slightly brown. Leave the stir-fried rinds in a ventilated area to complete the drying process and store accordingly.

E. Other Spices

Cloves (*Eugenia caryophyllata* Thumb.), licorice (glycyrrhia), orange or citrus peel (*Citrus reticulata* Blanco.) of the Rutaceae family, and matrimony vine fruit (*Lycium barbarum* L.) of the Solanaceae family are also spices commonly used as foods and medicines. The technologies to dehydrate these spices are basically similar. They should be dehydrated immediately after harvest to avoid loss of quality and medicinal effectiveness. The main dehydration processes are natural dehydration, sun-drying, and dehydrator-drying. Due to their individual characteristics, their dehydration process procedures vary accordingly. Natural dehydration is more suitable for products that change color and odor with solar and high temperature treatments. Sun-drying is suitable for products that do not require a consistent color. The main advantage of dehydrator-drying is that it is not affected by the weather conditions, and the dehydration temperature, time, and moisture content can be controlled manually based on the individual product characteristics. This is important for today's large-scale production.

V. DEHYDRATED SEASONINGS (27–37)

The application of seasonings is common in the preparation of animal products, such as meat, seafood, and poultry. Without the seasonings in their preparation, there is no assurance of food with proper flavor and appearance. Therefore the proper application of seasonings is an assurance of quality food (Table 6).

In food preparation, the actual usage of seasonings varies with the types of raw material, food to be prepared, their desired quality, and the technique to be used in order to achieve the best quality. The principles described below should be followed in food preparation.

Seasonings have their characteristic odors and hot tastes. Some have even their special colors. Therefore the basic principles in food preparation are (a) to increase appetite, (b) to eliminate undesirable odor, (c) to increase desirable odor, and (d) to color the food. In addition, spicy and hot seasonings have antibacterial, preservative, and antioxidative effects (See Table 7).

Table 6 Compatabilty of Meat and Seasonings

Meat	Seasonings
Beef	Pepper, nutmeg, cinnamon, onion, garlic, Chinese chive, ginger, cardamom, allspice, wine, fennel
Pork	Pepper, nutmeg, mace, allspice, clove, fennel, laurel, cumin, Chinese celery, onion, garlic, wine
Lamb/mutton	Pepper, nutmeg, cinnamon, cloves, allspice, laurel, Chinese chive, wine, fennel
Fish	Pepper, ginger, onion, garlic, nutmeg, Chinese celery, curry, allspice, wine
Poultry	Onion, garlic, ginger, mustard, pepper, chili pepper, fennel, wine, cinnamon

In general, they are made into powder for easy storage. After absorption into the human body, spices can affect the biological functions, e.g., they increase saliva secretion, increase the secretion of starch hydrolysis, thus causing the mouth to be cleaner so as to avoid the various infections, and increase food digestion efficiency. Many reports show that spices can also activate the suprarenal glands, increase the immunity ability, and regulate the heartbeat, blood pressure, and blockage in an artery.

A. Ginger (*Zingiber official* Rosc.)

From ancient times, ginger has been used as an important seasoning. Ginger contains 1.8% protein, 8% sugars, 4.7% crude fiber, and considerable mineral substances. The ginger essential concentration is 0.25–3%, its main components being zinberene, phellandrene, and camphanol. Substances providing the characteristic hot sensation of ginger are zingiberol and zingerone. The gingerol in fresh ginger can lower lipid content and low-density protein in blood. As a Chinese herb, ginger is used to cure headache and nose congestion and suppress coughing, vomiting, and abdominal cramps. Ginger is also used as an aromatic stomach strengthener.

a. Dehydrated Ginger Select well-developed fresh ginger (with shoots absent). Remove the skin, blanch in boiling water for 5 min. For every kilogram of ginger, use 150 g sulfur for fumigation. Wash the treated ginger with cold water. Dehydrate the ginger at 65–70°C.

B. Garlic (*Allium sativum* L.)

Garlic is one of the earliest spices used by man. It has a characteristic odor and hot taste. It was recognized very early in traditional Chinese medicine that garlic drives off wind, helps urination, and controls coughing. It caught people's attention that it has bacteriocidal and strengthening

Table 7 Functions of Various Spices

Function	Representative spices
Increase appetite	Black pepper, chili pepper, ginger, mustard, garlic
Eliminate undesirable odor	Ginger, garlic, sage, musk grass, cloves
Increase desirable odor	Cardamom, Chinese chive, fennel, cumin, cinnamon
Coloring	Curcuma (yellow), safflower (red)
Antioxidative	Clove, sage, rosemary, musk grass, ginger
Antibacterial	Cinnamon, clove, sage, rosemary
Biological and medicinal	Chili pepper, ginger, garlic, cinnamon, pepper

effects. The odor and taste of garlic come from the volatile thiol ethers, mainly dipropyl disulfide and propyl propenyl disulfide. After ingestion, garlic stimulates the secretion of gastro juices and the movement of the gastrointestinal tract. In addition, it stimulates the secretion of gall bladder juice, suppresses cramps, and provides bacteriocidal effect in the intestine. Other reports mention the lowering of cholesterol and blood lipids.

Recent studies show that garlic contains much selenium, geranium, zinc, volatile oils, and superoxidative dimutase enzyme (SOD). Garlic also has very strong antibacterial and anti-fungal effects; it kills parasites, inhibits cancer cell growth, lowers blood lipids and blood sugar, and cures hypertension and arteriosclerosis. It is also antiaging and helps the complexion. Thus there is an upward trend of garlic consumption in Europe, Japan, and southeastern Asia. Garlic and its related products are well received.

a. Garlic Powder Select mature garlic that is free from insect stains and disease. Separate garlic into cloves. Soak the cloves in cold water for 1 h and remove the skins. Rinse with sanitary water and drip dry. Homogenize the garlic in water (one-third of the garlic weight). Filter with coarse cheesecloth and collect the residues. Centrifuge the residue at 1200 rpm or press the residue to remove the water. It is critical that the dewatering step is completed rapidly in one setting to avoid flavor change in the garlic paste. Spread the dewatered garlic particles on trays or mats. Bake dry the garlic at 50–60°C for about 5 h, or it can be conducted in an oven. Disintegrate the hot garlic particles. Sieve to recover the garlic powder.

C. Chili Pepper (Capsicum frutescent L.)

Chili pepper is used in European folk medicine for intermittent fever (like malaria). However, it is used in Chinese folk medicine for cold, headache, and vomiting. Chili pepper is characterized by its hot taste. The compound responsible for this hot taste is capsaicin. The concentration of capsaicin in chili pepper is between 0.1–0.9%. There are also related compounds such as dihydrocapsaicin and nordihydrocapsaicin. These compounds possess hot intensity units 100 times of that of piperine. In addition, there are home capsaicin and home dihydro-capsacin. The main compounds responsible for the hot taste are capsaicin and dihydro-capsaicin. They are water insoluble but soluble in alcohol and oil.

a. Chili Pepper Powder Select small chili pepper suitable for dehydration. Wash and drip-dry. Spread on trays and sun-dry. They can also be dried in dehydrators. After drying, they are ground to powder. Sieve and pack accordingly.

D. Mustard (*Sinalis alba* L.)

Mustard is made by grinding the dry seed of the mustard plant belonging to the Cruciferae family. In traditional Chinese medicine, it is used for curing gout and cramps. It is usually made into a topical medication for treating rhumatism and nerve pain. The compound responsible for the hot taste in mustard is the volatile isothioester. Experiments on animals showed that mustard increases saliva secretion, increases the activity of starch hydrolase, and stimulates gastric secretion and intestinal movement. Besides, it can also increase the heart rate, increase the blood pressure, and cause a partial expansion of blood vessels and a decrease in hematoplasts.

Mustard powder is usually mixed with water to make a paste. It is served with cold food.

E. Pepper (*Piper nigram* L.)

Pepper is the spice used most in the world. In the early days in Europe, pepper was already used as a treatment for rheumatism and in eliminating cramps and heat. In addition, pepper stimulates

salvia excretion and increases the activity of starch hydrolase. The aromatic compound in pepper is mainly α-phellandrene, and the compounds responsible for the hot taste are piperine and chavicine. The most basic compounds responsible for the hot taste in pepper are piperine and isopiperine (all trans structure). In addition, there are black piperin, isoblack piperin, piperanine, piperoleine A, and piperoleine B. In these compounds, the more cis double chains in the cis isomer, the hotter the substance. The hot taste of pepper decreases after exposure to sunlight and storage, because of the transformation of the cis isomer of piperine to its trans isomer. In pepper oil, the terpenes are the main source of its odor, with the sesquiterpenes having the spicy flavor.

The dehydration of pepper is similar to that of huajiao. After dehydration, it is ground to powder. After sieving and packaging it is the commercial pepper powder.

F. Scallions (*Allium fistulosum* L.)

Scallions contain several vitamins and minerals and is high in phosphorus. In traditional Chinese medicine, the scallion is considered to have the capability of treating less severe colds and removing the toxins. The main agents of the hot taste in scallions are dipropyldisulfide and methylpropyldisulfide. The volatiles from an extract of scallions can kill pathogens. The phosphosugars and malic acid can excite the nervous system and stimulate blood circulation, causing the sweat glands and digestive glands to secrete.

At the present time, scallions are not only dehydrated using dehydration technology but also freeze-dried into scallion powder.

G. Future Outlook

In 1989, the U.S. National Cancer Institute (NCI) proposed the Designer Food concept. This concept is designed to use phytocomponent-based food to prevent cancer. Not long after, the NCI announced over 30 plant foods having anticarcinogenic effects. This list includes spices such as garlic, ginger, celery, onion, and curcuma. In the Anticarcinogenic Effects of Plant Foods symposium, biologically active phytocompounds with anticarcinogenic effects were disclosed and discussed. These include components in some spices such as propenyloids in garlic, onion, and scallion, isothiocyanate compounds in mustard as well as hesperidene, and carvone in vanilla-type spices.

In the past, spices were used because their odors, hot tastes, and colors can stimulate the appetite. In addition, folklores also utilize the biological and medicinal principles of spices. In the future, with in-depth studies of the various aspects of the biological functions of spices, it is hoped that the anticarcinogenic and antiaging functions of spices can be discovered and utilized.

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23
Dehydrated Tomatoes

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I. INTRODUCTION

Tomato (*Lycopersicum esculentum*) is a true fruit, but is usually regarded and consumed as a vegetable with savory dishes. It is Australia's second largest commercial vegetable crop, with a harvest of 414,000 metric tons in 1999–2000. Victoria is the main growing state, accounting for 60% of the national harvest (1). The tomato is also the world's most widely grown vegetable after the potato. World tomato production in 2000 was estimated at almost 100 million metric tons, an increase of 31% over the last decade (2). Almost half of this increase is attributable to China alone. Figure 1 shows the top ten tomato producing countries in the world with China as the largest producer followed by the United States.

In order to preserve fruit or vegetables that have been detached from the host material, food technologists must know how to minimize further chemical and in particular microbiological changes from taking place. All the different methods of food preservation have one thing in common: the aim is to stop or slow chemical reactions and microbial growth. Drying is a preservation method that reduces both chemical and microbiological changes by removing the water component in food.

Dehydrated tomato products fall into three main categories: tomato paste and its derivatives, tomato powder, and dehydrated tomato. Tomato paste is usually considered as semifinished product because it is commonly used as an ingredient in other food products such as pizza. In addition, tomato paste is commonly used as a raw material for products like tomato sauce and tomato powder. Fully dehydrated tomatoes are usually rehydrated before use or simply added to recipes that include water and allowed to soften. Semidried tomatoes are gaining in popularity as a gourmet semiprocessed vegetable in many parts of Australia and overseas. They are used mainly as ingredients in salads, spaghetti dishes, and homemade pizzas, or they are simply sold as marinated "roasted tomatoes" in delicatessens. Dehydrated tomatoes are prepared from fresh tomatoes. They are dried to varying moisture contents from about 35% (wet basis) for semidried to about 10% for fully dried using a range of dryers. They are usually packed in canola oil with added garlic, herbs, and spices. Other forms of using dehydrated tomato include tomato spread, tomato salsa, and tomato pesto. The headspace is usually flushed with nitrogen in order to extend the shelf life of the product.

In this chapter, we discuss the unique nutritive value of the tomato, the potential pathogenic bacteria and mold in raw tomatoes, and the preservation and processing of dehydrated tomatoes, tomato paste, and tomato powder.

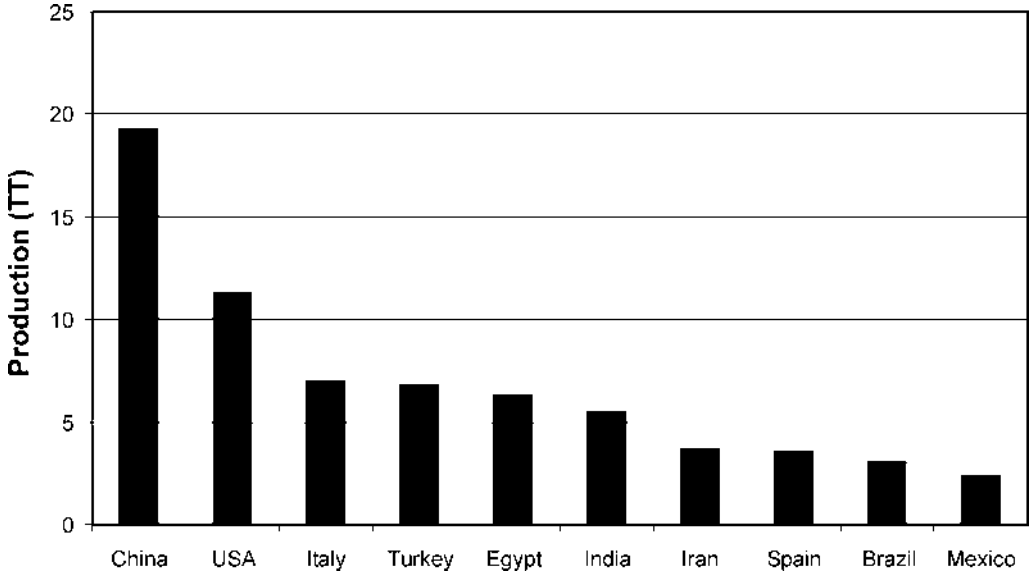

Figure 1 The top ten tomato production countries in the world. (From FAO, 2000.)

II. NUTRITIVE VALUE

A. Importance of Lycopene in the Human Diet

The tomato is made up of skin, pericarp (wall), and locule (jellylike parenchyma cells), which surrounds the seed and normally contains between 4.5 to 8.1% total solids and 91.9 to 95.5% water content (3). Table 1 gives an overall picture of the nutritive value of the tomato, based on data from the USDA Nutrient Database, 2001 (4). The tomato is generally considered a healthy food, as it is low in fat, free of cholesterol, and rich in vitamin A, vitamin C, and potassium. It is also a good source of fiber and protein. In addition, the tomato and tomato products are the major source of lycopene, an important contributor of carotenoid to the human diet. Lycopene is a natural pigment that gives the tomato and tomato products their characteristic red color and

Table 1 The Main Constituents of Red, Ripe, Raw Tomatoes Based on Year-Round Average

Nutrient	Units	Value per 100 grams of edible portion
Water	g	93.76
Energy	kJ	88
Protein	g	0.85
Total lipid (fat)	g	0.33
Carbohydrate, by difference	g	4.64
Fiber, total dietary	g	1.1
Potassium, K	mg	222
Vitamin C, total ascorbic acid	mg	19.1
Vitamin A	IU	623

Source: USDA Nutrient Database 2001.

represents about 83% of the total pigments present (3). Most of the lycopene is found in the fiber portion of the tomato (5–7). Researchers found that the concentration of lycopene in tomato skin is about 3 to 5 times higher than in the flesh of a tomato. Lycopene is a member of the carotenoid family and appears to possess unique nutritional properties. Extensive research in this field has revealed that lycopene may provide protection against prostate cancer, lung cancer, and a range of epithelial cancers (8–11). It is an excellent singlet oxygen quencher, almost twice as good as beta carotene (12,13). It also has other good antioxidative properties (14–16).

According to work done by Boileau et al. (17), the total lycopene content in tomato alone does not determine its nutritional and health benefits; rather, these properties are dependent to a large extent on the distribution of lycopene isomers. These researchers found that the cis isomers are more bioavailable than the trans form. This is in agreement with earlier work done by Britton (18) and by Stahl and Sies (19). This work suggests that cis isomers of lycopene might be better absorbed than their all trans parent structure. It is generally accepted that fresh tomato contains over 95% of the all trans isomers (20,21), and processing the tomato causes lycopene to undergo isomerization: the amount of cis isomers increases as a function of temperature and processing time (22,23). The type of processing, such as dehydration method, is also important and will be discussed later.

B. Factors Affecting Lycopene Content

The amount of lycopene in fresh tomato fruit normally ranges between 3 and 5 mg lycopene per 100 g of raw material (24). This quantity is dependent on a number of factors including variety (24), season (25), and maturity (26) of the tomatoes. Storage also affects the lycopene content. For example, tomatoes picked green and allowed to ripen in storage have a substantially lower lycopene content than vine-ripened tomatoes (27). In addition, Lurie et al. (28) reported that high temperature (38°C) inhibits lycopene production, while low temperature inhibits both fruit ripening and lycopene production.

C. Stability of Lycopene During Processing

Several researchers have studied the effects of different cooking methods on the levels of lycopene (23,29). Shi and Le Mague (23) showed the effect of dehydration methods (osmotic treatment, vacuum drying, conventional air-drying) on lycopene degradation and isomerization (Table 2). Conventional air-drying was found to bring about the highest lycopene loss, and the work showed a significant increase in cis isomers with a simultaneous decrease in the all trans isomers. In

Table 2 Total Lycopene and Cis Isomer Content in the Dehydrated Tomato

Sample	Total lycopene (μg/g dry basis)	Lycopene loss (%)	All trans isomers (%)	Cis isomers (%)
Fresh tomato	755[a]	0	100	0
Osmotic treatment	755[a]	0	100	0
Osmotic-vacuum dried	737[b]	2.4	93.5	6.5
Vacuum dried	731[c]	3.2	89.9	10.1
Air-dried	726[d]	3.9	84.4	16.6

Note: Data presented as means of triplicate determinations. Means in a column not sharing common superscript (a–d) are significantly different ($p < 0.01$).
Source: Ref. (23).

addition, Khachik et al. (29) studied the effect of food preparation on qualitative and quantitative distribution of major carotenoid constituents of tomatoes and several green vegetables. These researchers show that cooking and various food preparation techniques affect the levels of carotenoids in vegetables, but lycopene in stewed tomato and tomato paste were found to survive the heat treatment. The qualitative distribution of lycopene in tomato paste remains identical to that of raw and stewed tomatoes.

D. Stability of Lycopene During Storage

The most important factors contributing to the degradation of lycopene are temperature, light, and the availability of oxygen during storage (30–32). Work done by Lovric et al. (33) showed that lycopene in processed tomato products such as tomato powder is influenced by storage atmosphere and temperature (Fig. 2). They found that the percent retention of lycopene decreased at high temperatures and in the presence of oxygen.

Anguelova and Warthesen (34) studied lycopene stability in tomato powders and concluded that lycopene degradation during storage of two types of tomato powder (hot-break and cold-break) proceeded to the same extent with oxidation as the predominant mechanism of all trans lycopene loss. Exposure to air and increased temperature (up to 45°C) was found to have the most unfavorable effect on lycopene stability with an increase in autoxidation of lycopene while light and increased temperature appeared to be unimportant factors for the stability of lycopene in tomato powders during storage.

There is an emerging market for semidried tomatoes, and this product is found to have adequate shelf life with minimum oxidative heat damage (35). In addition, Zanoni et al. (36)

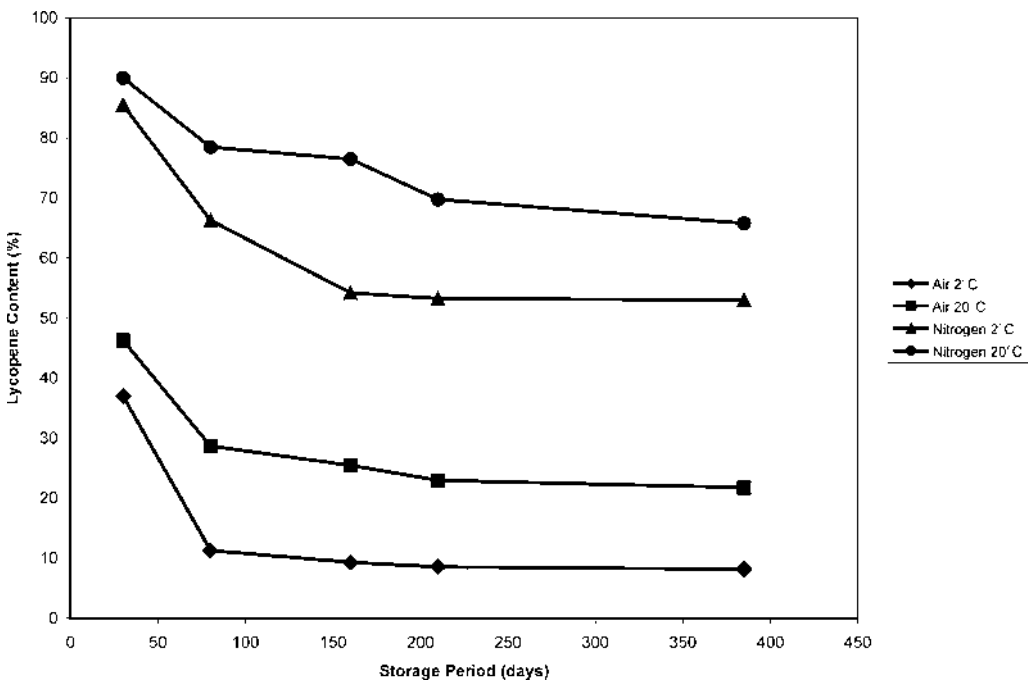

Figure 2 Total lycopene retention in tomato powder stored in different atmospheres, temperatures, and time periods. (From Lovric et al., 1970.)

found that lycopene appears stable during drying and there is no loss of lycopene content during drying at 80°C, even though it is well known that lycopene is usually stable up to 60–65°C. However, they found that both the storage temperature and exposure to air and light affects the lycopene content of air-dried tomato halves.

III. MICROBIOLOGY

Contamination of tomatoes can occur at various points during their journey from harvest to the processing plant, and identification of the likely source of contamination is important. Several outbreaks of human gastroenteritis have been linked to the consumption of contaminated tomatoes associated with pathogens such as *Salmonella javiana* and *Listeria monocytogens* (37,38). In addition, botulism food poisoning has been associated with tomatoes contaminated with mold (39,40).

The tomato fruit contains 90–95% moisture content and is capable of supporting bacterial growth. According to Gould (3), the pH of tomato varies considerably, depending on important factors such as cultivar, maturity, and seasonal variation. However, the tomato is not considered a high-risk food, as the pH of the fruit generally ranges from pH 4.2 to 4.9 with an average of about 4.5. At this pH, most pathogens are unlikely to grow. However, the growth-limiting pH for *salmonella* was demonstrated to depend on the acid molecule itself in the test media (41). Wei et al. (42) found that low pH values (4.2–4.4) in wounded red tomato flesh did not inhibit bacterial growth and attributed this observation to the acid molecule in tomato. Draughon et al. (39) found that *C. botulinum* is capable of growing in fresh tomato inoculated with mold. They suggested that the presence of molds probably causes the destruction of acid, and the pH of tomato rises above the minimum required for growth and toxin production of *C. botulinum*. This finding is in agreement with work done by Robinson et al. (40) where it was demonstrated that *clostridium* only grew when mold was present.

Mold contamination is an important indicator of low quality raw product in the tomato processing industry. According to Battilani et al. (43), the species most frequently associated with spoiled tomatoes are *Alternaria alternata*, *Botrytis cinerea*, *Fusarium oxysporum*, *Geotrichum candidum*, *Phoma lycopersici*, *Rhizoctonia solani*, and *Rhizopus nigricans*. Yeong et al. (44) studied the effect of storage temperature on keeping quality of tomato and concluded that storing it from 0 to 10°C is the best way to minimize mold growth, as mold infection is found to occur only at 15, 20, and 25°C.

IV. PROCESSING

A. Preparation

1. Raw Material

Figure 3 shows an overview of the processing of dehydrated tomato and tomato products. High quality attributes of fresh tomatoes are critical in order to obtain high-quality tomato end products. According to Goose and Binsted (45), a variety suitable for tomato paste manufacture should have a high soluble solids content, an intense red color, a good flavor, low acidity, and a reasonable amount of pulp. Before tomatoes are transported to the factory, they are graded according to grade standards. Grade standards will vary from country to country and may be used to determine the price to be paid per kilogram of tomato. For example, standards based on the FDA (46) put fresh tomatoes into different grades, sizes, and maturity classifications based on

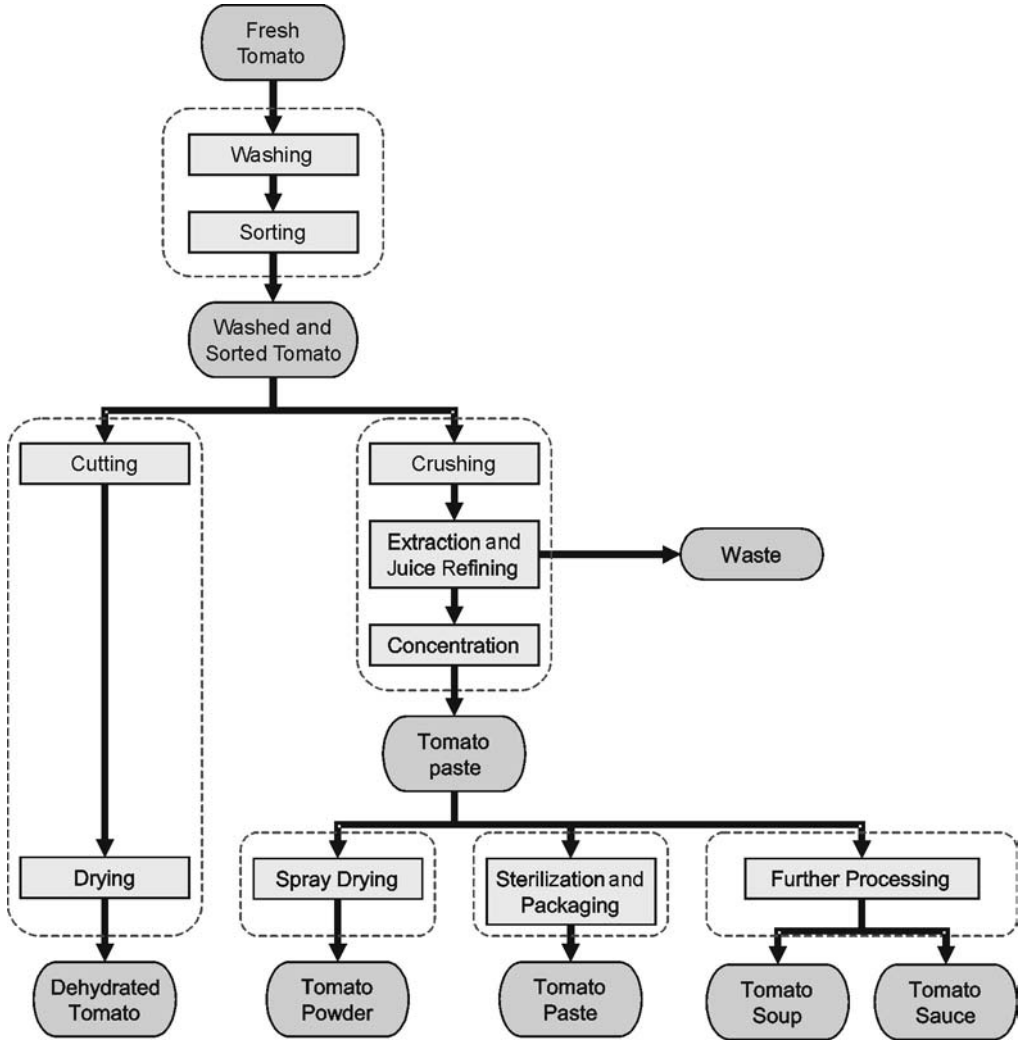

Figure 3 Process flow diagram of dehydrated tomato and tomato products.

color, size measurements, and defects such as mold, blemishes, and mechanical damage. Grade A is considered the best. Off-grade are those that fail to meet requirements. Tomatoes may also be classified according to total soluble solids (°Brix) with a specified minimum acceptable level. The average total soluble solids for tomato processing is about 4.7°Brix and rarely goes below 4.0°Brix or above 5.2°Brix. At the factory, incoming loads of tomatoes are carefully checked for uniformity of color, size, maturity, mold growths, insect infestations and the presence of foreign matter.

Fresh tomato used for manufacturing into dehydrated tomato halves or wedges needs to be consistent in size, free from blemishes, red in color but not too ripe, firm with thick-walled flesh, and most importantly free from mold and bacteria rot. The most important parameters indicating tomato quality appear to be color and firmness.

2. Washing

Water supplied to the factory for washing tomatoes must be clean, potable, and uncontaminated. Its essential role is to remove contaminants and reduce the initial microbial load on the tomato, although water is also used to cushion the unloading of tomatoes into the holding tank or soaking vat. According to Lund (47), proper washing of tomatoes at this stage can reduce the microbial load by a factor of 10–100, but it may not remove pathogens from the product surface. Washing methods vary from factory to factory and may be as simple as soaking the tomato in a static tank. The tank is regularly changed and maintained at up to 200 ppm of available chlorine. More complex modern devices employ high-pressure water jets and agitation within the tanks by compressed air. However, the most commonly used method to control microbial populations in water for washing tomatoes is the addition of hypochlorite in the form of available chlorine, which produces hypochlorous acid at concentrations ranging from 10 to 200 ppm. According to Dychdala (48), concentrations as low as 0.5–10 ppm are sufficient to kill the suspended vegetative cells of bacteria. Both Dychdala (48) and Robbs et al. (49) found that higher concentrations are required to kill bacterial or fungal spores. Recommendations for water chlorination in tomato processing plants usually range from 100–300 ppm (well above the minimum lethal dose for spores) because chlorine is highly unstable in solution and is easily inactivated by the presence of soil.

3. Sorting and Trimming

Methods of sorting and trimming vary. Sorting and trimming are usually done on a roller conveyor where the tomatoes are rotated to allow sorters full view of the raw material. This task requires skill in differentiating between tomatoes that must be rejected and those that only require trimming to remove partly defective parts. The defective tomatoes are removed manually. Goose and Binsted (45) give a summary of defects such as ground rot and sunscald found in tomatoes during sorting, and this summary is a useful guide during the sorting and trimming stage. The extent or strictness of sorting depends on the quality of end product desired.

B. Fresh Tomato to Dehydrated Tomato

1. Cutting

After sorting and grading, the tomatoes are washed in chlorinated water (50–200 ppm), rinsed, and transported to the cutting machine prior to the drying process.

2. Drying

a. Background Over the decades, the technology for the dehydration of foods has improved tremendously. A great variety of sophisticated drying techniques have been developed to retain product quality and improve energy efficiency. In the late 1970s, freeze-drying was considered the most promising method of drying foods because of its superior end product quality, which was lacking in air-drying. However, freeze-drying is an expensive process and may not be economically viable for drying low-value products. Over the last decade, the heat-pump dryer is emerging as a promising alternative to the conventional hot-air dryer.

b. Hot-Air Drying Conventional drying using preheated air is by far the dominant and most economical system used in the food industry. In conventional dryers, preheated air (usually at 60°C to 110°C, air velocity of 0.5 to 2 m/s and varying relative humidity depending on the

weather) is blown across the product surface (50,51). Water extracted from the product is then carried away by the air moving out of the chamber as water vapor. As the air becomes depleted in the chamber, more ambient air is drawn into the drying chamber and reheated. Drying times are usually very long (10 to 20 hours) and depend on the load. These long drying processes at high temperature in the presence of oxygen are typical conditions for oxidative heat damage of the product (36). The low efficiency of conventional dryers is due to the loss of latent heat of water vapor and the heating of the replacement air. Other limitations of hot-air drying include the dependency of the drying rate on the thermal conductivity of the material, and the overheating of the surface, which causes case hardening. This leads to an inferior product quality and a poor drying rate.

c. Heat-Pump Dehumidifier System The major differences between the heat-pump dryer and the conventional hot-air dryer are that the relative humidity (typically 8 to 15%) can be controlled in heat pump system; also the heat pump dryer removes water from products without ventilation, and the system is totally recirculatory. In the heat-pump dehumidifier system, warm dry air (typically 50 to 55°C) is taken off the condenser and pumped through a drying chamber containing the wet product. As moisture is removed from the product, the air is cooled and becomes more humid. The cool, humid air moves over the evaporator, which causes condensation. The same air is then pumped back over the condenser to heat it again—completing the cycle. As the system is totally enclosed, there is the possibility that microbes from raw material could be distributed throughout the dryer via the evaporator and condenser coils. The key features of the heat-pump dryer system are shorter drying times and lower drying temperatures, resulting in less oxidative heat damage of the product.

d. Microwave Drying Microwave drying may produce better quality dehydrated products while considerably reducing the drying duration (52). However, it is well known that microwave heating results in uneven cooking.

To make drying successful with microwaves alone, it is necessary to dry the tomato at such a rate that its interior never reaches the critical temperature at which the product deteriorates. This requires a sophisticated feedback control system. In addition, water that has been evaporated must not be allowed to condense in the drying chamber. This tends to occur when there is no airflow to carry the vapor away. One of the key advantages of microwave drying is the rapid heating and drying. Energy extracted from the electric field is preferentially absorbed by the water molecules at the points where the water resides in the product. This eliminates the need for the heat to be conducted in from the surface of the product, as is the case in conventional dryers.

e. Combined Systems The use of microwave energy alone for drying is not feasible, as the evaporated moisture must be carried away from the product and the drying chamber, otherwise the condensate will be reabsorbed by the microwave energy. The combination of microwaves and hot air offers a practical solution, as the hot air not only imparts energy to the product but also carries the evaporated moisture away.

Attempts have been made by several researchers (52–54) to combine microwaves and hot air. Bhartia et al. (53) performed preliminary studies on the optimization of temperature, air velocity, and microwave power level on the drying of material with varying hygroscopicity. The results indicate that the combined process reduces the total energy required to about one-third when compared with hot air only. Smith (54) reviewed dryers that use a microwave–hot air system for the drying of pasta, onions, and bacon and found that work done on macaroni achieves a quality that is superior for both cooked and uncooked pasta in terms of enhanced color, better "bite," and reduced infestation. There was also a reduction of the bacteria count (by 90%) in the finished product. The combined system has advantages such as less shrinkage, increased rehydration capacity, and increased drying rate. A further advantage of combining microwave and conventional heating methods is the more uniform heating of foods and destruction of bacteria (55).

C. Fresh Tomato to Tomato Paste

1. Crushing or Breaking

After a final wash and spray using water jets, the sorted and trimmed tomatoes are quickly preheated before chopping/crushing to form the pulp. Alternatively, the tomatoes are chopped at room temperature and immediately, or within seconds of crushing, heated to a temperature range of 60 to 90°C (depending on the type of desired final product specification). This type of treatment is known as hot break treatment.

Rapid heating is essential to destroy enzymes and prevent the breakdown of pectin in tomatoes for some tomato products such as paste. It also liberates the locules that surround the tomato seeds and contribute to the overall texture or body of the finished product (45). As soon as the tomato is crushed, enzymes are released that could lead to the breakdown of pectin. Pectin occurs naturally in ripe tomatoes. Both pectin and protopectin are the major components found mainly between adjacent microscopic cells known as the middle lamella, which serves to cement the cells together and is partly responsible for the firm texture of the fresh tomato. However, as tomato ripens, the firmness of the tomato is reduced. This could be explained by the breakdown of protopectin into pectin, while the pectin in the cell walls is degraded into soluble compounds that have little binding power. The presence of pectin contributes to the viscosity of the final product. To prevent pectin breakdown, enzymes released from the crushing or chopping of tomatoes need to be destroyed as quickly as possible. According to McColloch and Kertesz (56) and Foda and McCollum (57), the enzymes involved are pectinesterase, polygalacturonase, and cellulase. These enzymes are promptly inactivated when the tomatoes are heated rapidly above 82°C.

In cold-break treatment, the tomatoes are crushed at room temperature. In some tomato products such as soup, where "thickness" is not the sought-after quality, attention is usually focused on the color and flavor. These products are processed using lower break temperatures of between 60 and 65°C. Sherkat and Luh (58) demonstrated that pectic retention and consistency of tomato pastes are influenced by the break temperature, where pectin retention decreases as the break temperature is lowered from 104 to 70°C.

2. Extraction and Juice Refining

To refine the juice, broken and preheated tomato pulps are screened by pumping to a series of extractors or cyclones using an initial screen with a sieve diameter of about 1 mm followed by a second screen with a sieve diameter of between 0.4 and 0.7 mm. These screens are designed to remove the seed, the skin, and any other pulp. This waste stream contains a high proportion of lycopene and can be an important source of lycopene for the food industry (5,59). In addition, the seed, which is a major part of the solid waste, can be utilized as a source of oil (60). A yield of 3% skins and seeds and 97% juice is considered high extraction. However, it may be commercially more feasible to extract only 70–80% juice and leave the residues for use in other tomato products. According to Leonard (61), a low extraction yield at 70% is desirable, since the extracted juice will be of improved quality by containing a higher percentage of soluble solids and a lower percentage of insoluble solids. Once the juice is refined, it is ready to be concentrated.

3. Concentrating

The concentrating stage (by evaporation of water) results in progressive increase in solids content of the pulp until a paste of the desired concentration and viscosity is reached (usually approximately 30% solids content). The method by which the juice is concentrated varies from tanks with coils in batch-type vacuum evaporators to continuous vacuum evaporators with a series of effects such as single effect to quadruple effect. The tomato soluble solids (TSS) define the

range of tomato products. For example, according to the FDA's standard of identity (62), tomato paste must contain not less than 24% TSS while tomato puree or pulp must contain not less than 8% TSS but less than 24% TSS.

4. Sterilization and Packaging

After concentration, the tomato paste is held in a closed tank and is canned conventionally or aseptically packaged. Canned tomato paste is usually hot-filled at a minimum temperature of 90°C into cans of varying size depending on the end use. It is then sealed without further heat treatment and passed through a water spray to remove any residue on the outside, cooled, and packed. Aseptic packaging of tomato paste usually involves heat treatment at a temperature of 105 to 110°C, cooling to 35 to 38°C, and filling aseptically into high-barrier aseptic bags.

5. Finished Product Evaluation

The best quality tomato paste is that which consistently meets the specifications of the customer or end user. The FDA's standard of quality for tomato concentrates (62) specifies (a) the strength and redness of color of the concentrate, (b) the number of whole seeds per 600 g of concentrate, (c) the number of defects such as pieces of peel, seeds, or black particles per 100 g of the product. In addition, routine laboratory analysis is usually used as a measure of quality and consistency for the customers. These include (a) natural total soluble solids—°Brix expressed as percentage of sucrose, (b) consistency—Bostwick consistometer [12.5 dilution, 30 seconds, expressed in cm], (c) serum separation—blotter test, for hot break only, expressed in mm, (d) the total acidity and pH—significant variations between varieties (3) but usually aimed at a final pH of about 4.3 in the tomato paste, and (e) the mold count—the presence of large numbers of mold usually indicates the use of moldy raw material and poor sorting and trimming.

D. Tomato Paste to Tomato Powder

1. Overview

Further concentration of tomato solids from 30–40% in tomato paste to about 97% results in tomato powder. The raw material used for tomato powder is tomato paste that is usually prepared by the hot break method. According to Masters (63), powder produced from cold break paste tends to have fewer desirable characteristics on reconstitution, as the solids generally settle after approximately 60 seconds rather than remain in homogeneous suspension. As tomato powder is usually not produced from a seasonal raw material, production can occur throughout the year.

2. Drying

Tomato powder is usually manufactured from roller-drum-dried, foam-mat-dried, or spray-dried material. Of all the drying techniques tried, spray-drying appears to be the most suitable to produce high-quality powder economically (63). Owing to the thermoplastic nature of tomato powder, the drying chamber needs to be designed to enable droplet drying to proceed without overheating. In addition, the system needs to be designed to handle the hygroscopic nature of the finished product from the drying chamber to the packing stage without contact with the surrounding air.

The traditional types of spray-dryer designs tend to suffer from deposit losses, product quality degradation, and frequent cleaning procedures. More recently, a high-capacity spray-dryer designed especially to overcome the shortcomings of the traditional spray-dryers was introduced. The drying chamber consists of a cocurrent nozzle tower dryer with a built-in conveyor belt, into

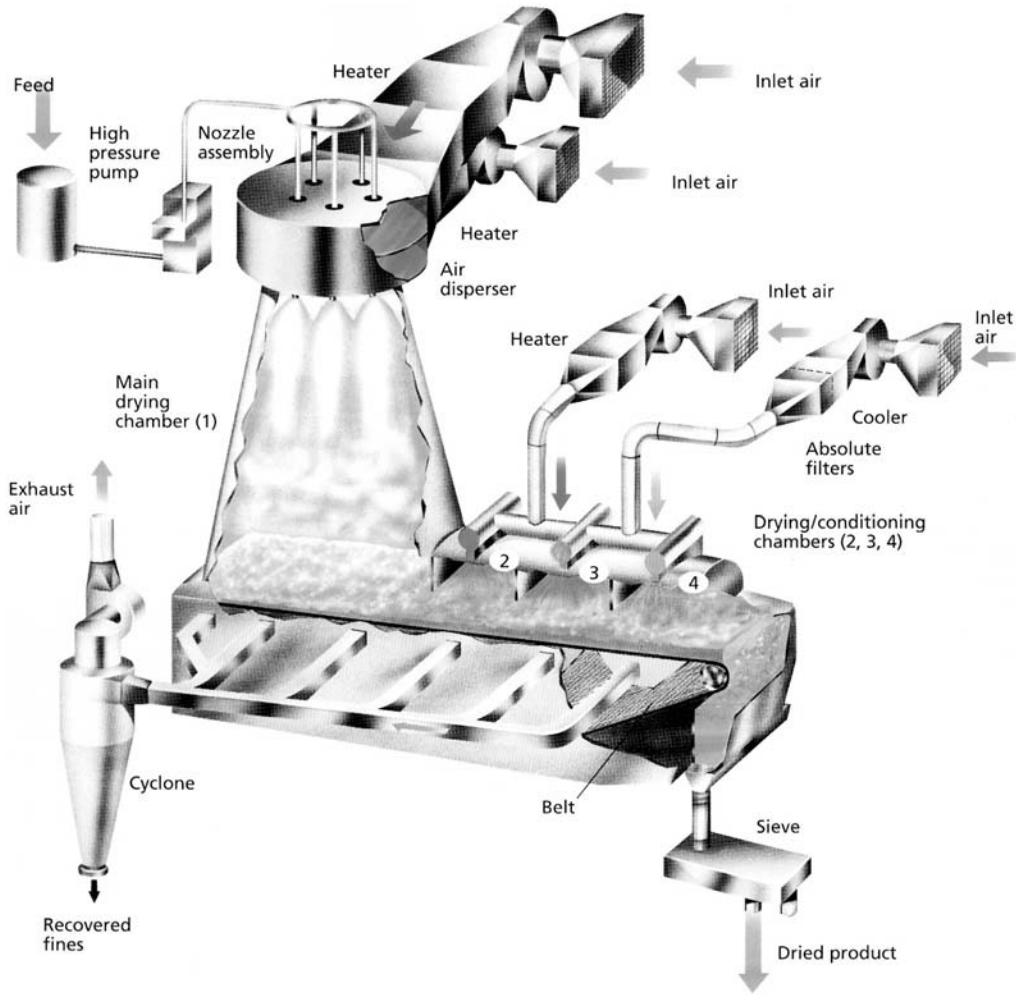

Figure 4 A schematic diagram of a Filtermat Dryer. (Courtesy of Niro.)

which atomized paste and drying hot air are introduced from the ceiling. Figure 4 shows a schematic diagram of a filtermat dryer. The main drying chamber 1, with an airflow pattern, directs the particles downwards onto the moving belt, which forms the first stage of drying. The second stage takes place as the semidried particles are conveyed through drying chambers 2 and 3. The ability to control the air temperatures in these chambers allows much control and flexibility regarding the finished product specification. The tomato powder is cooled and conditioned in the last chamber 4, where it is usual to use dehumidified, cooled air, after which the powder falls off the belt and is sieved prior to being packed or conveyed into silo storage.

3. Finished Product Evaluation

Two of the most important factors affecting the shelf life of the finished product are the exclusion of oxygen and the temperature of storage of the packaged powder (33,34). Vacuum packaging and

hermetic seals are important in maintaining the required shelf life in tomato powder. Other quality tests usually carried on the powder are moisture content, color, dispersibility, and ease of reconstitution.

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Minimal Thermal Processing: Cook–Chill and Sous Vide Technology

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I. INTRODUCTION

Food quality depends on a combination of intrinsic factors (food composition and structure) and extrinsic (environmental) factors (1), which are inevitably altered during food processing. Clearly, the food processing industry aims to enhance quality, in terms of palatability and digestibility (2). However a number of less obvious negative changes can also result, such as a reduction in sensory and nutritional quality. One of the main factors responsible for such negative changes in the quality of processed foods is exposure to extreme temperatures (3). In response to this food quality issue and the increasing consumer demand for freshlike convenience food, there has been considerable interest in the use of minimally processed chilled foods. These foods attempt to reconcile many contradictory consumer demands, for high organoleptic and nutritional quality (freshness), extended durability, safety, exclusion of preservatives, and environmentally friendly packaging (3–5).

Minimally processed chilled foods rely on the combination of minimal processing (65–100°C) and storage under controlled chill conditions to prevent growth of pathogenic organisms and microbiological safety. The process is unlike conventional thermal processing, which relies on thermal destruction of any pathogens present and as such minimizes the processing impact on sensory and nutritional aspects of product quality (6,7).

II. COOK–CHILL TECHNOLOGY

Cook–chill technology is one of the most successful preservation technologies, based on minimal thermal processing and chilled storage. This technology pasteurizes, rapidly cools, and holds food under chilled conditions for an extended period, before reheating and consumption (8,9). Production is therefore separated, in both time and location, from consumption. Products produced by cook–chill technology can be stored for up to 5 days (including the day of consumption) (10).

Cook–chill technology has developed applications within two sectors of food production and service, namely the commercial catering and the retail sectors. Currently, the technology is receiving renewed attention within the commercial catering sector (11), as the impact of economic

and quality factors on buying behavior increase; and the mechanisms to control the potential safety and management problems become accepted. Within the retail sector, the application of cook–chill technology continues to be an expanding segment of the consumer product market (12).

A. Benefits of Cook–Chill

When cook–chill technology was developed in the 1960s it offered new benefits to the commercial caterer and to the consumer. These included value for money, convenience, freshness, and extended shelf life and improved nutritional and sensory quality compared to other food preservation technologies (9). Cook–chill technology delivered these benefits by controlling the causes of negative changes in quality, such as exposure to light, extreme temperatures, moisture gain or loss, spoilage organisms, and pests.

B. Limitations of Cook–Chill

Although cook–chill technology offered economic and quality benefits compared to conventional catering practices, the concomitant limitations in the system began to be widely recognized. Limitations of cook–chill technology have been reported mainly as a loss of sensory, nutritional, and microbiological quality (9). These limitations have resulted in product shelf lives that are shorter than those demanded by the commercial caterer, the retailer, and the consumer. These losses are primarily due to exposure to oxygen in all stages of manufacturing, storage, and reheating.

1. Loss of Sensory Quality (in Cook–Chill Vegetable Products)

Poor sensory quality is considered to be the most limiting factor in the consumer acceptance and industrial application of cook–chill products (13). Sensory problems include excessive dehydration, undesirable color changes, and the development of flat and off flavors. Studies have concentrated on changing processing parameters to improve sensory quality, without compromising the ultimate safety of the product.

a. Influence of Rapid Chilling Cook–chill products should reach the end of the chilling process ($<5^{\circ}C$) within 2 hours of thermal processing (10). Slower chilling (i.e., longer than 2 hours) has been reported (14) to cause a significant decrease in the sensory quality of cook–chill sprouts, reported to be particularly affected by slow chilling rates. This author (14) also reported that a decrease in sensory quality was directly related to slow chilling rates and that the relationship was proportional.

b. Influence of Chilled Storage The influence of chilled storage ($0–5^{\circ}C$) on product sensory quality has been shown to be predominately product dependent. Vegetable products have been reported to cause negative color changes and the development of flat and acid/pungent flavors within 2 days chilled storage (14).

c. Influence of Oxygen The presence of oxygen in the cook–chill system is reported to produce undesirable changes in the sensory quality of these products (15). It has been well documented that exposure to oxygen during thermal processing, chilling, storage, and regeneration results in the oxidation of lipids (15,16) and is initiated more readily in lipid-containing unsaturated fatty acids (17). Hence the oxidation of polyunsaturated lipids is rapid. Lipid oxidation produces a characteristic off flavor in products containing meat, generally described as warmed over flavor (WOF) (18). WOF is usually detected within 24 to 48 hours after cooking (19), but it has been detected within 1 hour in turkey meat (15).

d. Influence of Reheating and Warmholding The final stages in the cook–chill process, i.e., reheating and warmholding, have been reported to produce decreased sensory quality (20). The type of sensory damage is influenced by the type of reheating used. Dry heat in regeneration ovens has been reported to produce a larger decrease in sensory quality, through dehydration (21), than regeneration in convection or microwave ovens (22,23).

Although cook–chill technology was partly designed to minimize warmholding, this undesirable stage is still present in many cook–chill systems. Warmholding practices of 7.5 hours at temperatures between 29 and 93°C have been reported for cook–chill products (20). This practice has a serious impact on the sensory quality of all products, as it allows undesirable or excessive aspects of the cooking process to continue and any associated undesirable or excessive changes to occur. Meat and vegetable products in particular have been reported to be more susceptible to damage during excessive warmholding (24).

2. Loss of Nutritional Quality

The presence of oxygen in the cook–chill system causes a loss of nutritional quality. Oxidative damage of a range of vitamins including vitamin C (8,15), riboflavin, vitamin A, and thiamine in particular have been reported in cook–chill products (25,26).

3. Microbiological Risks

The risk of microbial growth and the accompanying risk of food poisoning in cook–chill products has led to concern about the microbiological status of such products. The risk of microbial growth in cook–chill products is high for a number of reasons. Some pathogenic microorganisms can grow under temperature abuse conditions (>5°C) and in the presence of oxygen (see Table 1). They can survive the initial cooking process or may attach to the unprotected food if cross-

Table 1 Growth Limits of Some Pathogenic Microorganisms Capable of Growth in Cook–Chill and Sous Vide Products

Microorganisms	Minimum growth temperature (°C)[a]	Aerobic/anaerobic
Bacillus cereus		
(*mesophilic*)	15	Facultative
(*psychrotrophic*)	4	Facultative
Clostridium botulinum		
(*mesophilic*)	10	Anaerobic
(*psychrotrophic*)	3	Anaerobic
Clostridium perfringens	12	Anaerobic
Escherichia coli	7	Facultative
(*0157*)	6.5	Facultative
Listeria monocytogenes	0	Facultative
Salmonella	7	Facultative
Staphylococcus aureus	6	Facultative
Vibrio cholerae	10	Facultative
Vibrio parahaemolyticus	5	Facultative
Yersinia enterocolitica	−1	Facultative

[a]These figures are indicative only, and not necessarily representative of all strains of microorganisms in food.

contamination occurs after cooking (27). The absence of antimicrobial additives in cook–chill products poses an increased microbiological risk. Hence cook–chill products can pose a serious risk to public health (28).

4. Short Shelf Life

The microbiological risks and subsequent legislation associated with cook–chill technology have resulted in a short shelf life of 5 days for such products. The legislatively controlled short shelf life of cook–chill products has been highlighted as a major limiting factor in the development of the cook–chill market (21). 32.6% of cook–chill producers in the UK would welcome an extension of the existing 5 day shelf life (9). Of these respondents, 50% indicated that a 7 day shelf life would be sufficient to reduce wastage and increase flexibility in commercial catering. In the retail sector, longer product shelf lives are reported as having even greater value, within the longer distribution chain and with consumer demand for longer life products (3).

III. ENHANCED COOK–CHILL TECHNOLOGY

In an attempt to overcome the limitations of conventional cook–chill (i.e., undesirable loss of sensory, nutritional, and microbiological quality), enhancements to the process have been developed. Process developments include the creation of a barrier (usually a plastic pouch or tray) between the food and the surrounding environment, and extraction of the air surrounding the food, either prior to or immediately following thermal processing. These developments have become known as enhanced cook–chill technology.

The initial enhanced cook–chill techniques included the Nacka system (29), the AGS system (30), and the Capkold system (31). All of these systems involved the creation of a barrier, thermal processing between 75 and 90°C, and chilled storage at 0–4°C to enable a shelf life of 5 days. Such developments in enhanced cook–chill technology have controlled or moderated many of the factors that previously limited the application of conventional cook–chill. As outlined, many of these enhancements are related to the exclusion of air, through the use of barrier, and vacuum technology, to reduce a range of undesirable oxidative changes.

Such alterations in the technology, procedures in enhanced cook–chill technology having resolved or reduced some problems, have led to the development of a new range of quality problems. A different set of microbiological problems emerges with the growth of anaerobic bacteria. Sensory and nutritional quality can also be limited by the exposure of food to extreme temperatures during several heat-processing stages. Extensive thermal processing of enhanced cook–chill products is reported (9,13) to reduce flavor intensity and produce a “tired” taste.

IV. SOUS VIDE TECHNOLOGY

In recent years one particular form of enhanced cook–chill technology, sous vide, has created immense interest in the commercial catering and retail sectors. The term sous vide is used to describe the process of vacuum packaging food before the application of low-temperature thermal processing and storage under chill conditions (32,33). Despite being hailed as “a revolutionary technique” (34,35), sous vide technology originally evolved from *cuisson en papillote* (food cooked in oiled paper bags), taking on aspects of the Nacka, AGS, and Capkold systems. Georges Pralus (a French chef) formally developed the technology in 1974 to reduce weight and juice loss

in the production of pâté de foie gras (36). Pralus found that foie gras cooked in three layers of plastic retained 95% of its original weight, compared to 60% retention in the traditional cooking process.

A. The Sous Vide Process

The sous vide process is more than a catering technique (37) and involves industrial product formulations (38) and a precise, carefully designed, and extensive manufacturing procedure. See Fig. 1.

1. Pre–Heat Treatment

Various sous vide products require a pre–heat treatment to enable a browning effect, a sauce thickening effect, the maintenance of vegetable color, and/or the release of powerful flavors and aromas. Products such as green vegetables require prior blanching and chilling to avoid color loss. Root vegetables and brassica possessing a strong flavor also require prior blanching to avoid the accumulation of acids in the pouch during heat treatment, which can produce an unpalatable product (9,40,42).

2. Thermal Processing

Sous vide products are vacuum packaged and sealed before thermal processing, in a water bath or a steam combination oven (32). It is recommended that products receive a heat treatment sufficient to achieve a 6-log reduction in the numbers of psychrotrophic *Clostridium botulinum* (*C. botulinum*) (32,43). A number of regulatory and advisory bodies have specified a range of temperature time combinations to achieve this 6-log reduction (see Table 2). In general, lower temperatures and longer processing times are recommended for meat products, while higher temperatures and shorter processing times suit fish and vegetable products (44). Temperatures as high as 80–100°C have been recommended to soften vegetables and allow the partial solubilization of pectic substances, a degradation of hemicellulose, and the gelatinization of starch (45,46). The exact processing time, however, can require a level of skill in judging the quality and freshness of the raw ingredient, as in general the fresher and younger the product, the less time it takes to cook (40).

3. Rapid Chilling

Rapid chilling in the sous vide process can be carried out using a blast chiller or through the application of iced water or liquid nitrogen (47). Rapid chilling is recommended (6) within 30 minutes of the completion of thermal processing and aims to result in a core temperature of 0–3°C within a further 90 minutes. This processing parameter aims to prevent negative quality changes and the germination or growth of surviving *C. botulinum* spores, associated with a slow rate of temperature change after thermal processing.

4. Application of HACCP to the Sous Vide Process

The vast majority of academic, regulatory, and industrial food scientists recommend that sous vide products should be produced and distributed with a HACCP approach (43,48). The application of HACCP to the sous vide process has been widely documented (6,49–52). Recommended critical control points (CCPs) for the sous vide process are shown in Fig. 1 and described in Table 3. The critical control points (CCPs) that have the potential for absolute control (CCP1) include the level of thermal processing, the cooling of cooked product, and the temperature and duration of storage.

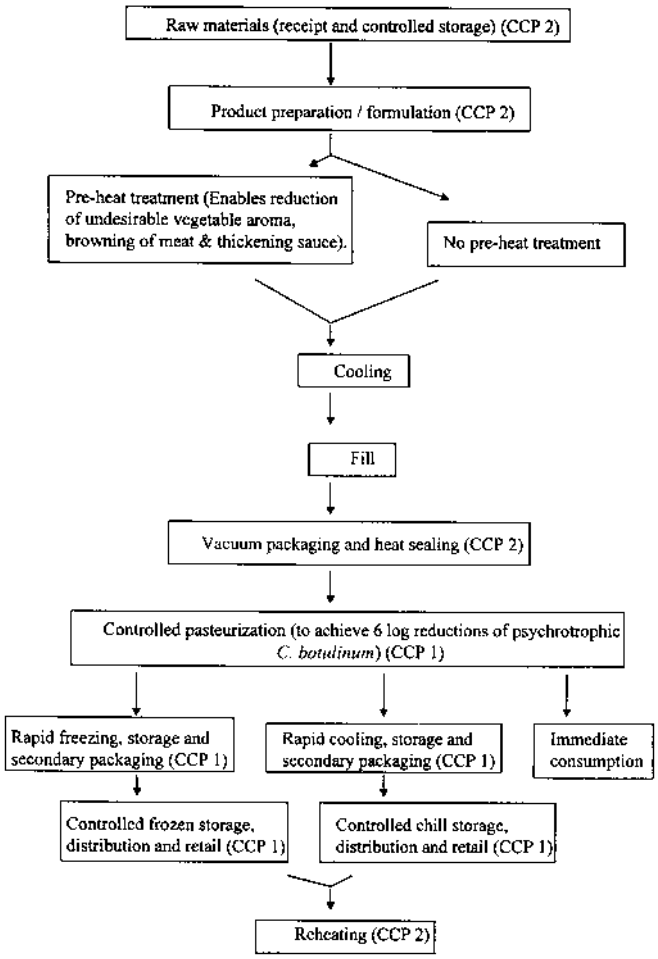

Figure 1 Flow diagram of the sous vide process and its critical control points. (Adapted from Refs. 32, 39, 40, 41.)

Although producers can ensure that HACCP is applied during production and processing of sous vide products, they cannot ensure adequate monitoring of CPPs during retail and domestic operations. Owing to the characteristics of sous vide products as requiring high levels of control, when such controls are not available, particularly throughout distribution, retail markets, and consumer environments (53–57), many sous vide producers have not introduced their products into consumer markets. Canadian and UK retailers, however, appear to be prepared to take an increased responsibility in ensuring consistent temperature controls, to encourage the development of the sous vide market (6,58). Such markets are investigating the application of time–temperature-integrating systems (59) that change color or become visible upon significant temperature abuse as means of attaining adequate monitoring and control of distribution and storage temperatures.

Table 2 Recommended Process Parameters and Shelf Life for Sous Vide Products (When Combined with Refrigerated Storage [0–3°C] and a Restricted Shelf Life)[a]

Reference	Pasteurization		Recommended shelf life (days)
	Temperature °C	Minutes	
Advisory Committee on the Microbiological Safety of Foods (ACMSF), 1992	70	1675	10
	75	464	10
	80	129	10
	85	36	10
	90	10	10
Department of Health Guidelines (DOH), 1989	70	2	5
European Chilled Food Federation (ECFF), 1996	80	270.3	10
	85	51.8	10
	90	10	10
	95	3.2	10
	100	1	10
French Regulations, 1974, 1988	70	40	6
Syndicat National des Fabricants de Plats Préparés (SYNAFAP), 1989	70	100	21
	70	1000	42
Sous Vide Advisory Committee (SVAC), 1991	80	26	8
	85	11	8
	90	4.5	8
	95	2	8

[a]Owing to the use of different *z* values, different equivalent heat treatments have been recommended.
Source: Adapted from Refs. 6 and 43.

Table 3 Critical Control Points in Sous Vide Processing

Critical control points	Processing specifications
Raw materials CCP2	Purchasing specifications to be set for raw materials
Raw material preparation CCP2	Air temperature to be a maximum of 10°C
Filling and vacuum packaging CCP2	Specifications to be set for product fill temperatures. Seal integrity of pouches to be monitored
Pasteurization CCP1	Sufficient to achieve a 10^6 reduction in numbers of psychrotrophic *C. botulinum*. Representative packs temperature monitored
Cooling CCP1	0–3°C to be achieved within 120 minutes after pasteurization
Storage CCP1	Temperatures to be in the range of 0–3°C and representative packs' temperature monitored
Reheating CCP2	A minimum of 70°C for 2 minutes to be given. Service to be within 15 minutes and >63°C

Source: Adapted from: Refs. 6, 49–51.

B. Benefits of Sous Vide

The sous vide process has been reported to have a number of benefits (4) (see Table 4). The unique benefits of sous vide in comparison with earlier enhanced cook–chill technologies include a substantial increase in sensory and nutritional quality and an increase in shelf life (33). The process produces these benefits by controlling the causes of negative changes in quality, such as exposure to oxygen and extreme temperatures (33).

1. Increased Sensory Quality (in Sous Vide Vegetable Products)

The high sensory quality of sous vide products is considered to be the greatest benefit (61,62). The perceived sensory quality benefits ensured that this technique received international support and acclaim until the microbiological risks associated with it began to be more clearly recognized (63). Improved flavor quality in sous vide products has been reported to be due to vacuum packaging, which prevents the development of oxidative off flavors and flavor volatiles from escaping (40,64). Improved texture quality, particularly meat tenderness and juiciness, has been reported (40) to be due to moist cooking at temperatures below 100°C in sous vide processing.

a. Influence of Time–Temperature Combinations During Thermal Processing Different time–temperature combinations (70°C for 2 min; 80°C for 10 min; and 80°C for 30 min) in the thermal processing of potato have been reported to produce differences in organoleptic properties and in overall acceptance of samples (65). Products processed at 80°C for 10 min were reported to be the most acceptable and contained the highest level of moistness. Further heat treatment (80°C for 30 min) resulted in samples being so soft as to affect acceptance detrimentally.

Different core temperatures (65–95°C) in the thermal processing of a range of vegetables by Picoche (45) showed that lower temperatures resulted in enzymatic changes that made products unacceptable.

b. Influence of Storage on Sensory Quality The literature indicates that sensory quality and consumer acceptability of sous vide products can be retained well beyond the present 5 day limit imposed by the DOH (66). The maximum quality shelf life for sous vide products would appear to be product dependent (67). There is general agreement (13) that meat products have a substantially longer shelf life (21–40 days) than fish and vegetable products (7–21 days), under ideal (0–3°C) storage conditions.

Results from studies evaluating a courgette provencale product (67) and a broccoli product (68) indicated acceptable sensory quality up to 7 days storage. Storage above 7 days (>21 days)

Table 4 Benefits of Sous Vide Technology

Enhanced sensory quality
Enhanced nutritional quality
Extended shelf life
Reduced need for additives
Increased flexibility/convenience
Centralized production
Reduced meat costs/weight loss
Reduced risk of postprocess contamination
Wider variety of produced goods
Increased portion control

Source: Adapted from Refs. 4, 40, 60.

was reported to result in a "soggy, poorly coloured and unpleasant" product. A study on green beans (42) reported no significant loss of odor, flavor, or texture until after 8 days of storage. However, the color of the beans changed from bright green to dull grey/green after 7 days.

Although green vegetables are susceptible to color loss during sous vide processing and chilled storage, a recipe dish containing broccoli and cauliflower mornay (69,70) has been reported to be acceptable for up to 20 days storage. In this study, a trained quantitative descriptive analysis (QDA) panel ($n = 12$) indicated that the product had significantly changed during a 40 day storage period, particularly in relation to vegetable color and quality. However, not all product changes impacted on consumer acceptability. Consumers ($n = 40$) indicated no significant preference between fresh and day 10 and day 20 products. This extension of shelf life may have been achieved because the vegetables were steamed or blanched prior to vacuum packaging and because the product contained a sauce component (38).

Vegetables such as carrots, which contain mainly carotenoids, are not so susceptible to color losses and have been reported to have a longer shelf life. Werlein (71,72) reported that carrots stored for 21 days were acceptable and considered to have a more intensive and sweeter flavor than fresh samples. In addition, the author reported an intensification of the orange-red color of the carrots during storage.

c. Sous Vide Processing Compared to Other Food Processing Systems The sous vide system has been reported (13) to maintain and enhance the sensory quality of many foods, more than other food processing systems. Studies comparing products produced by the sous vide and cook–chill systems have reported differences in flavor and texture. Products (chicken breast and potato) (64,65) produced by the sous vide system have been reported to be more juicy and moist and to have a better flavor than those produced by the cook–chill system.

Significant differences in sensory quality have been reported in chicken, vegetable, and potato based products (73), produced by sous vide and traditional cooking techniques. The author reported significant differences in juiciness, moistness, initial flavor, and aroma depth. The effect of these differences on consumer acceptability, however, was not reported. Carrots (71) produced by the sous vide system have been reported to have better color, taste, and aroma than traditionally cooked carrots. Furthermore, after 21 days' storage the author reported higher scores for the sous vide carrots than those of the traditionally cooked carrots immediately after processing.

2. Increased Nutritional Quality

The sous vide process has been claimed to minimize the loss of nutritional quality (63). This claim is based on the fact that water-soluble vitamins that would normally break down under thermal duress or be lost by leaching or oxidation, during traditional cooking processes, are retained within the food or in juices trapped within the bag, particularly when the products are processed at low temperatures (51). Studies of vitamin damage during sous vide processing (19,74) indicate that the sous vide process causes less vitamin damage than traditional cooking methods. One recent study (75) reported that sous vide green beans and cauliflower had significantly retained more ascorbic acid than those processed by other catering techniques (modified atmosphere packaging, warmholding, cook–chill). Furthermore, during storage for up to 14 days no significant difference in ascorbic acid retention was observed in the sous vide samples.

3. Extended Shelf Life

The shelf life of sous vide products is between 5 and 42 days, depending on the product and the severity of the time/temperature treatment applied (see Table 2). The more intense the thermal process, the longer the shelf life, and vice versa (76). The risk to sous vide food associated with

survival, growth, and toxin production of *C. botulinum* has been reviewed by Betts (32). This review suggested shelf life maxima of <10 days in products processed at 70°C for 100 minutes and <42 days in products processed at 90°C for 10 minutes.

C. Limitations of Sous Vide

The wider application of sous vide technology is limited by the microbiological risks associated with the process and by the lack of scientifically rigorous research on the sensory quality of sous vide products.

1. Microbiological Risks

Concerns about the microbiological safety of the sous vide process have been reported (4,6,28). These concerns are due to the risks associated with inadequately controlled pasteurization and storage in the sous vide process (9,49). Such failure to apply adequate temperature control during both heating and chill storage may permit the survival of thermally injured cells, capable of repair during any subsequent inadequate storage (77,78). This can readily occur in the production of gourmet type sous vide products, which receive minimal thermal processing as a means of retaining desirable sensory attributes (79,80). The challenge in sous vide cooking is therefore in the design of a thermal process that can balance the diametrically opposing demands of safety and high sensory quality (27,37,81).

a. Common Microorganisms Recovered from Sous Vide Products Numerous microorganisms can survive and grow in sous vide products that have received insufficient heat treatment during primary processing and temperature abuse during chilled storage (82). Microorganisms that can occur in sous vide products and their growth limits are included in Table 1.

The organism that poses the greatest threat to sous vide products is *C. botulinum*, types A, B, E, and F (49,79). It is reported that as little as 0.1 g of food containing *C. botulinum* toxins can cause botulism, which is potentially fatal (32). *C. botulinum* is a particular hazard in sous vide processing as it can withstand mild heat processing (6D value = 70°C for 1675 min) and storage temperatures as low as 3°C (49,83). Although vegetables are considered to be less favorable substrates, *C. botulinum* has been shown to be able to grow in a wide range of vegetables (84,85). A further concern is that *C. botulinum* has been reported to inactivate normal spoilage microflora (48,77,86). Hence growth and toxin production of *C. botulinum* may have occurred before the food is perceived to be spoiled (87).

Aerobic organisms may also occur in sous vide products, if an insufficient vacuum has been applied as a means of retaining appearance in delicate products. An unacceptable level of aerobic microorganisms was reported in a rolled stuffed fish product, which had received an insufficient vacuum to maintain high appearance quality (67).

2. Application of Multiple Hurdle Technology

The application of multiple hurdle technology to the production of sous vide products has been recommended (87,88) to control further the microbiological hazards associated with sous vide. In addition to the universal heat treatment of 90°C for 10 minutes or equivalent lethality, refrigerated storage and a restricted shelf life, a pH of 5 or below, a minimum salt content of 3.5%, and available water of 0.97% or less have been recommended (87,88). Following these recommendations, research efforts have focused on the formulation of products with low pH, salt, and water activity (44,89). Simpson et al. [90] demonstrated the benefits of multiple hurdle technology in a sous vide spaghetti and meat sauce product, inoculated with *C. botulinum* (types

A and B spores). For example, the spaghetti and meat sauce product was reformulated to ensure a pH value <5.25 or a salt content of $>1.5\%$ and was reported to inhibit *C. botulinum* toxin production throughout a 42 day storage period.

However, the hurdles need to be carefully selected to minimize negative changes in sensory characteristics and to ensure the production of acceptable products. Many workers (91,92) have reported a need for such research as a means of increasing the safety and shelf life of sous vide products in the retail market, where the chill chain is not robustly controlled.

V. FUTURE TRENDS

Minimal thermal processes, such as cook–chill and sous vide, have been shown to minimize the processing impact on sensory and nutritional aspects of product quality. Sous vide technology in particular can provide high sensory and nutritional quality in addition to an extended shelf life. The extent of the shelf life, however, relies on the application of HACCP and/or good manufacturing practice throughout processing and storage (93). Recent studies (70) indicate that the developmental aspects of product formulation, which concentrate primarily on retaining appearance and aroma attributes, can also enable extension of product shelf life.

In view of recent food trends (5) highlighting a demand for "creative convenience, freshness, close to natural, quality, and culinary sophistication," minimal thermal processing has significant market potential. Minimally processed chilled vegetable products are one product category that can satisfy consumer demands for prepared meals that are more natural and provide greater balance and nutritional convenience. The description of cooking techniques, such as sous vide, is thought to provide flavor cues to packaged foods and menus, as consumers actively seek more sophisticated gourmet products. With the home meal replacement market projected to reach $109 billion by 2002 (5), research and development efforts in minimally processed chilled foods will surely be a good investment. However, the challenge of future research within the vegetable market will be to ensure premium quality and safety allowing an acceptable time for distribution (94).

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Salads and Cold Soups

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I. INTRODUCTION

Minimal processing of agricultural commodities has been defined as the handling, preparation, packaging, and distribution of fruit and vegetables in a freshlike state (1). The process steps involved in minimal processing can include trimming, cutting, chemical dipping, pH reduction, reduction of water activity, mild heat treatment, low level irradiation, and modified atmosphere packaging (2).

Examples of minimally processed vegetable products include

Salads incorporating a dressing, such as potato salad, pasta salad, caesar salad, and coleslaw. The dressing may be mixed through the salad or may be contained in a sachet within the pack of salad.
Dry salads (no dressing), such as mixed salad and dryslaw.
Stir fry and soup mixes.
Single component products, such as baby spinach, shredded lettuce, shredded carrot, celery sticks, baby cut potatoes, and pumpkin portions.

These products may be packed in pouches and tubs for retail, or sold through salad bars in supermarkets, delicatessens, and restaurants. Minimally processed vegetables may be packaged in air, in either sealed or unsealed containers, or under modified atmospheres (MA), in which an appropriate gas mixture, e.g., 5–10% carbon dioxide (CO_2) and 2–5% oxygen (O_2), is introduced into the package by gas flushing. When the vegetables are contained in a sealed package, made of a material that impedes the free passage of CO_2 and O_2 in and out of the package, respiration of the vegetables will modify the package atmosphere (Sec. 3). The shelf life of minimally processed vegetable products is both product and packaging dependent, and ranges between 4 and 12 days when chill stored ($<5^{\circ}C$).

A minimally processed vegetable has three characteristics that impact on its shelf life. Firstly, it is a living entity and so active metabolism continues in its tissues. Secondly, cut surfaces are composed of damaged cells, and the rates at which metabolic processes occur are enhanced in cells that have been damaged by cutting. Cutting also introduces microorganisms into the nutritious, but normally sterile, plant tissue. Thirdly, there is no processing step in the production of a minimally processed vegetable that will eliminate microorganisms from the product.

Consequently, methods to extend shelf life focus on ways to reduce the metabolic rate of plant cells, the microbial load of uncut vegetables, and the rate of growth of microorganisms in cut vegetables.

The minimally processed vegetable industry is about 20 years old. Its genesis and continued growth is due to society's changing eating patterns and lifestyles. Today's consumer is health conscious, and so the appeal of minimally processed vegetables lies in their fresh, all-natural image. Minimally processed vegetables also offer a convenience factor in minimizing food preparation times within the home. The challenge of future research is to produce minimally processed vegetables with premium quality and adequate shelf life allowing an acceptable time for distribution, without impacting upon the microbiological safety of the product (1).

II. MINIMAL PROCESSING

Minimal processing of vegetables involves the following steps: receipt of vegetables from the grower; precleaning, prewashing, and pretrimming; size reduction; washing and dewatering; mixing; packaging; and storage and distribution (3,4). Cleaning and washing are the only treatments given to minimally processed vegetables that are specifically designed to reduce their microbial load. Cleaning refers to the removal of objects such as sticks, soil, and insects from the vegetable. Processors should include the criterion, in their raw material specifications, that growers supply vegetables in a clean state (Sec. 6). Brushing, before washing, may be required to remove excess dirt, which will interfere with the washing/sanitizing step that follows.

The objectives of washing are to remove debris, reduce the microbial load, limit the development of physiological disorders such as browning, and lower product temperature (4). Washing is generally done by immersing vegetables in water containing chlorine and agitated by bubbling from jets of air. This turbulence assists with the removal of foreign material without damaging the product. The selection of the washing system is dependent on product type. Delicate produce like broccoli and lettuce should receive a gentle washing treatment in wide flumes or wash tanks. Rod–reel washers and scrubbing–peeling washers can be used with more robust produce such as carrots (4).

The washing agent most commonly used by fresh-cut processors is chlorine. In solution, chlorine forms hypochlorous acid (HOCl), which is a powerful oxidizing agent that kills microorganisms by disrupting their cell walls (5). The pH of the solution determines the relative proportions of hypochlorous acid and hypochlorite (OCl^-), the other reaction product of chlorine in water. At pH 7.9 and at 0°C, HOCl and OCl^- are present in equal proportions. As the pH decreases, the concentration of HOCl increases. However, at low pH, the water becomes corrosive on the washing and water cooling equipment. For this reason it is important to monitor pH levels during the sanitizing procedure. The IFPA (5) recommends maximum total chlorine levels of 100 to 150 ppm at pH 6 to 7. Other key parameters in washing vegetables include the quantity of water used, which ideally should be between 5 and 10 L/kg of product; the temperature of the water, which ideally should be 4°C to cool the product; the time the vegetable is in contact with the sanitizer; and the organic content of the water (3,4).

Beuchat and Ryu (6) have reviewed studies on the antimicrobial efficacy of chlorine washing. One study indicated that the total microbial count on lettuce leaves was reduced by 92.4% after washing in tap water and by 97.8% after washing in chlorine solution, containing 100 ppm free available chlorine. In other studies, it was shown that dipping brussels sprouts in 200 ppm chlorine solution for 10 s caused a 2 $\log_{10}$ colony forming unit (cfu) g^{-1} reduction in counts of *Listeria monocytogenes*, and that dipping shredded lettuce and cabbage in the same concentration of chlorine but for 10 min resulted in 1.3–1.7 $\log_{10}$, and 0.9–1.2 $\log_{10}$ cfu g^{-1}

reductions in counts of this pathogen, respectively. *Salmonella* counts in alfalfa sprouts were reduced by about 2 $\log_{10}$ cfu g^{-1} after dipping in 500 ppm chlorine for 2 min. However, probably owing to the high levels of organic matter in the juice binding the active chlorine in the sanitizing solution, a <1 $\log_{10}$ cfu g^{-1} reduction in *Salmonella* counts was reported for cantaloupe dice. Hence the effectiveness of chlorine as a sanitizer depends upon the product being sanitized.

The usefulness of chlorine as a sanitizing agent for vegetables is limited by several factors. Microorganisms found in creases, pockets, and natural openings on vegetables will be protected from the effects of chlorine because of their inaccessibility. The hydrophobic waxy cuticle on the skin of vegetables also protects microorganisms from the action of aqueous chlorine (7). Chlorine does not have residual activity, and it will combine with organic materials in the wash water, hence reducing its effective concentration. More importantly, chlorine can react with organic materials, in water and the vegetable itself, to form potential toxic reaction products, such as the carcinogenic trihalomethanes. Research is being undertaken worldwide to find an effective, economically feasible, and environmentally acceptable alternative to chlorine. Alternatives to chlorine washing treatment include chlorine dioxide, hydrogen peroxide (H_2O_2) vapor treatment and wash, ozone, peroxone (ozone/H_2O_2 combination), and trisodium phosphate (4,8).

Peeling may be done by several procedures: by hand or mechanical means; with steam, including high-pressure steam, or boiling water; with alkali (sodium or potassium hydroxide) or acid; by dry caustic peeling with infrared heat; by flame; and by freezing (3). Peeling should be as gentle as possible: hand peeling with a sharp knife is the ideal method.

Slicing, dicing, shredding, and chopping methods are used to cut vegetables. Cutting damages plant cells, which reduces the shelf life of the vegetable (Sec. 3). Cutting also introduces microorganisms to the nutrient rich, normally sterile, plant tissue, where they can grow to numbers that produce spoilage or an unsafe product (Sec. 4). Bolin et al. (9) reported that the sharpness of the cutting blade and the method of slicing influenced the shelf life of shredded lettuce. Lettuce sliced with a sharp blade had a shelf life that was about twice as long as that of lettuce prepared by chopping with a sharp blade, or chopping or slicing with a dull blade. Microscopic examination of a lettuce leaf being sliced showed exudation of cellular fluids. In contrast, when the lettuce was torn into strips, no noticeable exudation occurred. Cellular fluids released by slicing were enzymatically active. Consequently a significantly longer shelf life resulted if cellular fluids were removed with a water rinse and centrifugation (10).

Water jet and carbon dioxide (CO_2) laser cutting are techniques with potential future application in fully automated cutting of fruit and vegetables (11). Both methods allow precise cutting, with minimal generation of fine tissue particles, and are more hygienic than traditional cutting methods. Initial costs and the availability of suitable equipment design and technology are major barriers to the implementation of these technologies by industry.

A second washing step is usually performed after peeling and/or cutting operations. Three liters of water per kg of product is recommended for this purpose (12). Preservatives, such as sorbic acid, antioxidants, such as ascorbic acid, and organic acids, such as acetic acid, can be added to the wash water, or as a postwash dip, to improve microbiological safety and product quality, if permitted by the national food regulations. Commercial dips/sprays are available. Postwash dips may also include the application of edible coatings (4) (Sec. 3). Because moisture and cell exudate on the surface of vegetables stimulates both the growth of microorganisms and enzymatic deterioration, the product is dried after washing. Centrifugal drying is frequently used. Centrifugation of about 30 to 60 s at 1000 rpm is recommended with shredded lettuce.

Minimally processed vegetables are normally packaged in rigid or flexible plastic containers, e.g., tub and pouch. Depending upon the product, it may be packaged in air, in either sealed or unsealed containers, or under modified atmosphere (MA), in which a specific gas mixture is introduced into the package by gas flushing, most often following evacuation of air.

The factors that should be taken into account when using modified atmospheres to extend shelf life are discussed in Sec. 3. In general terms, it is important that the type of packaging selected be process friendly. Packages should be able to be filled and sealed at acceptable rates and have mechanical and thermal properties that tolerate the conditions likely to be encountered during storage and distribution of the product. Packages must be labeled with the appropriate information mandated by national standards (13).

Ideally, trimming and cleaning operations should be conducted at temperatures $\leq 12^{\circ}C$ and processing and packing areas should be between 4 and $6^{\circ}C$. The finished product should be stored between 0 to $4^{\circ}C$. The objective is to maintain the core temperature of the product at $\leq 4^{\circ}C$. The plant layout should enable the unidirectional flow of product to prevent contamination of the final product with raw and unfinished product. Ideally, equipment and personnel should be dedicated to specific production areas. Because there is no kill step in the production of minimally processed vegetables, good manufacturing practice is essential to ensure the microbiological safety of the product (Sec. 6).

III. PHYSIOLOGICAL CHANGES IN VEGETABLES INDUCED BY MINIMAL PROCESSING

Unlike other forms of processing, minimal processing increases perishability rather than making products more stable (14). The rate of physiological and microbiological deterioration (Sec. 4) increases as a direct result of minimal processing.

Biological processes such as respiration, ripening, and senescence continue in fruit and vegetables after harvest. Respiration supplies energy for biological processes including the synthesis of typical pigments, odors, and flavors, maintenance of membrane integrity, and synthesis of ethylene (15). Ethylene has many effects on plant physiology, such as the induction of ripening in fruit and the development of premature yellowing in many vegetables (16). Senescence is the name given to the processes that follow maturity and lead to death of tissue, resulting in deleterious changes in appearance, flavor, and texture of a fruit or vegetable. These changes are induced or enhanced by cutting (17) and lead to shortened shelf life (16). An immediate effect of cutting some fruit and vegetables is the production of undesirable brown pigments through a complex series of reactions involving polyphenol oxidases (18). Another important enzyme is lipooxidase, which catalyses peroxidation reactions, causing the formation of numerous bad-smelling ketones (12).

Traditionally, sulphites have been used to prevent browning. However, they can have dangerous side effects in people with asthma, and alternative treatments are being sought. Promising alternative treatments for potatoes and apples involve treatment with mixtures containing citric acid, ascorbic acid, and potassium sorbate, and citric acid, ascorbic acid, and 4-hexylresorcinol, respectively. Storage of potatoes at $15^{\circ}C$ for 14 days prior to peeling resulted in a decrease in the concentration of reducing sugars and hence reduced browning (12). Commercially available antibrowning solutions are available. Typically, they contain a reducing agent, e.g., ascorbic acid, an acidulant, e.g., citric acid, and a chelating agent, e.g., sodium acid pyrophosphate. Commercial dips/sprays can be used to retard yellowing in broccoli, white-blush in carrot, and browning in lettuce (4).

Edible coatings are thin layers of material that can be eaten by the consumer as part of the whole food product (12). Edible coatings may reduce moisture loss from the vegetable, modify atmospheres to delay the respiration rate of the vegetable, and retain natural color pigments and nutrients of the vegetable by controlling the migration of water-soluble solutes. Additives that inhibit microbial growth and that preserve the color and flavor of the vegetable may be

incorporated into edible coatings. Coatings have been successfully applied to abrasively peeled carrots, to reduce white-blush, and to celery sticks, to reduce moisture loss. Calcium may be used in coatings, because of its role in improving product firmness, maintaining cell adhesion, and inhibiting the activity of cell wall degrading enzymes (4). Reviews by Huxsoll and Bolin (2) and King and Bolin (18) give further information on methods used to control enzymatic deterioration in vegetables.

Brocklehurst et al. (19) and Brocklehurst and Lund (20) showed that addition of vegetables to mayonnaise, as in a dressed salad, caused an increase in acetic acid concentrations in vegetable tissue and a decrease in pH and acidity of the mayonnaise, within 6 hours of mixing. Acetic acid partitioned predominantly in the water phase of the mayonnaise and rapidly equilibrated with water in vegetable tissue (21). Acid migration limits the shelf life of dressed salads in two ways. Firstly, loss of water from plant tissue causes it to become translucent and modifies its texture (22). Secondly, it permits the growth of microorganisms in mayonnaise, where they would otherwise have been inhibited because of the low pH (23).

Modified atmosphere packaging (MAP) extends the shelf life of fruit and vegetables through suppression of respiration, ripening, and senescence. This is due to a diversity of effects caused by low O_2 and elevated CO_2 concentrations, inhibition of ethylene induced effects, and reduction of moisture loss due to the moisture barrier properties of the plastic film (16). Respiration rates of many fruit and vegetables are slowed when O_2 concentrations are decreased below about 10%, but O_2 concentrations of less than 1 to 2% can lead to anaerobic respiration and the associated production of off odors and flavors. Elevated CO_2 levels can also slow respiratory processes, although at higher than optimal levels, certain physiological or ethylene induced disorders are enhanced (14). In some cases, the use of high CO_2 and low O_2 concentrations together has a greater effect than either gas alone (16).

Over time, O_2 and CO_2 within a package of minimally processed vegetables will reach an equilibrium that is dependent upon the initial gas mixture and whether the pack is gas flushed with or without first applying a vacuum, the respiration rate of the commodity, the O_2:CO_2 transmission rates of the film, and the temperature (24). Packaging materials and gas mixtures should be selected on an individual product basis. Although optimal atmospheric storage conditions for whole fruit and vegetables have been available for some time, little information on the ideal atmospheric storage conditions for sliced fruit and vegetables have been published. Reference can be made to methods used by O'Connor-Shaw et al. (25) for the determination of an optimum storage atmosphere for a minimally processed product, in this case diced cantaloupe. Modified atmospheres containing low O_2 concentrations can be used to control pinking of lettuce.

IV. MICROBIOLOGICAL CHANGES IN VEGETABLES INDUCED BY MINIMAL PROCESSING

Microorganisms are transferred from the surface of the whole vegetable to its interior during cutting. With certain limitations, such as tissue pH, content of organic acids, and presence of antibacterial compounds such as are produced by carrots, cabbage, and onions, microorganisms will grow in the nutrient-rich plant tissue. Generally speaking, the inner tissue of sound vegetables is considered to be microbiologically sterile (26).

Many investigations on the microflora of leafy vegetables have been undertaken. Total bacterial counts of freshly prepared lettuce, endive, and chicory have been reported to range from 2.4 to 8 $\log_{10}$ cfu g^{-1} (27–31). Pseudomonas accounted for between 50 to 60% of isolates from freshly prepared and chill-stored leafy vegetables, with *Pseudomonas fluorescens* (*P. marginalis*) the dominant species; between 20 to 40% of isolates were enterobacteria (29,32), mostly

Enterobacter agglomerans (31). Magnusson et al. (32) found that 25% of enterobacteria strains isolated from lettuce which had been stored for 14 days at 1°C in air were *Erwinia carotovora.* This bacterium is an important cause of soft rot (7). Selective enrichment procedures are required for the isolation of *Erw. carotovora*, which might explain why it was not found in the aforementioned studies.

Several groups of researchers have shown that total counts of the outer leaves of lettuce, endive, and chicory were between 10 and 100-fold higher than counts of inner leaves (27,28,30). Finding that this difference persisted during 6°C, 7 day storage of the leaves, Jacques and Morris (27) concluded, and then went on to prove, that leaf physiology had a significant influence on bacterial population densities. Hence they recommended that only the inner three-quarters of a head should be used for minimal processing.

Jacques and Morris (27) demonstrated that *P. fluorescens* (strain T53) produced soft rot in endive stored at 6°C, at counts of at least 6.7 $\log_{10}$ cfu cm^{-2}. Decay in 90% of leaf pieces occurred when counts were ≥ 7.5 $\log_{10}$ cfu g^{-1}. Nguyen-the and Prunier (31) experimentally produced symptoms of soft rot in chicory leaves using *P. marginalis*, and observed greater deterioration in salads with higher numbers of this bacterial species. *Pseudomonas marginalis* was shown to be a weak pathogen: >8 $\log_{10}$ cfu g^{-1} were required to produce disease symptoms (in 4 days at 10°C); not all strains produced soft rot (in 7 days); and frequently only one or two of the three leaves used in pathogenicity testing developed soft rot.

Lactic acid bacteria have been reported in a wide variety of salads including grated carrots, shredded lettuce, and mixed salads. Lactic acid bacteria counts in shredded carrots, stored for 7 days at 10°C, ranged from 4 to 8 $\log_{10}$ cfu g^{-1}. Representative isolates of the lactic acid bacteria microflora were identified as *Leuconostoc mesenteroides.* Softening and the development of off flavors in carrots, were associated with package atmospheres containing $>30\%$ CO_2, high numbers of lactic acid bacteria and yeasts, and the production of ethanol, acetic, and lactic acid. These factors are indicative of the growth of *L. mesenteroides* (33). Marchetti et al. (29) subsequently reported that marked growth of lactic acid bacteria in carrots during 7 day storage at 5°C was accompanied by increases in CO_2, lactic acid, acetic acid, and ethanol concentrations.

Lactobacilli and yeasts were the predominant microorganisms in chilled mayonnaise based salads (34). The yeasts *Saccharomyces dairensis* and *S. exiguus* dominated the microflora of coleslaw after 16 days storage at 10°C and were present at numbers of 7 $\log_{10}$ cfu g^{-1} (19). Vegetable and potato salads spoiled because of gas production by *S. exiguus* and possibly lactobacilli, and because of visible surface colonies of *Pichia membranaefaciens* and *Geotrichum candidum.* Gas production by *S. exiguus* caused spoilage of Florida salad and coleslaw. The addition of cabbage or carrot to a mayonnaise allowed the growth of two spoilage yeasts, *S. dairiensis* and *S. exiguus*, as a result of acid migration between vegetables and dressing (Sec. 3).

Despite the work mentioned above, little information is available on the microflora of many minimally processed products, especially fruit. Relatively few studies have reported the incidence of individual species on vegetable salads. In a recent review, Heard (35) summarized the results of studies that have established the predominant spoilage microflora of minimally processed vegetables. In addition, information on the responses of individual predominant strains of minimally processed vegetables to MA is limited.

Consequently, Bennik et al. (36) identified the predominant colony types from mung bean sprouts and cut chicory endive before, and after, CA storage, to examine the effects of enhanced CO_2, and reduced O_2 concentrations on their growth. The vegetables were stored under a CA containing 20% CO_2 and 1.5% O_2, with nitrogen (N_2) comprising the balance, at 8°C for 7 days. *Pantoea agglomerans*, *Enterobacter cloacae*, *P. fluorescens*, *P. corrugata*, *and P. viridilivida* were the predominant species in stored mung bean sprouts, whereas *Escherichia vulneris* and *P. fluorescens* were the main species in stored chicory endive. Both the Enterobacteriaceae and

the *Pseudomonas* isolates had reduced maximum specific growth rates (μ_{max}) at high CO_2 concentrations. For example, for *Pseudomonas* strains (μ_{max}) was reduced by 60 to 75% in 20% CO_2. However maximum population densities were not reduced for either group of bacteria at CO_2 concentrations of $\leq 20\%$. There were no significant differences in growth of Enterobacteriaceae and *Pseudomonas* strains between 1.5 and 21% O_2. The conclusion made by the authors on the basis of this work was that, since competition between epiphytes and pathogens may retard the outgrowth of pathogens on minimally processed vegetables, the inhibitory effect of MA storage on a subgroup of the epiphytes may counterbalance this safety feature. This is further discussed in Sec. V.B.

V. MICROBIOLOGICAL SAFETY

A. Introduction

In the past decade, outbreaks of human illness associated with the consumption of raw vegetables and fruits, and the unpasteurised juices produced from them, have increased in the United States. Changes in agronomic, harvesting, distribution, processing, and consumption patterns and practices have undoubtedly contributed to this increase (6). The association of food-borne disease with the consumption of raw vegetables and salads distributed through restaurant salad bars is increasingly being reported in the literature. Consideration of food safety prompted the introduction of a Code of Practice for the operation of salad bars in Australia (35).

There are three major reasons to be concerned about pathogenic microorganisms in fresh-cut produce. Firstly, minimally processed produce does not undergo a kill step during its manufacture. Secondly, the long shelf lives that are made possible by sophisticated packaging and good temperature control may provide sufficient time for pathogens to grow to infectious numbers. Thirdly, modified atmospheres may suppress the growth of spoilage microorganisms, that organoleptically signal the end of shelf life, while favoring the growth of pathogenic microorganisms that do not produce visible signs of their presence (5). Berrang et al. (37) studied the effect of CA storage on the growth of *L. monocytogenes* on fresh asparagus spears, broccoli, and cauliflower florets stored at 4°C. "The most important finding" of this study was that although CA storage extended the length of time the vegetables remained acceptable for consumption by 7 days, it had no effect on the growth of *L. monocytogenes.* For example, *L. monocytogenes* populations were significantly higher in asparagus that had been stored under CA for 21 days, compared with populations in asparagus that had been stored in air for 14 days. Yet both storage times were end points with regard to consumer acceptability.

Contamination of produce with pathogenic microorganisms can occur in the field; during harvesting, postharvest handling, processing, shipping, or marketing; or in the home. Preharvest sources of contamination include soil, irrigation water, water used to apply fungicides and insecticides, green or inadequately composted manure, faeces, air (dust), wild and domestic animals, insects, and human handling. In addition to the latter six factors, sources of postharvest contamination include harvesting equipment, transport containers (from field to packing shed), wash and rinse water, sorting, packing, cutting and further processing equipment, ice, transport vehicles, improper storage, improper packaging, cross-contamination, improper display temperature, and improper handling after wholesale or retail purchase (6).

The bacterial species, *Clostridium botulinum*, *L. monocytogenes*, *Salmonella*, and *Shigella sonnei*, the protozoan *Giardia lamblia*, and viruses have been implicated in food-borne illness involving raw fruit and vegetables in western countries (38,39). The products involved in these incidents included shredded cabbage in coleslaw, shredded lettuce, raw salad vegetables, bean sprouts, cantaloupe, and watermelon. Various surveys have shown the presence of

Aeromonas hydrophila, *Bacillus cereus*, *Campylobacter jejuni*, *Escherichia coli* 0157:H7, *L. monocytogenes*, *Salmonella*, *Shigella*, *Staphylococcus aureus*, *Vibrio cholera*, and *Yersinia enterocolitica* in minimally processed vegetables (26,38,39).

B. Pathogens

The tolerances of pathogenic bacteria to extremes in environmental conditions vary between species. Factors such as time, pH, storage temperature, nutrient availability, presence of preservatives, the gaseous composition of the storage atmosphere, and the composition of the indigenous microflora must be taken into account when considering the growth potential of a particular pathogen in a minimally processed vegetable. Betts (40) lists minimum growth temperatures, pH, and O_2 requirements of food poisoning bacteria of potential concern to chilled MAP foods. These data represent approximate values for these growth limits under otherwise optimal conditions. Exact values will vary depending on the particular strain of microorganism and food composition. Interactions between factors are likely to alter these values considerably. Six pathogens are listed as having minimum growth temperatures of 4°C, the maximum storage temperature for minimally processed vegetables. These are *Salmonella* spp., *L. monocytogenes*, *A. hydrophila*, *Y. enterocolitica*, *B. cereus*, and psychrotrophic *C. botulinum.* The minimum growth pH of these pathogens ranges from 4.0 to 4.6, with *A. hydrophila* and *Y. enterocolitica* able to grow at pH 4.0 to 4.2. All six pathogens have reduced O_2 requirements, being either anaerobic, in the case of *C. botulinum*, or facultatively anaerobic. Vescovo et al. (41) determined maximum growth rates, expressed as $\log_{10}$ cfu g^{-1} day^{-1}, of 0.326 for *A. hydrophila*, 0.35 for *L. monocytogenes*, 0.008 (virtually no growth) for *S. typhimurium*, and 0.005 (virtually no growth) for *S. aureus* in mixed salads stored at 8°C for 6 days. Predictive microbiology (Section V.C) can be used to determine safe shelf lives of food as it takes into account the hurdle effect (42) caused by the interaction between growth limiting factors. However, it must be noted that the results derived from predictive microbiology should always be validated in the food of interest.

Bennik et al. (43) described the behavior of pure cultures of four pathogens, *A. hydrophila*, *Y. enterocolitica*, *L. monocytogenes*, and a cold tolerant strain of *B. cereus* on agar surfaces under eight modified atmospheres. These atmospheres contained either 1.5 or 21% O_2 combined with 0, 5, 20, or 50% CO_2, with N_2 providing the balance. From the results of these experiments, the authors concluded that all four pathogens would grow equally well in vegetables stored under typical MAP conditions, i.e., 1–5% O_2 and 5–10% CO_2, as in vegetables stored under 21% O_2. Furthermore, maximum specific growth rates and maximum population densities of these bacteria would not be inhibited by the CO_2 concentrations generally prevailing in MAP vegetables. Nutrient availability is a crucial factor affecting pathogen growth. The endogenous microflora of MAP vegetables consists mainly of pseudomonads (Sec. 4), which are capable of excreting cell wall degrading enzymes to release nutrients. Since these bacteria are sensitive to CO_2, their suppression may influence nutrient availability for other microorganisms.

The Australia New Zealand Food Standards Code (44) has not specified microbiological standards or guideline criteria for minimally processed vegetables, with the exception of cultured seeds and grains, such as bean or alfalfa sprouts. The mandatory microbiological limit imposed on this category of food is the absence of *Salmonella* in 25 g of produce in five sample units taken from the same production lot. An additional advisory level has been set, which is the absence of *E. coli* per gram of product, in five sample units from the same production lot. Microbiological standards are only given, in the Code, when risk assessment shows that the risk of food-borne illness associated with consumption of a food is relatively high and that a standard could

contribute to the management of the identified risks. Where justification for a standard does not exist, advisory criteria have been developed. Microbiological safety of minimally processed vegetables is best ensured using a properly verified and validated food safety plan (Sec. 6).

The main microorganisms of concern in vacuum packed or MAP chilled foods are psychrotrophic *C. botulinum* and *L. monocytogenes* (40). Hence these pathogens are discussed in more detail below.

1. *Clostridium botulinum*

It is not possible to be certain that food will not contain *C. botulinum* spores (45). *Clostridium botulinum* is ubiquitous and is found in soil, freshwater, and gastrointestinal tracts of animals, as well as in other environments (46,47). Natural contamination levels with *C. botulinum* range from 0.4×10^{-7} to 0.2×10^{-2} spores g^{-1} (48). The resistance of spores to adverse environmental conditions and their capacity for dormancy results in their survival for long periods in the environment. The presence of spores in foods is not of public health significance unless the spores can germinate, outgrow, and multiply into toxin-producing vegetative cells. This only occurs when the O_2 supply is limited. Little is known about the incidence rates of *C. botulinum* on commercially available fresh-cut vegetables. Austin et al. (49) reported a relatively low incidence of 0.36%. Ercolani (50) found clostridial spores in numbers of <1 to >50 cfu cm^{-2} on mature leaves of 19 species of horticultural plant.

Limiting shelf life is one way of controlling toxigenesis, when conditions enable the vegetative growth of *C. botulinum.* Betts (40) categorized products in terms of safe shelf life with respect to *C. botulinum*, as follows:

Short shelf life—≤ 10 days at $>3-8^{\circ}C$ where temperature is the sole controlling factor.
Long shelf life—>10 days at $>3-8^{\circ}C$ provided products meet at least one of the following controlling factors (only factors applicable to minimally processed vegetables have been listed):
pH ≤ 5 throughout food
Presence of any combination of preservative factors that have been shown to prevent growth and toxin production by *C. botulinum*
Storage life at $\leq 3^{\circ}C$—*C. botulinum* will not grow. Growth of other microorganisms or quality issues will determine shelf life. It should be noted that growth and toxin production by *C. botulinum* has since been reported at $3.0^{\circ}C$ in 49 days (42).

The more stringent guidelines of ACMSF (46) may be used for temperatures between 5 and $10^{\circ}C$, because of results that indicate that psychrotrophic *C. botulinum* can produce toxin at temperatures between 5 and $10^{\circ}C$ within 10 days, under ideal conditions. These guidelines recommend

A shelf life of ≤ 10 days at $5^{\circ}C$.
A shelf life of ≤ 5 days at $5-10^{\circ}C$.

The ability of *C. botulinum* to grow in cooked vegetables was shown to be both vegetable and strain specific (51,52). For example, at $5^{\circ}C$, the time to a 1000-fold increase in pathogen numbers was more rapid in mushrooms than in cauliflower, and was more rapid in cauliflower than in potatoes. Austin et al. (49) undertook challenge studies in which *C. botulinum* was inoculated into fresh-cut salads and vegetables packaged in air. Headspace CO_2 levels increased to 40–50% within 7 days and then decreased, O_2 levels decreased to below 2% within 1 to 2 days and remained at this level, and the pH of most samples decreased from 7 at day 0 to 4–5.

Clostridium botulinum growth in MAP stir-fry and mixed salad followed a typical growth curve, with a lag phase of 4 to 7 days followed by logarithmic growth. Samples that became toxic usually contained $>30{,}000$ cfu g^{-1}.

There is a commonly held belief that psychrotrophic *C. botulinum* does not grow in the presence of atmospheric O_2. Various studies have shown that O_2 levels up to 4.4% are required to inhibit growth (53). Toxin was produced by *C. botulinum* in aerobic coculture with psychrotrophic *Bacillus* cells, which depleted both O_2 concentration and redox potential (Eh) (42). Upper Eh levels allowing outgrowth of spores are generally accepted to be about 200 mV. Optimum Eh is -350 mV. Once growth is initiated, Eh drops rapidly to < -200 mV. In food there may be localized areas of lower Eh (54). Most food 5.08 cm deep in a pan provides an environment that is conducive for growth of *C. botulinum* (55).

2. *Listeria monocytogenes*

Listeria monocytogenes is ubiquitous in soils, plant matter, and surface and spring water. A large variety of animals, including man, can serve as hosts of *Listeria* and excrete it (56). There have been many studies conducted on the ecology of *L. monocytogenes* in food processing environments, where it has been detected most often on floors, in drains, and from wet areas of factories, especially in areas that are missed during cleaning. The major environmental areas to target for control of *L. monocytogenes* are the separation of raw and processed product, proper cleaning and sanitation of factory surfaces and interior environments, operator hygiene, good air/aerosol control, keeping as dry an environment as possible, and avoidance of high-pressure hosing and cleaning (which disseminates this bacterium). This pathogen has the ability to form biofilms, creating problems for its control in sanitation programs. Another area of concern is effluent ponds and treatment plants located within the food processing premises from which *L. monocytogenes* can be reintroduced into the processing environment.

Listeria monocytogenes has been isolated from minimally processed fresh vegetables at frequencies that vary from 0 to 19% of samples and usually at numbers of <100 cfu g^{-1} (57). Farber (58) proposed a microbiological limit of 100 cfu g^{-1} of *L. monocytogenes* in minimally processed vegetables at the manufacturing level. However, later results have indicated that an initial level of *L. monocytogenes* of 10 cfu g^{-1} on endive leaves could increase to 0.5 to 5.0×10^5 cfu g^{-1} after storage of the leaves at 10°C for 4 days, without extensive spoilage (59). Survival and growth of *L. monocytogenes* on produce is affected by many different factors, such as product age, product type, level of contamination by the pathogen and by epiphytic microflora, and storage temperature and atmosphere (60).

Several studies have compared the growth of *L. monocytogenes* on different vegetables. Results have shown that growth is vegetable dependent (57,61–63). For examples, pathogen counts remained constant on whole rutabagas, onions, packaged Caesar salad, coleslaw mix, and stir-fry stored at 4°C for 9 days (64). In carrots counts decreased. Other investigators have also demonstrated an antilisteria effect for carrot (65,66). Counts increased in butternut squash. The higher levels of iron in squash compared with other vegetables were thought to have resulted in the improved growth of *L. monocytogenes* in squash.

An interesting finding was that *L. monocytogenes* grew better on vegetables with a low initial microbial load, such as chicory, than on vegetables with a high load, such as mung bean sprouts (60). Results from other studies have suggested that there is active competition between the epiphytic microflora on salad leaves and *L. monocytogenes* (60–62). When *L. monocytogenes* and individual isolates, representing the epiphytic microflora of chicory and endive leaves, were grown together in leaf extract medium at 10°C, pathogen numbers plateaued at a much lower level than when *L. monocytognes* was cultured in monoculture. The difference in pathogen growth

between mono- and co-culture was due, at least in part, to competition for nutrients. This observed competition phenomenon should be kept in mind when efforts are made to reduce spoilage bacterial numbers selectively, e.g., by disinfection, because such treatment will reduce the natural antagonism of a product against *L. monocytogenes* (60).

Growth of *L. monocytogenes* on chicory endive was found to be better in microaerophilic (1.5% O_2 and 20% CO_2) and anaerobic (20% CO_2) conditions than in air. Nitrogen comprised the balance of these atmospheres. Growth was also better under 10% O_2 and either 30 or 50% CO_2, than under air or 10% O_2 and 10% CO_2 (60–62). There is a general consensus that high levels of CO_2, >70%, are required in the absence of O_2 to inhibit *L. monocytogenes* (53). In contrast, growth of epiphytic bacteria was significantly reduced by increased CO_2 concentrations (60). Consequently, it can be seen that modified atmospheres change the composition of the microflora in favor of *L. monocytogenes*, although epiphytes still grow better than this pathogen on MAP produce.

C. Predictive Microbiology and Challenge Tests

Predictive microbiology can be used to determine safe shelf lives of food, and in developing HACCP systems (67). Predictive models are mathematical equations that predict microbial growth under defined conditions, using experimental results contained in a large database. Predictive models have been developed for a variety of pathogens, including psychrotrophic *C. botulinum* (40,48).

To indicate the usefulness and limitations of predictive microbiology, the following data were obtained from the USDA pathogen-modeling program (68). The times required for various pathogens to grow from initial counts of 10 cfu g^{-1} to counts of 1000 cfu g^{-1}, at pH 5.0 and 8°C, were calculated. Under these conditions, the model predicted that *L. monocytogenes* would grow to 1000 cfu g^{-1} in 19 days, and that growth of *A. hydrophila* and *E. coli* 0157:H7 was unlikely. No data were available for *Salmonella* sp. and *S. aureus* at temperatures of ≤ 10°C. At a temperature of 12°C, the model predicted that the time required to achieve a 2 log increase in bacterial numbers would be 17.9 days for *A. hydrophila*, 7.2 days for *E. coli* 0157:H7, 9.95 days for *L. monocytogenes* and 18.6 days for *S. aureus.* No data were available for *Salmonella* sp. at pH < 5.8.

Microbiological challenge testing is the laboratory simulation of what can happen to a product during distribution and subsequent handling (48,69). Challenge testing should always validate the results of predictive microbiology. A microbiological challenge test will involve the inoculation of a selected product with relevant microorganisms and/or the holding of that product under a range of controlled environmental conditions in order to assess the risk of food poisoning or to establish product stability. When designing a challenge test, consideration should be given to potential abuse conditions, different product formulation, preparation or processing conditions, and microbial numbers in the inoculum. A properly designed challenge test may be cited as part of the proof of innocence by a processor in a legal dispute over his product. Production equipment should not be used with inoculated product since removal of contaminating microorganisms may be difficult to achieve.

VI. HACCP BASED FOOD SAFETY PLANS

HACCP is an acronym for hazard analysis critical control point and is now part of the food industry's language. The HACCP concept is a systematic approach to the identification and assessment of hazards associated with the production, processing, distribution, and use of

a particular foodstuff. Hazards to food safety may be microbiological, chemical, or physical in nature. Critical control points (CCP) are points in a process where control can be applied to prevent or reduce a hazard to an acceptable level. Critical control points are monitored, by measurement or observation, to assess whether the process is under control. In a model HACCP plan developed by the IFPA (5) for shredded iceberg lettuce, microbiological hazards included pathogenic *E. coli*, *Salmonella* sp., *C. botulinum*, *L. monocytogenes*, *Shigella*, and food borne viruses; chemical hazards included poisons and toxic cleaning chemicals; and physical hazards included insects, wood, glass, sand, rocks, metal, and any other foreign object.

Processors should evaluate product ingredients, processing procedures, packaging, storage, shelf life and intended use, design and construction of manufacturing premises and equipment, and plant sanitation, to determine the potential effect of each on the safety of the finished product. The HACCP plan should be specific to each location and to each product that is processed at that location. Current good manufacturing practices (GMP) and standard operating procedures (SOP) for hygiene and sanitation and the design and construction of premises and equipment are prerequisites for HACCP. Hygiene and sanitation SOPs address such matters as the personal health and hygiene of food handlers, and the cleaning of food-contact surfaces.

Processors should develop raw product specifications for growers, which establish the appropriate conditions for growing and harvesting vegetables, the use of potable water for irrigation and washing of vegetables, the supply of vegetables in a clean state, product storage temperatures of $<7^{\circ}C$, and ripeness criteria. For example, carrots should not be fertilized with manure, and apples should be picked from trees and not the ground. Food poisoning has been linked to the consumption of salad vegetables, potatoes, and apples contaminated with manure containing *E. coli* 0157:H7 (70). Drop apples are more likely to be contaminated with *E. coli* than picked apples (71). Quarter ripe, rather than fully ripe, pineapples could be specified for the production of minimally processed pineapple cylinders, as the lower pH of the quarter ripe pineapples will act as a barrier to pathogen growth. Accredited suppliers of packaging materials should be used.

There are two possible means by which contamination on the surface/outer leaves of a vegetable can be introduced into the internal tissues/leaves. Firstly, disease or injury to the surface gives the opportunity for any pathogens present to gain access to the interior. This means of contamination can be controlled through grading and culling with a critical limit of zero defectives. Secondly, contamination from the surface of the vegetable can be introduced into its interior by cutting (Sec. 4). Washing, brushing, and sanitizing prior to cutting reduces the microbial load on the surface and thus the number of microorganisms transferred to the interior. This step is frequently a CPP in the minimal processing of vegetables with processors establishing critical limits for free chlorine (2 to 7 ppm free residual after contact), total chlorine (maximum of 100 to 150 ppm), pH (6.0 to 7.0), and water temperature ($4^{\circ}C$) (Sec. 2).

The two critical limits associated with packing are that there should be no metal in the product, and no defective seals. The technique for detecting improperly formed seals is to immerse bags in water, subject them to gentle hand pressure, and examine seals for escaping bubbles.

The physical parameters of the product, and how it will be handled after it leaves the processing plant and before it is consumed, must be considered in terms of potential microbiological hazard. Factors, such as time, temperature, pH, and O_2 and CO_2 concentrations, influence the rate at which microorganisms grow in food. Two effective measures for preventing the growth of pathogens to infective levels are temperature control and the setting of a reasonable shelf life for the product, which includes a safety margin to accommodate moderate temperature abuse during storage and distribution. Time-temperature indicators are small measuring devices that simulate the evolution of a time-temperature-related factor that is liable to affect the quality/safety of the foodstuff and can be used to monitor chilling and refrigerated storage (72).

The Australia New Zealand Food Authority (73) gives advice on the use of time to control the growth of food borne pathogens in potentially hazardous food. A potentially hazardous food is a food that has to be kept either at $\leq 5^{\circ}C$ or at $\geq 60^{\circ}C$ to minimize the growth of any pathogenic microorganisms that may be present in food, and as such includes minimally processed vegetable products. As a general rule, the total time that a ready-to-eat potentially hazardous food can be at temperatures between 5 and $60^{\circ}C$ is 4 hours. The total time is the sum of the time the food is in this unacceptable temperature range after it has been processed to make it safe, e.g., after chlorine dipping. If the food is to be rerefrigerated, the total time it can be at room temperature is 2 hours. Predictive microbiology is another way to establish the safe shelf life of a food under ideal and realistic storage conditions, and whether the product can safely be retained for sale, or should be rejected, in cases of temperature abuse (Sec. 5C).

To prevent the recurrence of food poisoning outbreaks involving unpasteurized juice, the United States Food and Drug Administration (74) recommended that processors of unpasteurized juice validate that the manufacturing process is under control using target pathogens. The most resistant pathogen under the circumstances should be selected as the target pathogen. In the absence of known specific pathogen–product associations, *E. coli* 0157:H7 or *L. monocytogenes* should be used. A tolerable level of risk for unpasteurized juices was defined to be at least a fivefold reduction in target pathogen numbers between the processor's initial treatment of the intact fruit/vegetable and the end of shelf life when the product is stored under normal and moderate abuse conditions. This criterion is not applicable to the production of minimally processed vegetables. However, processors of these products should understand the effect that each processing step has on numbers of the appropriate target pathogen so that they can develop a performance criterion for their process.

VII. CONCLUSIONS

The minimally processed vegetable industry is a relatively new industry, surging into prominence over the last 10 or 15 years (Sec. 1). Much research has been undertaken over this time, in order to understand the spoilage and safety issues associated with this group of products, with a view to producing a high-quality product allowing an acceptable time for distribution. Important points arising from this research have been summarized in this chapter. However there remain gaps in our understanding. In particular the issues that need addressing are

The replacement of chlorine with another sanitizer that is both safe and effective

Investigation of new size reduction technologies, such as high-pressure water jets and CO_2 lasers, to enable product to be cut with minimal damage and minimal opportunity for enzymatic and microbial contamination

Establishment of optimal storage atmospheres for minimally processed fruit and vegetables, taking into account both physiological and microbiological deterioration processes, that is, the atmosphere that is most effective in retarding physiological deterioration may not be the most effective in terms of delaying microbial growth

Determination of the effect of each processing step, used in the production of minimally processed vegetables, on pathogen counts

Identification of the components in a vegetable that support or inhibit microbial growth

Development of a greater understanding of the effect that metabolites, including respiratory gases produced during microbial growth, have on spoilage processes

Development of a greater understanding of the complexity of the ecological conditions to which microorganisms are subjected to, and which impact on their growth, during storage under modified gas conditions.

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Science and Technology of Tofu Making

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I. INTRODUCTION

China is the birthplace of the soybean. In Oriental countries such as China, Korea, and Japan, soy foods have been consumed for thousands of years. In the 1800s, soybeans were introduced into the U.S., but large-scale production of soybean began only after World War II. In the first part of the 20th century, soybeans have been known to Westerners as an oilseed and feedstuff only. Aside from the image problem, the major obstacles in the utilization of whole soybean for foods in Western society include the beany flavor and the flatulence factor. Substantial use of soybeans for foods did not take place until recent decades, when small portions of defatted soy meal were used or processed further for human foods. Since the 1980s, soybeans have been used for making a variety of soy foods in the U.S. Hence some soybeans are known as vegetable legumes, and soy foods are popular vegetable foods. In very recent years, because several soybean components have been discovered to possess health benefits, soy foods have become health foods. Consumption of soy foods in the U.S. has increased dramatically in the last few years. Soy foods are finding their way into mainstream supermarkets. The total retail value of soy foods has exceeded 2.5 billion U.S. The United States produces one half of the world's soybeans, which are estimated to be approximately 159 million metric tons (1). Only approximately 5% of U.S. soybeans are used for making foods. In the last three years, however, it was estimated that the annual soy food market had increased by 25% per year. Soymilk, tofu, and meat analogs are the three major soy food types in the USA. The increases in soymilk and tofu retail values in the USA are about 40–50% and 15–20%, respectively, each year since 1997 (P. Golbitz, personal communication, 2000), while the overall growth of the U.S. food industry has been only 3% per year. It has been predicted by the United Soybean Board that by the year 2010, soyfoods' retail value will reach 100 billion in the United States.

Soy protein has long been known to have a good nutritional quality. Recent discoveries of potential health benefits of soy foods include reducing the risk of cardiovascular diseases, preventing certain cancers, reducing postmenopausal syndromes, and increasing bone mass density, and all contribute to the recognition of soybean as a health food. The U.S. Food and Drug Administration has approved a health claim for processed foods containing soy proteins that states, "consumption of 25 g soy proteins per day in conjunction with a low cholesterol diet would reduce the risk of heart disease." All of these will continue to enhance the consumption of this ancient Oriental food crop in America and other parts of the world.

Tofu has found its history dated back to China's Han dynasty approximately 2000 years ago. Tofu has been an integral part of the Chinese food culture; it is indispensable in the diets of the Chinese and the peoples of several other East Asian countries, including Japan and Korea. Soybeans have contributed to the health of the Chinese people historically. We believe that a large-scale prolonged protein malnutrition has never occurred in China, which might be attributed to the ready availability of soy foods. Soy foods are not only nutritious but also very delicious, and they have been included in thousands of Chinese food dishes. Because of the functional properties and health benefits reported in recent years, soy foods are gaining acceptance increasingly in Western society.

Since its original invention, the tofu manufacturing process has been improved greatly. Many manufacture and utilization methods have been developed in various countries and regions. Japan has taken the lead in the advancement of the science and technology of tofu making. It is well known that making tofu is not difficult. Many people can claim that they make tofu. However, making excellent quality tofu consistently is not so easy. The principles of tofu making are simple and consist of two main stages: (a) the preparation of soymilk and (b) the coagulation of soymilk to form bean curd, which is then made into various types of tofu. Many factors involved in the processing of tofu and raw bean components affect substantially the quality of tofu. There have been several books related to tofu making, including *The Science of Tofu* (2), *Tofu and Soymilk Production* (The Book of Tofu, Volume 2) (3), and *Soybeans: Chemistry, Technology and Utilization* (4). In this chapter, we focus on recent studies related to soybean quality and tofu making and try to organize available information together to show how various factors affect tofu quality.

II. TOFU PROCESSING METHODS

Tofu manufacturing requires a series of unit operations. Generally, three steps are critical in determining product type: (a) soymilk extraction and solid content, (b) coagulation method (types of coagulants, breaking or not after curd formation), and (c) pressing or not. However, all methods for making various tofu products begin with similar steps for soymilk as shown in Fig. 1. The traditional Chinese method separates raw soymilk from the *okara* (residue) before heating. In the Japanese process, heating the *go* (slurry) prior to separation facilitates soymilk extraction and increases tofu yield. However, Beddows and Wong (5) reported that yield and quality of silken tofu made by a laboratory scale with the slurry filtration prior to heating are better than that with heating prior to residue separation. Both Chinese and Japanese methods for extracting soymilk are known as traditional Oriental methods because of the presence of a beany flavor in the final soymilk product. Regarding the beany flavor, several modern methods aimed at improving soymilk taste and flavor have been developed in the past decades. We will discuss these in more detail in the lipoxygenase section. In the tofu industry, many manufacturers worldwide have adopted the Japanese process because of higher tofu yield, available tofu manufacturing machines, and a lower beany flavor than the Chinese process. Some industries wash the *okara* one or two times to extract residual proteins/soluble solids and use the wash water in the grinding of the soybeans to improve yield.

After the soymilk is produced, various steps are used to manufacture different types of tofu. Tofu in the market is generally classified into soft, firm, and extra firm, based on water content and textural properties. Tofu is classified into *momen* (regular), *kinugoshi* (silken), soft, packed silken, and aseptic, depending on processing methods. Figures 2–5 describe the methods used in the tofu industry for the production of *momen* tofu, *silken* (Kinugoshi) tofu, filled packed silken tofu, and soft tofu, respectively.

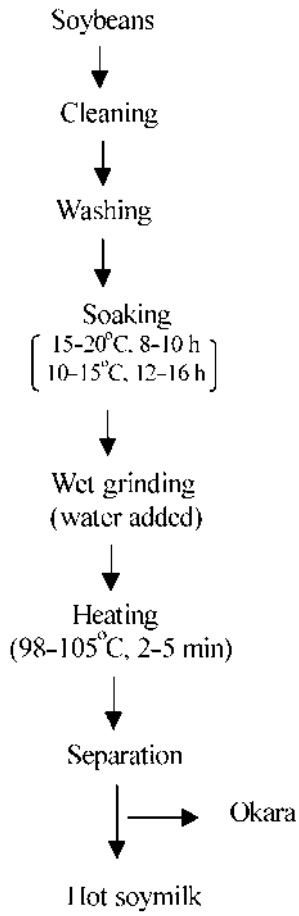

Figure 1 Initial steps in the preparation of soymilk for tofu making.

A. Soaking

After proper washing, soybeans are soaked in water to soften their cellular structure for water grinding. Soaking time depends on water temperature, the soybean variety, and the age of the soybeans. The temperature is the main factor affecting the rate of water uptake, a higher rate being associated with higher temperature (6). Generally, soaking in ambient water takes 8–10 hours in summer and 16–18 hours in winter. After soaking, the beans weigh approximately 2.2–2.3 times their initial weight (3).

B. Grinding

After soaking, soybeans are ground with water into a slurry using a stone mill or a stainless steel grinder. The amount of water added during grinding depends on the type of the final product. For example, the water dosage for silken tofu, soft tofu, and regular tofu is 5, 7–8, and 10 times of raw soybean weight, respectively (2). Proper grinding gives appropriate small particle sizes in the slurry and facilitates the extraction of solids and nutrients into the soymilk. The smaller the particles, the better the extraction, but *okara* (residue) becomes more difficult to separate. The

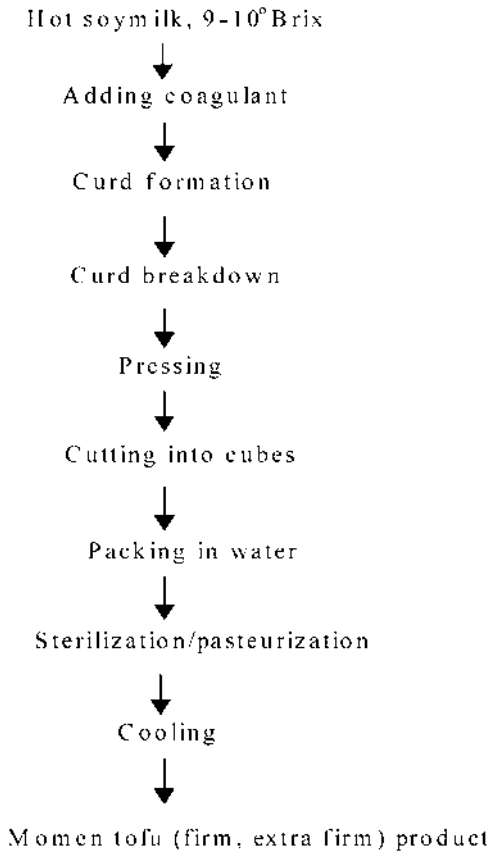

Figure 2 Scheme for momen tofu production.

water temperature of grinding affects not only the flavor of the soymilk but also the texture of the tofu. Tofu firmness decreases as the water temperature of grinding increases between 0°C and 50°C (7). They found that the relationship is related to the content of sulfhydryl groups (—SH) in soymilk. The decrease of the —SH group may be caused by a lipid oxidation activated by lipoxygenases in soybeans. Since water makes up 88–90% of tofu weight, it plays an important role in determining its taste. The source and quality of water are always important to tofu manufacturers. Water containing proper amounts of minerals (about 100 mg/L), including calcium, magnesium, sodium, potassium, iron, and manganese, provides a harmonious and mellow taste (2).

C. Heating

The heating step is essential during tofu processing not only for killing microorganisms in the slurry, thus improving nutritional quality by inactivating trypsin inhibitor (TI) and reducing beany flavor, but also for denaturing proteins so that they can coagulate into curd in the presence of a coagulant. Before heating, soy protein molecules maintain their native globular structures in which the hydrophobic regions are wrapped inside. Upon heating, the soy proteins are denatured, resulting in native molecules being unfolded, and their hydrophobic groups exposed to the outside, so that protein solubility decreases owing to aggregation. What extent of heat treatment is

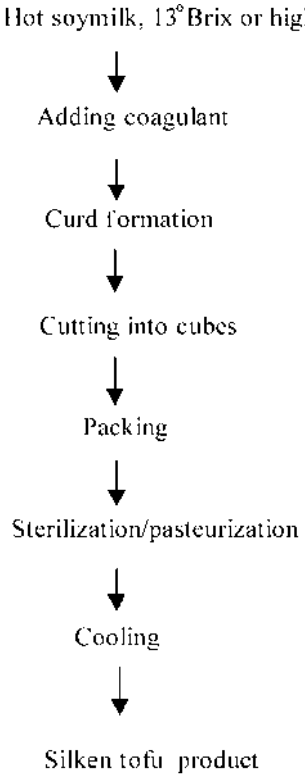

Figure 3 Scheme for silken (Kinugoshi) tofu production (no curd breaking and no pressing).

considered adequate for soymilk and tofu making? Hackler et al. (8) conducted a study of heat treatment on the nutritive value of soymilk protein fed to weaning rats and found that heat treatment should be sufficient to inactivate 80–90% of trypsin inhibitors for maximizing nutritive values. Trypsin inhibitors are heat resistant. At 100°C, 14 min are required to inactivate 80% TI or 30 min for 90% TI destruction. Wilson (9) suggested that the time/temperature requirement for soymilk be based on 85% TI inactivation. Trypsin inhibitors are water-soluble proteins, a part of which may be released in the whey during the pressing stage of tofu making. Thus the slurry used for tofu making requires shorter heating times than that for soymilk as the final product. Watanabe (2) recommends that boiling at 100°C for 3–5 min be required for tofu making.

The optimum heating time of soymilk for making tofu corresponds approximately to the maximum amount of sulfhydryl groups. If heating is not adequate, soy proteins do not dissociate into subunits; but in excessive heating, sulfhydryl groups are oxidized by air (10). Tofu prepared with soymilk that has been heated at 100°C up to 60 min is softer than that from the usual preparations (100°C, 3 min) (11). This may be due to the oxidation of sulfhydryl groups of soy protein during excessive heating, resulting in decreases of sulfhydryl group content and tofu hardness. In the Japanese method, cooking the slurry for about 7 to 14 min at 100°C gives the best soymilk solid and protein recovery, especially for tofu (12). In the Chinese method, the hardness of tofu increases slightly from 0 to 12 min of boiling soymilk, but decreases significantly after 30 min and 60 min of boiling (13). The amino acid composition of soymilk shows no significant changes when heated at 93°C, but the amount of cystine and tryptophan decrease on heating at 121°C from 0 to 121 min (14). Approximately 30% of cystine and methionine are destroyed after

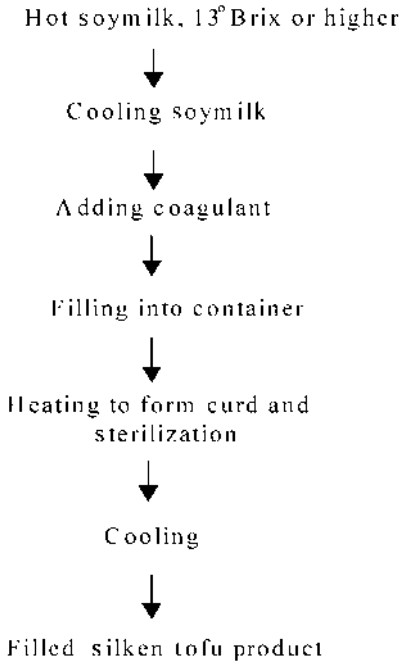

Figure 4 Scheme for manufacturing filled silken tofu (cold filling and curd formed in container).

30 min of boiling soymilk (15). In some tofu factories, the slurry is heated by a continuous pressure cooker at various pressures increasing from 80°C to 105°C for times ranging from 4 to 20 min.

D. Separation of Soymilk

In the Japanese process, soymilk is extracted from the slurry after heating. The separation of a small volume of slurry can be done by filling the slurry into a cotton cloth bag which is then pressed by the hands. Industrial processing can be done by drum pressing, screw pressing, centrifugation, or shaker filtration. The efficiency of soymilk separation depends on the extraction pressure and pressing time, the pore size of the filter or screen, the particle size of the slurry, and whether the *okara* is rewashed or re-pressed. When the *okara* is rewashed and re-pressed to extract more protein and solids, the yield of tofu can increase by 15–20%. *Okara* contains 76–80% of moisture (24–20% solids) after being well pressed. About 29% of the solids and 17% of the protein in the original soybeans remain in the pressed *okara* that has not been washed (3). On a dry weight basis, *okara* includes 25–28% protein, 9–11% lipid, 40–44% insoluble fiber, 13–15% soluble fiber, and 4–5% soluble carbohydrate (16). Most of the total fiber in soybeans is concentrated in the *okara*.

E. Coagulation of Soymilk

Coagulation is the most important and the most difficult step in tofu making because it depends on the complex interrelationship of many variables, including soybean variety, soymilk concentration and pH, temperature, type and amount of coagulant, and coagulation method. Hot soymilk is usually coagulated to form curd by the addition of a salt or an acid coagulant. Tofu coagulants are

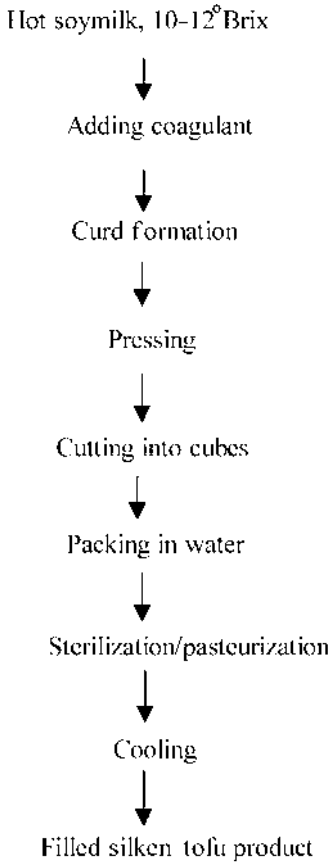

Figure 5 Scheme for manufacturing soft tofu (no curd breaking).

classified into four basic types: (a) *nigari*-type or chloride-type coagulant, including magnesium chloride, calcium chloride, and sea water; (b) sulfate-type, including calcium sulfate and magnesium sulfate; (c) glucono-delta-lactone (GDL); (d) acidic coagulants including citrus juices, vinegar, and lactic acid (3). Each type of coagulant has its advantages and disadvantages.

1. Type of Coagulants

Nigari or chloride-type coagulants include natural *nigari*, refined *nigari*, calcium chloride, and seawater. Natural *nigari*, known as bittern in the West, is extracted from seawater by removing most or all of the table salt (NaCl) and water. It consists primarily of $MgCl_2 \cdot 6H_2O$ (92.3%) plus all of the other salts and trace minerals in seawater (3.8% $MgSO_4$, 1.7% NaCl, 1.2% KCl, and 1% $CaSO_4$). Refined *nigari* is a relatively pure magnesium chloride (99.5%). Calcium chloride ($CaCl_2$) is not found in seawater, so it is not a traditional *nigari*-type coagulant. However, it gives tofu excellent flavor, almost identical to that made from natural *nigari* or magnesium chloride *nigari*. Moreover, it is the cheapest *nigari*-type coagulant and the food-grade variety produced in the U.S.A. is on the GRAS (generally recognized as safe) list. In Japan, most tofu industries use *nigari*-type coagulants in combination with calcium sulfate rather than alone. *Nigari*-type coagulants make the most delicious tofu, prized for its wonderful subtle sweet flavor and aroma. However, they show some disadvantages compared with calcium sulfate and GDL. They react

very rapidly with soymilk, so their use requires skill and attention, and they must be added slowly. Owing to the extremely quick reaction of *nigari* with soymilk, the coagulated bean curd is destroyed while agitation is still going on. The *nigari*-coagulated bean curd does not incorporate so much water as the sulfate type, so it produces tofu with lower yields and coarser texture than that made with calcium sulfate. *Nigari* alone is not suitable for making silken tofu from hot soymilk, because the high temperature and high solids content of soymilk make it extremely difficult to solidify uniformly with *nigari* in a short reaction time. However, filled silken tofu can be made with *nigari* if the soymilk is cooled to a low temperature (e.g., 4°C) prior to coagulant addition, and then heated to coagulate the proteins slowly.

Sulfate-type coagulants (especially calcium sulfate, known as gypsum) are the most widely used tofu coagulants in the world. They have low water solubility (3.0 g/L at room temperature), which is an important factor in determining the speed of the coagulation reaction. Because of their low solubility, they react slowly with the soymilk; consequently they allow the formation of bean curds with high water-holding capacity. Thus they give 15 to 20% higher bulk yields than *nigari*. The resulting tofu has a soft and smooth texture. Calcium sulfate can be used to make regular, firm, soft, silken, and even packed (package-filled) tofu, whereas it is not easy to make the latter two types with *nigari*. Calcium sulfate is easy to use even by relatively unskilled tofu makers. Even if agitation is carried out slowly or the dosage varies slightly, the differences in tofu yield and texture are not very large. Calcium sulfate as a tofu coagulant produces tofu with a mild or bland flavor; however, the taste is slightly inferior to that of *nigari* tofu.

GDL is an oxidation product of glucose. It is manufactured from corn starch by a fermentation process and was first used for silken and packed tofu production during the 1960s in Japan (3). GDL is fundamentally different from *nigari* and gypsum-type coagulants, in which an acid rather than a salt does the coagulation. Upon being dissolved in water, it is slowly hydrolyzed (about 2–3 h) to gluconic acid by water. The pH of 1% fresh aqueous solution at room temperature is 3.5; it drops to 2.5 owing to the conversion to gluconic acid within 2 or 3 h. For packed and silken tofu, GDL is dissolved in previously cooled soymilk and forms gluconic acid gradually; then heat coagulates the soymilk with this acid to form homogeneous solidified curd with rich water holding property in the container. The GDL gives tofu a slightly acidic flavor and a tender jello-like texture. For better flavor and texture, GDL is often used in combination with a calcium sulfate.

The acid-type coagulants, including lactic acid, acetic acid, and lemon juice, work well as natural coagulants. However, the yield of tofu is low, the texture is slightly crumbly, and the flavor of tofu is a little tart, when compared with *nigari* and calcium sulfate as coagulants (17,18).

2. Soymilk Concentration

The solids concentration of soymilk is related to the water-to-bean ratio, which is defined as the total weight of water added to the beans during soaking, grinding, and cooking divided by the original weight of the soybeans (3). The ratio of water to beans can be critical for the protein extraction yield and the properties of the tofu. In the range of 9 : 1 to 14 : 1, 10 : 1 gave the best result in protein recovery (19). For making regular tofu, the best water-to-bean ratio is about 10 : 1, which results in a soymilk with 6.0 to 6.3% solids and 3.0% protein (12). However, 5 : 1 to 7 : 1 ratios are required for making soft tofu or silken tofu (10). The amount of coagulant required to reach the optimum coagulation varies with the concentration of soymilk. Watanabe et al. (12) reported that more coagulant is required for more concentrated soymilk (in the range of 3 to 8%) to reach the same level of whey transparency, and the dosage for calcium sulfate was about 10–20% more than that for *nigari*. In our laboratory, we found that the coagulant concentration

required to reach the optimum coagulation of silken tofu increases linearly with the soymilk solid content in the range of 6 to 11%, and the concentration for magnesium chloride is about 13–15% more than that for calcium chloride (unpublished data).

3. Coagulant Concentration

The amount of coagulant added to soymilk affects greatly the yield, texture, taste, and aroma of tofu. In general, by observing curd formed and whey produced during pressing, tofu makers can tell whether the amount of coagulant is appropriate. When a proper amount of coagulant is used, the whey is transparent and amber or pale yellow. In the case of too much coagulant, the whey is yellowish in color and the curds have a coarse or crumbly texture. If too little coagulant is added, the whey is cloudy and some uncoagulated soymilk may remain. Several methods have been compared to determine the optimum amount of coagulant in tofu making, including the light transmittance of the whey (%T), the whey volume, the pH of the whey, and the conductance of the whey (19). Among these methods, they found that whey transmittance and conductance correlated with coagulant concentration and concluded that measuring the conductance of the coagulating soymilk was faster and more reproducible than obtaining the pH and transmittance values of the whey. A rotational viscometer (viscograph) is applied by researchers to measure the optimum concentration of coagulant for the coagulation of soymilk (20,21). Among the five coagulants studied, with an increase in coagulant concentration from the minimum required concentration (from 0.15 to 0.5% of soymilk volume depending on the coagulant), there is an increase in whey volume and a decrease in the moisture of the tofu (22). Sun and Breene (23) found negative correlations between calcium sulfate concentration and both yield and protein recovery of tofu from five soybean varieties.

4. Coagulation Temperature

The soymilk temperature for adding coagulant affects the coagulation rate as well as the tofu quality. The yield and moisture content of tofu decrease as the temperature of coagulation increases, whereas the hardness and elasticity increase (15). When soymilk is at high temperature, proteins possess high active energy that can lead to fast coagulation, resulting in the formation of curd with low water holding capacity and thus a tofu with a hard texture and a low bulk yield. The hotter the soymilk at the time of coagulation, the less the amount of coagulant required. When tofu is coagulated at a high temperature, a small increase in the amount of coagulant may lead to a large decrease in yield. In the tofu industry, the temperature of coagulation varies from one factory to another, depending on the type of coagulant used. Generally, coagulation temperature ranges from 68 to 95°C for those using *nigari*, while those using calcium sulfate prefer the range from 70 to 80°C in Japan. Beddows and Wong (5) reported that the optimum coagulation temperature is 75–80°C for silken tofu with gypsum as coagulant on a small bench scale. Shih et al. (24) reported that the optimum coagulation temperature is 85–91°C for soft tofu with modified *nigari* (mostly $CaSO_4$) on a medium scale. The operational temperature of coagulation also varies from one region to another. In the U.S., tofu makers prefer a relatively high temperature, 85°C, for using *nigari* and calcium sulfate; and since less coagulant is required, the curd forms quickly, and the tofu has a firm and dense texture but no significant drop in yield.

5. Coagulation Methods

The addition method, the stirring speed at which the coagulant is added, and the continuous stirring time after the coagulant is added have very definite effect on tofu yield and quality. Traditionally, calcium sulfate in a suspension is added to soymilk, which has been stirred

vigorously by hand with a paddle, and the mixture continues to be mixed 6 to 8 more times. *Nigari*-type coagulant can be divided into three portions and added in three steps in order to coagulate the soymilk slowly and obtain high yield and a smooth texture. The first portion of the *nigari* is poured from a height of several feet into the soymilk being swirled with a paddle. Coagulation starts from the bottom of the container and slowly works upwards, while the uncoagulated soymilk constantly rises to the surface. The second portion is sprinkled over the soymilk surface, which is covered and let stand for about 5 min; then the last portion is also sprinkled over the surface, and allowed to stand for 15–20 min to solidify completely (3). Generally, the controlling techniques of this coagulation rely on the experienced tofu maker's judgment.

The stirring of soymilk by a motorized stirrer and the effect of mixing speed and time have been investigated by researchers (25,26). By using a small scale for silken tofu (250 mL soymilk), Beddows and Wong (25) found that the stirring speed during coagulant addition was critical and the optimum speed for tofu yield, texture, and protein recovery was 240–280 rpm for 30 s. By using medium scale research equipment for soft tofu (4.5 L soymilk per batch, mold size as in Fig. 6), tofu stirred at 285 rpm (stirrer Model RZR1, Caframo LTD, Wiarton, Ontario, Canada, equipped with a paddle 7 × 7 cm) has a lower yield but higher firmness than tofu made at 207 rpm (26) (Table 1). We found that yield decreased when stirring time increased to 30 s, and tofu texture was affected as stirring time increased to 25 s. By using a medium scale and a stirrer fixed at 285 rpm, we have determined the optimum combinations of soymilk solids, coagulant concentration, soymilk temperature for adding coagulant, and stirring time after adding coagulant for soft tofu making (24). Tofu yield is affected mainly by soymilk solid content and coagulant concentration. Tofu solids and protein content are affected by soymilk solids, coagulant concentration, and stirring time. Solid content of soymilk is the most important factor

Figure 6 The tofu mold used by the medium-scale method. (Size: 25 L × 25 W × 7 H cm)

Table 1 Effects of Stirring Speed and Time on Tofu Yield and Hardness*

	Tofu yield (g/100 g soybeans)**		Tofu hardness (g)	
Stirring time (s)	Stirring at 207 rpm	Stirring at 285 rpm	Stirring at 207 rpm	Stirring at 285 rpm
10	533 ± 0[a]	535 ± 12[a]	2005 ± 186[a]	2120 ± 199[a]
15	539 ± 8[a]	535 ± 9[a]	1993 ± 302[a]	2232 ± 211[a]
20	541 ± 8[a]	532 ± 10[a]	1838 ± 109[a]	2016 ± 158[a]
25	540 ± 10[a]	511 ± 14[a]	1597 ± 142[b]	1528 ± 122[b]
30	513 ± 10[b]	462 ± 38[b]	1580 ± 47[b]	2187 ± 92[a]

* Data are expressed as means ± s.d. and are means of three replicates.
** Data of yield are on a wet weight basis.
[a–b]: Means within the same column not followed by the same letters significantly different ($p < 0.05$).
Souce: Data from Hou et al. (1997).

affecting the textural properties of tofu. The optimum combinations are soymilk 11.8 to 12.3°Brix, coagulant 0.27 to 0.32% of soymilk volume, stirring temperature 85 to 91°C, and stirring time 5 to 11.3 s (24).

F. Pressing of Curd

For *momen* tofu and soft tofu, pressing the bean curd to expel the soy whey is necessary as shown in Fig. 2 and Fig. 5. The pressure and the duration of pressing can influence moisture content, yield, and texture. A range of values has been used for both parameters among different researchers (Table 2). Generally, silken tofu is not pressed after coagulation, but Beddows and Wong (25) reported the optimum pressure applied to silken tofu was 4 to 6 g/cm^2 for pressing until dripping ceased. They found that below 4 g/cm^2 the tofu was very soft with little or no retention of cut shape, and that above 8 g/cm^2, the tofu was hard and rubbery. Gandhi and Bourne (27) showed that when the pressure increased from 4.79 to 19.1 g/cm^2, the moisture content

Table 2 Pressure and Duration of Tofu Processing Applied by Tofu Investigators

Investigators	Pressure (/cm^2)	Duration
Pontecorvo and Bourne, 1978	9 kg	20–30 min
Lu et al., 1980	2.58 g	2–3 h
Skurray et al., 1980–1981	5.56 g	2 h
Wang et al., 1983	10.0 g	1 h
deMan et al., 1986	31.4 g	15 min
Beddows and Wong, 1987c	4.0–6.0 g	—[a]
Gandhi and Bourne, 1988	4.79–19.1 g	15 min
Wang and Cavins, 1989	10.0 g	1 h
Lim et al., 1990	15.7 g	15 min
Sun and Breene, 1991	10.0 g	2 h
Metussin et al., 1992	2.78 g	30 min
Wang and Chang, 1995	7.6 g	40 min
Hou et al., 1997	21.8–65.4 g	50 min
Torres-Penaranda et al., 1998	2–6 kg	15 min
Moizuddin et al., 1999	1–3 kg	8 min

[a]No data presented.

decreased from 82 to 60% and the yield decreased from 2.0 to 1.2 kg per kg whole dry soybeans. From a commercial standpoint, most manufacturers apply a light initial pressure of 2 to 4 g/cm^2 for about 5 to 10 min and a stronger pressure of about 5 to 15 g/cm^2 for 10 to 15 min to make soft tofu; for firm tofu, a pressure of 20 to100 g/cm^2 is used for 20 to 30 min (3). In our laboratory, we apply a pressure of 21.8 g/cm^2 for 10 min, followed by 43.6 g/cm^2 for another 10 min, and adding to 65.4 g/cm^2 for 30 min for making soft tofu on a medium scale (24,26). Because of several variables, the tofu making process differs in various research laboratories, which report data that were difficult to compare. Thus there is a need to standardize the procedures for determining the quality of soybeans for tofu making.

III. ROLES OF SOY PROTEINS IN TOFU MAKING

A. Storage Proteins of Soybeans

Soy proteins constitute about 35–45% of soybeans on a dry basis. Approximately 90% of the proteins are storage protein and are extractable with water or dilute salt solutions. Most of the storage proteins in soybeans are globulin. As soybean seeds mature, many organelles, such as the nucleus, mitochondria, and endoplasmic reticulum, disappear and storage proteins deposit in large protein bodies that are surrounded by many small oil bodies. Storage proteins show no biological activities, and 90% of them are located in the cotyledons (28). Soy proteins consist of discrete groups of polypeptides that have a wide range of molecular sizes. A typical ultracentrifuge pattern of water-extractable soy proteins has four major fractions designated as 2S, 7S, 11S, and 15S on the basis of their sedimentation rates. Each fraction is a complex mixture of proteins. The 7S and 11S proteins are the two major storage proteins in soybeans, which comprise approximately 70% of storage protein. The 2S fraction accounts for about 20% of the extractable proteins, which contain protease inhibitors (the Kunitz and the Bowman–Birk trypsin inhibitors) and cytochrome C (29). The 7S fraction has been classified into three major components with different physicochemical properties named β-conglycinin, γ-conglycinin, and basic 7S globulin (30,31). β-conglycinin is the most prevalent of these three and accounts for about 30 to 35% of the total seed protein, which is used interchangeably with 7S protein since it is the major 7S protein. The 11S fraction, designated as glycinin, accounts for an additional third of the total seed protein and is generally simple protein. The 15S fraction accounts for approximately 10% of the total seed protein, which is an aggregate of 11S protein (32).

B. β-Conglycinin (7S Protein)

β-conglycinin (7S) is a complex protein that exhibits polymorphism in its subunit composition. It is a trimer with a molecular mass of 150–200 kDa. Four subunits are identified: three major (α, α', and β) and one minor (γ) (33). β-Conglycinin exhibits molecular heterogeneity, in which seven molecular species are isolated and their subunit composition identified as $\alpha'\beta\beta$, $\alpha\beta\beta$, $\alpha\alpha'\beta$, $\alpha\alpha\beta$, $\alpha\alpha\alpha'$, $\alpha\alpha\alpha$, and $\beta\beta\beta$ (34–36). β-conglycinin is a glycoprotein; its α and α' subunits contain two carbohydrate moieties and the β subunit one (33). β-Conglycinin undergoes a complex association–dissociation phenomenon in response to changes in ionic strength and pH. At neutral pH, β-conglycinin is a 7S-form globulin when the ionic strength is ≥ 0.5 but a 9S dimer at ionic strength of ≤ 0.2 (37). The subunits of β-conglycinin are held primarily by hydrophobic forces (38). The molecular mass of subunits of β-conglycinin are estimated to be 57–59 kDa for α and α' subunit and 42–44 kDa for β and γ subunits by gel electrophoresis and gel filtration (33).

C. Glycinin (11S Protein)

Glycinin is a major storage protein of soybeans and accounts for approximately 35% of the total seed protein. It is a hexamer with a molecular weight of around 300–380 kDa. Each subunit is composed of an acidic polypeptide (A_n) with a molecular mass of approximately 35 kDa and a basic polypeptide (B_n) with a molecular mass of approximately 20 kDa. The acidic and basic polypeptides are linked together by a single disulfide bond shown as A_n-S-S-B_n (39). It is known that initially a single polypeptide precursor is synthesized and then processed posttranslationally to form the acidic and basic polypeptides (40). The disulfide linkage between the acidic and basic polypeptides forms after subunit synthesis and may help stabilize the subunit after posttranslational modification. Five subunits are identified by Nielsen et al. (41) and Utsumi et al. (42): $A_{1a}B_{1b}$ (G1), A_2B_{1a} (G2), $A_{1b}B_2$ (G3), $A_5A_4B_3$ (G4), and A_3B_4 (G5). Among these subunits, two groups can be separated based on sequence homologies (39). Group I subunits, $A_{1a}B_{1b}$, $A_{1b}B_2$, A_2B_{1a}, are uniform in size (~58 kDa), relatively rich in methionine and cysteine, and exhibit about 90% sequence homology. Group II subunits, A_3B_4 and $A_5A_4B_3$, exhibit a smaller level of homology (about 60–70%), and contain less methionine and cysteine, but are larger (~62–69 kDa) than group I. The $A_5A_4B_3$ (G4) subunit is synthesized as a single polypeptide precursor similarly to the others, but the acidic polypeptide is cleaved to produce A_5 and A_4 polypeptides (40). Most major subunits of glycinin are present in most soybean varieties except the subunit $A_5A_4B_3$ (39). In Japan, about 20% of soybean varieties are absent of subunit $A_5A_4B_3$ in glycinin (43). Glycinin, having different subunit compositions, exhibits distinguishable functional properties.

Glycinin hexamers can dissociate to their constituent polypeptides, subunits, and half-molecules under various pH, ionic strength, and temperature (42). At pH 7.6 and an ionic strength of 0.5, glycinin forms hexamer complexes (11S), whereas at pH 3.8 and an ionic strength of 0.03, glycinin exists as trimers (7S) (44,45). The dissociation of 11S to 7S seems to be correlated with significant changes at the secondary and, to a lesser extent, the tertiary structures. When ionic strength is below 0.2, the basic polypeptides shift more to the exterior of the molecule (44).

D. Gelation of Purified Soy Proteins

Generally, denaturation is essential for proteins to form gel, which results in an altered conformation of the protein and changes in physical and biological properties. Upon heating, soy proteins initially undergo a stepwise dissociation of subunits, followed by unfolding of the polypeptides that subsequently associate and aggregate to form precipitates or progels (46). Glycinin and β-conglycinin exhibit apparent denaturation temperatures of 90°C and 75°C, respectively. The difference in the thermal transition temperatures of these two proteins results from inherent differences in their structures. Glycinin is more heat-stable than β-conglycinin (47).

The gel-forming ability induced by heating soy proteins is one of the most important functional properties with respect to their usage in food systems. Glycinin and β-conglycinin show different gel-forming properties, and their gelation mechanisms are different. A soluble aggregate model describes how glycinin forms the gel structure (48–50). The model could be regarded as a three-stage process. When glycinin solution (5%) is heated, glycinin aggregates (MW 8000 kDa) are formed; then on subsequent heating, it undergoes association resulting in gel formation; finally, the gel network structure is stabilized through further formation of noncovalent bonding (such as hydrophobic interaction and hydrogen bonding) and disulfide cross-links by subsequent heating. The network structure of β-conglycinin heat-induced gel is hypothesized as a randomly aggregated assembly of clusters (51). Upon heating of β-conglycinin (7.5%), soluble aggregates are formed (MW about 1000 kDa) and then associate with each other randomly to form

a cluster; finally, the clusters aggregate randomly to form a gel. The gelation rate of β-conglycinin is slower than that of glycinin (52). 11S gels prepared in the presence of calcium sulfate are harder and show larger breaking stress, breaking strain, and Young modulus than crude 7S gels (52,53). The 11S gel has a higher water-holding capacity, higher tensile value, and higher hardness and expands more on heating than the 7S gel (54). The sulfhydryl–disulfide interchange reaction is important in the formation and maintenance of the structural matrix of 11S-globulin gel. No SH/S-S exchange reaction participates in the 7S-gel formation, whereas hydrophobic interactions and hydrogen bonds play an important role in the formation and maintenance of the gel network of 7S protein (55). The gel formed by β-conglycinin is transparent, in contrast to the turbid gel of glycinin globulin (51).

For glycinin, the rates of gelation and the hardness and turbidity of gels are affected markedly depending on the subunit composition (56). Subunit $A_5A_4B_3$ is closely related to gel formation because of an easy cleavage of hydrophobic bonds between A_5 and A_4 polypeptides during heating. Cultivars containing the A_4 polypeptide in glycinin form glycinin gels faster than cultivars without A_4 (57). Soybean cultivars without the A_4 polypeptide that is identified as A_5 by Nishinari et al. (58) produce a harder and more solid-like protein gel than those cultivars with the A_4 polypeptide in glycinin (59). Subunit A_3B_4 is related to the gel hardness because the A_3 acidic polypeptide plays an important role in increasing the hardness of the gel. Nakamura et al. (57) found that the hardness of glycinin gels is different among varieties, depending on the percentage of A_3, which is the largest constituent acidic polypeptide of glycinin. However, Tezuka et al. (60) reported that tofu curd made from soybeans containing glycinin with only subunit $A_5A_4B_3$ is the hardest among those made from soybeans containing subunit A_3B_4 or Group I subunit ($A_{1a}B_{1b}$, $A_{1b}B_2$, A_2B_{1a}) in their glycinin protein. The roles of glycinin and β-conglycinin subunits in influencing certain characteristics of tofu texture remain to be clarified in the future.

The turbidity of the gels is positively related to the numbers of the free —SH residues, and is caused by the basic polypeptides that are dissociated from glycinin during heating (61). The turbidity of the gel from the glycinin globulin containing A_3B_4 subunit is the smallest because of fewer —SH groups in this subunit. The contribution of the constituent subunits of β-conglycinin to the physical properties of β-conglycinin gels is not clear. In a mixed system, glycinin is related to hardness and unfracturability of the gels, while β-conglycinin largely contributes to the elasticity of the gels (42). During gel formation, glycinin and β-conglycinin interact with each other through association between basic polypeptides of glycinin and β-subunits of β-conglycinin to form composite aggregates (62).

E. Soy Proteins in Tofu Making

Generally, crude proteins constitute more than 50% of the total solids of tofu on a dry basis. Soy proteins are the dominant components in tofu dry matter, which provides the major network structure of tofu gel. Soy proteins form gel by a combination of heating and the addition of a coagulant, which is either an acid or a divalent salt or a combination of both. Tofu is a complex food system that is very different from the thermally induced purified protein gels. Although both types of gels require protein denaturation, the exact mechanisms for tofu gelation are not identical. Tofu is made from heated soymilk that is a turbid solution containing approximately 5% protein and 3% lipid. Therefore tofu is an emulsion gel system. The tofu emulsion is permanent since heating is not able to separate lipids from the protein system. For tofu making, a coagulant is required, while heat-induced protein gel does not need a coagulant. Besides protein and lipid, other components in soymilk such as phytate, isoflavones, saponins, and lipoxygenases also may play important roles in the coagulation of proteins during curd formation. Because of the complexity of the soymilk–tofu system, the mechanisms of tofu formation are also complex and

are not fully understood. To identify the mechanisms clearly that affect the tofu gel properties by using real soymilk is difficult. Some studies have been conducted to understand the interactions between nonprotein constituents (e.g. phytate and lipid) and proteins on coagulative reaction in tofu making (53,63). However, there is a lack of a comprehensive approach to put all factors together in one picture to understand gel formation in tofu making.

Early researchers found that isolated glycinin-rich proteins produce firmer gels than β-conglycinin-rich proteins by either heat or calcium (53,54). Recent studies have shown that various soybean cultivars have various ratios of 11S/7S proteins that may influence the textural quality of tofu. In our laboratory, we found that the β-conglycinin (7S) and glycinin (11S) contents in 13 varieties are 17.2–23.1% and 36.3–51.3% of total proteins, respectively, and the 11S/7S protein ratio varied from 1.64 to 2.51 among the varieties (64). Furthermore, we found that positive correlations existed between tofu firmness and the 11S/7S ratios in various (13 to 16) soybean cultivars (64,65). However, conflicting results on the relationships between 11S/7S ratio and tofu firmness have been reported by other researchers (55,59,66,67). The conflicting results may be partly due to different methods used for processing, because of a lack of standard methods for tofu research. We have found that processing methods affect 7S- and 11S-protein content of tofu and their contribution to tofu hardness, yield, and sensory quality. Thus processing methods have an impact on the relationships between 11S/7S ratios and textural quality since different coagulation processes and pressing steps are used for preparing tofu (64).

Yagasaki et al. (68) reported that cultivars having a higher glycinin/β-conglycinin ratio had a higher gel firmness than that with a lower ratio. However, on a closer examination of their report, it is apparent that firmness does not increase above 1.3 of the 11S/7S ratio in four cultivars (Fig. 7). Therefore, in a complex system such as soybeans/soymilk (which is very different from the purified protein system), there is a limit of the firming effect due to the increase in 11S/7S ratio. In other words, above a certain ratio, the tofu firmness does not increase. A similar phenomenon has been observed in one of our studies (69). We added purified 11S protein to the soymilk systems prepared from three cultivars while maintaining a constant protein concentration in soymilk for tofu making. The results showed that the increase in firmness was cultivar dependent and the increase was not substantial (Fig. 8). Therefore, in the soymilk system as opposed to the purified protein system, other biochemical constituents may play important roles in determining the tofu yield and quality. Further research is needed to continue to elucidate the effect of individual components and their interactions to understand the fundamental biochemistry of tofu making.

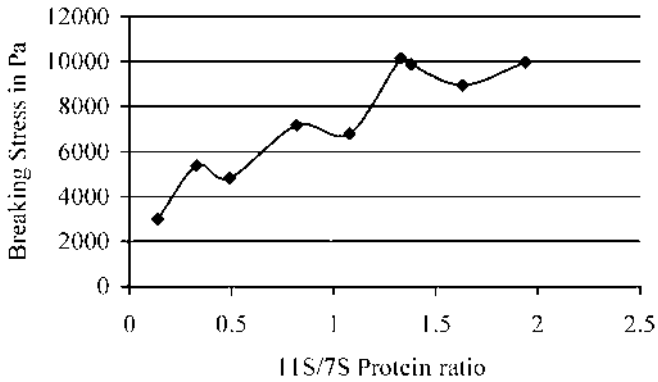

Figure 7 Hardness of tofu made from various 11S/7S ratio in soybeans. (From Ref. 68.)

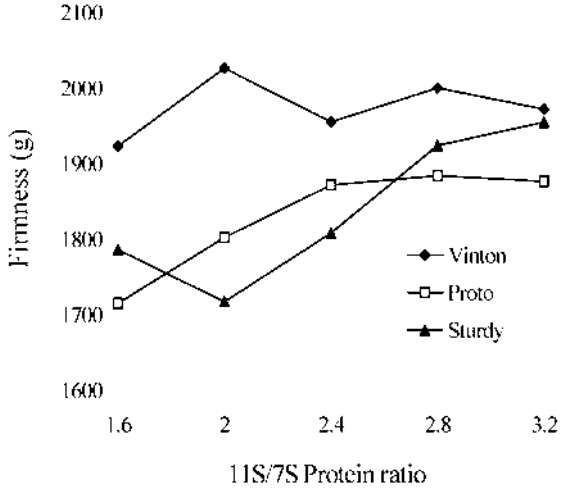

Figure 8 Firmness of tofu as affected by modified 11S/7S protein ratio in soymilk (means of two treatment replicates).

IV. MOLECULAR MODELS FOR TOFU CURD FORMATION

A. Role of Protein Charges

The gelation process of tofu has been studied in a mixed protein system by adding glucono-δ-lacton (GDL) or calcium sulfate (70). For both GDL and calcium systems, a protein mixture containing a higher 11S proportion has faster gelation. 11S-protein forms a continuous matrix and 7S is a discontinuous filler. The roles of 11S and 7S are interchanged with each other at a lower 11S proportion. The gelation mechanism of tofu gels induced by coagulants in an imitative 7S and 11S protein mixture has been hypothesized (70). The negatively charged groups of soy proteins denatured by heat are decreased by adding cations through the action of coagulants such as GDL, calcium sulfate, and magnesium chloride; then the neutralized protein molecules are able to aggregate owing to a reduction in electrostatic repulsion. Finally, the gel network is stabilized by the formation of hydrogen bonds and hydrophobic interactions.

B. Role of Lipids in Curd Formation

Soymilk and tofu contain approximately 30% lipids on a dry basis. Lipids influence the gelation of soy proteins and play an important role in texture and in sensory quality of the products (71,72). In raw soymilk, approximately 60% of total lipids are associated with the protein particles, but only 3% of total lipids are found in the protein particles of cooked soymilk (73). After being heated to 65°C, a part of the lipids and almost all the α and α' subunits of β-conglycinin in the particulate fraction begin to liberate to soluble fraction. Above 90°C, almost all neutral lipids in the protein particles of raw soymilk are liberated to a floating fraction, but about one-half of the phospholipids remain in the particles (73,74). Coagulation of soymilk depends on the concentration of coagulant, the pH of soymilk, and the temperature, which is an external factor and accelerates the soymilk coagulation. In fact, the addition of coagulant causes not only protein

coagulation and gelation but also the incorporation of lipids into the protein gel (75). It has been observed that when soymilk coagulates and forms a gel, the lipid droplets are located in the networks of the protein gel (53).

C. Role of Phospholipids in Curd Formation

The polar phospholipids are believed to play an important role in combining the particulate proteins with neutral lipids (73). Some significant amount of lipids exist in isolated 11S and 7S proteins from hexane-defatted soy meal (0.8% and 2.3%, respectively); more than 50% of these lipids are phospholipids. Phospholipids bind to the hydrophobic sites of β-conglycinin (76). Phospholipids bind stronger to the 7S protein than to the 11S protein, because 7S protein is more hydrophobic than 11S protein. The removal of lipids, particularly the phospholipids, from the surface of 7S proteins by extraction with chloroform : methanol solution makes 7S proteins vulnerable to form insoluble aggregates thus decreasing the ability to complex with protein particles. Adding phospholipids to soymilk increases the formation of protein particles. Lecithin-supplemented gels exhibit a fine network structure. Soy proteins depleting in phospholipids could be damaging to their neutral lipid binding ability. Therefore soybean curd network structure could be promoted by phospholipids that act to combine neutral lipids in the protein network.

D. Hypothesized Molecular Model of Tofu Curd Formation

A protein particle theory with the incorporation of soy lipids into the protein network for understanding the mechanism of tofu formation has been proposed (73,74,77–80). In raw soymilk, proteins can be separated into particle and soluble fractions by centrifugation. The particle fraction is composed of large (>100 nm) and medium (100–40 nm) particles. The soluble fraction is considered as the supernatant proteins (<40 nm). The large particles, in which 70% are 11S globulin, constitute 40% of the total proteins in raw soymilk. The medium-sized particles are formed by a combination of the supernatant proteins with each other. Lipids are mainly present in the particle (large) fraction. The protein particles play an essential role for tofu curd formation with calcium chloride; the content of the particles in soymilk determines the density of the network; the more particles, the finer a network is formed (78). Tezuka and Ono (81) reported that 11S protein-rich cultivars contain more protein particles than the 7S protein-rich cultivars. Therefore the glycinin (11S) is essential for protein particle formation in soymilk. The cultivars having greater protein particle contents produce firmer tofu than those with lower protein particle contents (60).

As mentioned above in the section on the role of lipids, soymilk lipids can be separated in the floating fraction by centrifugation after heating. When $CaCl_2$ is added to soymilk, the floating fraction (lipids) decreases, which occurs before the formation of protein aggregates. When half of the proteins coagulate, almost all the lipids are trapped and become inseparable. The decreases in the floating fraction with the addition of $CaCl_2$ are parallel to the increases of the coagulation of particulate proteins. This indicates that lipid conjugates with particulate and soluble proteins and becomes inseparable by the association with particulate protein. The protein particles are essential for the incorporation of lipids into aggregates. The lipid incorporation due to the conjugation of lipids and protein particles explains why lipids incorporated are stable against oozing and separation of the oil phase from the continuous hydrophilic phase in further storage and cooking of tofu.

The pH decrease and calcium binding with proteins also play important roles in the formation of tofu curd. A decrease of pH was observed when calcium chloride combined with soy

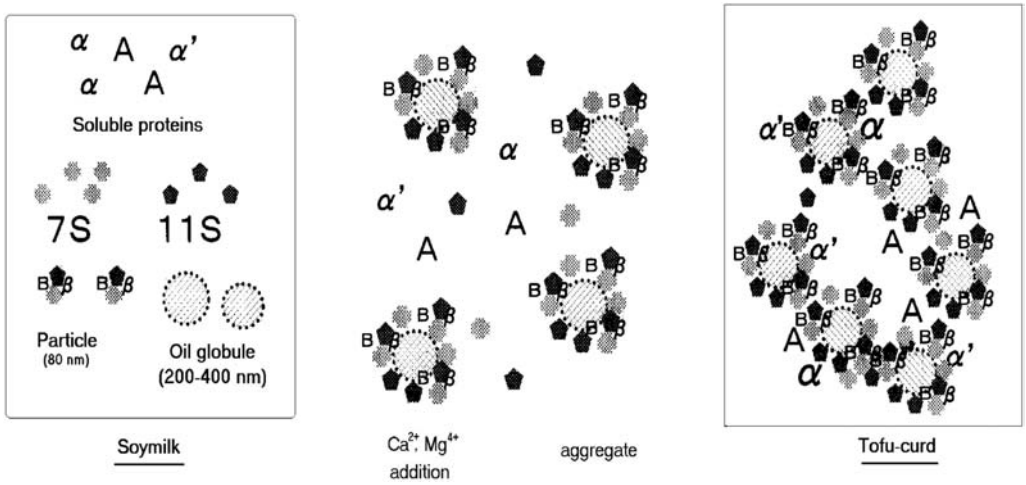

Figure 9 Postulated molecular models of the formation of tofu curd. (From Ono, 2000.)

proteins (53). When a coagulant such as calcium chloride is added to soymilk, the protein particles precipitate at lower concentrations of calcium than the soluble proteins, resulting in protein solubility decreases and accompanying a pH decrease. The pH decrease promotes protein aggregation by reducing the electric repulsion and liberates the hydrated water of proteins, while calcium ions bind to proteins through the carboxyl groups of the glutamyl and aspartyl residues and the imidazole groups of the histidine residues. The binding of calcium to proteins brings the association of protein molecules and accelerates the formation of curd.

According to the studies reviewed above, the mechanism of tofu curd formation can be summarized in the following three steps. (a) In raw soymilk before heating, the total of the large- and medium-sized particles constitutes more than 50% of the proteins in soymilk. Most of the particles are large particles. Most lipids are present in the protein particles. (b) When the soymilk is heated up to 90°C, the proteins denature and the lipid droplets are liberated to the floating fraction. Approximately three-quarters of the large particles are degraded to supernatant proteins, but the medium-sized particles increase due to the combination of the β subunit of 7S and the basic polypeptide of 11S from the supernatant proteins that contain mainly 11S and 7S globulin. (c) The addition of coagulant (calcium ion, magnesium ion, or GDL) to the heated soymilk is the key step. At low concentration of coagulants, protein particles combine with lipid droplets, and the gel network is first formed through the binding of calcium to protein particles to neutralize the negatively charged protein molecules and to cause protein aggregation due to a reduction in electrostatic repulsion. When half of the proteins coagulate with coagulant, almost all the lipids in soymilk are trapped and become inseparable by association with the particulate proteins. Further addition of coagulants leads to a decrease in pH. The soluble proteins aggregate at a higher concentration of coagulant and bind to the protein particles–oil droplet complex to form a stable tofu-curd emulsion network. These reactions are illustrated stepwise in the postulated models from left to right (Fig. 9).

V. ROLE OF PHYTIC ACID IN TOFU MAKING

The phytic acid content in seeds varies widely; it comprises 1–2% of soybeans on a dry basis and accounts for about 70–80% of the phosphorus in seeds (82). Phytate is structurally integrated

with the protein bodies as phytin, a mixed potassium, magnesium, and calcium salt of inositol (83). It is reported that phytate attaches to the glycinin at pH between 2.5 and 5.0, and the extent of binding increases with decreasing pH; above the pI (isoelectric point) of glycinin (pH 4.9), no binding is found (84). Phytate has a strong chelating ability with multivalent metallic ions, especially zinc, calcium, and iron. According to Graf (85), the calcium ion can bind to phytic acid over a wide pH range (pH 4.8 to 10.4); the degree and tightness of binding are affected by pH, temperature, ionic strength, and size and valence of the cation. The affinity of phytic acid for calcium increases sharply with pH; the higher the pH (alkaline), the higher the affinity; the affinity in pH 10.4 is a thousandfold higher than in pH 4.8. A portion of phytate in soymilk is bound to particulate and soluble proteins (about 35% and 23%, respectively); the others are present in the free form (about 42%) (78). Therefore when calcium is added to soymilk, it binds to phosphate groups of phytate and to proteins as well. The role of phytic acid in the coagulation step during tofu making has been related to a decrease in pH after calcium salt is added (78,81). When calcium is added, the phytate-calcium salts form at approximately the neutral pH (6.6), and hydrogen ions are liberated, which are bound originally with phosphate groups in phytate. Therefore the pH decrease upon the addition of calcium may be mainly due to the formation of phytate-calcium salts. The decrease in the pH of soymilk from approximately 6.6 to 5.8 after adding calcium chloride allows the use of a lower concentration of Ca salts for coagulation. When calcium is present, it binds simultaneously to proteins and phytate; calcium binding to proteins can retard the decrease of pH because of less phytate-calcium formation. Tofu curd contains both types of calcium bound to protein or phytate.

Phytate is very important in relation to the speed of coagulation during tofu making. It has been found that a higher content of phytic acid results in a slower coagulation of soymilk during tofu making and gives a higher yield (53). Therefore the phytate content in soymilk can affect the textural properties of tofu. In other words, a decrease in phytate increases the speed of coagulation and makes the gel harder. We have found that phytic acid contents in soybeans and in soymilk are correlated positively to tofu yield, but negatively to tofu hardness ($p < 0.01$) (86). Significant positive relationships exist between soybean phytate and tofu yield ($r = 0.93$) and between soymilk phytate and tofu yield ($r = 0.95$). Negative correlations between soybean phytate and tofu hardness and brittleness are observed ($r = -0.92$ and -0.84, respectively). Negative correlation coefficients are found between soymilk phytate and tofu hardness and brittleness ($r = -0.94$ and -0.86, respectively).

VI. ROLES OF ISOFLAVONE AND SAPONINS IN TOFU MAKING

Isoflavones are a subclass of the more familiar flavonoids and have an extremely limited distribution in nature. Soybeans and soy foods are the major foods containing significant amount of isoflavones. The main isoflavones found in soybeans are genistein, daidzein, and glycitein, each of which exists in four chemical forms, as an aglycone form (genistein, daidzein, and glycitein), a β-glucoside form (genistin, daidzin, and glycitin), a malonylglucoside form (6″-*O*-malonylgenistin, 6″-*O*-malonyldaidzin, and 6″-*O*-malonylglycitin), and an acetylglucoside form (6″-*O*-acetylgenistin, 6″-*O*-acetyldaidzin, and 6″-*O*-acetylglycitin). Saponins are widely distributed in plants, which are glycosides and composed of a sapogenin that makes up the aglycone moiety, and a sugar. The sapogenin is a triterpeneoid alcohol; at least five sapogenins have been found in soybeans (87). Xylose, arabinose, galactose, glucose, rhamnose, and glucuronic acid have been found in the glucoside portion of soy saponins. Saponins exist in two groups, A and B (88–90). The group A saponins consist of six different kinds of saponins (Aa, Ab, Ac, Ad, Ae, and Af), which are acetyl-soyasaponins. The group B saponins, on the other hand, consist of eight kinds of saponins (Ba, Bb, Bb′, Bc, Bd, Be, BdA, and BeA), which are not

acetylated and are different from the group A. BdA is the major natural soybean saponin in soybean seeds (90). Saponins are polar compounds because of the associated sugars (oligosaccharides), which are found in the soybean meal in amounts of approximately 0.5% of the dry weight (91).

Isoflavone content varies among soybean varieties, which contain approximately 1 to 4 mg/g soybean. The isoflavone content of soybeans is markedly affected by crop year and growing conditions (92,93). Isoflavones are quite heat stable. Although isoflavones are not destroyed by heat in conventional food processing operations, heating causes a change in the conjugation profile of the isoflavones in soy products. Baking or frying of isolated soy protein and textured vegetable proteins does not alter total isoflavone content but increases the β-glucoside conjugates at the expense of 6″-*O*-malonylglucoside (94). Wang and Murphy (92) reported that cooking did not influence the isoflavone retention during tofu making, but alters the distribution of isoflavones by dramatically decreasing in malonylglucoside forms and increasing in acetylglucoside forms. Minimal heat processing can convert substantial amounts of malonylglucoside to the β-glucosides. Total isoflavone content in soy products decreased most likely owing to leaching of isoflavones into water during processing. Wang and Murphy (95) reported that 61, 44, and 53% of total isoflavones were lost during the processing of tempeh, tofu, and soy protein isolate, respectively.

It is known that isoflavones and saponins impart the bitter and astringent aftertastes in the flavor of soy products. Okubo et al. (96) reported that glucoside forms of saponins and isoflavones are the major compounds that cause objectionable aftertastes in soybeans, and saponin A groups contribute most strongly to the undesirable taste. This becomes weaker when saponins decompose from glucoside forms to aglycone forms, while isoflavone glucosides show a reverse tendency. The aglycones of isoflavones have stronger objectionable aftertastes than those of glucosides (96,97).

Saponins, glycitin, and glycitin derivatives are present primarily in hypocotyl, and all of these substances can give objectionable aftertastes. The previous consideration has been to remove these compounds by processing methods. In Japan, good-tasting tofu has been prepared by the Namashibori technique by squeezing raw extract, which is prepared from seedcoat-removed and hypocotyl-removed soybean materials (2). In this method, the soybean is first cracked, and the seedcoat and the hypocotyl are removed. The resulting materials are soaked in water for a short period of time and then ground to make the slurry *go* and filter. The raw soymilk is boiled and the brown foams (which contain saponins) are scooped away. However, in light of potential health benefits of these isoflavone and saponin compounds (98), a different strategy may be needed to preserve these compounds to produce soy foods with maximum health benefits.

There are many excellent reviews (99,100–102) addressing the potential benefits and adverse effects of consuming diets containing isoflavones from soy foods. Four major potential benefit effects include (a) heart disease prevention (103,104); (b) cancer prevention, particularly with respect to breast (105–107), prostate (108,109), and colon (110) cancers; (c) bone mass density increase to prevent osteoporosis (111,112); and (d) reducing postmenopausal syndrome in women (99). In an animal study, soybean isoflavones can reduce experimental metastasis of melanoma cells in mice (113). The two major concerns are potential adverse effects in infants having a high intake of isoflavones from soy-based formula (114,115) and possible reproductive disorders in adults having high isoflavone intakes (116). However, there is no direct evidence to show the adverse effects of isoflavones in humans. Among 12 isoflavones, genistein has been reported as the most potent inhibitor of cancer-cell growth (117). Aglycone forms of isoflavones have been found with faster absorption and in higher amounts than their glucosides in human gut (118,119). Genistein has been reported having the highest antioxidant activity over genistin, daidzin, and daidzein (120).

VII. EFFECT OF LIPOXYGENASE ON TOFU MAKING

Lipoxygenase is an iron-containing dioxygenase that catalyzes the oxidation of polyunsaturated fatty acids such as linoleic acid, producing unsaturated fatty acid hydroperoxides, which are broken to produce *cis-n*-hexenal, which is the major source of the grassy–beany off-flavor in soy foods. Soybeans are the most abundant lipoxygenase source known to researchers; they contain four lipoxygenase isozymes, identified as L-1, L-2, L-3a, and L-3b. The L-3a and L-3b are so similar in behavior and composition that they are often considered as a single type, L-3 (121). Lipoxygenase separates with the 7S fraction in the ultracentrifuge with a molecular weight of about 100,000, which contains one atom of iron per mole of protein. The lipoxygenase L-1 is heat stable; its activity loses 50% by heating at 69°C for 25 min (122); it has an optimum pH at 9 and is most active on free fatty acids but is not activated by calcium ions. In contrast, L-2 and L-3 are less heat stable, with activities losing 50% by heating at 69°C for only 0.7 min or less (122), with pH optimum at 7. Lipoxygenase L-2 and L-3 are more active on fatty acid esters and triglycerides than on free fatty acids, and their activities are increased by calcium ions. It has been reported that L-3 is the most abundant one in mature soybeans. The L-2 is the least abundant but has the highest specific activity, which is mainly responsible for the production of grassy–beany flavors (123). The lipoxygenase isozymes show differences in their product region specificity. When linoleic acid is a substrate, the L-1 prefers the 13 position as the site for hydroperoxidation, whereas the L-2 prefers equally the positions 9 and 13, and the L-3 prefers position 9 (65%) over position 13 (35%) (124,125).

The lipoxygenases are rapidly activated when the substrate is available and in the presence of water. The beany flavor is mainly developed in the step of grinding, because the enzyme and lipid are liberated then and excess water is present. Wilkens et al. (126) found that as the temperature of the slurry increases, both the number and the volume of volatiles decrease; when beans are ground at 80°C or above, no volatiles are formed. Heat inactivation of lipoxygenases during grinding in the presence of hot water and/or in the absence of air/oxygen is critical in eliminating beany flavor from soybeans, since it is difficult to eliminate after it is formed. Additional vacuum treatment of hot soymilk may reduce it, but using heat to inactivate lipoxygenases in whole soaked beans may cause a decrease of protein solubility, loss of protein functionality, and loss of solids recovery. Thus several techniques involving milder heat treatment of soybeans, adjusting moisture or pH, or using aqueous alcohol to soak soybeans or their combinations have been developed to make non- or low-beany-flavor soy products (4). Genetic elimination of lipoxygenases from the seeds provides a new approach to eliminate beany flavor (127,128). A lipoxygenase-null soybean variety has the functional properties of normal soybeans but with less beany flavor (129). Soymilk made from lipoxygenase-free soybeans has less cooked beany aroma, less cooked beany flavor, and less astringency, and it is rated darker and more yellow than that made from soybeans with normal lipoxygenase (130).

In addition to potential deterioration of tofu flavor, lipoxygenase has been found to affect tofu texture (7,131). Grinding soaked soybeans in the temperature range of 2 to 50°C promotes lipoxygenase activity, which oxidizes lipids to hydroperoxides and subsequently oxidizes the free —SH group to disulfide bonds, and possibly cysteinic acid or cysteic acid. The oxidation of —SH affects its availability to participate in the interchange of free —SH groups with disulfide bonds during heating to form protein networks, thereby decreasing the firmness of the tofu product. Firmer tofu products can be prepared by grinding soybeans under anaerobic conditions. Lipoxygenases can degrade the sulfhydryl group in soymilk during grinding even at low temperatures (2°C) or in a nitrogen atmosphere (N_2) (131). Among lipoxygenases, L-2 isozyme has the greatest SH— degrading capability.

VIII. EFFECT OF SOYBEAN STORAGE ON TOFU MAKING

Soybeans are subject to transportation and storage after harvest before processing into various products. Soybeans may be stored up to 1 year or longer after harvest in a wide variety of environmental circumstances before they are processed. It has been understood that both the quality of edible soybeans and the viability of the soybean seeds decrease gradually with prolonged storage. The process of storage-induced biological changes in soybean seeds is generally known as aging. The mechanism of soybean aging has not been completely understood. A commonly accepted hypothesis is that lipid peroxidation plays an important role in the initial stage of the seed aging process (132–134). Hydroperoxides, which are highly reactive free radical compounds generated from lipid peroxidation of polyunsaturated fatty acids in the presence of oxygen, can abstract hydrogen from adjacent hydrocarbon chains, resulting in not only the destruction of the lipid itself but also in damage to cell membranes and other cellular components. In addition, hydroperoxides can break down to form secondary volatile oxidation products, which may contribute to the off-flavor formation in soy products during the storage of soybean (135). Both enzymatic and nonenzymatic oxidation may be involved in the deterioration of the aged seeds.

The magnitude of the quality deterioration of seeds depends upon storage conditions, including time, temperature, relative humidity (RH), and microbial contamination. Among these factors, relative humidity/water activity is the most important. Low humidity may effectively preserve the original bean qualities even at a high temperature (136). The reported changes of components in soybeans induced by storage include surface discoloration that may be caused by enzymatic reactions such as polyphenolase on tannins and by nonenzymatic Maillard reactions between reducing sugars and free amines, a loss in protein extractability (137,138), an increase in the acidity or decrease in pH (139), and a decrease in phospholipid content (140). Phospholipids are completely destroyed by storing beans at 14% moisture and 40°C for 4 weeks (141). Nakayama et al. (142) also found that phospholipids were decreased during soybean storage at 35°C. Storage of soybeans influences physicochemical properties of proteins including decreases in nitrogen solubility index (NSI), decreases in extractability of glycinin and β-conglycinin, and changes in subunit composition of glycinin (59,143). When soybeans are stored in adverse conditions, soymilk quality is significantly decreased by a darkened color and a lower solid extractability, and the yield and quality of tofu are decreased by having off-flavor and a coarser texture (139). The deterioration of functional properties of soy proteins, including viscosity, gel forming ability, and emulsion stability during storage has been reported (144). Soybeans stored in adverse conditions (84% RH and 30°C) deteriorate significantly after 2 months, in which mold appears and off-flavor is generated, tofu yield decreases significantly, and the texture of the tofu becomes coarse and hard. However, soybeans in conditions of 57% RH and 20°C, cooled to 4°C, or in an uncontrolled ambient temperature condition in North Dakota could remain their soymilk and tofu qualities for up to 18 months (86).

In general, whole soybeans are more resistant to deterioration during storage than soy meal or damaged beans including split beans and seedcoat cracking. Usually, the amount of broken or damaged beans tends to increase with prolonged storage, especially when moisture content is low ($<$13%) (144). The yield of tofu decreases significantly beyond 30 days of storage in the condition of 85% relative humidity and 30°C for both whole and physically damaged soybeans. Furthermore, higher damage ratios cause greater losses in tofu yield (139). The off-flavor of tofu develops as soybean storage time increases. Since soybeans contain a high amount of polyunsaturated lipids, oxidation of unsaturated lipids caused by lipoxygenases, the secondary products of hydroperoxides caused by lyase, and volatile materials derived from the Maillard reactions may play important roles in off-flavor formation of tofu during storage of soybeans in

adverse conditions. Besides flavor deterioration, the hydroperoxides as well as their secondary products may interact with food proteins or amino acids through protein–protein cross-links, protein scission, protein–lipid adducts, and amino acid damage to cause deterioration (145).

Locher and Bucheli (146) stored soybeans under conditions of 4°C, 45% RH, and 30°C, 82% RH to assess the degradation of soluble sugars and their relationship with seed deterioration. They reported that substantial hydrolysis of stachyose, raffinose, and verbascose occurred under condition of 30°C, 82% RH, and that reducing sugar content in soybeans was first reduced, and later nonreducing oligosaccharides in the soybeans were hydrolyzed. A part of the reducing sugars formed by hydrolysis of the oligosaccharides may participate in the nonenzymatic glycosylation and in the Maillard reactions with the amino residues in the soy proteins (147). Sugar content in soybeans and tofu has significance for the color and sweetness of the products. As mentioned in the previous section, phytic acid affects the coagulation of soymilk during tofu making by decreasing pH after calcium salt is added. We found that phytate in soybeans degrades gradually with storage time in the adverse environment. However, under the mild or cold conditions, the hydrolysis of phytate also could occur, but to a lesser degree (86). The hydrolysis of phytate in soybeans during storage contributes not only to the decrease of soymilk pH but also to the loss in chelating ability with calcium ions and subsequently affects protein coagulation behavior to lead to a reduction in the product yield and changes of textural quality (Table 3).

The enzyme β-glucosidases can hydrolyze glucosides of isoflavones to their aglycones (148). Storage of soybeans may affect the activities of β-glucosidases in the conversion of glucosides of isoflavones to more bitter aglycones. In raw soybeans, malonylgenistin is the major isoflavone form, representing 48% of overall total isoflavones, followed by malonyldaidzin, malonylglycitin, and genistin (149). The three malonylglucosides compose of 87% of overall total isoflavones. As the storage time is prolonged in adverse conditions such as 84% relative humidity and 30°C, the contents of malonylglucosides are significantly decreased to less than 1% of the overall total isoflavones after 9 months. In contrast, the content of aglycones shows a significant increase along with storage time. In the beginning, aglycones compose only 1% of the overall total isoflavones, whereas they compose 80% in 5 months and then up to 97% of the overall total

Table 3 Phytate Content of Soybean and Tofu Yield and Textural Properties Made from Soybeans Stored at 84% RH, 30°C

Storage month	Soybean		Tofu	
	Phytate[a], %	Yield[b], g/100 g	Hardness, g	Fracturability, g
0	1.332 ± 0.030	512 ± 5	2090 ± 42	1020 ± 57
1	1.199 ± 0.013	503 ± 3	2182 ± 12	1033 ± 81
2	1.178 ± 0.074	481 ± 3	2465 ± 21	923 ± 25
3	1.163 ± 0.033	435 ± 25	2704 ± 107	873 ± 11
4	1.101 ± 0.063	382 ± 12	3080 ± 113	920 ± 57
5	1.056 ± 0.017	372 ± 35	3287 ± 39	945 ± 14
6	1.054 ± 0.034	232 ± 28	>5000	>5000
7	0.993 ± 0.011	71 ± 1	>5000	>5000
8	0.932 ± 0.083	NA[c]	NA[c]	NA[c]
9	0.873 ± 0.011	NA[c]	NA[c]	NA[c]

[a]Data are expressed as percentage of means ± sd of three replicated on a dry weight basis.
[b]Data of yield are means of two replicates on a wet weight basis (5.4% moisture).
[c]Tofu did not form.
Source: Data from Hou and Chang (2001a).

isoflavones after 9 months of storage under adverse conditions (Table 4). Tofu made from soybeans stored under high-humidity and high-temperature conditions have stronger aftertastes than that made from soybeans stored under mild conditions, because the former contains more aglycone isoflavones (genistein and daidzein), which have much stronger aftertastes than the corresponding glucoside isoflavones (genistin and daidzin). Soybeans for tofu making can be kept in cold or mild conditions (57% RH, 20°C) for a long period of time (up to 18 months) without increasing the aftertaste because very little conversion occurred from malonylglucosides to aglycones (Table 5).

IX. EVALUATION OF SOYBEAN CULTIVARS FOR TOFU MAKING

It is well known that good tofu can only be prepared from good soybeans. Cultivar, location (environment of growth), and handling practice at harvest, and storage practices postharvest, can affect soybean chemical compositions, which affect curd formation and the sensory properties of tofu. The differences in tofu properties may be truly from the soybeans themselves, but there is the possibility of difference owing to differences in preparation methods. The soybean cultivar is one of the factors influencing the quality of tofu. The cultivar, the quality, the cultivation environment, and the processing conditions all affect the resulting tofu. Over the years, substantial interest has been devoted to the understanding of the quality of various soybean cultivars for tofu making. This has a practical importance in soybean trading, since a good quality identity-preserved soybean cultivar can commend a higher price. Several researchers have reported the differences in the quality of various soybean cultivars for making tofu. Those with higher protein content have generally a lower oil and total sugar content. The chemical composition of soybeans is closely related to that in soymilk and tofu (150–152). The higher the protein content in soybeans, the higher the protein contents in soymilk or in packed tofu. Soybean cultivars vary in chemical composition, resulting in significant differences in textural properties of tofu, and the cultivars with higher protein contents may not produce tofu with a harder texture, because the protein content alone is not adequate to explain the observed hardness. Therefore a thorough understanding of the protein structures in various cultivars is important to tofu quality. The structures of soy proteins may be affected by cultivar as well as storage of soybeans.

In marketing soybeans for foods, buyers and processors are interested in knowing the suitability of the soybeans for making tofu because the quality will affect the processing procedures, the yield, consumer acceptability, and the sales and profit of the tofu products. The desire for good quality soybeans in the processing industries have led the breeders to breed specialty soybeans for tofu. Tofu makers prefer beans of large size, round shape, yellow color with clear hilum, high protein, high sugar, and high nitrogen solubility (153). These physical and chemical characteristics are associated with variety. However, the color of the hilum is not related to the color of the tofu. Tofu with white and less reddish color is preferred in Japan. Even though large soybeans are preferred in the market, the size of the soybeans does not affect tofu yield or quality (151,154–156). Some small size beans could also make good tofu. Uniformity is important. Soybeans that fail to be hydrated will adversely affect the yield of tofu.

There is no standard method of evaluating soybean quality for making tofu. It is important that an evaluation method have the ability to detect the differences of soybeans with different quality characteristics, and such a method could produce a similar trend of results in a large-scale tofu manufacturing process. Since manufacturing processes vary from manufacturer to manufacturer, one evaluation method cannot be applied to all. However, for the simple purpose of comparison among different varieties for tofu making, one method developed for a specific tofu

Table 4 Isoflavone Content of Soybeans Stored in 84% RH and 30°C for up to 9 Months (μg/g Dry Weight)

	Glucosides			Malonylglucosides			Acetylglucosides			Aglycones			Total individuals			
Month	Din	Gin	Gly	Din	Gin	Gly	Din	Gin	Gly	Dein	Gein	Glein	Dein	Gein	Glein	Overall total
0	142^{d}	180^{d}	121^{c}	1248^{a}	1837^{a}	251^{a}	17	3	13	12^{i}	7^{f}	1^{g}	734^{d}	1072^{d}	218^{abc}	2024^{f}
1	254^{b}	368^{b}	143^{b}	1089^{b}	1758^{b}	199^{b}	0	12	2	33^{h}	27^{f}	4^{g}	734^{d}	1174^{c}	201^{d}	2109^{e}
2	376^{a}	481^{a}	172^{a}	949^{c}	1489^{c}	194^{b}	2	4	0	100^{g}	114^{e}	11^{f}	807^{c}	1187^{bc}	223^{ab}	2217^{c}
3	232^{c}	315^{c}	142^{b}	531^{d}	884^{d}	123^{c}	0	1	0	430^{f}	558^{d}	71^{e}	838^{b}	1213^{ab}	227^{ab}	2278^{b}
4	113^{e}	145^{e}	85^{d}	296^{e}	571^{e}	70^{d}	0	0	0	594^{e}	794^{c}	133^{d}	812^{b}	1181^{bc}	224^{abc}	2216^{c}
5	30^{f}	45^{f}	57^{e}	99^{f}	274^{f}	26^{e}	0	0	0	784^{c}	1045^{b}	174^{c}	852^{a}	1215^{a}	224^{abc}	2292^{a}
6	15^{gh}	16^{h}	49^{e}	31^{h}	106^{h}	9^{fg}	0	0	0	820^{b}	1107^{a}	176^{c}	845^{a}	1172^{ab}	212^{bc}	2230^{bc}
7	21^{g}	32^{g}	60^{e}	65^{g}	173^{g}	14^{f}	0	0	0	761^{d}	1040^{b}	178^{c}	806^{b}	1149^{bc}	224^{ab}	2179^{cd}
8	12^{gh}	14^{h}	51^{e}	29^{h}	94^{h}	8^{fg}	0	0	0	827^{b}	1081^{ab}	196^{a}	849^{a}	1138^{bc}	233^{a}	2220^{c}
9	8^{h}	0^{i}	34^{f}	4^{h}	17^{I}	0^{g}	0	0	0	854^{a}	1106^{a}	188^{b}	861^{a}	1115^{bc}	210^{c}	2186^{cd}

Values are the mean of two replicates and in the same column with different superscripts are statistically different at $P \leq 0.05$.
Din = daidzin; Gin = genistin; Gly = glycitin; Dein = daidzein; Gein = genistein; Glein = glycitein.
Total individuals = moles of isoflavone × molecular weight of aglycone form isoflavone.
Overall total = sum of total individuals of aglycones.
Source: Data from Hou and Chang (2001b).

Table 5 Isoflavone Content of Soybeans Stored in 57% RH and 20°C for up to 18 Months (μg/g Dry Weight)

	Glucosides			Malonylglucosides			Acetylglucosides			Aglycones			Total individuals			
Month	Din	Gin	Gly	Din	Gin	Gly	Din	Gin	Gly	Dein	Gein	Glein	Dein	Gein	Glein	Overall total
0	142^{f}	180^{f}	121^{d}	1248^{b}	1837^{b}	251^{ab}	17	3^{e}	13	12^{d}	7^{c}	1	734^{c}	1072^{d}	218^{b}	2024^{d}
3	181^{e}	233^{e}	150^{b}	1398^{a}	1987^{a}	262^{a}	9	10^{d}	9	16^{c}	13^{b}	2	833^{ab}	1193^{b}	241^{a}	2267^{ab}
6	239^{d}	292^{d}	137^{c}	1256^{b}	1830^{b}	223^{cd}	9	17^{c}	8	19^{c}	16^{b}	0	800^{b}	1155^{c}	210^{b}	2165^{c}
9	297^{c}	397^{c}	151^{b}	1206^{b}	1832^{b}	237^{bc}	10	21^{b}	8	23^{b}	14^{b}	0	816^{ab}	1221^{b}	227^{b}	2264^{ab}
12	328^{b}	478^{b}	161^{b}	1123^{c}	1717^{c}	220^{d}	10	24^{b}	10	24^{b}	13^{b}	0	793^{b}	1214^{b}	225^{b}	2231^{bc}
18	477^{a}	652^{a}	180^{a}	1015^{d}	1538^{d}	190^{e}	6	38^{a}	7	41^{a}	33^{a}	4	845^{a}	1258^{a}	223^{b}	2326^{a}

Values are the mean of two replicates and in the same column with different superscripts are statistically different at $P \leq 0.05$.
Din = daidzin; Gin = genistin; Gly = glycitin; Dein = daidzein; Gein = genistein; Glein = glycitein.
Total = moles of isoflavone × molecular weight of aglycone form isoflavone.
Overall total = sum of total individuals of aglycones.
Source: Data from Hou and Chang (2001b).

product may be appropriate. Most methodologies reported for tofu making are small-scale methods and have not been described in detail. Except the method reported by our lab (154), no reported studies have compared the reported small-scale method with a large-scale method.

A small-scale (139 g bean per experiment) and a large-scale (6500 g bean per experiment) processing method were developed and applied for making soymilk and soft tofu from 13 soybean varieties (154). A diagram for making soft tofu on a small scale is shown in Fig. 10. The tofu molds for small- and large-scale are shown in Fig. 11 and Fig. 12, respectively. The automatic production-scale soymilk and tofu machine in our laboratory is shown in Fig. 13. The results revealed that the small-bench and the large-scale method correlated significantly ($P \leq 0.05$) in tofu yield, color, texture, and chemical composition (moisture, protein, lipid, ash, calcium, and magnesium) (Table 6). Since tofu quality made by the small-bench scale was well correlated to the production method, the bench-scale method may be used for determining the quality of soybeans

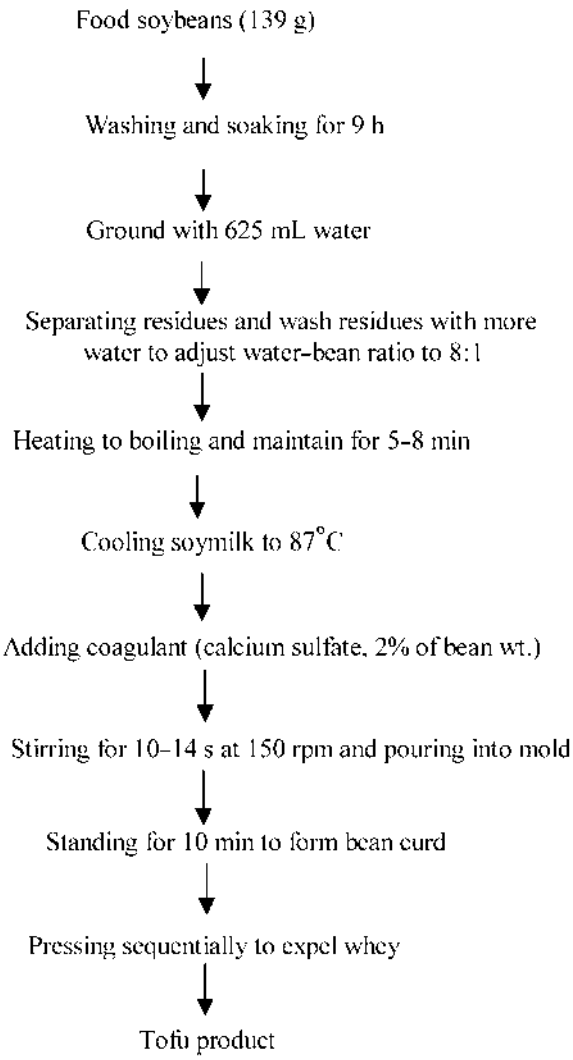

Figure 10 Procedures of tofu making for a small-scale method.

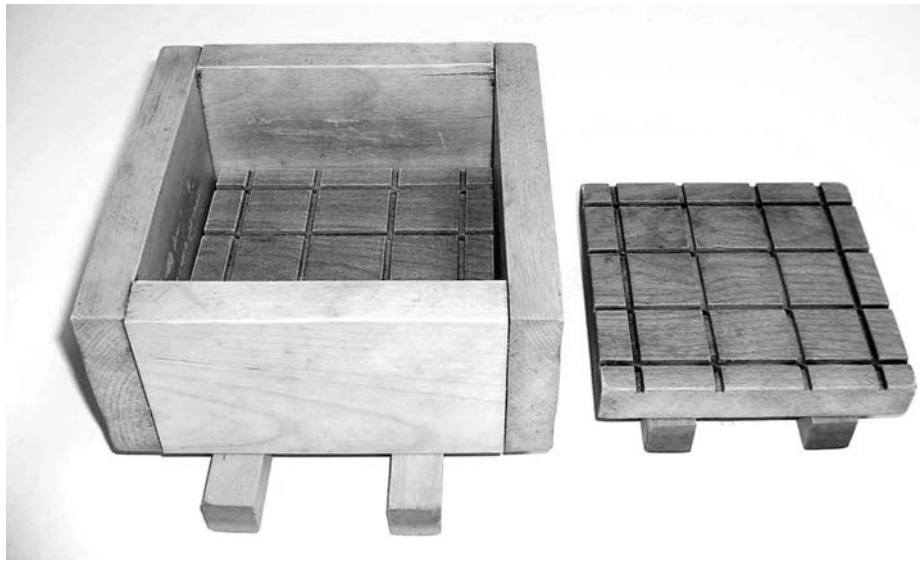

Figure 11 The tofu mold used by the small-scale method. Right: Top piece for pressing. (Mold size: 12.5 L × 12.5 W × 5.5 H cm.)

Figure 12 The tofu mold used by the production-scale machine at North Dakota State University. (Size: 40 L × 40 W × 4.5 H cm.)

Figure 13 The automatic production-scale machine (made by Ta-Ti-Hsing Machinery Co., Taoyuan, Taiwan) for soymilk and tofu production at North Dakota State University.

Table 6 Correlation Coefficient of Soymilk and Tofu Physicochemical Properties Between Small Bench-Scale Method and Large-Scale Methods

Physicochemical property	Correlation coefficient (r)[a]
Soymilk	
Protein	0.94***
Lipid	0.71**
Ash	0.93***
Tofu	
Yield	0.82***
Moisture content	0.78**
Protein	0.80***
Lipid	0.65*
Ash	0.96***
Calcium	0.72**
Hardness	0.54*
Elasticity	0.60*

[a]Significant levels: $*P \leq 0.05$, $**P \leq 0.01$, and $***P \leq 0.001$.
Source: Data from Cai et al. (1997).

Table 7 Effect of Processing Method and Soybean Variety on Tofu Yield and Tofu Hardness[a]

	Yield (g/100 g raw bean)		Hardness (g)	
Variety	Bench	Production	Bench	Production
Proto	551.5 a*	434.8 ab	1460 e	3058 a
T5	521.9 ab*	438.1 a	2122 bcde	3023 a
Corsoy-79	229.3 f*	341.5 g	3766 a	3035 a
Vinton	522.7 ab*	402.1 cd	2006 bcde	2807 ab
Kato	480.9 bc	430.3 ab	1587 de	2638 abc
Hardin	469.8 c	411.8 cd	1742 cde	2307 cd
Sturdy	404.1 d	358.1 fg	1937 bcde	2592 abc
SBB100ND	471.3 c*	424.3 abc	1707 cde	2431 bcd
SBB100SD	387.8 de	373.2 ef	2547 bc	3105 a
Stine 2220	411.3 d*	335.3 g	2227 bcde	3045 a
Stine 1590	351.4 e	346.8 g	2350 bcd	2763 abc
Stine 0380	395.9 d	359.7 fg	2683 b	3082 a
Stine 1570	499.0 bc*	393.6 de	1602 de	2057 d

[a]Data are means of two replicates (one determination per replicate except that hardness on production scale had four determinations per replicate). Yield is based on the wet weight basis. Means within the same column followed by different letters are significantly different ($P \leq 0.05$).
*Means are significantly different ($P \leq 0.05$) from the production counterparts.
Source: Data from Cai et al. (1997).

for making tofu. Our research indicated that the quality and yield of tofu were significantly affected by soybean cultivars and processing methods (Table 7). Although a production-scale method has been suggested by Murphy et al. (59) for determining the soybean quality for suitability for commercial processing, the bench-scale method developed in our laboratory is appropriate for evaluating soybean quality using a small quantity, since tofu quality made by the small-bench scale is well correlated to a production method.

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27

Vegetables as Food Ingredients, Including Nutraceutical

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I. INTRODUCTION

As a food group, vegetables provide a concentrated source of many vitamins, minerals, and other phytochemicals with a relatively low calorie content. Despite their nutritional value, vegetables fall into the least desired of the food groups for many people. This relative dislike of vegetables likely begins in childhood and carries into adult years. The lack of enthusiasm for vegetables may be related to the low energy content of most vegetables, a natural lack of sweetness, and the presence of various phytochemicals that can impart a mild to strong bitter flavor (1).

Since vegetables are most commonly eaten as basic foods with simple preparation, using vegetables as food ingredients can be an excellent way to incorporate more of the nutrients and phytochemicals of vegetables into the diet. Also, the use of vegetables or parts of vegetables as ingredients in foods can produce food products that fit into the new categories of functional foods and/or nutraceuticals.

This chapter presents both the benefits and the hindrances of using vegetables as ingredients in foods. This view will keep in mind both culinarian and food processor and address the virtually unlimited potential for using vegetables as ingredients. An introduction to food labeling issues that may relate to using vegetable ingredients is presented, and a brief discussion of functional foods and nutraceuticals sets the stage for a discussion of dietary supplements in Chapter 29.

A stroll through a supermarket in the United States might lead a person to think that there are only about 30 edible vegetables. Most of these plants are prepared simply and served separately. There are, however, over 225 edible vegetables, primarily from Asia (2), and over 100 culinary herbs and spices (3).

II. REASONS FOR VEGETABLES AS FOOD INGREDIENTS

Besides the numerous health reasons for consuming vegetables indicated in Chapter 2, vegetables offer an enormous array of culinary options. Complimentary flavors, a broad spectrum of color, mouth-feel variety, and low-calorie, low sodium, and no-cholesterol content represent a few of the culinary and nutritional benefits of utilizing vegetables as food ingredients.

A. Flavor

Some of the most popular foods for all age groups include vegetables as major ingredients. For example, pasta and pizza generally contain tomatoes as well as various other vegetables such as onions and bell peppers.

Vegetables often are used to provide a significant balance to other flavors. For example, most high-end culinary sauces contain the flavor essence of vegetables in the form of mirepoix (clear stock made from celery, onion, and carrots), even if they do not contain the actual vegetables themselves.

Owing to their great variety and versatility, vegetables can be used not only to enhance other flavors but also as flavor carriers for a range of taste preferences. The combination of classic vegetables (tomato juice, carrots, celery, beets, parsley, lettuce, watercress, and spinach) processed into a V-8™ juice cocktail has been a highly acceptable way of "getting your vegetables" for decades. For today's younger generation, which prefers sweeter food choices, V-8 Splash™ utilizes carrot juice as a sweet base to carry other vegetable flavors.

B. Appearance

As individual foods, most vegetables have clearly recognizable colors, shapes, and sizes. With the possible exception of desserts, vegetables are often the most colorful items in a meal. Their colors span the rainbow, and if processed correctly vegetables retain their colors in the finished product. Vegetables also have an almost limitless adaptability to create a great variety in eye appeal.

Vegetables also can be used to color food. Unlike artificial dyes, the following vegetable dyes are allowed in human food without certification: β-apo-8′-carotenal (specific use restrictions apply), beta-carotene, beet powder, canthaxanthin, carrot oil, paprika, paprika oleoresin, saffron, turmeric, turmeric oleoresin, and vegetable juice (4).

C. Mouth-feel and Texture

In the raw state or slightly cooked, the texture of many vegetables (e.g., carrots, cucumbers, and jicama) adds a crisp and crunchy mouth-feel. The crunchiness of food is one factor that can decrease eating speed in some people (5–7). Thus the crunchy nature of many vegetables along with their low caloric content could play a significant role in creating more effective weight loss products.

Once cooked, many vegetables can take on a smooth and almost silky consistency (e.g., carrots, potato, and pumpkin). This allows for vegetables to be incorporated into what would otherwise be high-fat sauces. Various culinary and food processing techniques make vegetables almost limitless in their versatility. This allows their incorporation (along with their numerous nutrients and phytochemicals) into unsuspecting food products (e.g., tomato, pumpkin, or zucchini breads).

Vegetable extracts also can be exceptionally useful as ingredients. For example, phycocolloids primarily extracted from brown (*Phaeophyta*) and red (*Rhodophyta*) seaweeds have the ability to provide gel strength and stability to aqueous mixtures (8). These provide alginates (salts of alginic acid) from brown algae and the sulphated galactans, agars, and carrageenans from red algae.

D. Nutrition Image

The nutrition image of vegetables etched into people's minds is that vegetables are "good for health." However, for many people, the image of vegetables is almost synonymous with weight loss foods. Raw vegetables, whose sugars and vitamins have broken down with inappropriate storage time and conditions, have set the benchmark for expected taste quality. Consequently, the most difficult factor in promoting vegetables as nutraceuticals may be overcoming the image that was brought about by weight loss foods that compromised flavor.

III. FOOD SAFETY ISSUES

As with any food product, it not acceptable to have a product that has been contaminated with rot, filth, or deleterious substances (9). In the past, food safety has not been a major issue related to fresh vegetables. The risk of microbial contamination of canned vegetables has been minimized by the development of carefully controlled manufacturing practices (10,11). However, specific issues related to the food safety of fresh and processed vegetables are of current concern owing to new food trends. This makes having an appropriate good manufacturing practice more important than ever.

A. Vegetable Alkalinity and Botulism

Most vegetables and their products are naturally low in acid. The term "low-acid food" is commonly used to refer to a food with a pH greater than 4.6. *Clostridium botulinum*, a microorganism that produces a deadly toxin, thrives under anaerobic conditions with a pH greater than 4.6. Since these conditions exist in most canned vegetable products, proper canning techniques are essential to kill *C. botulinum* and its spores. Consequently, handling, processing, and packaging must prevent the growth of *C. botulinum*.

The U.S. Food and Drug Administration (FDA) enforces regulations for the processing of low-acid heat-processed foods, other than alcoholic beverages, that have an acidity greater than pH 4.6 and a water activity greater than 0.85 and are packaged in hermetically sealed containers. Water activity refers to a measure of the water available for microbial growth. A hermetically sealed container includes any package (metal, glass, plastic, polyethylene-lined cardboard, etc.) that is capable of maintaining the commercial sterility of its contents without refrigeration after processing (10).

All commercial processors of low-acid canned foods, including foods acidified by the addition of acids, must register their establishments and file processing information with the FDA for all such products. This includes foreign processors that export such foods to the United States (12,13). In addition, specific quality standards exist for canned vegetables (14).

Flavored oils with added herbs or garlic pieces also support the growth of *C. botulinum*. The oil creates an anaerobic environment around the particles that is ideal for the growth of *C. botulinum* (15). Other products that have developed *C. botulinum* contamination include roasted eggplant in oil and peppers in oil (16). Such products must be processed under strict conditions using microbial inhibitors or acidifying agents to avoid this serious danger.

B. Fresh Produce

Recently, microbial contamination of fresh vegetables has caused some illness and raised the concern for the safety of fresh produce. Generally, these problems have been due to contact with

contaminated water, untreated raw manure, or direct human contamination or mishandling that results in cross-contamination from other common sources of pathogenic bacteria. Advisories and guidelines have been published by the FDA (17,18).

C. Pesticides and Environmental Concerns

Concerns for pesticide residues and the environmental effects of chemical fertilizers have led to the increased use of organically grown foods. In addition to problems related to the use of improperly treated animal manure mentioned above, a food safety problem has been associated with organically grown sprouts. Most types of sprouts can support the growth of *Salmonella* or *Escherichia coli*. Although organically grown sprouts were initially implicated, microbial contamination of sprouts is not limited to organically grown sprouts. This problem is likely due to seeds that have been contaminated during harvesting (19–21).

The FDA has issued advisory warnings about the food safety risks associated with consuming raw sprouts, particularly alfalfa, clover, and radish sprouts. In particular, they stress that children, the elderly, and persons with weakened immune systems should avoid eating raw sprouts until their safety can be assured. Various techniques are being investigated to prevent sprout contamination using various antimicrobial procedures (22,23).

D. Biotechnology

A variety of current food safety concerns are related to the application of biotechnology to produce genetically modified plants and other organisms. Although the application of biotechnology to agriculture can overcome extremely challenging problems, it is not free of potential risks and is the target of very intense concern. For example, people are concerned about the potential for creating plants that produce new toxins or new proteins with unknown allergenic potential. Genetic engineering of the more commonly allergenic plants like wheat and peanuts may make them free of their known allergenic proteins.

In addition to concerns for the effects on human and animal health, the potential for serious environmental consequences is likewise an issue. As regulatory groups develop systematic approaches to oversee the development and use of genetically modified organisms, it will be essential to evaluate carefully the risks and the risk–benefit ratios (24).

IV. TERMINOLOGY OF FUNCTIONAL FOODS AND NUTRACEUTICALS

The use of foods for health and medicinal purposes has been extolled for many centuries. For example, ancient medical texts from Egypt, Greece, Rome, China, and India all refer to the use of garlic for health purposes. Early Olympic athletes used garlic for performance enhancement, and even Hippocrates was known to prescribe garlic for various conditions (25). Also as early as 1000 B.C., traditional Chinese medicinal literature used terms for medicinal and special foods having healing properties (26).

Today in China, more than 3000 food products are considered functional and are called health foods (27). Japan has created a regulated food class called Foods for Specified Health Use (FOSHU), and all foods in this class must be approved before being marketed (28).

The terms functional foods, nutraceuticals, and dietary supplements often are used interchangeably and have caused a fair amount of confusion. Depending on who defines these terms, their meanings can be quite narrow or all-encompassing.

A. Functional Foods

A functional food can be defined as "any modified food or food ingredient that may provide a health benefit beyond the traditional nutrients it contains" (29,30). For example, orange juice fortified with calcium is an example of a functional food because orange juice does not normally contain significant amounts of calcium.

B. Nutraceuticals

In 1989, Stephen L. DeFelice, M.D., founder and chairman of the Foundation for Innovation in Medicine, coined the term nutraceutical "on the Piazza Navona in Rome after a wonderful meal" (SL DeFelice, personal communication, 2002). Nutraceutical includes "any substance that may be considered a food or part of a food and provides medical or health benefits, including the prevention and treatment of disease" (29). Under this definition, food products, medical foods, foods for special dietary use, and dietary supplements (isolated nutrients and herbs) are all included.

C. Medical Foods

The FDA defines a medical food as

> a food which is formulated to be consumed or administered enterally [taken by mouth or provided through a tube directly to the stomach or gastrointestinal tract] under the supervision of a physician and which is intended for the specific dietary management of a disease or condition for which distinctive nutritional requirements, based on recognized scientific principles, are established by medical evaluation. (31)

Medical foods are specially formulated and processed foods intended for specific medical or rare health conditions affecting less than 200,000 individuals in the United States. These foods are not intended to decrease common health conditions such as obesity or hypertension; neither low-calorie, low-fat, or low-sodium products, nor products with a single nutrient, are medical foods. A product specially formulated with low levels of phenylalanine for use by persons with phenylketonuria, a rare genetic condition requiring restricted intake of this amino acid, is an example of a medical food.

D. Special Dietary Use Foods

Special dietary use foods include a plethora of miscellaneous food categories including foods formulated for specific physical, physiological, pathological, or other conditions such as convalescence, pregnancy, lactation, allergic hypersensitivity to food, underweight, and overweight. Foods also may be designed specifically for particular age groups or to supplement or fortify a diet with any vitamin, mineral, or other dietary property. Artificially sweetened foods to control calorie or carbohydrate intake for use in diabetic diets are special dietary use foods, as well as hypoallergenic foods (gluten free) and infant foods (32).

E. Dietary Supplements

It is important to understand that a nutraceutical may be considered a functional food or a dietary supplement. To determine whether a vegetable or vegetable ingredient falls within the statutes of

the Nutrition Labeling and Education Act (NLEA) (33) or the Dietary Supplement Health and Education Act (DSHEA) (34), the formal definition of "dietary supplement" is summarized by the FDA (35). A dietary supplement is

> a product (other than tobacco) that is intended to supplement the diet that bears or contains one or more of the following dietary ingredients: a vitamin, a mineral, an herb or other botanical, an amino acid, a dietary substance for use by man to supplement the diet by increasing the total daily intake, or a concentrate, metabolite, constituent, extract, or combinations of these ingredients.

[It] is intended for ingestion in pill, capsule, tablet, or liquid form.
[It] is not represented for use as a conventional food or as the sole item of a meal or diet.
[It] is labeled as a "dietary supplement."
[It] includes products such as an approved new drug, certified antibiotic, or licensed biologic that was marketed as a dietary supplement or food before approval, certification, or license (unless the Secretary of Health and Human Services waives this provision).

V. LABELING AND REGULATIONS

A. History

The history leading to present-day food labeling regulations in the United States Nutrition Labeling and Education Act (NLEA) (33) started in the thirteenth century (1202) in England when the king prohibited the adulteration of bread with legumes (36). Seven hundred years later (1906), the United States started its regulation of food and drink. Initially the focus was on misbranded and adulterated products, followed by food safety of additives and then fair packaging information for products crossing interstate lines.

Under the FDA's jurisdiction, domestic and foreign foods are now regulated through the Federal Food, Drug, and Cosmetic Act (1938) and its subsequent amendments such as the Fair Packaging and Labeling Act (1966). Conventional foods, functional foods, and culinary herbs fall under 1993 NLEA regulations (33). Dietary supplements and medicinal herbs are regulated under the 1994 Dietary Supplement Health and Education Act (34).

B. Food Label Claims

Vegetables have many of the healthful qualities that can encourage manufacturers to promote their products through various types of nutrient and health claims. There are, however, strict guidelines as to what claims can be made, and all claims are dependent upon nutrients contained in the foods.

Nutrition labeling is voluntary for raw vegetables as long as point-of-purchase nutrition information is available for the 20 most frequently eaten raw vegetables, which are asparagus, bell pepper, broccoli, cabbage (green), carrot, cauliflower, celery, corn (sweet), cucumber, green bean, green onion, lettuce (iceberg), lettuce (leaf), mushroom, onion, potato, radish, squash (summer), sweet potato, and tomato (37,38). Nutrient information for these vegetables can be found in the Code of Federal Regulations (39).

Processed and packaged foods, whether conventional or functional, require compliance with NLEA. Food labeling regulations are relatively complex, and all federal updates are listed annually in Title 21 of the Code of Federal Regulations, Part 101. The latest proposed changes to NLEA and final rulings are published in the Federal Register daily. Both can be found online at the

Office of the Federal Register, National Archives and Records Administration, on the United States Government Printing Office web site located at www.access.gpo.gov/su_docs/index.htm or purchased through the Office of Documents.

The FDA Center for Food Safety and Applied Nutrition has electronically published a document titled "Food Labeling and Nutrition Overview" with a specific section for "Industry Information, Guidance & Regulations." This is available online at http://vm.cfsan.fda.gov/label.html. Listed below are the basic labeling concepts related to all foods and vegetables in particular.

1. Required Basic Label Components

All food labels require two types of display panels, the Principal Display Panel (PDP) and the Information Panel (IP) immediately to the right of the PDP unless package dimensions do not allow (40). Each panel is required to contain specified information that also meets specific criteria for format and accuracy.

The PDP must include the "Statement of Identity" (the common or usual name of the food, including a description of the food if sold in different optional forms) or the "Standard of Identity" (for foods with a common or usual name established by regulation) (41). No standard of identity exists for fresh or dried vegetables, but there are standards of identity for canned vegetables (42), vegetable juices (43), and frozen vegetables (44).

Beverages that contain vegetable juice must declare the percentage of vegetable juice. Specific wording requirements can be found at 21 CFR 101.30. Also all vegetable juices must be clearly identified and labeled as coming from concentrate or reconstituted (45).

The IP is required to include the Nutrition Facts Panel, the Ingredient List, and pertinent contact information of the manufacturer, packer, or distributor including name and address (40).

The Nutrition Facts Panel requires a set of mandatory nutrients and food components to be listed on each food label. If a manufacturer wants to promote other healthful nutrients with a claim or has fortified or enriched a food product with optional components, then the label must provide nutrient information on these nutrients. Table 1 indicates all mandatory and voluntary food components in the order that they must appear on the Nutrition Facts Panel. Only these nutrients and food components are allowed on the panel. For a complete description of Nutrition Facts Panel Requirements see the Code of Federal Regulations (46).

The Ingredient List must present ingredients in the prioritized order by decreasing weight and must list all components of a main ingredient (47). A partial Ingredient List for a poi pancake mix might read: Enriched bleached wheat flour (wheat flour, niacin, reduced iron, thiamine mononitrate, riboflavin), sugar, dehydrated poi, etc.

Most spice and natural flavor ingredients can be listed as "spices" or "flavor;" vegetables used as flavoring agents in a powder form must be declared by common or usual name (e.g., garlic powder) (48). Likewise, noncertified colors like "beet juice" must be listed as "beet juice" rather than "flavor" (49).

2. Labeling Requirements When Making Claims

There are three broad categories of claims (Nutrient, Health, and Structure/Function) and an additional category that disqualifies a product from using any claim. Which claims are allowable is dependent on whether the claim is made for a conventional or "functional/nutraceutical" food or a dietary supplement (Table 2).

Table 1 Reference Values for Nutrition Labeling of Foods

Mandatory			Voluntary		
Nutrient	Daily values		Nutrient	Daily values	
Total fat	65 g	DRV[a]	Vitamin D	400 IU	RDI
Saturated fatty acids	20 g	DRV	Vitamin E	30 IU	RDI
Cholesterol	300 mg	DRV	Vitamin K	80 mcg	RDI
Sodium	2400 mg	DRV	Thiamin	1.5 mg	RDI
Potassium[b]	3500 mg	DRV	Riboflavin	1.7 mg	RDI
Total carbohydrate	300 g	DRV	Niacin	20 mg	RDI
Fiber	25 g	DRV	Vitamin B6	2.0 mg	RDI
Protein	50 g	DRV	Folate	400 mcg	RDI
			Vitamin B12	6.0 mcg	RDI
Vitamin A	5000 IU	RDI[c]	Biotin	300 mcg	RDI
Vitamin C	60 mg	RDI	Pantothenic acid	10 mg	RDI
Calcium	1000 mg	RDI	Phosphorus	1000 mg	RDI
Iron	18 mg	RDI	Iodine	150 mcg	RDI
			Magnesium	400 mg	RDI
			Zinc	15 mg	RDI
			Selenium	70 mcg	RDI
			Copper	2.0 mg	RDI
			Manganese	2.0 mg	RDI
			Chromium	120 mcg	RDI
			Molybdenum	75 mcg	RDI
			Chloride	3400 mg	RDI

g = grams; mg = milligrams; mcg = micrograms; IU = International Units;
[a]Daily reference values; based on diets containing about 2000 kcal per day for adults and children over 4 only.
[b]Not mandatory, but if potassium is used, it should appear in this order.
[c]Reference daily intake.
Nutrients in this table are listed in the order in which they are required to appear on a label. The second column of nutrients follows directly after the first column. (21 CFR 101.9(c))
This list includes only those nutrients for which a Daily Reference Value (DRV) has been established in 21 CFR 101.9(c);(9) or a Reference Daily Intake (RDI) in 21 CFR 101.9(c);(8);(iv) [http://www.cfsan.fda.gov/~dms/flg-7a.html]; Revision Jan 30, 1998.

In most cases, claims are related to particular serving size quantities called Reference Amounts Customarily Eaten (RA). At present there are over 100 RA food categories which are set by FDA (50). Table 3 illustrates the variation in RAs established for various types of products derived from tomatoes.

Foods that contain any nutrient, health, or functional food claims also must meet General Claim Criteria (51,52). Below is a summary of these required criteria.

All information must be in one place without intervening material.
The information must present the benefit that intake or reduced intake, as part of a total dietary pattern, may have on a disease or health-related condition.
Information must be easy to understand and present the significance as related to total daily diet.
Information must be complete, truthful, and not misleading.
Without fortification, the food product contains at least 10% Daily Value (DV) for one of six nutrients (dietary supplements excepted): protein, dietary fiber, iron, calcium, vitamin A or C (Table 4).

Table 2 Claims that are Allowed on Conventional Foods, "Functional/Nutraceutical Foods," and Dietary Supplements

	Conventional/"functional foods"	Dietary supplement
NUTRIENT CONTENT CLAIMS Authoritative Statements in Accordance with FDAMA http://www.fda.gov/cber/fdama.htm http://www.cfsan.fda.gov/~dms/hclmguid.html	Allowed	Allowed
Percentage claims for dietary ingredients for which there are no established DV. 21 CFR 101.13(q)(3)(ii) http://www.cfsan.fda.gov/~lrd/cf101-13.html	Not allowed	Allowed
HEALTH CLAIMS NLEA Authorized Health Claims http://www.cfsan.fda.gov/~dms/hclmguid.html	Allowed. See Table 6	Allowed
Health Claims Based on Authoritative Statements http://www.cfsan.fda.gov/~dms/flg-6c.html.	Allowed	Not allowed
Qualified Health Claims (64 FR 67289 Dec. 1, 1999)	Not allowed	Allowed http://www.cfsan.fda.gov/~lrd/fr991201.html http://www.cfsan.fda.gov/~lrd/fr001006.html http://www.cfsan.fda.gov/~dms/ds-labl.html#qualified
STRUCTURE/FUNCTION CLAIMS January 6, 2000 Federal Register (65 FR 1000) http://www.cfsan.fda.gov/~lrd/fr000106.html	Allowed This claim is allowed only for nutrients meeting the claims without any fortification.	Allowed
FDA/Center for Food Safety and Applied Nutrition Letter to Manufacturers Regarding Botanicals and Other Novel Ingredients in Conventional Foods 1/30/01 http://vm.cfsan.fda.gov/~dms/ds-ltr15.html		
"Dear Colleague" Letter—Clarifying FDA Contacts for Structure/Function Claims of Dietary Supplements http://vm.cfsan.fda.gov/~dms/ds-ltr5.html		

Table 3 Examples of Required Reference Amounts for Various Tomato Products

Product type	Reference amount
Fresh tomatoes	85 g
Fresh tomato as garnish	15 g
Canned tomato in liquid	130 g
Vegetable juice	8 fluid oz. 240 g
Tomato soup	245 g
Major main entree sauce, e.g., marinara sauce	125 g
Minor main entree sauce, e.g., pizza sauce	1/4 cup 60 mL
Minor sauce, e.g., barbeque sauce	2 tablespoons 30 mL
Major condiment, e.g., ketchup	1 tablespoon 15 mL
Minor condiment e.g., hot sauce	1 teaspoon 5 mL
Tomato as ingredients:	
tomato sauce	60 g
tomato puree	60 g
tomato paste	30 g

Source: 21 CFR 101.12

Claims are not represented for infants or toddlers less than 2 years of age.
The terms "may" or "might" must be used to express the relationship between substance and disease.
Claims do not quantify any degree of risk reduction.
Information must indicate that the disease depends on many factors.
The food product contains less than the specified levels of four disqualifying nutrients per RA (Table 5).

A very likely problem in making (nutrient, health, or structure/function) claims for products containing vegetables will be exceeding the "disqualifying nutrient" amounts listed in Table 5. For example: if a serving of pasta sauce contains more than 13 grams of fat per reference amount or

Table 4 Daily Values Criteria Necessary (without fortification) per Reference Amount (RA)[a] to Allow the Use of Health Claims

	"Good source," "Contains," "Provides"	"High," "Rich in," "Excellent source of"
Nutrient	10% DV	20% DV
Vitamin A	500 IU	1000 IU
Vitamin C	6 mg	12 mg
Iron	1.8 mg	3.6 mg
Calcium	100 mg	200 mg
Protein	5 g	10 g[b]
Fiber	2.5 g	5 g

[a]If RA is small, criteria are based on 50 grams.
[b]DV must be equal to or greater than 10% of DV; protein quality may affect DV.
Source: 21 CFR 101.14

Table 5 Nutrient Criteria That Disallow the Use of Any Health Claim for Individual Foods, Main Dish Items, and Meals Based on Established Reference Amounts

Disqualifying nutrient	Food[a]	Main dish[b]	Meal product[c]
Fat	13.0 g	19.5 g	26.0 g
Saturated fat	4.0 g	6.0 g	8.0 g
Cholesterol	60 mg	90 mg	120 mg
Sodium	480 mg	720 mg	960 mg

[a]Food = Individual food serving based on Reference Amount (RA)*.
[b]Main dish = greater than or equal to 6 ounces; contains at least 2 food groups**.
[c]Meal = greater than or equal to 10 ounces; contains at least 3 food groups**.
* = If RA is small, criteria are based on 50 grams.
** = Smallest food group must equal at least 40 grams.
Source: 21 CFR 101.14.

labeled serving, then no claims can be made even though it might contain greater than 10% DV vitamin C, contain no cholesterol, be low in sodium, and contain high levels of lycopene, a beneficial phytochemical.

a. Nutrient Content Claims Nutrient Content Claims describe the quantity of a nutrient or dietary component contained in the Reference Serving Size for a particular food product. NLEA regulations define the specific criteria that a food product must meet in order to use a claim. With few exceptions, nutrient content claims can be made only for nutrients or dietary substances that have an established Daily Value.

Daily Values (DV) are the reference values used as standards in food labeling. They represent the recommended intake of specific nutrients and food components for someone consuming a 2000 kilocalorie diet. DVs are based on two sets of standards, Daily Reference Values (DRVs) and Reference Daily Intakes (RDIs). The current DVs are listed in Table 1.

The DRVs were established for the major components of foods that are of nutritional concern (fat, saturated fatty acids, cholesterol, total carbohydrate, fiber, sodium, potassium, and protein). It is recommended that the average person consuming a diet of approximately 2000 kcal should consume less than the DRVs for fat, saturated fatty acids, cholesterol, and sodium. The DRVs for carbohydrate and fiber are considered to be goals for reasonable daily intake.

Generally, protein is not expressed as a percentage of the DV on food labels. Only the amount in grams is given. However, the protein DRV of 50 grams serves as a reference value for making nutrient content claims about protein. Also, this DRV for protein (50 g) does not apply to certain populations. Reference Daily Intake (RDI) values for protein have been established for children 1 to 4 years (16 g), infants under 1 year (14 g), pregnant women (60 g), and nursing mothers (65 g). Thus products designed for specific use by one of these groups must use the appropriate DV reference amounts.

Specific Criteria for using nutrient content descriptors such as "Free," "Low," "Reduced," "Less," "Good Source of," "Contains," etc. are available in the FDA publication "A Food Labeling Guide" (53).

i. Absolute Nutrient Claims. Absolute nutrient content claims can directly express nutrient quantity (contains 50 calories) or indirectly refer to a variable quantity (low fat). Although it may appear that low fat is subjective, it is strictly defined as equal to or less than 3 grams fat per RA (54).

Specific synonyms are allowed for some of the defined words used in nutrient claims. Some of the key terms, their synonyms, and examples of definitions for specific nutrients include

1. Free: zero, no, without, trivial source of, negligible source of, insignificant dietary source of; for total fat, defined as less than 0.5 grams fat per RA.
2. Low: "few" for calories, contains a small amount of, low source of; for total fat, defined as 3 grams fat or less per RA.
3. Reduced/Less: Lower ("fewer" for calories), "modified" may be used in statement of identity; for total fat, defined as at least 25% less fat per RA than an appropriate reference food.
4. High Potency: contains 100% RDI or more per RA for individual vitamins or minerals.
5. High: rich in, excellent source of; must contain 20% or more of the DV.
6. Good source of: must contain 10 to 19% of the DV per RA (cannot be used for carbohydrate).
7. More: added, extra, plus; must contain at least 10% DV per RA; can only be used for vitamins, minerals, protein, dietary fiber, and potassium.
8. Any Fiber Claim: must also be low in fat.

When a food naturally meets the criteria for "free," "very low," or "low," additional criteria are necessary before a claim can be made. Foods must meet the criteria without any special processing, formulation, or alteration of the food. Also, these claims cannot be used if any disqualifying nutrient levels are exceeded (see Table 5). Examples of allowable wording for plain canned vegetables include "carrot, a fat-free food" or "tomato, a low-calorie food."

ii. Relative/Comparable Claims. Relative or comparable nutrient content claims include those based on meeting a minimal percentage Daily Value and are based on a nutritionally beneficial comparison to an "original" food. Relative claims and their synonyms include terms such as light or lite; reduced; added; fortified; enriched; more; less; or fewer. Relative claims require obtaining nutrient information from the top three representative foods or from a valid data base (51,54). A web site with guidelines for relative claims can be found at http://vm.cfsan.fda.gov/~dms/flg-6b.html.

iii. Implied Nutrient Claims. Implied claims also require certain nutrient standards to be met (48). There are three main types of implied claims.

1. The claim "healthy" is an explicit nutrient content claim and requires that the food meet guidelines for low fat (i.e. contain $\leq$3 grams of fat per RA). Adding a vegetable ingredient to a moderate or high-fat food does not allow a claim to be made.
2. A claim that declares a food is "as good as" or "contains as much as" is an implied Equivalence Claim. This type of claim requires that both the reference food and the labeled food meet the criteria of "good source" (i.e., contains $>$10% DV for the particular nutrient).
3. If a particular ingredient is used to imply that a food has beneficial properties, then the food must be a "good source" or "low in" the nutrients associated with the claim (see above).

b. Health Claims Health claims describe a relationship between a food substance and a disease- or health-related condition. Health claims must also meet the general criteria for claims as listed in Sec. 2 of this chapter (Labeling Requirements When Making Claims) (above). Unless health claims are made according to NLEA regulations, the food will be deemed as misbranded.

There are two ways that health claims may be used on a conventional or functional food label. A food claim may be authorized after the FDA has thoroughly reviewed the scientific

literature (52). Examples on the standard for significant scientific agreement can be found at http://www.cfsan.fda.gov/~dms/ssaguide.html. Table 6 lists the approved health claims (as of April 2002) and examples of the appropriate wording of such claims.

Under the 1997 Food and Drug Administration Modernization Act (FDAMA), a health claim for a food may be made after a successful submission of a "notification," based on an authoritative statement by a "scientific body of the U.S. government or the National Academy of Sciences" (55). Examples of health claims based on authoritative statements may be found at http://www.cfsan.fda.gov/~dms/flg-6c.html.

There is a third type of health claim called a "Qualified Health Claim." This type of claim, however, is for dietary supplements only and will be covered in Chapter 29. Additional information on Qualified Health Claims can be found at http://www.cfsan.fda.gov/~dms/ds-labl.html#qualified.

c. Structure Function Claims Under DSHEA, an additional category of claims was created for dietary supplements and recently (but more limited) for foods (56). These claims may describe the role of a nutrient or dietary ingredient as it affects a human structure or function (e.g., calcium builds strong bones). No claims or implied claims relating to disease are allowed. Structure function claims also may be used to describe the general well-being from consumption of a nutrient or dietary ingredient.

The manufacturer is responsible for the accuracy and truthfulness of structure function claims; they do not need to be approved by the FDA, but it must be notified of such claims within 30 days after marketing the product.

For both conventional foods and functional foods, these structure function claims are limited to nutrients already found in foods rather than added to foods. More details can be found on the web at: http://www.cfsan.fda.gov/~lrd/fr000106.html.

3. Food Claims on the Internet

The Internet has opened marketing to the world in a way never previously seen. Even small food companies can market their conventional and functional foods worldwide. However, as with regulations relating to drugs and drug companies, the FDA and the courts have interpreted company web site information as a form of labeling even if the product is not sold over the Internet. This information is viewed as if it were distributed with the product. Information on noncompany websites may also be considered as labeling.

As of November 1, 2001, the FDA is using a case-by-case approach to Internet food claims, in the hope that innovation will not be stifled. The FDA is posting responses to citizen or food company requests on the Internet in an effort to decrease confusion in this new marketing arena (54).

VI. OTHER REGULATIONS RELATING TO BOTANICAL INGREDIENTS

Although traditional edible vegetables are not a concern in food ingredients, there has been an increasing number of botanical ingredients added to conventional foods. In some cases, these ingredients were added to enhance the perceived nutraceutical properties of products like herbal teas. In other cases, these ingredients were added to promote more drug-like attributes in products like the popular energy drinks.

With the exception of botanical ingredients already approved as food additives that are generally recognized as safe (GRAS), many of these novel ingredients do not meet the FDA's long-standing legal requirements. The status of botanical (or other) ingredients can be deter-

Table 6 Approved Health Claims for Conventional Foods[a]

Diet-disease relationship	Example of approved claim	Reference
Calcium and osteoporosis	Regular exercise and a healthy diet with enough calcium helps teen and young adult white and Asian women maintain good bone health and may reduce their high risk of osteoporosis later in life.	21 CFR 101.72
Dietary lipids and cancer	Development of cancer depends on many factors. A diet low in total fat may reduce the risk of some cancers.	21 CFR 101.73
Sodium and hypertension	Diets low in sodium may reduce the risk of high blood pressure, a disease associated with many factors.	21 CFR 101.74
Dietary saturated fat and cholesterol and risk of coronary heart disease	While many factors affect heart disease, diets low in saturated fat and cholesterol may reduce the risk of this disease.	21 CFR 101.75
Low-fat diets that contain high-fiber from grain, fruit, and vegetables and risk of cancer	Low fat diets rich in fiber-containing grain products, fruits, and vegetables may reduce the risk of some types of cancer, a disease associated with many factors.	21 CFR 101.76
Fruits, grains, and vegetables which contain fiber; particularly soluble fiber and heart disease	Diets low in saturated fat and cholesterol and rich in fruits, vegetables, and grain products that contain some types of dietary fiber, particularly soluble fiber, may reduce the risk of heart disease, a disease associated with many factors.	21 CFR 101.77
Fruits and vegetables and cancer	Low fat diets rich in fruits and vegetables (foods that are low in fat and may contain dietary fiber, vitamin A, and vitamin C) may reduce the risk of some types of cancer, a disease associated with many factors. Broccoli is high in vitamins A and C, and it is a good source of dietary fiber.	21 CFR 101.78
Folate and neural tube birth defects	Healthful diets with adequate folate may reduce a woman's risk of having a child with a brain or spinal cord birth defect.	21 CFR 101.79
Sugar alcohol-containing foods and dental caries	Frequent between-meal consumption of foods high in sugars and starches promotes tooth decay. The sugar alcohols in [name of food] do not promote tooth decay.	21 CFR 101.80

Soluble fiber from certain foods and risk of coronary heart disease	Diets low in saturated fat and cholesterol that include [___ grams of soluble fiber specified in paragraph (c)(2)(i)(G) of this section] of soluble fiber per day from [name of soluble fiber source from paragraph (c)(2)(ii) of this section and, if desired, the name of the food product] may reduce the risk of heart disease. One serving of [name of food] provides ___ grams of this soluble fiber.	21 CFR 101.81
Soy protein and risk of coronary heart disease	25 grams of soy protein a day, as part of a diet low in saturated fat and cholesterol, may reduce the risk of heart disease. A serving of [name of food] supplies ___ grams of soy protein.	21 CFR 101.82
Plant sterol or stanol esters and coronary heart disease	For plant sterol esters: Diets low in saturated fat and cholesterol that include two servings of foods that provide a daily total of at least 1.3 g of vegetable oil sterol esters in two meals may reduce the risk of heart disease. A serving of [name of the food] supplies _____ grams of vegetable oil sterol esters. For plant stanol esters: Diets low in saturated fat and cholesterol that include two servings of foods that provide a daily total of at least 3.4 g of vegetable oil stanol esters in two meals may reduce the risk of heart disease. A serving of [name of the food] supplies _____ grams of vegetable oil stanol esters.	21 CFR 101.83
Potassium and blood pressure and stroke	Diets containing foods that are good sources of potassium and low in sodium may reduce the risk of high blood pressure and stroke.	FDA Docket No. 00Q-1582
Whole grains and heart disease and cancer	Diets rich in whole grains and other plant foods and low in total fat, saturated fat, and cholesterol may reduce the risk of heart disease and some cancers.	FDA Docket No. 99P-2209

[a]Other criteria are required to make these health claims. For a summary of these criteria see: http://www.cfsan.fda.gov/~dms/flg-6c.html
Source: Code of Federal Regulations, April 1, 2002.

Table 7 Useful Regulatory Websites Related to Vegetable Products

U.S. FOOD and DRUG ADMINISTRATION MAIN HOME PAGE
http://www.fda.gov/
SAFETY
Center for Food Safety and Applied Nutrition—Division of FDA responsible for food and cosmetic safety and labeling.
http://vm.cfsan.fda.gov/list.html
Information and regulations on acidified and low-acid canned foods
http://www.cfsan.fda.gov/~comm/lacf-toc.html
LABELING
FDA Food Labeling web site that addresses the labeling requirements for foods, including a section for industry.
http://www.cfsan.fda.gov/label.html
CSFAN page for industry and consumer information on food ingredients and packaging regulations
http://www.cfsan.fda.gov/~lrd/foodadd.html
DIETARY SUPPLEMENTS
FDA's Site of Dietary Supplement Regulation
http://www.cfsan.fda.gov/~dms/supplmnt.html
Office of Dietary Supplements main home page
http://www.dietary-supplements.info.nih.gov/
FDA GENERAL INFORMATION
Web site for the FDA Consumer, the official magazine of FDA.
http://www.fda.gov/fdac/fdacindex.html
Subscribe to email list including dietary supplements and labeling
http://www.fda.gov/emaillist.html
CODE OF FEDERAL REGULATIONS AND FEDERAL REGISTER
http://www.access.gpo.gov/su_docs/index.html
FDA site for searching Title 21 CFR.
http://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/cfrsearch.cfm
MISCELLANEOUS REGULATIONS OF IMPORTANCE
Legal resource for direct selling, multilevel, and network marketing specifically addressing legal definitions and regulations.
http://www.mlmlaw.com/library/guides/fda/compguides/Cpg5_10.html
Requirements of laws and regulations enforced by FDA.
http://www.fda.gov/opacom/morechoices/smallbusiness/blubook/blubook2.htm

mined by using the "Everything" Added to Food in the United States (EAFUS) database (http://vm.cfsan.fda.gov/~dms/eafus.html), which provides references to the relevant sections of the Code of Federal Regulations.

When unapproved ingredients are added to a food, the food is then deemed to be adulterated. If claims related to the food do not meet the claim guidelines, the food is deemed as misbranded. In both cases the food cannot be legally imported or marketed in the United States (55). Recently a number of manufacturers were notified to remove unapproved botanicals, such as echinacea, ginseng, and ginkgo from their beverages (56), and this will continue with unapproved botanicals.

The reader is cautioned that even with GRAS status, there are use and concentration limitations to most added substances. The FDA advises those using novel ingredients to view the Summary of All GRAS Notices updated approximately monthly on the Internet at http://www.cfsan.fda.gov/~rdb/opa-gras.html, or to contact the FDA by electronic mail at premarkt@cfsan.fda.gov.

VII. CONCLUSION

Both traditional public health agencies and the health food industry are promoting the increased use of vegetables for health. However, whether vegetables are being used in foods as conventional culinary ingredients (e.g., tomatoes in chili sauce or mushrooms in canned cream soups), as enhanced flavoring and color additives (e.g., powdered spinach incorporated into pasta), or as botanical ingredients added to promote a nutraceutical purpose (e.g., chamomile added to tea to aid in relaxation), all vegetables and vegetable parts must meet the same standards of safety.

In addition to safety, all foods containing traditional vegetables and/or botanicals must comply with the same labeling standards, including the use of claims. The attached website list includes pertinent websites for meeting federal regulations (Table 7).

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Vegetable and Plant Parts as Legal Dietary Supplements

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I. INTRODUCTION

There is an increasing number of epidemiological studies that support the health benefits of increasing vegetable consumption (1–3). These benefits are generally associated with the typical intake of fresh and cooked vegetables. In addition, there is much interest in potential health benefits from other vegetable components such as fresh and dried culinary herbs, as well as medicinal herbs in the form of dietary supplements (4,5).

This chapter describes many of the known and potential healthful characteristics of typical vegetables consumed as foods or as nonfood vegetable components. Also, potential contraindications are identified for the use of various medicinal plants. In addition, regulations related to the use of vegetable components as dietary supplements are discussed along with the labeling and advertising of these products.

II. BENEFITS AND POTENTIAL RISKS OF VEGETABLES AS DIETARY SUPPLEMENTS

A. Benefits and Risks

With the numerous health-promoting aspects of vegetables and their components, the growing interest in incorporating these into dietary supplements is not surprising. Many of the purported health benefits of commonly consumed vegetables are presumed to be beneficial in dietary supplements that use vegetable products and their components as ingredients (see Chapter 2) (6).

Medicinal herbs of botanical origin extend the use of vegetables into the medical realm. Many plant products have been used in the development of purified drugs with many of the known health benefits claimed by various cultures from traditional use (7,8).

Along with the many benefits, associated health risks related to herbs are quite complicated. Because of the genetic complexities of humans, the variety of potential health/disease conditions, and the addition of an almost limitless number of potential herb and pharmaceutical drug combinations, it is nearly impossible to predict the complete safety of any dietary supplements. And although there is a long history of traditional use for many botanical components of dietary supplements, this is not always the case with new or processed herb products.

1. Culinary Vegetables in Supplement Form

Many popular claims of efficacy and safety are based on beliefs derived from reports of traditional use and ethnobotanical literature. However, when a botanical product is processed into the form of a dietary supplement and used by thousands of people from multiple racial groups for a great variety of health problems, complications are possible. Manufacturers of herbal dietary supplements can reduce their risk by consulting reliable resources related to the ingredients to be used in a product.

Frequently, assumptions are made that the health benefits of vegetables (as indicated by epidemiological studies) are due to specific compounds in vegetables such as carotenoids, isoflavones, etc. As a major carotenoid in many vegetables, β-carotene has often been considered to be a major beneficial compound. This prompted studies of β-carotene supplements that resulted in the unexpected result of increased incidence of lung cancer in smokers who received the β-carotene supplements (9).

Similarly, traditional use of herbal plant materials does not always translate to similar efficacy and safety when the herb is processed into the forms of powders and pills for use as dietary supplements. A highly controversial situation recently developed when the German Federal Institute for Drugs and Medical Devices (BfArM) cancelled all registrations for medicinal products containing kava (*Piper methysticum*) owing to reports of liver damage. In the light of centuries of traditional use of kava or kava-kava in South Pacific cultures, this was unexpected by the supplement industry (10).

2. Functions, Contraindications, Side Effects, and Dangerous Interactions

Major references on botanicals can be contradictory on some issues. It is the authors' opinion that the most reliable science-based references available are *The Complete German Commission E Monographs* (*Commission E*) published in 1998 and *Herbal Medicine: Expanded Commission E Monographs* (*Expanded Commission E*) published in 2000 (11,12). In order for a botanical to be marketed in Germany as an over-the-counter product, approval by the German Commission is required. In addition, these evaluations frequently agree with approvals by both the World Health Organization (WHO) (13) and the European Scientific Cooperative on Phytotherapy (ESCOP) (14).

Commission E includes 380 monographs on various herbs and herbal preparations (11). *Expanded Commission E* focuses on about 100 of the herbs commonly sold in the United States (12). Each monograph is expanded from the original *Commission E* monograph to include updated information on botany, history, composition, safety, efficacy, and therapeutic use. Also, extensive references are included that are not included in *Commission E*. Although many would imply that these references are too limited or outdated, the authors believe that it is important to use a conservative approach both in evaluating function claims based on science and in dietary supplement safety.

Table 1 provides a list of factors that can affect both the functionality of the botanical and the toxicity of the botanical. The uncontrollable nature of these factors makes standardization of active compounds somewhat of a challenge.

Table 2 provides a list of common English names for vegetables and herbs with their botanical (Latin) and pharmacopeial names. Since different species of herbs can sometimes have identical English names, verification of the botanical name for an herb is essential. In addition, various parts of a given plant may be used for very different effects and consequently are not interchangeable. To avoid confusion, the pharmacopeial names identify the plant name and part or type of preparation. For example, the pharmacopeial names basilici herba, basilici folium, and

Table 1 Factors That Can Affect the Functionality and Toxicity of Dietary Supplement Botanicals

Conditions affecting active compound concentrations

1. Growing conditions (soil type and nutrition, climate, weather, and geographical conditions)
2. Processing effects on botanical compounds (powders, extracts, tinctures, dried plant part)
3. Pharmaceutical quality of supplement
4. Standardization of active ingredients concentration

Conditions affecting botanical safety for humans

1. Dosage (per body size, age, gender, health)
2. Mode of administration (pill, powder, gel, liquid)
3. Health status of individual (immune system status, as well as free of illness or injury or already in a disease state)
4. Reproductive state of individual (pregnancy, lactation)
5. Children and elderly
6. Intake of potentially conflicting substances (pharmacological drugs, over-the-counter drugs, nutrient dietary supplements, and other botanical dietary products)
7. Duration of dosage

basilici aetheroleum refer to the whole above-ground herb, the leaf, and the oil of the herb, respectively. See *Commission E* for a more complete discussion of this nomenclature.

Table 2 also identifies the *Commission E* approval status and provides quick reference to various positive and negative properties that each plant part may have. The table information is derived from three key sources (11,12,15) with supplemental information from other respected sources (13,16). Table 2 often reflects that a botanical can have both a positive and a negative effect on the same physiological system depending on dosage, duration of use, or other factors listed in Table 1. Contradictory information can be readily identified by comparing stated uses for an entry and the contraindications and side effects given.

Contraindications are conditions with which an herb or other botanical should not be used. Examples of the types of contraindications identified in *Commission E* for various herbs include allergies, children and infants, diabetes, gallstones, HIV, and renal inflammation or disease.

Side effects are potential adverse reactions that have been reported for an herb. As with purified drugs, the occurrence of an adverse reaction to a particular herb (side effect) may be rare and should not be considered to be an inevitable result of using an herb or herbal product.

Reproduction, lactation, and the effect of botanicals on children are listed in the table only when there has been a known effect. However, it should be cautioned that these populations are at greater risk from potential toxicity side effects of botanicals.

3. Adverse Events Monitoring

The U.S. Food and Drug Administration, Center for Food Safety and Applied Nutrition, Office of Special Nutritionals has established a Special Nutritionals Adverse Event Monitoring System (SN/AEMS). This system obtains and records information from a wide variety of sources with the purpose of identifying emerging public health problems related to marketed products. Since an adverse event associated with a product may or may not have been caused by the product, the system is designed to identify patterns of adverse and unanticipated or unintended safety problems that may call for public health action (17).

Table 2 Examples of Edible Botanicals and their Pharmacological Actions When Consumed as Dietary Supplements

Names			Comm E approval status	Primary sources	Known functions	Known contraindications	Known side effects	Known interactions
English	Scientific	Pharmacopeial						
Allspice	*Pimento officialis*	—	—	3	—	Ca/G/(Rp/Rpc)	CNS/Np1/G	d
Anise	*Pimpinela anisum*	*Anisi fructus*	*a-1*	1/3	G1/R	Da/Rp	D/R/G/Np/E/Rh3	n
Artichoke leaf (globe)	*Cynara scolymus*	*Cynarae folium*	*a-1*; *a-2*	2	G1	Da/L2	—	—
Asparagus root	*Asparagus officinalis*	*Asparagi rhizoma*	*a-1*; *a-2*	2	U1/U2	U2	D	—
Basil herb	*Ocimum basilicum*	*Basilici herba*	*u-1*	1/3	—	E1/Rpc	E/L1CA	d
Bitter melon; balsam pear	*Momordica charantia L.*	—	—	3	—	Rpc/Da	L1/G1/NP1	d
Black pepper	*Piper nigrum*	—	—	3	—	Rpc/Da/L1	G/R/Rpc	d
Borage flower	*Borago officinalis*	*Boraginis flos*	*u-1*	1/3	—	(Rpc)	L1	—
Borage herb	*Borago officinalis*	*Boraginis herba*	*u-1*	1/3	—	(Rpc)	L1	—
Burdock root	*Arctium lappa*	*Bardanae radix*	*u-1*	1/3	—	E1/CV	E2/CV	d
Burdock root	*Arctium minus*	*Bardanae radix*	*u-1*	1/3	—	E1/CV	E2/CV	d
Burdock root	*Arctium tomentosum*	*Bardanae radix*	*u-1*	1/3	—	E1/CV	E2/CV	d
Caraway oil	*Carum carvi*	*Carvi aetheroleum*	*a-1*	1/3	G	Da	D/G3	—
Caraway seed	*Carum carvi*	*Carvi fructus*	*a-1*	1/3	G	Da	D/G3	—
Cardamom seed	*Elettaria cardamomum*	*Cardamomi fructus*	*a-1*	1/3	G1	L2/G1/(Rpc)	L2/Da	—
Cayenne	*Capsicum spp.*	*Capsici fructus*	*a-2*	2/3	Rh1	(Rpc)	D	d
Celery	*Apium graveolens*	*Apium graveolens*	—	3	—	Rp/(Rpc)/U1	CNS/Rp/D/Da/	—
Celery herb	*Apium graveolens*	*Apii herba*	*u-1*	1/3	—	Rp/(Rpc)/U1/Da	CNS/Rp/D/Da/	—
Celery root	*Apium graveolens*	*Apii radix*	*u-1*	1/3	—	Rp/(Rpc)/U1/Da	CNS/Rp/D/Da/	—
Celery seed	*Apium graveolens*	*Apii fructus*	*u-1*	1/3	—	Rp/(Rpc)/U1/Da	CNS/Rp/D/Da/	—
Chamomile, German	*Chamomilla recutita*	*Matricariae flos*	*u-1*; *a-2*	2	G	D	—	h
Chamomile, German	*Matricaria chamomilla*	*Matricariae flos*	*u-1*; *a-2*	2	G	D	—	h
Chamomile, Roman	*Chamaemelum nobile*	*Chamomillae romanae flos*	*u-1*	1/3	—	Rp/R/Da	R/Da	d/h
Chamomile, Roman	*Anthemis nobilis*	*Chamomillae romanae flos*	*u-1*	1/3	—	Rp/R/Da	R/Da	d/h
Chicory	*Cichorium intybus*	*Cichorium intybus*	*a-1*	1/3	—	Rpc/CV/Da/L2	D	—
Cinnamon	*Cinnamomum verum*	*Cinnamomi ceylanici cortex*	—	3	—	(Rpc)	Cv/CNS/G/R	—
Cinnamon bark, Chinese	*Cinnamomum aromaticum*	*Cinnamomi cassiae cortex*	*a-1*; *a-2*	2	Np1/G	D/Rpc	D	—
Cinnamon bark, Chinese	*Cinnamomum cassia*	*Cinnamomi cassiae cortex*	*a-1*; *a-2*	2	Np1/G	D/Rpc	D	—
Cinnamon flower	*Cinnamomum aromaticum*	*Cinnamomi flos*	*u-1*	1	—	—	D/G	—
Cinnamon flower	*Cinnamomum cassia*	*Cinnamomi flos*	*u-1*	1	—	—	D/G	—
Cloves	*Eugenia caryophyllus*	*Caryophylli flos*	*a-1*	1/3	G	(Rpc)	G/R/D	—
Cloves	*Syzgium aromaticum*	*Caryophylli flos*	*a-1*	1/3	G	(Rpc)	G/R/D	—

Cloves	*Jambosa caryophyllus*	*Caryophylli flos*	*a-1*	1/3	G	(Rpc)	G/R/D	—
Coffee	*Coffea canephora*	*Coffeae carbo*	*a-1*	1/3	G3/G	Rp/Rp1/CV	CV/Np/G/U/Rh1	I/d
Coffee	*Coffea liberica*	*Coffeae carbo*	*a-1*	1/3	G3/G	Rp/Rp1/CV	CV/Np/G/U/Rh1	I/d
Coffee	*Coffea arabica*	*Coffeae carbo*	*a-1*	1/3	G3/G	Rp/Rp1/CV	CV/Np/G/U/Rh1	I/d
Cola nut	*Cola nitida/Cola spp.*	*Colae semen*	*a-1*; *a-2*	2	Np2	G/(Rpc)/CV/NP	Np3	d/f/h
Comfrey herb	*Symphytum officinale*	*Symphyti herba*	*a-1*	1/3	D	(Rpc)/L1	L1/G/G1	—
Comfrey leaf	*Symphytum officinale*	*Symphyti folium*	*a-1*	1/3	D	(Rpc)/L1	L1/G/G1	—
Comfrey root	*Symphytum officinale*	*Symphyti radix*	*a-1*	1/3	D	(Rpc)/L1	L1/G/G1	—
Coriander seed	*Coriandrum sativum*	*Coriandri fructus*	*a-2*	2/3	Np1/G	(Rpc)	G/L1/Da	d
Cranberry	*Vaccinium macrocarpon*	*Vaccinium fructus*	—	3	U	U1	G3/Da	—
Dandelion herb	*Taraxacum officinale*	*Taraxaci herba*	*a-1*; *a-2*	2/3	G	Rp/E1/U1/G	G/Da	d
Dandelion root w/herb	*Taraxacum officinale*	*Taraxaci radix cum herba*	*a-1*; *a-2*	2/3	G	Rp/E1/U1/G/L2	G/Da	d
Dill seed	*Anethum gravelons*	*Anethi fructus*	*a-1*	1	—	(Rpc)/U1	U1/D	—
Fennel oil	*Foeniculum vulgare*	*Foeniculi aetheroleum*	*a-1*; *a-2*	2	G/R	(Rpc)	CNS/D/R/Ca/G	d
Fennel seed	*Foeniculum vulgare*	*Foeniculi fructus*	*a-1*; *a-2*	2	G/R	(Rpc)	CNS/D/R/Ca/G	d
Fenugreek seed	*Trigonella foenum-graecum*	*Foenugraeci semen*	*a-1*; *a-2*	2/3	Np1	Rp/D	D/CV/E	d
Flaxseed	*Linum usitatissimum*	*Lini semen*	*a-1*; *a-2*	2/3	G	(Rpc)/G2/U1	G/D/Np2/CNS/R	d, f
Garlic	*Allium sativum*	*Allil sativi bulbus*	*a-1*; *a-2*	2/3	CV/H	Rpc/G/D	CNS/G/E2/D	d, h
Ginger root	*Zingiber officinale*	*Zingiberis rhizoma*	*a-1*; *a-2*	2/3	G/H/I/E	L2/(Rp)	G1/D	d
Green tea	*Camellia sinensis*	*Camellia folium*	—	3	I	U2/G1/CV	CV/CNS/G/D	d, f, h
Horseradish	*Armoracia rusticana*	*Armoraciae rusticanae radix*	*a-1*; *a-2*	2/3	R/G/Rh1	G/U2/Rpc/E2	G/D	—
Kava kava	*Piper methysticum*	*Piperis methystici rhizoma*	*a-1*; *a-2*	2/3	—	(Rpc)/NP	L1/Ca/G/H/R/D	d, f
Kelp	*Laminaria lyperborea*	*Laminariae stipites*	*u-1*	1	—	Rp/E2/D	H/Rp/CV/G/Da	d
Lemon balm	*Melissa officinalis*	*Melissae folium*	*a-1*; *a-2*	2	Np3/G	(Rpc)/E2/D	G1/Np1	—
Lemon grass	*Cymbopogon citratus*	*Cymbopoginis citrati herba*	*u-1*	1/3	I	—	R	—
Licorice root	*Glycyrrhiza glabra*	*Liquiritiae radix*	*a-1*; *a-2*	2/3	R/G	L1/CV/U2/(Rpc)	CV/CNS/G1/D/	d, I
Lovage root	*Levisticum officinale*	*Levistici radix*	*a-1*	1/3	U	U2/CV/H/(Rpc)	G/D	d
Marjoram herb	*Origanum majorana*	*Majoranae herba*	*u-1*	1/3	—	(Rpc)	G1/G3/Np1/D	—
Marjoram oil	*Origanum majorana*	*Majoranae aetheroleum*	*u-1*	1/3	—	(Rpc)	G1/G3/Np1/D	—
Mint/Peppermint oil	*Mentha arvensis*	*Menthae arvensis aetheroleum*	*a-1*; *a-2*	2/3		G/L2/R/Rh	L/G1/D/(Rpc)	
G1/G3/D/Da	—							
Nutmeg	*Myristica fragrans*	*Myristica frangrans*	*u-1*	1/3	—	Rp/(Rpc)/Np	Rp/Np/G/D	d
Onion	*Allium cepa*	*Allii cepae bulbus*	*a-1*; *a-2*	2	Np1/CV	—	—	—
Oregano	*Origanum vulgare*	*Origani vulgaris herba*	*u-1*	1	—	(Rpc)/D	R/G/D/	—
Parsley herb and root	*Petroselinum crispum*	*Petroselini herba/radix*	*a-1*; *a-2*	2/3	U1/U2	L1/U2/CV/(Rpc)	CV/G/L1/U2/R/D	d
Peppermint leaf	*Mentha × piperita*	*Menthae piperitae folium*	*a-1*; *a-2*	2/3	G/L	L/G1/D/(Rpc)	G1/G3/D/Da	—

(*continued*)

Table 2 Continued

Names			Comm E approval status	Primary sources	Known functions	Known contraindications	Known side effects	Known interactions
English	Scientific	Pharmacopeial						
Peppermint oil	*Mentha × piperita*	*Menthae piperitae aetheroleum*	*a-1*; *a-2*	2/3	G/L2/R	L/G1/D/(Rpc)	G1/G3/D/Da	—
Plantain	*Plantago lanceolata*	*Plantaginis lanceolatae herba*	*a-1*; *a-2*	2/3	R	(Rpc)/G2/D	G/Da/	d
Psyllium seed husk, blonde	*Plantago isphagula; P. ovata*	*Plantaginis ovatae testa*	*a-1*; *a-2*	2	G2/G3	G1/E1	Da	d
Psyllium seed, black	*Plantago psyllium; P. afra*	*Psyllii semen*	*a-1*; *a-2*	2	G/G2	G1	Da	d
Psyllium seed, blonde	*Plantago ovata; P. isphaguta*	*Plantaginis ovatae semen*	*a-1*; *a-2*	2	G/G2/G3	G1/E1	Da	d
Pumpkin seed	*Curcurbita pepo*	*Cucurbitae peponis semen*	*a-1*; *a-2*	2/3	U	(Rpc)/D	U1/CV/G1/D	d
Radish root	*Raphanus sativus*	*Raphani sativi radix*	*a-1*	1	G1/R	L2	—	—
Rhubarb root	*Rheum palmatun; R. officinale*	*Rhei radix*	*a-1*	1	G2	G/(Rpc)	G/U/CV/G3	—
Rosemary leaf	*Rosmarinus officianlis*	*Rosmarini folium*	*a-1*; *a-2*	2	G1	Rp	—	—
Saffron	*Crocus sativa*	*Croci stigma*	*u-1*	1	—	—	Rp/G3/Np/O/D	—
Sage leaf	*Salvia officinalis*	*Salviae folium*	*a-1*; *a-2*	2/3	G1	Rp/(Rpc)/ E1/CNS	CNS/Rh3/G1/D	—
Spinach leaf	*Spinacia oleracea*	*Spinaciae folium*	*u-1*	1	—	NSI	—	—
Thyme	*Thymus vulgaris*	*Thymi herba*	*a-1*; *a-2*	2	R	Rp	—	—
Turmeric root	*Curcuma longa*	*Curcumae longae rhizoma*	*a-1*; *a-2*	2/3	G1	L/G1/(Prc)	G1/Np1/D	d
Watercress	*Nasturtium officinale*	*Nasturtii herba*	*a-1*; *a-2*	2*	R	G/U1/Rp-c	G	—

Commission E approval status: *a* = approval, *u* = unapproval, (#) refers to primary source.
Known functions: presence of a code for a system or function indicates that reasonable evidence exists for potential benefit.
Known contraindications: presence of a code for a system or function indicates that reasonable evidence exists for potential negative effects.
Known interactions: presence of a code indicates that evidence exists for potential negative interactions (d = drug; f = food; h = herb; n = nutrient; l = laboratory tests).
(#) = paranthesis around any of the following initials indicates precautionary steps necessary until information indicates otherwise.
CV = cardiovascular system; Ca = Cancer; CNS = central nervous system problems; D = dermatitis; Da = allergic reaction including anaphylactic shock; E = endocrine functions; E1 = diabetes; E2 = thyroid; G = gastrointestinal tract; G1 = upper GI functions; G2 = constipation; G3 = diarrhea; H = hematology/lymphatic; I = immune system; L = liver + gall bladder; L1 = liver; L2 = gall bladder; NP = neural/psychological; NP1 = appetite; NP2 = fatigue; NP3 = normal sleep; NSI = not sufficient information to make claims; O = ophthalmologic; R = respiratory system; Rh = muscle/joint system; Rh1 = muscle; Rh2 = joint; Rh3 = convulsions; Rp = pregnancy and lactation; Rpc = Pregnancy, lactation, and children; U = urinary tract and kidney; U1 = bladder; electrolyte balance; U2 = kidney function.
Source: Primary sources used: 1 = Commission E (Ref. 11); 2 = Commission E, Expanded (Ref. 12); 3 = Mosby's Handbook of Herbs and Natural Supplements (Ref. 15).

B. Additional Sources of Reliable Information

Although there seem to be more sources available that rely on information about the traditional use of herbs than on science-based data, there are additional science-based sources available for the public (18–21).

It has become obvious that herbal dietary supplement information on Internet web sites must be used with caution. In July 2002, the Federal Trade Comminssion (FTC) sent a press release warning consumers about more than 280 web sites making questionable health claims. This evaluation was made by a 19-member international Internet health network of consumer protection law enforcement agencies led by the Australian Competition and Consumer Commission and can be found at http://www.ftc.gov/opa/2002/07/biopulse2.htm.

Because the area of dietary supplements is changing so rapidly, valid web sites may be the best way to stay current. Table 3 provides web sites of particular interest for dietary supplements.

III. DIETARY SUPPLEMENT HEALTH AND EDUCATION ACT OF 1994

In October 1994, the Dietary Supplement Health and Education Act (DSHEA) was enacted (Public Law 103-417). This legislation was developed with the intention to provide consumers with the option to include dietary supplements in their overall health choices to decrease both disease and health-care expenses (22).

Rather than view dietary supplements as drugs, DSHEA regulates dietary supplements more like foods. Dietary supplement labels are required on every supplement with a number of similarities to the nutrition facts panel found on foods. In both cases, the manufacturers must ensure that the label information is truthful and not misleading (23).

There are four key features of DSHEA, besides labeling, which include

1. Legal definition of the term dietary supplement.
2. Placement of the premarket burden of safety on the manufacturers of dietary supplements.
3. Identification of constraints for written information relating to dietary supplement sales requiring that it be scientifically valid and not misleading.
4. Creation of the Office of Dietary Supplements (ODS) in the National Institutes of Health (NIH) to coordinate dietary supplement research within NIH. It is also the responsibility of ODS to advise other federal agencies regarding dietary supplements.

A. Dietary Supplement Terminology

The FDA traditionally considered dietary supplements to be composed only of essential nutrients including vitamins, minerals, and proteins. In 1990 the Nutrition Labeling and Education Act identified herbs and similar nutritional substances as dietary supplements. In 1994, DSHEA legally defined dietary supplement to include nonnutrients such as herbs, fish oils, psyllium, enzymes, glandulars, and mixtures of these (22).

The short formal definition of a dietary supplement is a product (other than tobacco) that is intended to supplement a diet and that bears or contains one or more of the following dietary ingredients (23):

A vitamin
A mineral
An herb or other botanical
An amino acid

Table 3 Internet Resources for Information on Medicinal and Culinary Herbs

AGRICOLA (Agricultural online access). National Agricultural Library. Provides access to a large bibliographic database of information on herbs. http://www.nal.usda.gov/ag98/.

AMERICAN BOTANICAL COUNCIL. A comprehensive and current source of information on herbs; membership required for full access. http://www.herbalgram.org/.

AMERICAN HERBAL PHARMACOPOEIA AND THERAPEUTIC COMPENDIUM. Good source of authoritative monographs on botanicals; new monographs are published on a regular basis. http://herbal-ahp.org/.

AMERICAN HERBAL PRODUCTS ASSOCIATION. A national trade association that promotes responsible commerce of products that contain herbs. http://www.ahpa.org/.

AMERICAN HERBALISTS GUILD. A professional organization promoting standards of competency in herbal medicine. http://www.americanherbalistsguild.com/.

AMERICAN SOCIETY OF PHARMACOGNOSY. A professional scientific organization promoting the science of pharmacognosy. http://www.phcog.org/.

BOTANICAL MEDICINE INFORMATION RESOURCES. Website of the Rosenthal Center for Complementary and Alternative Medicine; provides many links to journals, mailing lists, and regulatory information. http://www.rosenthal.hs.columbia.edu/Botanicals.html.

BRITISH HERBAL MEDICINE ASSOCIATION. Professional society founded to advance the science and practice of herbal medicine in the United Kingdom. http://info.ex.ac.uk/phytonet/bhma.html.

CONSUMER LAB.COM. Independent organization that tests herbs and health and nutrition products for purity and accuracy in labeling. http://www.consumerlab.com/.

FDA CENTER FOR FOOD SAFTEY AND APPLIED NUTRITION. Location for industry guidance on labeling. http://www.cfsan.fda.gov/~dms/supplmnt.html.

HERB RESEARCH FOUNDATION. A nonprofit research and education organization that strives to improve world health through the informed use of herbs. http://www.herbs.org/.

HERBAL ABSTRACT PAGE. Provides hundreds of Medline and other abstracts dealing with herbal and traditional Chinese medical therapies. http://www.seanet.com/~vettf/Medline4.htm.

HERBAL MEDICINE FROM MEDLINEplus. Provides links to the latest news on herbs and other practical sources of information. http://www.nlm.nih.gov/medlineplus/herbalmedicine.html.

INTERNATIONAL BIBLIOGRAPHIC INFORMATION ON DIETARY SUPPLEMENTS. IBIDS is a database of published, international, scientific literature on dietary supplements, including vitamins, minerals, and botanicals produced by the Office of Dietary Supplements (ODS) at the National Institutes of Health. It presently contains 676,453 unique scientific citations and abstracts (8/02).

JOURNAL OF NATURAL PRODUCTS. Full text access to the journal of the American Society of Pharmacognocy. http://pubs.acs.org./journals/jnprdf/index.html.

NATIONAL CENTER FOR COMPLEMENTARY AND ALTERNATIVE MEDICINE. (NCCAM). http://www.nccam.nih.gov.

OFFICE OF DIETARY SUPPLEMENTS (National Institute of Health). ODS supports research and disseminates research results in the area of dietary supplements. http://ods.od.nih.gov/index.asp.

ROCKY MOUNTAIN HERBAL INSTITUTE. Offers continuing education courses and other resources on Chinese herbal sciences for medical and health professionals. http://www.rmhiherbal.org/.

WHO MONOGRAPHS OF MEDICINAL PLANTS. Provides online access to a variety of resources on medicinal plants. http://www.who.int/medicines/library/trm/medicinalplants/medplantsdocs.shtml.

U.S. PARMACOPEIA Dietary Supplement Verification Program (DSVP). http://www.usp-dsvp.org/.

A dietary substance for use by man to supplement the diet by increasing the total daily intake. This might include enzymes or tissues from organs or glands
A concentrate, metabolite, constituent, extract, or combinations of these ingredients

and

Is intended for ingestion in pill, capsule, tablet, or liquid form
Is not represented for use as a conventional food or as the sole item of a meal or diet
Is labeled as a "dietary supplement"

The expanded definition can be found at the web site of the Office of Dietary Supplements National Institutes of Health at http://ods.od.nih.gov/whatare/whatare.html.

Botanical ingredients include all plant-derived materials whether fresh, preserved, or dried full plants, plant parts, plant species mixtures, plant extracts, and compounds found in such materials. Items that are commonly termed herbs or herbal products, regardless of whether they meet the dictionary definition of herb or are composed of parts, extracts, or preparations of woody plants, are included as botanical ingredients. Botanicals also include fungi and algae. Herbs are considered to be flowering plants whose stems above ground do not become woody (24).

Any dietary ingredient that was not marketed in the United States in a dietary supplement prior to October 15, 1994 is considered a "new dietary ingredient" (25). If a new dietary ingredient is to be marketed in a dietary supplement, the following conditions must be met:

1. The substance is first considered to be a "dietary ingredient" (26).
   A dietary ingredient is defined as a vitamin, a mineral, an herb or other botanical, an amino acid, a dietary substance for use by man to supplement the diet by increasing total dietary intake, or a concentrate, metabolite, constituent, extract, or combination of any of the above dietary ingredients.
2. The product qualifies for the definition of dietary supplement (see DSHEA terminology above) and is not presently nor has it been authorized for investigation as an approved drug, certified antibiotic, or licensed biologic (26).

Also a dietary supplement containing a new dietary ingredient shall be deemed adulterated unless it meets at least one of two requirements:

1. The dietary supplement contains only dietary ingredients that have been present in the food supply as an article used for food in a form in which the food has not been chemically altered.
2. There is a history of use or other evidence of safety establishing that the dietary ingredient, when used under the conditions recommended or suggested in the labeling of the dietary supplement, will reasonably be expected to be safe, and, at least 75 days before being introduced or delivered for introduction into interstate commerce, the manufacturer or distributor of the dietary ingredient or dietary supplement provides the FDA with information, including any citation to published articles, which is the basis on which the manufacturer or distributor has concluded that a dietary supplement containing such dietary ingredient will reasonably be expected to be safe (25).

B. DSHEA Responsibilities

1. Manufacturers

The greatest difference between the regulation of food products and that of dietary supplements is that the manufacturer is responsible for ensuring that its product is safe prior to marketing. Under

DSHEA's guidelines, manufacturers also are responsible for ensuring that product information is both truthful and not misleading.

Manufacturers must also follow the FDA's Current Good Manufacturing Practices in manufacturing, packing, and holding dietary supplements (27).

The DSHEA amends the adulteration provisions of the FD&C Act. Under DSHEA a dietary supplement is adulterated if it or one of its ingredients presents "a significant or unreasonable risk of illness or injury" when used as directed on the label, or under normal conditions of use (if there are no directions). A dietary supplement that contains a new dietary ingredient (i.e., an ingredient not marketed for dietary supplement use in the U.S. prior to October 15, 1994) may be adulterated when there is inadequate information to provide reasonable assurance that the ingredient will not present a significant or unreasonable risk of illness or injury. The Secretary of HHS may also declare that a dietary supplement or dietary ingredient poses an imminent hazard to public health or safety. However, as with any other food, it is a manufacturer's responsibility to ensure that its products are safe and properly labeled prior to marketing.

2. Food and Drug Administration

Under DSHEA, the FDA's responsibility for dietary supplements begins after a product reaches the market. This responsibility includes evaluating product information on labels, package inserts, and accompanying literature which may make a product unsafe. The FDA recently expanded their evaluations to include product information on company web sites.

DSHEA also grants the FDA the authority to establish Good Manufacturing Practices (GMPs) for dietary supplements that are similar to those used for food products. These GMPs should ensure the safety of dietary supplements throughout formulation, manufacturing, packaging, storage, and shipping.

3. Federal Trade Commission

The Federal Trade Commission (FTC) bears the responsibility of regulating false advertising claims for both food and dietary supplements. Under DSHEA, the FTC is the lead agency to assure that information within and on dietary supplement packages is both truthful and not misleading. This responsibility carries over to accompanying literature as well.

C. Constraints on Written Product Information

There are multiple levels of dietary supplement information available to the consumer, with a significant amount based primarily on traditional uses and "word-of-mouth" testimonials. Prior to passage of DSHEA, information linked to supplement sales was not always based on science, but DSHEA now requires that written information relating to the sale of dietary supplements be scientifically valid and not be misleading to the consumer. This includes constraints on product labeling described below in Section IV.C, "Claims."

D. Office of Dietary Supplements

DSHEA's intention is for the Office of Dietary Supplements (ODS) to be the coordinating body for dietary supplement research within NIH. This responsibility includes (a) promoting scientific research on supplements related to their potential for decreasing the incidence of chronic diseases, (b) becoming a worldwide reservoir for dietary supplement scientific data, and (c) being a scientific adviser to other federal agencies including Human Health Services and the FDA.

IV. LABELING OF DIETARY SUPPLEMENTS

A. General Labeling Information

As with food products, there is a set of information that must be supplied on the product label. This includes a descriptive name of the product that clearly identifies the product as a "dietary supplement" on the front label (e.g., Vitamin E Dietary Supplement). Also required is the name and place of business of the manufacturer, packer, or distributor; a complete list of ingredients; and the net contents of the product. To access current information on basic and specific dietary supplement regulations, see Industry Information and Regulations at the U.S. Food and Drug Administration Center for Food Safety and Applied Nutrition Dietary Supplements web site, http://www.cfsan.fda.gov/~dms/ds-ind.html.

All dietary supplements also require a "Supplement Facts" panel and not "Nutrition Facts," even if the dietary supplement is a nutrient. Below the panel, a statement of ingredients should list all dietary ingredients not already identified in the "Supplement Facts" panel (e.g., rose hips as the source of vitamin C). And the ingredient statement should include other food ingredients (e.g., water, oil, and sugar), and technical additives or processing aids (e.g., colors, flavors, gelatin, preservatives, and stabilizers). See http://www.cfsan.fda.gov/~lrd/fr97923a.html.

In addition, it is also required that ingredient statements clearly indicate which part of the plant is used including those in extracts, oils, and any other form.

B. Supplement Facts Panel

The "Supplement Facts" must include the quantity for each dietary ingredient per serving. The listing may include the source of a dietary ingredient (e.g., "300 mg calcium from calcium gluconate"). If an ingredient is listed in the "Supplement Facts" panel, it is not required to be listed also in the statement of ingredients.

For dietary supplements containing significant amounts of nutrients that have recommendations for daily consumption (Daily Values), ingredient lists must list nutrients in the order that the FDA has established for labeling (28). See Table 4.

For supplements containing botanicals, including proprietary blends, the total quantity of all dietary ingredients in the blend (excluding inert ingredients) must be listed. Also for products containing herbal and/or botanical ingredients, the label must indicate the part of the plant from which the ingredient is derived (e.g., root, leaf, bark).

DSHEA indicates that when an official compendium exists for a dietary supplement, then the supplement must meet the specifications of the compendium or the product can be considered to be misbranded. Three such official compendia include the U.S. Pharmacopeia, the Homeopathic Pharmacopeia of the United States, and the National Formulary.

C. Claims

1. Types of Claims

Based on DSHEA, dietary supplement label claims may only be described in relation to (a) classical nutrient deficiency diseases, (b) the "well-being" achieved by consuming the dietary ingredient, or (c) the "structure/function" of the dietary supplement on the body. In the case of deficiency diseases, the prevalence of the disease in the United States must be disclosed on the supplement label. A guide for industry on dietary supplement claims can be found at http://www.cfsan.fda.gov/~dms/sclmguid.html (29).

Table 4 Reference Nutrient Values for Dietary Supplements

MANDATORY			VOLUNTARY		
Nutrient	Daily Values		Nutrient	Daily Values	
Total fat	65 g	DRV[a]	Vitamin D	400 IU	RDI
Saturated fatty acids	20 g	DRV	Vitamin E	30 IU	RDI
Cholesterol	300 mg	DRV	Vitamin K	80 mcg	RDI
Sodium	2400 mg	DRV	Thiamin	1.5 mg	RDI
Potassium[b]	3500 mg	DRV	Riboflavin	1.7 mg	RDI
Total carbohydrate	300 g	DRV	Niacin	20 mg	RDI
Fiber	25 g	DRV	Vitamin B6	2.0 mg	RDI
Protein	50 g	DRV	Folate	400 mcg	RDI
			Vitamin B12	6.0 mcg	RDI
Vitamin A	5000 IU	RDI[c]	Biotin	300 mcg	RDI
Vitamin C	60 mg	RDI	Pantothenic acid	10 mg	RDI
Calcium	1000 mg	RDI	Phosphorus	1000 mg	RDI
Iron	18 mg	RDI	Iodine	150 mcg	RDI
			Magnesium	400 mg	RDI
			Zinc	15 mg	RDI
			Selenium	70 mcg	RDI
			Copper	2.0 mg	RDI
			Manganese	2.0 mg	RDI
			Chromium	120 mcg	RDI
			Molybdenum	75 mcg	RDI
			Chloride	3400 mg	RDI

g = grams; mg = milligrams; mcg = micrograms; IU = International Units.
Nutrients in this table are listed in the order in which they are required to appear on a label. The second column of nutrients follows directly after the first column. 21 CFR 101.9(c).
This list includes only those nutrients for which a daily reference value (DRV) has been established in 21 CFR 101.9(c);(9) or a reference daily intake (RDI) in 21 CFR 101.9(c);(8);(iv). http://www.cfsan.fda.gov/~dms/flg-7a.html. Revision Jan 30, 1998.
[a]Daily Reference Values (DRVs); Based on diets containing about 2000 calories a day for adults and children over 4 only.
[b]Not mandatory, but if potassium is listed, it should appear in this order.
[c]Reference Daily Intake (RDI).

Just as important as the above stipulations, DSHEA mandates that no supplement can claim directly nor can it be implied that the use of a dietary supplement will assist to diagnose, prevent, mitigate, treat, or cure a specific disease (unless approved under the new drug provisions of the FD&C Act). In other words, it is not permissible to imply that a dietary supplement may detoxify the liver, nor can a dietary supplement prevent osteoporosis (29,30). Numerous examples of permitted and prohibited claims can be found at the MLMLAW site, http://www.mlmlaw.com/index.html.

2. Disease Criteria

Disease is defined as "damage to an organ, part, structure, or system of the body such that it does not function properly (e.g., cardiovascular disease), or a state of health leading to such dysfunctioning (e.g., hypertension); except that diseases resulting from essential nutrient deficiencies (e.g., scurvy, pellagra) are not included in this definition" (30).

Listed below is a summary of ten major criteria that determine if a statement is considered to be a disease claim (30). Additional examples of permissible and nonpermissible claims can be found at http://www.mlmlaw.com/saleswatch (31).

A claim is not permissible if it

1. Claims to have an effect on a disease or class of diseases
2. Claims to have an effect on characteristic symptoms of disease
3. Claims to have an effect on a condition associated with a natural state such as pregnancy
4. Implies to have an effect on a disease because of product name, formulation, or graphics
5. Implies an effect by belonging to a class of products that are intended to diagnose, mitigate, treat, cure, or prevent a disease
6. Portrays a product as promoting health when in reality the function is disease therapy
7. Assists a therapy or drug intended to diagnose, mitigate, treat, cure, or prevent a disease
8. Relates to preventing a disease or to a vector of disease
9. Implies that the product can treat, prevent, or mitigate adverse events associated with a disease therapy
10. Suggests an effect on a disease or diseases

For FDA authorized health claims related to specific nutrients in vegetables (6,32), a dietary supplement may make the appropriate claim only if the product meets all criteria to bear the claim.

3. Disclaimers and Warnings

To make any claim on dietary supplements, a manufacturer must verify that the statements are truthful and are not misleading. Supplement product labels with a claim must also bear the phrase, "This statement has not been evaluated by the Food and Drug Administration. This product is not intended to diagnose, treat, cure, or prevent any disease."

Unlike health claims, structure/function statements do not need to be approved by the FDA before a manufacturer markets the supplement product bearing the statement. However, the FDA should be notified within 30 days after a product that bears the claim is first marketed (29,33).

4. Point of Purchase Supporting Literature

To assist the consumer in choosing dietary supplements, DSHEA allows retail outlets to provide "third-party" materials (e.g., book chapters, scientific abstracts) related to any health-related benefits of dietary supplements. These materials may not contain false or misleading information and cannot promote a specific supplement brand or have product promotional literature attached (23).

5. Internet Claims

The FDA recently indicated that commercial web sites for a product must comply with the same regulations established for product labels and point of purchase supporting literature. Therapeutic claims that indicate that a product is intended for use in the cure, mitigation, treatment, or prevention of disease can force the FDA to establish the product as a drug, placing the product under much more stringent regulation (35).

For more information on dietary supplement labeling and claims that can be made, see the Report of the Commission on Dietary Supplement Labels (36).

V. OTHER CONSIDERATIONS

Staying current in the area of dietary supplements will be a challenge for anyone. To prevent wasting valuable time and resources, staying abreast with FDA responses on safety issues will be crucial. For updated warning and safety information on dietary supplements see http://www.cfsan.fda.gov/~dms/ds-warn.html (37).

VI. CONCLUSION

Both potential benefits and potential risks associated with the use of vegetable and plant parts in dietary supplements can be compelling. These botanical components range from rather basic and harmless culinary vegetables to powerful herbal extractions that can cause death with inappropriate use. Between these extremes, there is a large gray area. As the studies of this gray area continue, surprises related to both benefits and risks are to be expected.

Developers and manufacturers of dietary supplements need to be aware of the regulatory requirements involved in production and marketing of supplements as well as the rapidly growing body of research literature. Like the products' potential effects on people, the financial benefits and risks to manufacturers can be great. The risks can be extremely great for an uninformed manufacturer. Use of the resources reviewed in this chapter can certainly help to reduce the risks.

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25. 21 CFR 190.6.
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29
Safety of Vegetables and Vegetable Products

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I. INTRODUCTION

From its inception, the retail segment of the food industry has prepared foods in consumer-sized portions, using commercially available equipment for cutting, grinding, slicing, cooking, and refrigeration, and applying herbs and spices readily available to consumers at their local grocery.

Over the past several years, some retail segment operators have expanded into food manufacturing/processing-type operations, often using sophisticated new technologies and equipment that are sometimes microprocessor-controlled. Many now desire to alter the atmospheres within food packages or apply federally regulated chemical food additives as a method of food preservation. Food processing operations now being conducted or proposed include cook–chill, vacuum packaging, sous vide, and so on. Most of these involve some forms of vegetable and vegetable products.

II. FACTORS AFFECTING THE GROWTH OF MICROORGANISMS IN FOODS

The U.S. Food and Drug Administration (FDA) has issued the following guidelines regarding the factors affecting the growth of microorganisms in foods.

Food including vegetables and vegetable products is a chemically complex matrix, and predicting whether or how fast microorganisms can grow in any given food is difficult. Most foods contain sufficient nutrients to support microbial growth. Several factors encourage, prevent, or limit the growth of microorganisms in foods. The most important are a_w, pH, and temperature.

A. a_w (Water Activity or Water Availability)

Water molecules are loosely oriented in pure liquid and can easily rearrange. When other substances (solutes) are added to water, water molecules themselves on the surface of the solute

Table 1 Water Activity of Various NaCl Solutions

Percent NaCl (w/v)	Molal	Water activity (a_w)
0.9	0.15	0.995
1.7	0.30	0.99
3.5	0.61	0.98
7.0	1.20	0.96
10.0	1.77	0.94
13.0	2.31	0.92
16.0	2.83	0.90
22.0	3.81	0.86

and the properties of the solution change dramatically. The microbial cell must compete with solute molecules for free water molecules. Except for *Staphylococcus aureus*, bacteria are rather poor competitors, whereas molds are excellent competitors.

a_w varies little with temperature over the range of temperatures that support microbial solutions. Pure water has an a_w of 1.00. The addition of solute decreases the a_w to less than 1.00 (Table 1).

The a_w of a solution may dramatically affect the ability of heat to kill a bacterium at a given temperature. For example, a population of *Salmonella typhimurium* is reduced tenfold in 0.18 minutes at 60°C if the a_w of the suspending medium is 0.995. If the a_w is lowered to 0.94, 4.3 min are required at 60°C to cause the same tenfold reduction.

An a_w value stated for a bacterium is generally the minimum a_w that supports growth. At the minimum a_w, growth is usually minimal, increasing as the a_w increases. At values below the a_w minimum for growth, bacteria do not necessarily die, although some proportion of the population does die. The bacteria may remain dormant but infectious. Most importantly, a_w is only one factor, and the other factors (e.g., pH, temperature) of the food must be considered. It is the interplay between factors that ultimately determines if a bacterium will grow or not. The a_w of a food may not be a fixed value; it may change over time, or it may vary considerably between similar foods from different sources.

B. pH (Hydrogen Ion Concentration, Relative Acidity, or Alkalinity)

The pH range of a microorganism is defined by a minimum value (1, at the acidic end of the scale) and a maximum value (14, at the basic end of the scale). There is a pH optimum for each microorganism at which growth is maximal. Moving away from the pH optimum in either direction slows microbial growth.

Appendix C provides the pH ranges for a number of vegetables and vegetable products. Ranges are used because the pH of foods, even those of a similar type, varies considerably. Shifts in pH of a food with time may reflect microbial activity, and foods that are poorly buffered (i.e., do not resist changes in pH), such as vegetables, may shift pH values considerably.

A food may start with a pH that precludes bacterial growth, but as a result of the metabolism of other microbes (yeasts or molds), pH shifts may occur and permit bacterial growth.

C. Temperature

Temperature values for microbial growth, like pH values, have a minimum and maximum range with an optimum temperature for maximal growth. The rate of growth at extremes of temperature determines the classification of an organism (e.g., psychrotroph, thermotroph). The optimum growth temperature determine its classification as a thermophile, mesophile, or psychrophile.

D. Interplay of Factors Affecting Microbial Growth in Foods

Although each of the major factors listed above plays an important role, the interplay between the factors ultimately determines whether a microorganism will grow in a given food. Often, the results of such interplay are unpredictable, as poorly understood synergism or antagonism may occur. Advantage is taken of this interplay with regard to preventing the outgrowth of *C. botulinum*. Food with a pH of 5.0 (within the range for *C. botulinum*) and an a_w of 0.935 (above the minimum for *C. botulinum*) may not support the growth of this bacterium. Certain processed cheese spreads take advantage of this fact and are therefore shelf stable at room temperature even though each individual factor would permit the outgrowth of *C. botulinum*.

Therefore predictions about whether a particular microorganism will grow in a food can, in general, only be made through experimentation. Also, many microorganisms do not need to multiply in food to cause disease.

Before 1990, the FDA's concern with the safety of the food supply in this country was focused on food chemicals, contaminants, and pathogens related to meat, poultry, milk, and dairy products. Pathogens causing disease outbreaks in other categories of food were also carefully monitored, of course. However, in the last 10 years, the FDA has spent much of its resources on the safety of fruits and vegetables. This affects both retail and commercial processing. The discussion in this section will be concerned with vegetables and their processing from the following perspectives.

III. FRESH AND FRESH-CUT VEGETABLES AND SPROUTS

A. Pathogens

Fresh fruits and vegetables are important to the health and well being of the American consumer. Consumers enjoy one of the safest supplies of fresh produce in the world. However, over the last several years, the detection of outbreaks of food-borne illness associated with both domestic and imported fresh fruits and vegetables has increased. In a January 1997 radio address, President Clinton announced a Food Safety Initiative to improve the safety of the nation's food supply from farm to table. In May of 1997, as part of the president's Food Safety Initiative, the Department of Health and Human Services, the U.S. Department of Agriculture, and the Environmental Protection Agency sent to the President a report that identified produce as an area of concern. In October of 1997, President Clinton announced a plan entitled "Initiative to Ensure the Safety of Imported and Domestic Fruits and Vegetables" (Produce Safety Initiative) to provide further assurance that fruits and vegetables consumed by Americans, whether grown domestically or imported from other countries, meet the highest health and safety standards.

Most fresh fruits and vegetables are grown in fields and orchards that are nonsterile environments. Growers have less control over conditions in the field than in an enclosed processing facility. The surfaces of produce have a microflora that is generally composed of microorganisms that are not of human health significance. Occasionally, low level, sporadic

contamination of produce with human pathogens may occur. Usually such contamination is not of public health significance. For example, the pathogen may not survive until harvest, harvest workers may be instructed to avoid harvesting produce with obvious contamination, such as bird droppings, or postharvest treatments, such as washing cooking or peeling, may remove or inactivate pathogens. However, the processes involved in further commercial manipulation (e.g., washing, cutting, slicing, packaging) or fresh produce offer additional opportunities for product to become contaminated with pathogens or for pathogens on products to grow.

1. Pathogens in Vegetables and Sprouts

Indicators and surrogate microorganisms may be used for evaluating the safety of vegetable products (fresh or fresh-cut) and sprouts by assessing or validating the effectiveness of microbial control measures. Although frequently used on an informal basis within a specific company, the use of indicators is highly dependent upon microbiological criteria that are in place for the specific produce item or category. All the considerations that must be addressed in establishing microbiological criteria must also be in place if indicators are to be utilized in process verification. Sampling design, stringency, and statistical significance are critical to the evaluation of indicators or surrogates in the assurance of food safety. General ideal qualities of indicators and surrogates are valuable starting points when developing a safety program. The importance of selecting the significant target pathogen for the specific product, its source, handling practices, and distribution practices cannot be overemphasized. The same is true for the selection of the indicator or surrogate to represent those pathogens. The extensive lists of considerations and procedures should be helpful when using indicators and surrogates with vegetable produce and sprouts. The use and limitations of indicators and surrogates to determine or validate treatment effectiveness have been delineated. Challenges are identified for selection of an indicator or surrogate for the specific situation and conditions of an individual produce item, including growing, harvesting, processing, handling, storage, and packaging.

2. Surveillance and Sampling

Numerous microorganisms, most of them from enteric environments (for example, *Salmonella* spp., *Escherichia coli* O157:H7, *Campylobacter jejuni*), but also some from other sources (for example, *Clostridium botulinum* and *Listeria monocytogenes*). Although isolation rates can be high, they are not consistent. The percentage of samples contaminated ranges from 0 to 50%, depending upon the product and target pathogen. Because of differences in their production systems, surface morphology, or other factors, some produce items such as lettuce and seed sprouts seem to provide conditions for survival and/or growth.

The number of food-borne illness outbreaks linked to fresh vegetables and reported to the United States Centers for Disease Control and Prevention (CDC) has increased in recent years. Some of this increase is due to improved surveillance, but other factors may also come into play, such as increases in consumption, changes in consumers' habits, and complex distribution systems. Food-borne illness resulting from the consumption of any food is dependent upon a number of factors. For example, the produce must be contaminated with a pathogen that survives and/or grows to infective dose levels at the time of consumption. Temperatures abuse and growth are not always necessary for food-borne illness to occur.

Conditions for survival and/or growth of pathogens necessary for illness are influenced by the type of microorganism, the produce item, and the environmental conditions in the field and the subsequent handling and storage. For example, free moisture on leaves resulting from condensation, rain, or irrigation may promote the survival and growth of microbial populations in an otherwise inhospitable environment. After harvest, pathogens will survive but not grow on the

outer surface of most fresh fruits and vegetables. In some cases, pathogen levels will decline on the outer surface. The rate of decline is dependent upon produce type, humidity, and temperature, as well as the atmosphere and type of packaging used. An important factor that influences microbial growth is the epidermal barrier. Survival and multiplication of pathogens on produce is significantly enhanced once the protective epidermal barrier has been broken by physical damage, such as puncture or bruising, by degradation from plant pathogens, or by processing (for example in fresh-cut produce), especially at nonrefrigerated temperatures. At refrigerated temperatures the ability of the microorganisms to multiply is controlled with the exceptions of psychrotrophic pathogens (for example, nonproteolytic *C. botulinum*, *L. monocytogenes*, *Yersinia enterocolitica*).

Under some circumstances (for example, pressure differentials), wash water may enter intact vegetables such as squash, green pepper, carrots through the stem scar or other opening, permitting pathogen infiltration. Access to nutrients inside the product may allow pathogen multiplication to hazardous levels. Conditions that reduce infiltration of plant pathogens should also prevent infiltration of human pathogens. Another factor to consider is packaging of the product. Packaging of the product under modified atmospheres changes the growth rate of pathogens that may become a concern (for example, growth and toxin production by *C. botulinum*). It should also be noted that specifications requiring very low microbial counts may, in some cases, compromise produce safety because the high populations of nonpathogenic bacteria are potentially a barrier to pathogen growth and reduce the risk of illness associated with fresh-cut products.

Appendix D reproduces following tables from FDA documents:

Table D-1 Examinations of lettuce or salad greens for the presence of pathogens
Table D-2 Examination of mixed raw vegetables for the presence of pathogens
Table D-3 Examination of raw herbs or spices for the presence of pathogens
Table D-4 Examination of raw vegetables other than lettuce and salad greens for the presence of pathogens
Table D-5 Examination of seed sprouts for the presence of pathogens
Table D-6 Examination of unsprouted seeds for the presence of pathogens
Table D-7 Survival and growth of pathogenic bacteria on raw tomatoes
Table D-8 Survival and growth of pathogenic bacteria on raw vegetables other than tomatoes, sprouts, lettuce
Table D-9 Survival and growth of pathogenic bacteria on raw lettuce and salads
Table D-10 Survival and growth of pathogenic viruses on raw vegetables
Table D-11 Survival and growth of pathogenic bacteria on sprout seeds or raw sprouts

IV. MODIFIED ATMOSPHERE PACKAGING

When we discuss the safety of packaged fresh produce, fruits or vegetables, we mention modified atmosphere packaging (MAP) and controlled atmosphere storage (CAS) for the preservation of fresh produce. There have been great technological advances in this area of preservation, particularly as it refers to improving the quality and shelf stability of highly perishable food products, such as produce. However, when using these technologies, careful attention must be paid to the effect on the survival and growth of pathogenic organisms. This section focuses on food safety aspects of packaging technologies that are either commercially available or under investigation. The information has been modified from "Analysis and evaluation of preventive control measures for the control and reduction/elimination of microbial hazards on fresh and fresh-cut produce," Section VI, Microbiological safety of controlled and modified atmosphere

packaging of fresh and fresh-cut produce, FDA, September 2001. All original references are omitted from this section. In view of the modification, consult the original document for unabridged data.

Over the past 20 years, there has been an enormous increase in the demand for fresh fruit and vegetable products that has required the industry to develop new and improved methods for maintaining food quality and extending shelf life. Owing to the complexities involved with produce, that is, varying respiration rates, which are product and temperature dependent, different optimal storage temperatures for each commodity, water absorption, by-product, and so on, many considerations are involved in choosing an acceptable packaging technology. One of the areas of research that has shown promise, and had success, is that of modified atmosphere packaging (MAP). This technique involves either actively or passively controlling or modifying the atmosphere surrounding the product within a package made of various type and/or combinations of films. In North America, one of the first applications of this technology for fresh-cut produce was introduced by McDonald's, which used MAP for lettuce in bulk-sized packages to distribute the product to retail outlets.

The major factors responsible for extending the shelf life of fruits and vegetables include careful harvesting so as not to injure the product, harvesting at optimal horticultural maturity for intended use, and good sanitation. When these are practiced, the implementation of optimum storage conditions through modified atmospheres can be quite effective at maximizing the shelf life and quality of the product.

A modified atmosphere can be defined as one that is created by altering the normal composition of air (78% nitrogen, 21% oxygen, 0.03% carbon dioxide and traces of noble gases) to provide an optimum atmosphere for increasing the storage length and quality of food/produce. This can be achieved by using controlled atmosphere storage (CAS) and/or active or passive modified atmosphere packaging (MAP). Under controlled atmospheric conditions, the atmosphere is modified from that of the ambient atmosphere, and these conditions are maintained throughout storage. Examples of this type of storage and the commercial systems available are listed in Appendix E. MAP uses the same principles as CAS; however, it is used on smaller quantities of produce, and the atmosphere is only initially modified. Active modification occurs by the displacement of gases in the package with a desired mixture of gases. Passive modification occurs when the product is packaged using a selected film type, and a desired atmosphere develops naturally as a consequence of the products' respiration and the diffusion of gases through the film. The numerous film types used in MAP are listed in Appendix E, and some commercially available MAP systems are listed in Appendix E.

Oxygen, CO_2, and N_2 are most often used in MAP/CAS. Other gases such nitrous and nitric oxides, sulfur dioxide, ethylene, chlorine, as well as ozone and propylene oxide have been suggested and investigated experimentally. However, owing to safety, regulatory, and cost considerations, they have not been applied commercially. These gases are combined in three ways for use in modified atmospheres: inert blanketing using N_2, semireactive blanketing using CO_2/N_2 or $O_2/CO_2/N_2$, or fully reactive blanketing using CO_2 or CO_2/O_2.

Normally, the concentration of O_2 in a pack is kept very low (1–5%) to reduce the respiration rate of fruits and vegetables. Reducing the rate of respiration by limiting O_2 prolongs the shelf life of fruits and vegetables by delaying the oxidative breakdown of the complex substrates that make up the product Also, O_2 concentrations below 8% reduce the production of ethylene, a key component of the ripening and maturation process. However, at extremely low O_2 levels (that is, $<1\%$), anaerobic respiration can occur, resulting in tissue destruction and the production of substances that contribute to off-flavors and off-odors, as well as the potential for growth of food-borne pathogens such as *Clostridium botulinum*. Therefore the recommended percentage of O_2 in a modified atmosphere for fruits and vegetables for both safety and quality

falls between 1 and 5% (see Appendix E). However, it is recognized that the oxygen level will realistically reach levels below 1% in MAP produce. It is generally believed that with the use of permeable films, spoilage will occur before toxin production is an issue; MAP of produce, however, should always incorporate packaging materials that will not lead to an anoxic package environment when the product is stored at the intended temperature. This recommendation should be qualified, however, by saying that all films are permeable to oxygen to some degree; the difference pertains to the rate of gas transfer through the film: some films allow greater transfer rates that others. Moreover, the elimination or significant inhibition of spoilage organisms should not be practiced, as their interaction with pathogens may play an integral role in product safety. A number of packers of fresh prepared green vegetables in the United Kingdom have been experimenting with O_2 mixtures between 70 and 100%. The treatment, referred to as "oxygen shock" or "gas shock," has been found to be very effective in inhibiting enzymatic discoloration, preventing anaerobic fermentation reactions, and inhibiting aerobic and anaerobic microbial growth. High levels of O_2 can inhibit the growth of both anaerobic and aerobic microorganisms, since the optimal O_2 level for growth (21% for aerobes, 0–2% for anaerobes) is surpassed. However, there have also been reports of high O_2 (that is, 80–90%) stimulating the growth of food-borne pathogens such as *Escherichia coli* and *Listeria monocytogenes*. Recent studies examining the use of superatmospheric O_2 levels to control microorganisms on produce have found that only O_2 atmospheres close to 100 kPa or lower pressures (40 kPa O_2), in combination with CO_2 (15 kPa), are truly effective. These requirements may be difficult to achieve in industry, since working with such high O_2 levels can be hazardous owing to its flammability. As with most MAP gases, superatmospheric O_2 has varied effects depending on the commodity, and further research is required in this area to elucidate the utility of this technique in the fresh-cut produce industry. A high O_2 MAP group has been formed in the United Kingdom; it includes a number of industry groups distributing MAP foods. More recently, the "high O_2 MAP club" has provided a base for the new "Novel Gases MAP Club" in the United Kingdom, a group that will investigate the use of novel high O_2, argon, and nitrous oxide MAP for extending shelf life and quality of fresh-cut produce. Their main focus is research into the commercial application of this process.

Nitrogen has three uses in MAP: displacement of O_2 to delay oxidation, retardation of the growth of aerobic spoilage organisms, and action as a filler to maintain package conformity. Of the three major gases used in MAP, CO_2 is the only one that has significant and direct antimicrobial activity. A number of theories have been suggested to explain this antimicrobial effect. In general, CO_2 in MAP results in an increased lag phase and generation time during the logarithmic phase of growth of the organisms involved, with inhibition being concentration and temperature dependent. Theories to explain the antimicrobial action of CO_2 have been summarized:

Alteration of cell membrane function including effects on nutrient uptake and absorption
Direct inhibition of enzymes or decreases in the rate of enzyme reactions
Penetration of bacterial membranes leading to intracellular pH charges
Direct changes to the physicochemical properties of proteins

The inhibitory action of CO_2 has differential effects on microorganisms. Thus, while aerobic bacteria such as the pseudomonads are inhibited by moderate to high levels of CO_2 (10–20%), microorganisms such as lactic acid bacteria can be stimulated by CO_2. Furthermore, pathogens such as *Clostridium perfringens*, *C. botulinum*, and *L. monocytogenes* are minimally affected by CO_2 levels below 50%; and there is concern that by inhibiting spoilage microorganisms, a food product may appear edible while containing high numbers of pathogens that may have multiplied due to a lack of indigenous competition. More research needs to be done on the interactions of the background microflora with food-borne pathogens in various modified atmospheres used for

produce, as well as on the effects of different gaseous environments on the survival and growth of bacterial food-borne pathogens on whole and fresh-cut produce. The optimal MAP conditions for produce quality and respiration for a number of fruits and vegetables are listed in Appendix E, which includes the following reference tables:

Table E-1 Commercially available controlled atmosphere systems
Table E-2 Polymers, film types, and permeability availability
Table E-3 Commercially available modified atmosphere packaging systems for small and large quantities of vegetables
Table E-4 Some characteristics and optimum storage conditions of vegetables for MAP
Table E-5 Properties and characteristics of edible films
Table E-6 Edible coating applications and functions
Table E-7 Conditions supporting growth and toxin production by *Clostridium botulinum* on fresh-cut MAP vegetables

V. DEFECTS AND POISONOUS SUBSTANCES IN VEGETABLES AND VEGETABLE PRODUCTS

A. Food Defection Action Levels (FDALs)

The FDA has established maximum levels of natural or unavoidable defects in vegetable and vegetable products for human use that present no health hazard. Such levels are known as Food Defect Action Levels (FDALs). Examples of such defects are insect fragments, molds, rat hair, mammalian excreta, and so on. When a vegetable product contains such defects that exceed the levels defined by the FDAL, such food is adulterated under the law.

Appendix F reproduces the FDALs for selected vegetables and vegetable products.

B. Action Levels for Poisonous Substances in Vegetables and Vegetable Products

The FDA has established action levels and tolerances for poisonous or deleterious substances in vegetables and vegetable products. Action levels and tolerances represent limits at or above which the FDA will take legal action to remove product from the market. Where no established action level or tolerances exists, the FDA may take legal action against the product at the minimal detectable level of the contaminant. Examples of such contaminants are aflatoxin, aldrin, and DDT.

Appendix G reproduces such levels and tolerances for vegetables and vegetable products.

VI. MACROANALYTICAL METHODS FOR VEGETABLES AND VEGETABLES PRODUCTS

Since 1984, the FDA ahs issued a document titled FDA Technical Bulletin Number 5, Macroanalytical Procedures Manual, printed version 1984; electronic version 1988. The agency will be revising this document chapter by chapter.

"Macroscopic" analysis of a product refers to an evaluation of the substance through the use of the unaided senses (primarily sight, smell, or taste) of an individual. Every consumer in our society who exercises some judgment in the purchase of foods, cosmetics, and other consumer goods, knowingly or unknowingly conducts some form of macroscopic examination to detect apparent or obvious defects. In the case of foods, this usually occurs upon purchase or utilization of the product. The examination may range from a cursory, perhaps unconscious visual check of

the product to confirm that everything looks right to a much more detailed scrutiny to check for specific defects. The scene at the fruit or vegetable stand where the careful shopper squeezes and sniffs the produce prior to purchase is probably repeated thousands of times daily across the country. This is a typical consumer macroscopic examination.

Regulatory authorities, in fulfilling responsibilities for protecting public health and safety, conduct more systematic examinations to disclose not only apparent defects but also hidden defects. Over the years, standardized methods of macroscopic examination have evolved for determining filth, decomposition, and foreign matter in foods, drugs, and cosmetics and other products subject to the laws enforced by the U.S. Food and Drug Administration. These methods of analysis have evolved with the input of producers and consumers as well as regulatory authorities.

The objective of this manual is to compile and organize in one volume the standardized methods of macroscopic analyses that are useful in determining defects in various types of foods. Although in a general sense, the term macroscopic is not as broad as the term macroanalytical, for the purposes of this manual, the terms are used interchangeably.

We are concerned of course with vegetables and vegetable products, and Appendix H reproduces those methods affecting these products: asparagus, brussels sprouts, ground horseradish, lettuce, mushrooms, peas and beans, pickled vegetables and relishes, pimientos, potato chips, corn husks, and garlic bulbs.

VII. SAFETY OF VEGETABLE JUICES: LABELING AND PROCESSING

A. Warning Statements and HACCP

Recently, the FDA has issued regulations to cover two aspects affecting the commerce of fruit and vegetable juices in this country: warning statements and HACCP requirements in juice production.

1. Warning Statement

FDA requires labeling with a warning statement those fruit and vegetable juice products (i.e., juices and beverages containing juice) that have not been pasteurized (i.e., heat treated) or treated in another way capable of preventing, reducing, or eliminating harmful bacteria by 100,000-fold. This reduction in bacteria is referred to as a 5-log reduction.

The product label must bear the following label statement:

> **WARNING:** This product has not been pasteurized and, therefore, may contain harmful bacteria that can cause serious illness in children, the elderly, and persons with weakened immune systems.

Appendix 1 reproduces the legal notice.

2. HACCP Requirement

The FDA has issued a new rule designed to improve the safety of fruit and vegetable juices and juice products. Under the rule, juice processors must use Hazard Analysis and Critical Control Point (HACCP) principles for fruit and vegetable juice processing. Implementation of a HACCP system will increase the protection of consumers from illness-causing microbes and other hazards in juices. The FDA has issued the following analysis.

The rule comes after a rise in the number of food-borne illness outbreaks and consumer illnesses associated with juice products during the past several years, including a 1996 *E. coli*

O157:H7 outbreak associated with apple juice products and two citrus juice outbreaks attributed to *Salmonella* spp. in 1999 and 2000. The apple juice outbreak sickened 70 people in the western United States and Canada, including a child who died from hemolytic uremic syndrome caused by the infection. The *Salmonella* enteritidis outbreak in 2000 was caused by unpasteurized orange juice and resulted in 88 illnesses in six western stats. The *Salmonella* Muenchen outbreak in 1999 was caused by unpasteurized orange juice and resulted in 423 illnesses in 20 states and three Canadian provinces and contributed to one death. Food-borne infections are especially dangerous for young children, older adults, and those with weakened immune systems. The FDA estimates that there are between 16,000 to 48,000 cases of juice-related illnesses each year. It is estimated that the action taken due to the rule will prevent at least 6,000 illnesses per year.

HACCP systems call for a science-based analysis of potential hazards, determination of where the hazards can occur in processing, implementing control measures at points where hazards can occur to prevent problems, and rapid corrective actions if a problem occurs. Firms will be required to maintain records in association with implementation of their HACCP plans and verification of those plans. HACCP systems are already federally required for seafood, meat, and poultry processors.

The juice HACCP regulation applies to juice products in both interstate and intrastate commerce. Juice processors will be required to evaluate their manufacturing processes to determine whether there are any microbiological, chemical, or physical hazards that could contaminate their products. If a potential hazard is identified, processors will be required to implement control measures to prevent, reduce, or eliminate those hazards. Processors are also required to use processes that achieve a 5-log, or 100,000-fold, reduction in the numbers of the most resistant pathogens in their finished products compared to levels that may be present in untreated juice. Juice processors may use microbial reduction methods other than pasteurization, including approved alternative technologies (such as the recently approved UV irradiation technology) or a combination of techniques.

Processors making shelf-stable juices or concentrates that use a single thermal processing step are exempt from the microbial hazard requirements of the HACCP regulation.

See Appendix I for the relevant regulations on warning and processing for vegetable juices.

B. Standardized Tomato Juices

The FDA has issued a standard for only one vegetable juice and that is tomato juice. A better understanding of the warning and processing regulations can be reached if one studies the contents of this standardized product. Appendix I reproduces the FDA requirements for standardized tomato juices.

VIII. VEGETABLE PROCESSING ESTABLISHMENTS: PRODUCTS AND WORKERS' SAFETY

When it comes to a food manufacturing plant, the federal and state governments are concerned mainly with three important aspects:

Is the food safe?
Is there any economic fraud?
Are there frequent injuries among workers?

Two federal agencies are responsible for the above: the FDA and the OSHA (Occupational Safety and Health Administration). Each state has its own counterparts with the same mandate.

This section gives a brief overview of these topics.

A. Product Safety and Economic Fraud

For more than half a century, the FDA or its predecessor has been relying on factory inspection to ascertain two variables:

1. Is there any contamination of the product during the manufacturing process to make it unsafe?
2. Is there any attempt to substitute an expensive ingredient with an inexpensive one? Or, is there any attempt to include less than the amount stated on the label?

B. An Example: An Establishment Manufacturing Tomato Products

Neither this chapter nor this book is the proper forum to explain in detail how the FDA inspects a food processing plant. Instead, the critical factors in the FDA's inspection of an establishment processing tomatoes and tomato products are presented here.

The information here has been modified from documents distributed by the U.S. FDA. Although most data are transmitted in a teacher/student format, most quality control officers in a food processing plant can easily adopt the approaches to its in-plant periodic inspection.

1. General Considerations

When conducting a cannery inspection, ascertain the pH of products produced. If the pH is at or above 4.6, determine compliance with FDA regulations. *Note:* Recently developed strains of tomatoes are tending to move some tomatoes from high acid to low acid.

2. Raw Materials: Belt Examination and Evaluation

The first step is randomly to sample sorted tomatoes from the ends of processing belts. Collect at least 100 tomatoes for each examination. During the inspection take sufficient samples from each belt in operation to evaluate sorting practices.

List results for each sample examination using the rot classification method. Smell "sour" tomatoes to confirm decomposition. Evaluate rot pickout percentages.

3. Examination of Field Containers

Sample field containers and other tomato lots awaiting processing and examine, evaluate, and note as for belt samples. A clearly violative condition correlates examinations of sorted tomatoes with similar or worse pickouts of unsorted tomato stocks. This must be differentiated from a single violative belt examination indicative of one small lot of unfit raw stock.

In violative situations,

Note the average holding time, storage conditions, and amount of static and incoming stock.

Note the origin of tomatoes where long-distance hauling with subsequent deterioration of stock is involved.

Determine area growing conditions, such as disease, insects, and weather, bearing on the availability of workable raw stock.

Examine incoming and recently received field stocks, especially broken and cracked tomatoes for fly eggs and maggots.

Examine several lots to establish the relative level of field infestation.

In like manner, examine lots held for several hours or more, especially lots with significant drosophila infestation. Estimate the number of insects. Differentiate between house and vinegar flies in examinations of tomato stocks.

Note the number and percentage of tomatoes examined that show fly eggs and maggots.

4. Processing

a. Sorting, Trimming, and Blending Practices Check sorting and trimming equipment and practices in detail where violative belt examinations are encountered. If processing equipment contains product and slime buildup, note and take scrapings. Include the number of sorters, the length, width, and speed of the belt, the dumping rate, and the estimated load per foot of the belt, as well as the lighting conditions. Note particularly any sudden changes in belt flow, i.e., increase in the number of sorters, or unusual increase in tomato waste disposal, after you arrive. Additional belt examinations under these circumstances are useful in showing that the firm can handle the operation properly.

Determine and note the disposition of tomato waste. Where comminuted products are prepared from skins and cores, and sorting and trimming are poor, raw material pickout data is important.

Borderline pickout results may be indicative of deliberate or accidental blending of good and bad lots on belts.

Determine whether plant quality controls extend to supervising sorting and trimming operations or whether sole reliance is placed on mold counts. Observe the frequency of such counts in relation to raw stock quality.

Be alert for practices indicative of the possible blending of tomato products to reduce or obscure high mold counts. Finished stocks in segregated or "hold" status are particularly suspect. Examine the mold count results to determine the condition of such stocks.

Attempt to determine the disposition or intended usage of any product that the control records show as questionable.

Note that blending can lead to an adulterated product.

b. Sorted and Peeled Stock During rot examinations of sorted stock going into the chopper, also check for the presence of fly eggs and maggots in the cracks and broken areas of the tomatoes.

Examination for fly eggs and maggots in sorted stock is more difficult than in the field hampers. Results normally reflect only minimal counts.

Where field examinations have revealed significant insect infestations and the stock is to be peeled, evaluate the peeling process for inadequacies in washing, scalding, and peeling.

Note, particularly, whether cracked or broken tomatoes are trimmed.

c. Product Codes Be alert for any stocks on plant premises bearing codes deviating from the firm's normal code system. These may be violative products so identified for surreptitious disposition.

d. Standards Determine if a firm's products comply with the requirements of the Standards issued by the FDA and grades issued by the USDA.

Review the firm's Quality Control records to help determine compliance with the various Standards for tomato products.

e. Sample Collection Tomato products in 55 gallon drums or similar large containers, either aseptically filled or heat processed, should not be sampled while the shipment is en route unless the owner accepts responsibility for the portion remaining in the opened containers. Arrange sampling of these products at the consignee (user) so the remaining portion can be immediately used or stored under refrigerated conditions. Use aseptic technique when sampling products in these types of containers.

f. Investigational Collect representative finished product samples where

Average accumulated point score of sorted tomato examinations, based on three or more pickouts, exceeds 10 (in tomatoes for comminution) and rots are predominately fungal (anthracnose, alternaria, etc.).

Average accumulated point score of sorted tomato examinations, based on three or more pickouts, exceeds 10 (in tomatoes for comminution) and rots are predominately bacterial (sours).

An average accumulated point score of five will be used as a criterion for follow-up in the examination of peeled tomatoes with rot entering noncomminuted products (canned tomatoes, canned tomatoes with other vegetables).

Point scoring is primarily directed to the weighing of fungal rots (anthracnose, alternaria, etc.) in tomatoes. Bacterial rots (sours) are included in Class 4, since their use in manufacturing reflects accompanying moldy tomatoes and poor sorting or improper control. Where a violative point score is due primarily to the inclusion of bacterial rots (sours), finished product mold counts may be within tolerance. Action may then be possible only on the basis of factory evidence against products made during the inspection.

To confirm rot type, collect samples of suspect bacterial rots for laboratory confirmation. Sample chopper juice or pulp to correlate with belt pickouts. Preserve samples in formaldehyde, 15 cc commercial formalin per pint of juice or pulp.

For exhibit purposes, submit representative rots obtained in belt pickout after sorting. Preserve these with 1% formaldehyde solution injected under the skin of the fruit, inject 3 mL in each of three locations. Place in a jar with a gel of 0.5% agar and 0.5% formaldehyde. Identify these investigational subdivisions as "exhibit."

If the firm is suspected of adding water to the product, prepare a "Commercial Authentic Pack" as follows:

Observe peeling of sufficient tomatoes to fill approximately thirty cans.

Place peeled stock in clean filling vat and have firm's employees fill in the normal manner into thirty marked cans.

Place cans on packing line for exhausting, capping, and cooking.

Collect the thirty premarked cans as a sample and collect an additional thirty cans of the same style product from previous days' production or from stock packed prior to arriving at the plant.

Submit both sets of subs for comparison against the "Commercial Authentic Pack."

g. Official Samples Note:

If canned tomatoes are to be analyzed for peel, collect a minimum of 48 cans in duplicate.

If samples are to be analyzed for added water, collect an additional 12 cans in duplicate, for analysis.

If sample is to be analyzed for mold only, collect 12 cans in duplicate.

h. Bulk Shipments (Larger than No. 10) If practical, collect aseptic subsamples of 2 pints, each aseptic subsample taken from the square root of the number of containers in the lot, with a minimum of 6 subsamples if possible. Fifteen (15) cc of 37% solution of formaldehyde (commercial formalin) should be added to each 1 pint jar, and jars must be labeled to show the addition of formaldehyde. If permission to subsample cannot be obtained, take I can from each code or batch number. This includes the required 702(b) portion. See note above concerning large containers.

C. Workers' Safety

1. OSHA Grouping of Vegetable Processing Establishments

OSHA has grouped vegetable processing establishments as follows: those engaged in processing canned vegetable products; dehydrated vegetables; pickled vegetables and vegetable sauces; frozen vegetables. These are described below:

a. Canned Vegetable Products These are establishments primarily engaged in canning vegetables and vegetable juices, and those engaged in manufacturing catsup and similar tomato sauces, e.g.,

Artichokes in olive oil, bottled
Catsup
Chili sauce, tomato
Juices, vegetable, canned, bottled, and bulk
Ketchup
Kraut, canned
Mushrooms, canned
Olives, including stuffed, bottled
Pastes, vegetable
Purees, vegetable
Sauerkraut, canned
Seasonings (prepared sauces), tomato
Tomato juice and cocktails, bottled and canned
Tomato paste
Tomato sauce
Vegetables, canned

b. Dried and Dehydrated Vegetables These are establishments primarily engaged in sun drying or artificially dehydrating vegetables. They include

Dehydrated vegetables
Freeze-dry food processing, vegetables
Olives, dried
Potato flakes, granules, and other dehydrated potato products
Vegetables, sulfured

c. Pickled Vegetables and Vegetable Sauces These are establishments primarily engaged in pickling and brining vegetables, and in manufacturing vegetable relishes, sauces, and seasonings. A list of products or processes involved in this industry is as follows:

Brining of vegetables
Horseradish, prepared
Kraut, bulk
Mustard, prepared (wet)
Olives, brined: bulk
Onions, pickled
Pickles and pickle salting
Relishes, vegetable
Sauces, vegetable
Sauerkraut, bulk
Seasonings (prepared sauces), vegetable

Vegetable sauces
Vegetables, pickled and brined
Vinegar pickles and relishes

d. Frozen Vegetables These are establishments primarily engaged in freezing and table cold packing (freezing) vegetables. A list of the products involved in this industry is as follows:

Frozen vegetables
Vegetables, quick frozen and cold pack (frozen)

2. Process of Preserving Vegetables

Food preservation processes employ one of the largest numbers of workers in the food industry and are engaged principally in operations that have one or more of the following main objectives:

To preserve food materials by preventing enzyme, microbial, and oxidative degradation
To prepare raw foods for direct uses
To process materials into prepared food products

The different processes employed in this industry include canning or packaging, dehydration or drying, freezing processes, and other preserving processes. Each of these is briefly discussed in the following sections (see Fig. 1).

Canning or packaging with thermal processing is used to destroy or inactivate the microorganisms and enzymes. Reinfection and oxidation are prevented by sealed containers. Temperature and time are controlled as required. Preheating or blanching with steam or hot water is required for vegetables to clean and deaerate the food. The cans or jars are first filled by machine or by hand, then exhausted with steam and sealed. The product is finally sterilized in pressure cookers, which are usually continuous and automatic types.

Dehydration or drying reduces the water content, thereby inactivating the enzymes and microorganisms that cause spoilage. Artificial drying as well as sun drying methods are used.

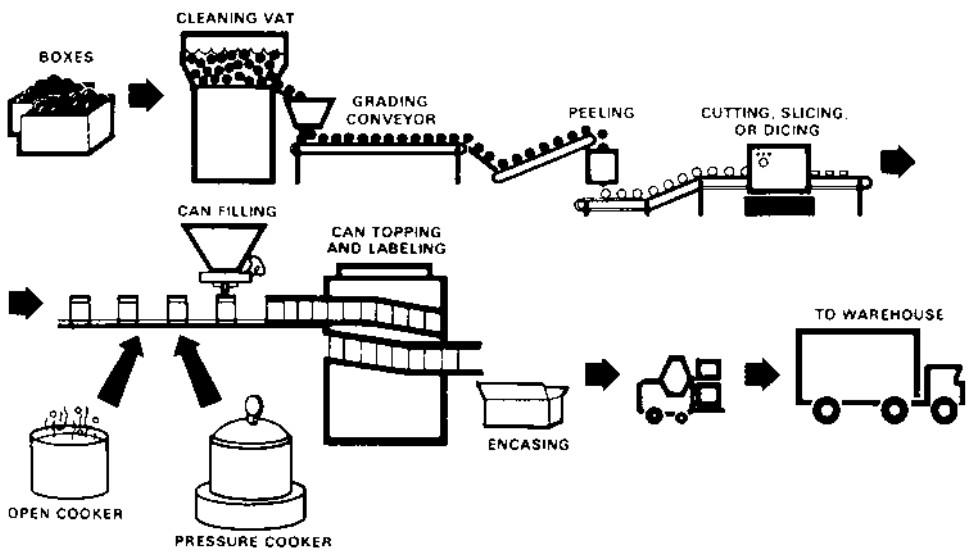

Figure 1 Process flow: canned and preserved fruits and vegetables.

Cabinet dryers, kilns, tunnel, drum, rotary spray, and other special types of dryers are used. Heated air is usually used to carry off the moisture. Freeze-drying, sublimination of the moisture under vacuum, dehydrates the product without raising the temperature.

Freezing processes used for preservation purposes inactivate enzyme and microbial actions. Preparatory blanching is required for some foods. There are three direct contact freezing processes, namely, (a) freezing the product in still air, in refrigerated rooms at nearly zero degree Fahrenheit, (b) blast freezing to improve heat transfer with further strong currents of cold air, and (c) immersion freezing in a bath of iced brine, syrup, or liquefied gas. Indirect contact freezing is also used by circulating refrigerated brine through the hollow metal plates that hold the product.

Other preserving processes include salting (which reduces microbial activity), ultraviolet radiation (which has some bacteriostatic action), and smoke curing. Tomatoes are concentrated into pastes, purees, catsup, etc. In addition to natural products, many cooked or prepared foods are made that are also canned, bottled, or packaged.

The foregoing processes employ a wide diversity in the machines and practices used to clean, screen, crush, grind, press, filter, clarify, preheat, dry, bottle, can, pasteurize, pressure cook, dehydrate, freeze, store, pack, transfer, and generally handle the raw vegetables and other materials during the processing steps. These include automatic machines for forming, filling, and closing the packages. A new process that uses radio frequency rays for package sealing has been developed.

3. Hazards Associated with Canning Vegetables

Canned vegetables are prepared from raw products by canning as individual items or in a mixture. They are received from the grower in open boxes, in crates, or in bulk, and as sources are cleaned by air, water, steam, brushing, or a combination of these methods. Peeling is done both by machines and by hand. Foods are canned both peeled and unpeeled and are canned whole, sliced, or diced. They may be seasoned with salt, sugar, or vinegar. When vinegar is used, the vegetables are normally pickled in open containers for a prescribed time before canning. When salt is used, they are normally cooked immediately and canned or canned and then cooked. When sugar is added, the products are usually canned s, size of immediately uncooked. After canning they are labeled, encased, and stored to await shipment. Except for some cutting and pulling, the operations are generally mechanical with little or no employee contact. See Fig. 1.

4. OSHA Hazards Analysis

See Table 2.

5. Injury Types and Sources

Employees are injured most frequently as a result of being struck by or striking against objects. In general, in canned vegetable plants, some common injuries are cuts, lacerations, punctures, contusions, crushings, and bruises.

6. Internal Plant Inspection

Inspection should begin in the receiving area where produce received in boxes is dumped into a hopper. Boxes must be checked for loose nails, boards, and other damage. The hopper must be inaccessible or guarded. The fork lift or front end loader must be checked for safety equipment, trained and authorized operators, and safe operation procedures. The cleaning process must be evaluated for employee exposure to dust, dirt, caustic materials, and hot substances. All conveyor systems must be evaluated for nip point guards, guards on V-belts and chain drives, and tagging

Table 2 OSHA Hazards Analysis

Type of hazards	Item	Location
Major hazards		
Falling objects from stacked materials and forklift trucks	Boxes, cases	Receiving, storing, and shipping
Overturning striking person, striking other vehicles	Forklift trucks	Cleaning area
Carbon monoxide poisoning, asphyxiation	Forklift trucks	Cleaning area
Burns from steam, hot kettles or caustics, foreign objects in eyes	Cleaning agent, dust and dirt	Cleaning area
Slips, trips, falls	Wet floors	Throughout plant
Unguarded nip points in conveyor chains and belts and on chain and belt drives	Conveyers	Throughout plant
Hearing loss	Noise	Throughout plant
Unguarded moving parts causing hand injuries	All machines	Canning room
Other hazards		
Back injuries, hernia, hand and foot injuries from manual loading pallets	Encasing and palletizing	Storage preparation
Fire, dermatitis	Glue	Labeling
Inhalation of toxic vapors	Acetic acid	Seasoning area

and lockout procedures. Exposed moving parts of other machines must be guarded, and locking and tagging procedures must be established. Means of egress must be provided for all employees from their work area. Machine tender stations must be located at the safest position possible with convenient egress. Personal protective equipment must be worn by employees exposed to eye and hand hazards and falling objects. Cases must be interlocked on pallets to prevent falling when stored. Employees in the warehouse, as well as in receiving, must wear head protection, and foot protection is required when moving cases by hand.

Slips, trips, and falls comprise the most frequent types of accidents because of wet floor conditions. Injuries to hands, feet, and the back occur rather frequently from handling cases and containers of products and canning, materials. There are hand injuries from moving machine parts.

IX. DISEASE OUTBREAKS: VEGETABLES AND VEGETABLE PRODUCTS

A. Introduction

Disease outbreaks from vegetables and vegetable related products derive from the following:

1. Contamination in fresh and fresh-cut vegetable produce
2. Contamination from processed (minimum, regular) vegetables and vegetable products
3. Contamination in seed sprouts

B. Fresh and Fresh-Cut Vegetables

Although the incidence of food-borne illness linked to fresh produce is still low, there is evidence that it is increasing. Fresh produce is of special concern because it is likely to be consumed raw, without any type of microbiologically lethal processing. According to the Centers for Disease Control and Prevention (CDC), the number of reported produce-related outbreaks per year doubled between the period 1983–1987 and 1988–1992, when illnesses due to botulism and mushrooms and "salad" were excluded. Substantial increases in produce-related human illness were also observed in 1995. Outbreak data linked *Salmonella* Stanley with alfalfa sprouts, *Shigella* spp. with lettuce and scallions, *Escherichia coli* O157:H7 with lettuce varieties, and hepatitis A virus with tomatoes. More recently, there have been outbreaks linking Cyclospora with mesclun lettuce and basil/basil-containing products, *E. coli* 0157:117 with alfalfa/clover sprouts, *Salmonella* spp. with clover and alfalfa sprouts, and *S. baildon* with raw tomatoes. These are only limited examples of identified outbreaks associated with fresh and minimally processed produce.

Appendix J reproduces the following reference tables distributed by the FDA:

Table J-1 Examples of reported outbreaks of food-borne disease associated with raw lettuce or salads.
Table J-2 Examples of reported outbreaks of food-borne disease associated with raw vegetables other than seed sprouts, and lettuce or salads.
Table J-3 Examples of reported outbreaks of food-borne disease associated with raw vegetables due to contamination during final preparation
Table J-4 Examples of reported outbreaks of food-borne disease associated with seed sprouts.

C. Disease Outbreaks from Tomato Contamination

The U.S. Centers for Disease Control (CDC) reported the following two cases of disease outbreaks from contaminated raw tomatoes.

1. Multistate Outbreak of *Salmonella enterica* Serotype Baildon Associated with Domestic Raw Tomatoes

Salmonella enterica serotype Baildon, a rare serotype, was recovered from 86 persons in eight states; 87% of illnesses began during a 3-week period ending January 9, 1999. Raw restaurant-prepared tomatoes were implicated in multiple case-control studies. Contamination likely occurred on the farm or during packing; more effective disinfection and prevention strategies are needed.

We report our investigation of a large, multistate outbreak of 86 cases of salmonellosis associated with eating raw domestic tomatoes; this is the third such outbreak in the United States in recent years.

Outbreak patients were persons from whom *Salmonella enterica* serotype Baildon was recovered between December 1, 1998, and March 1, 1999.

The traceback identified two tomato grower/packer cooperatives, in Florida, which could have supplied tomatoes eaten by the 14 patients who reported only one or two standard encounters during the exposure period. In April 1999, the only cooperative still packing tomatoes was investigated. Tomatoes had reportedly been hand-picked and were transported to the packing facilities in covered bins. Tomatoes were unloaded into a dump tank and moved by a flume system (water temperature 38.7°C, pH 6.5, target chlorine reported as 125 ppm but not measured) to a warm spray wash. Tomatoes were mechanically sorted (unacceptable tomatoes were manually removed), waxed, and boxed. Packed tomatoes were stored at 21.1°C in ripening rooms.

The tomato dicing operation in California was inspected in May 1999. Uncored tomatoes were washed, inspected for decay, color, and stem removal, and then conveyed to a mechanical dicer. Diced tomatoes were moved by a flume system to a perforated shaker-belt conveyor, mechanically packaged into 5-pound trays, sealed and stored at 4.4°C. Tomatoes were held for one day before being shipped by refrigerated truck to two distributors. Target water temperature, total chlorine, and hold times for the bath and flume were reported by the processor as 1.1°C, 100–130 ppm, and 1–2 minutes, respectively. Wash water temperatures and chlorine levels were maintained manually, whereas the flume system was chlorinated by an automated system. During inspection, this system's pH monitor did not work. Temperature was measured at 2.2°C.

Tomatoes served in Virginia were processed at the individual POS facilities. Whole uncored tomatoes were washed and cut by knife or mechanical chopper.

This large, multistate outbreak was caused by *S. baildon*, an unusual *Salmonella* serotype. The outbreak was associated with eating raw tomatoes. Because less than three percent of estimated *Salmonella* cases are officially reported nationwide, this outbreak could have included 3,300 cases.

Raw tomatoes were epidemiologically implicated as the source of this outbreak. This finding is supported by several observations. First, eating raw tomatoes was strongly associated with illness in the case-control studies, and nearly all patients ate them. Second, these studies were conducted independently, using different control recruitment strategies. Third, raw tomatoes have a 3-week shelf life, consistent with the brief occurrence of the outbreak.

That many restaurants across several states were involved suggests the tomatoes were likely contaminated early on, at the farm of during packing. *Salmonella* can grow on tomato skin surfaces and infiltrate core tissues during tomato harvest, packing, and transportation. Air spaces in tomatoes at high field-heat temperatures can constrict when submerged in cool water. As air space volume decreases, water and *Salmonella* can be drawn (by vacuum effect) from the dump tank into the fruit through the stem scar. For these reasons, postharvest process water should be potable and warmer than the incoming fruit.

Once tomatoes are contaminated, elimination of *Salmonella* can be difficult. While chlorine levels of 200–250 ppm would be expected to reduce *Salmonella* substantially, even higher levels of chlorine disinfection (320 ppm) did not eliminate *Salmonella* from tomatoes in one laboratory study. The efficacy of chlorine against *Salmonella* depends, in part, on the location and amount of contamination. *Salmonella* inoculated onto stem scars and growth cracks survived disinfection better than on smooth tomato skins.

The grower/packer cooperative we observed had at least some elements of a hazard analysis critical control point (HACCP) program for commercial tomato packinghouses including warm, chlorinated wash water. However, we observed operations after the outbreak and did not have access to historic water quality measures (free chlorine, pH, and temperature). Even if free chlorine levels of 125 ppm were maintained, such levels would not be expected to eliminate organisms in stem scars or damaged tomato skin.

Dicing and pooling of contaminated tomatoes in our outbreak may have played a role in amplifying the amount of contaminated product, just as these were suspected to have played a role in prior outbreaks. The diced tomato processor we observed in California exposed both whole and diced tomatoes to chlorine. However, laboratory experiments demonstrated that *S. baildon* could survive disinfection with 200 ppm chlorine in diced tomatoes. Microorganisms in tomatoes are highest around the stem scar and central core, where they are less accessible to chlorine. Therefore the practice of including stem scars and cores in pooled, finished product could have increased the opportunity for amplification, especially if the diced tomatoes were later mishandled. Contamination of internal tissue from the outer skin and stem scar can also occur during cutting and slicing. Numerous *Salmonella* serotypes, including our outbreak strain, grow rapidly

in cut tomatoes held at room temperature. If the involved restaurants maintained tomatoes at room temperature for extended periods, even small populations of *Salmonella* on sliced or diced tomatoes could have grown rapidly.

While chlorine-based water quality systems may markedly reduce *Salmonella* contamination, they cannot be relied upon to eliminate it. A terminal treatment step with demonstrated effectiveness against *Salmonella* such as irradiation, should be considered, particularly since tomatoes are commonly eaten raw and have now been implicated in three multistate outbreaks.

On July 16, 2002, the Minnesota Department of Health identified two cases of *Salmonella* Serotype Javiana infections among persons who had attended the 2002 U.S. Transplant Games held at Theme Park A in Orlando, Florida, during June 25–29. Isolates from both patients were indistinguishable by pulsed field gel electrophoresis (PFGE). The U.S. Transplant Games is a 4-day athletic competition among recipients of solid organ transplants (i.e., heart, liver, kidney, lung, and pancreas) and bone marrow transplants. Approximately 6,000 persons from the United States and five other countries, including 1,500 transplant-recipient athletes, participated in the games.

This report summarizes the results of an ongoing epidemiologic and laboratory investigation that has identified 141 ill persons in 32 states who attended the games.

Salmonellosis causes an estimated 1.4 million illnesses each year in the United States (see Table 3). *S. javiana* is the fifth most common *Salmonella* serotype in the United States and accounted for 3.4% of *Salmonella* isolates reported to CDC during 2001 (CDC, unpublished data, 2002). The majority of persons infected with *Salmonella* have diarrhea, fever, and abdominal cramps 12–72 hours after exposure. The illness usually lasts 4–7 days, and the majority of persons recover without treatment.

Persons with impaired immune systems are at increased risk for having a more severe illness, atypical symptoms, and complications of infection. Among organ transplant recipients, salmonellosis is associated strongly with antirejection therapy, and febrile illness with bacteremia is a more common presentation. Organ transplant patients are at increased risk for focal manifestations of illness including meningitis, urinary tract infections, abscesses of soft tissues, septic arthritis, osteomyelitis, and vascular infections, including infections of vascular grafts. Recurrence of nontyphoidal salmonellosis is common among this population and might occur in up to 35% of renal transplant recipients.

Physicians caring for recipients of solid organ and bone marrow transplants should be aware of possible exposure to *S. javiana* at the 2002 U.S. Transplant Games and should consider obtaining cultures (i.e., stool, blood, and urine) from ill patients with this exposure. The optimal therapy for *Salmonella* infection in transplant recipients is not known. However, because of the increased susceptibility to infection and the potential for complications, physicians might consider empirical antimicrobial therapy in transplant recipients with suspected salmonellosis from whom appropriate cultures have been obtained. The strain of *S. javiana* responsible for this outbreak is susceptible to several commonly used antimicrobials, including trimethoprim-sulfamethoxazole, ciprofloxacin, and ceftriaxone. Physicians should report culture-confirmed cases of salmonellosis to their local health department.

The use of a web-based survey in this investigation allowed a substantial number of persons who were dispersed geographically to be asked about potential exposures in a relatively short period of time. Twelve culture-confirmed cases of *S. javiana* among visitors to Theme Park A who did not attend the games were identified through PulseNet, indicating that the number of ill persons in this outbreak is probably much larger than what has been identified in the surveyed Transplant Games population. The combination of molecular subtyping, web-based technology, and routine public health surveillance facilitated the outbreak investigation.

Table 3 Characteristics of Patients with Culture-Confirmed *Salmonella enterica* Serotype Baildon

State	Cases (#)	Hospitalized[a] (#)	Deaths[a] (#)	Median age (years)	Age range (years)	Patients ≥18 years of age (%)	Female (%)	Range of onset dates[a]
CA	44	11	1	33	<1–82	89	65	12/18/98–02/02/99
VA	13	4	1	47	20–86	100	69	12/21/98–01/09/99
AZ	13	0	0	26	18–69	92	69	12/18/98–01/29/99
GA	8	1	1	38	17–86	88	75	12/19/98–02/02/99
IL	3	0	0	43	32–58	100	33	12/23/98–01/07/99
AL	2	0	0	66	45–86	100	100	01/07/99
TN	2	0	0	46	41–51	100	50	01/04/99–01/06/99
KS	1	0	0	22	22	100	100	12/06/98
Total	86	16	3	35	<1–86	93	67	12/06/98–02/02/99

[a]Outbreak of *Salmonella* Serotype Javiana Infections—Orlanda, Florida, June 2002.

The findings in this report are subject to at least two limitations. First, a web-based investigation limited responses to only those attendees with known e-mail addresses and Internet access. Second, although responses were received from both well and ill persons, households with ill persons might have been more likely to respond to a web-based survey. Therefore, it is difficult to calculate an accurate attack rate among attendees of the games.

Preliminary findings of the epidemiologic investigation have implicated fresh, prepackaged diced Roma tomatoes supplied to Theme Park A as the probable vehicle for this outbreak. Efforts are under way to identify the source of these tomatoes and possible routes of contamination. Tomatoes are not a commonly recognized vehicle for *Salmonella*, and no evidence exists for widespread contamination of tomatoes available for purchase. However, tomatoes have been implicated in at least one previous outbreak of *S. javiana* infections, and cut surfaces of tomatoes and other fresh fruits and vegetables can support the growth of *Salmonella* and other enteric pathogens. Produce is recognized increasingly as a source of *Salmonella* infections in the United States, and consumers should wash tomatoes and other produce items thoroughly before eating.

D. Disease Outbreaks from Sprouts

1. Outbreaks of *Escherichia coli* O157:H7 Infection Associated with Eating Alfalfa Sprouts—Michigan and Virginia, June–July 1997

In June and July 1997, simultaneous outbreaks of *Escherichia coli* O157:H7 infection in Michigan and Virginia were independently associated with eating alfalfa sprouts grown from the same seed lot. The outbreak strains in Michigan and Virginia were indistinguishable by molecular subtyping methods. This report summarizes the preliminary findings of the outbreak investigations.

These are the first reported outbreaks of *E. coli* O157:H7 infection associated with eating alfalfa sprouts. Since 1995, four outbreaks of *Salmonella* infection have occurred in the United States because of consumption of contaminated alfalfa sprouts. In 1996 in Japan, radish sprouts were associated with the largest recorded outbreak of *E. coli* O157:H7 infection, in which approximately 6,000 cases occurred.

As in previous alfalfa sprout–associated outbreaks of infection with *Salmonella* serotype, the Michigan and Virginia outbreaks of *E. coli* O157:H7 infection probably were caused by contaminated alfalfa seeds rather than contamination during the sprouting process. Because alfalfa seeds are a raw agricultural commodity, they can become contaminated with animal feces that may harbor pathogens such as *Salmonella* or *E. coli* O157:H7 during growth, harvest, processing, storage, shipping, or sprouting. The recurrent implication of alfalfa sprouts as a vehicle for foodborne illness highlights the need for strengthened prevention and control measures to ensure the safety of this product. Studies of alfalfa seed inoculated with low numbers of *Salmonella* suggest that the number of organisms present on seeds may increase up to 10,000-fold during the sprouting process. The effect of the sprouting process on the growth of *E. coli* O157:H7 is unknown. In April 1996, representatives of the sprout industry met with the Food and Drug Administration (FDA) and the CDC to discuss research needs to identify effective methods of alfalfa seed decontamination. However, research has not identified such a method; treatments such as soaking seeds in water with chlorine concentrations of 2,000 ppm (the highest allowable concentration) reduce the level of contamination but can leave viable microorganisms that may then be amplified during the sprouting process (4). Further efforts are needed to evaluate seed and sprout disinfection strategies.

In addition to seed decontamination, prevention of future alfalfa sprout–related outbreaks will depend on identification of critical control points to reduce the likelihood of contamination

during seed production and distribution. Additional prevention approaches could include categorizing sprout growers as food service workers rather than agricultural harvesters, along with systematic inspection and certification of sprouting facilities. As with all fresh produce, consumers should thoroughly rinse alfalfa sprouts before eating; however, the effectiveness of rinsing to reduce contamination is unknown. Persons at higher risk for severe complications of *E. coli* O157:H7 or *Salmonella* infection, such as infants and young children, the elderly, pregnant women, or immunocompromised persons, can reduce their risk by not eating raw alfalfa sprouts.

The Michigan and Virginia *E. coli* O157:H7 outbreaks demonstrate the value of molecular subtyping in the investigation of food-borne outbreaks. In both states, an increase in the number of reported cases of *E. coli* O157:H7 infection was suggested by pulsed-field gel electrophoresis (PFGE) analysis to be a common-source outbreak rather than an increase in sporadic cases. In addition, molecular subtyping of isolates from both states by PFGE and phage typing at the CDC demonstrated that these outbreaks were linked by a common strain, corroborating the epidemiological and traceback findings. The CDC has established a National Network for Molecular Subtyping, with four area laboratories in Massachusetts, Minnesota, Texas, and Washington serving as reference PFGE laboratories; other state laboratories also have begun using the same method. Standardized laboratory procedures and electronic links to share data among laboratories and the CDC make this network a key element of the recently announced President's Food Safety Initiative and an important aspect of outbreak detection and coordination.

2. Outbreak of *Salmonella* Serotype Kottbus Infections Associated with Eating Alfalfa Sprouts: Arizona, California, Colorado, and New Mexico, February–April 2001

On March 12, 2001, the California Department of Health Services (CDHS) identified a cluster of *Salmonella* Kottbus isolates with indistinguishable PFGE patterns. During February 1 to May 1, the CDHS identified 23 patients with *S.* Kottbus infections in several California counties and an additional patient from Arizona. This report summarizes the results of the investigation of this outbreak, which identified cases in four states and implicated alfalfa sprouts produced at a single facility.

A traceback investigation identified a single sprout producer as the source of the contaminated sprouts. Review of the sprouter's production records indicated that a single seed lot was temporally associated with the dates of illness onset. A culture of a sample of this seed lot yielded *S.* Kottbus. These seeds were imported from Australia in November 2000, but no further information about the distribution of this seed lot was available. Cultures from two floor drains in the production facility also yielded S. Kottbus. Patient, seed, and environmental isolates all had indistinguishable PFGE patterns.

The U.S. Food and Drug Administration (FDA) recommends decontamination of seeds with one or more treatments (e.g., soaking in a 20,000-ppm calcium hypochlorite for 15 minutes) that have been approved for reduction of pathogens in seeds. The effectiveness of alternative seed decontamination has not been established. The sprout producers subsequently agreed to use only the FDA-recommended 20,000-ppm soak when sprout production resumed.

S. Kottbus is a rarely reported cause of salmonellosis in the United States. During 1968–1998, a median of 42 S. Kottbus isolates were reported each year to the CDC through the Public Health Laboratory Information System. This was the second outbreak of *S.* Kottbus since 1985 and the first outbreak associated with sprouts. Since 1995, 15 outbreaks of *Salmonella* spp. and two outbreaks of *Escherichia coli* O157:H7 infections associated with sprouts have been reported to the CDC. Despite public health advisories about the risks of eating raw sprouts, persons at high

risk for systemic infection continue to eat sprouts. Two of the patients in this outbreak were immunocompromised, and one was a young child. In each case, persons perceived raw sprouts as a "healthy" food item.

Sprouts may be contaminated during seed production, germination, sprout processing, or consumer handling and preparation. On the farm, sprouts seeds may become contaminated through the use of untreated agricultural water, improperly composted manure as fertilizer, excretion from domestic or wild animals, runoff from domesticated animal production facilities, or improperly cleaned harvesting or processing machines. The association of specific seed lots with illness suggests that seeds are the most likely source for this and most other sprout-related outbreaks. Conditions suitable for seed sprouting also are ideal for increasing pathogenic bacterial counts by several logs.

The use of a 20,000-ppm calcium hypochlorite soak before sprouting might reduce the risk for sprout-related illness. However, use of this high-dose soak is not completely effective, and outbreaks continue to occur. Cracks and crevasses in the sprout seed may trap pathogenic bacteria, making them inaccessible to lethal concentrations of disinfectants. Because $>$20,000-ppm calcium hypochlorite soaks can impair seed germination, alternative methods are needed to reduce the risk for human disease following sprout consumption. In this outbreak, some of the implicated sprouts were from seeds that had undergone a combination of heat treatment and a 15-minute, low-dose calcium hypochlorite soak (2,000 ppm). The subsequent outbreak suggests that this hybrid technique using a heat treatment combined with a low-dose hypochlorite solution might not adequately reduce pathogenic bacterial colony counts in alfalfa seeds. Reducing pathogenic bacterial counts on seed during production and harvest could improve the effectiveness of postharvest decontamination.

Public education efforts about the risks of eating uncooked sprouts need to be continued, particularly among vulnerable populations (i.e., the elderly, young children, and immunocompromised persons). The CDC and the FDA recommend that persons at high risk for systemic infections not eat raw sprouts. For persons who continue to eat sprouts, the FDA recommends cooking before eating to reduce the risk of illness.

In response to this outbreak, the CDHS and the California Department of Education recommend that schools stop serving uncooked sprouts to young children. Public health officials should promote awareness of the role of raw sprout consumption in foodborne disease and consider package labeling as a method for improving consumer awareness. In addition, designation of sprout seed production for human consumption at seed planting could further reduce the risk of sprout-associated outbreaks. If sprout seed producers knew which sprout seed crops were dedicated for human consumption before harvest, producers could focus on reducing potential contamination in the field. Avoiding seed contamination in the field might reduce the risk of consumer exposure to foodborne pathogens.

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Critical Factors in the Manufacture of Acidified Vegetables and Vegetable Products

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I. INTRODUCTION AND HISTORY

All of us have bought canned foods, especially canned vegetables (corn, beans, shallots, and so on). Most canned vegetables are considered as low acid canned foods (LACF). To avoid the potential of botulism, the manufacture of such food products is tightly controlled by the federal government (U.S. Food and Drug Administration), for both domestic and imported products. The regulations have been in existence for many years and can be obtained from the U.S. Food and Drug Administration (FDA) in a variety of ways. All manufacturers of such products should become thoroughly familiar with such regulations.

Many of us enjoy pickles, marinated peppers, and similar items, most of which are available in cans or jars. Most of them are considered as acidified foods, and regulations similar to those for LACF have also been issued by the FDA. This chapter discusses acidified foods from the perspectives of critical factors affecting their manufacture. The data must be used with the following kept in mind:

1. All the information has been derived from the FDA's document *Guide to Inspections of Acidified Food Manufacturers*.
2. This chapter does not describe the process of manufacturing acidified vegetables or vegetables from A to Z. Rather, it points out those specific areas that may require special attention because if they are not done right, public health may be at risk. That is, it relates to the safety and not the manufacturing aspects.
3. One should consult the FDA regulations and the original document source for this chapter, since the information in this chapter does not cover all details.

In 1973, there were seven cases of botulism food poisoning in West Virginia after consumption of peppers that had been improperly acidified. There was also one case in Canada after consumption of marinated mushrooms packed in the United States, which were improperly acidified. In 1973 and 1974, the FDA found inadequately acidified pimentos and hearts of palm processed by 29 firms in other countries. No illnesses were ever documented.

In 1976, eight persons were diagnosed as having botulism food poisoning. Sweet cherry peppers were implicated epidemiologically. This evidence demonstrated that certain manufacturers of acidified foods did not realize the importance of adequate pH control.

In 1979, the FDA published the final regulations for GMP covering acidified foods (the term pickled was dropped because it can refer to acidified or fermented products).

Acidified foods rely almost entirely on reduced pH for preservation. The heat treatment given to acidified foods is primarily for the purpose of destroying the vegetative cells of microorganisms of public health significance and those not of health significance capable of reproducing in the food under the conditions in which the food is stored, distributed, retailed, or held by the user. Usually these treatments are applied at temperatures of 212°F (100°C) or less. These heat treatments are not sufficient to destroy heat resistant spore forming microorganisms, which are prevented from germinating and growing by the reduced pH.

II. DEFINITIONS

In the following, the word "foods" refers to vegetables and vegetable products.

Acid foods: foods that have a natural pH of 4.6 or below.

Natural pH: the pH prior to processing. However, if a processor receives an acid food (including fermented foods with a pH of 4.6 or below), and during processing allows the pH to rise above 4.6 (through washing, lye peeling, etc.), and then adds an acid or acid food to reduce the pH to 4.6 or below, that product would be considered an acidified food.

Acidified foods: low-acid foods to which acid(s)or acid food(s) are added and which have a water activity (a_w) greater than 0.85 and a finished equilibrium pH of 4.6 or below. These vegetable foods may be called pickles or pickled__.

Lot: the product produced during a period indicated by a specific code.

Low-acid foods: any foods with a finished equilibrium pH greater than 4.6 and a water activity (a_w) greater than 0.85. Tomatoes and tomato products having a finished equilibrium pH less than 4.7 are not classed as low-acid foods.

Scheduled process: the process selected by a processor as adequate for use under the conditions of manufacture for a food in achieving and maintaining a food that will not permit the growth of microorganisms having public health significance. It includes control of pH and other critical factors equivalent to the process established by a competent processing authority.

Water activity (a_w): a measure of the free moisture in a product and the quotient of the water vapor pressure of the substance divided by the vapor pressure of pure water at the same temperature. In simpler terms, it is a measure of relative humidity.

Equilibrium pH: The condition achieved when the solid and liquid parts of the product have the same pH. Where acid is added to large particles (e.g., whole peppers), equilibrium might not be reached for several hours or several days. If this is the case, the product may need to be refrigerated until a pH of 4.6 is reached. The anticipated equilibrium pH can be determined immediately after processing by blending the entire contents of the finished product container and taking the pH or blending the solid particles and acid brine in the proportion present in the finished product and taking the pH.

Fermented foods: low-acid foods subjected to the action of certain microorganisms, which produce acid during their growth and reduce the pH of the food to 4.6 or below. Fermented foods were defined as foods that have been prepared from low-acid ingredients and fermented to an equilibrium pH value of 4.6 or lower. They may be partially desalted, processed, or preserved in the original salt brine or in a new salt brine or in a vinegar solution with other ingredients. Foods partially fermented requiring addition of acid to reduce the pH to 4.6 or less are considered acidified foods.

It is often useful to state what is not an acidified food when defining acidified foods, as indicated below:

Acid foods: Those foods, such as most tomatoes and many fruits, which have a natural pH of 4.6 or less even if acid, which are added during processing.

Repacked acidified or fermented foods: Previously acidified or fermented foods, which are usually received in bulk, and which are then repacked into retail size containers, generally with the addition of a fresh acid brine, are not acidified foods as long as the repacker does nothing, such as washing, to raise the pH above 4.6 prior to packing. If there is a washing step to remove the old brine, or any other similar processing step, determine the pH of the product prior to the addition of the fresh acid brine.

Fermented foods: Foods, such as some kinds of cucumber pickles, most green olives, and sauerkraut, are not acidified foods, because pH reduction is not accomplished by the addition of acids or acid foods.

Refrigerated foods: Products which rely, in part, on refrigeration for preservation and are stored, distributed, and retailed under refrigeration are not regulated in the same manner as low-acid foods even if they are low-acid foods that are acidified. In order to qualify for this exclusion, the product must be refrigerated after processing and the label must prominently bear the statement "Must be kept refrigerated to maintain safety."

Water Activity 0.85 or less: Any food that always has a water activity of 0 85 or less is excluded.

III. IS IT AN ACIDIFIED FOOD?

A. Acid Foods with Small Amounts of Low-Acid Foods

This exclusion applies to acid foods (finished equilibrium pH of 4.6 or below) where the addition of small amounts of low-acid food(s) results in a finished equilibrium pH that does not significantly differ from that of the predominant acid or acid food. These products are referred to as "formulated acid foods." This category of foods covers a multitude of products including vegetable sauces, dressings, fillings, and toppings.

These terms are not definitive and are therefore subject to interpretation. It is therefore difficult to address this issue in a manner that applies to all products because of the diversity of products. Basically, it must be determined whether the acid(s) or acid food(s) are acidifying the low-acid ingredients(s) or whether the addition of the low-acid ingredients(s) significantly raises the pH of the acid(s) or acid food(s).

B. When Does the Finished Equilibrium pH Significantly Differ from the pH of the Acid or Acid Food?

This will depend on the closeness of the finished equilibrium pH to 4.6 and possibly other factors. For example,

Finished product pH = 4.5 and acid ingredients' pH = 4.4; this might be a significant difference.

Finished product pH = 3.8, and acid ingredients' pH = 3.4; this might not be a significant difference.

C. Predominant Acid or Acid Food

In a product like salsa, tomatoes characterize the food by odor and taste and may be predominant by weight. Jalapeno peppers (which are received acidified) characterize the product by taste even though the quantity may be small. The vinegar or other acids will be predominant by the amount of acidity provided.

As noted below, all acid ingredients are considered to be predominant for the purpose of determining if a product is an acidified food.

It is the processor's responsibility to determine the status of his or her products under these regulations. A processor should first request the assistance of an expert on acidified foods. Such assistance may be available at a university that has a food science extension service. In some cases, the processor may desire an opinion in writing from the FDA as to the status of their products.

The following list delineates the information needed about each product to determine whether they are acidified or acid foods:

1. Quantitative formula. Express ingredients in same units of measure (e.g., oz., lbs., fluid oz., liter, kilograms) or use percent of total formula.
2. Describe ingredients:

   particle size, dry, etc.
   Designate which ingredients are acid and low acid.
   By pH preferably or describe, e.g., fresh, dried, previously frozen or canned. [*Note*: some canned products can be acidified or LACF (thermally processed at temperatures, which will destroy spores, so the pH of the canned product may be needed).
   pH of each ingredient will be most helpful—range of pH value where appropriate.
   pH of the acid ingredients combined in the proportion in which they appear is the formula.
   At least 6 units of a code lot or batch and relate to ingredient pH values.

3. pH of the finished product (after addition of the low-acid ingredients to the acid ingredients and all processing and packing has been completed).
4. Should have several batches or days production to get a feel for normal variation.
5. Describe processing steps including times (e.g., how long in the acid brine) and temperatures (i.e., time of heat treatment, hot-fill temperature, and hold time), acidification method (i.e., batch, direct), and type of finished product container.
6. If a processor or his adviser/consultant determines that a product is not covered by the regulations as an acidified food, he should have this kind of information available as evidence to document that the product is not an acidified food.
7. If a processor states that a product is not acidified, but the investigator believes it is, ask them to provide the information as stated above to document their conclusion.

8. Processors of formulated acid foods (those multi-ingredient products determined to have been excluded, i.e., not acidified foods) are responsible for assuring that the food products that they manufacture are safe. This means that they should employ manufacturing procedures, that will ensure that their products are at a pH of 4.6 or lower.

IV. ACIDIFIED FOODS: CURRENT GOOD MANUFACTURING PRACTICE REGULATIONS

A. Personnel—Schooling for Supervisors

All operators of processing and packaging systems must be under the operating supervision of a person who has attended a specialized school. Supervisors who have satisfactorily completed the required portions of the required courses will be considered to be in compliance.

The required training may be obtained from either an approved Better Process Control school or an approved Acidified Food GMP school.

An operating supervisor is one who is routinely on duty during processing and packing. The person should be present or reasonably accessible on the premises during processing, packing operations, and container closing.

B. Processes and Controls

Many of the requirements in this section are very general in nature and speak to the desired result of the requirement and not how it should be achieved.

A manufacturer must employ appropriate quality control procedures to ensure a safe finished product. An example of a situation where this would require closer observation is where evidence from a firm's records shows a wide range of pH values in the finished product with the highest value close to 4.6.

This situation should of course be investigated further to determine the cause of the wide range of pH values. For example, the firm may not be controlling the solid-to-liquid (brine) ratio; the firm may have variation in the pH of the brine; there may be a wide range of pH values of the raw low acid ingredients or the acid ingredients.

A manufacturer must have a manufacturing process to pack acidified foods so that a finished equilibrium pH value of 4.6 or below is achieved and maintained in all finished foods.

The achievement of a pH of 4.6 or below may be dependent on the control of numerous factors as will be discussed later. The maintenance of a pH of 4.6 or below is equally important. Maintaining a pH of 4.6 or below means that the pH will never rise above 4.6 prior to consumption. Several factors may affect the maintenance of an adequate pH.

For example, insufficient heat treatment does not destroy all vegetative cells of microorganisms and eventually manifests itself in spoiled product or swollen cans (or lids on jars). Yeast and mold, which can grow in an acid environment, could be evidence of inadequate heat treatment, and some bacteria will also grow in an acid environment and often raise the pH because the acid is a nutrient they utilize during growth. Another example is improper container closure resulting in contamination with microorganisms.

However, the lack of control of container integrity by itself is not always sufficient evidence to document that pH will not be maintained.

Manufacturing must be in accordance with the scheduled process. As stated in the definition, the scheduled process includes pH control as well as control of other critical factors

that will achieve and maintain a food that will not permit the growth of microorganisms having public health significance. A processor is required to file their scheduled process. Therefore any critical factors filed with the FDA must be controlled.

A manufacturer must thermally process acidified foods to an extent necessary to destroy vegetative cells of microorganisms of public health significance and those not of health significance capable of reproducing in the food under the conditions in which the food is stored, distributed, retailed, and held by the user.

Permitted preservatives may be used to inhibit the reproduction of microorganisms not of health significance (in lieu of thermal processing).

It is important to keep in mind that a thermal process may be necessary to destroy vegetative cells of microorganisms not of health significance, which could grow and raise the pH to a level where microorganisms of public health significance could grow. In this case, the thermal process could be considered a critical factor. However, without knowing that those microorganisms are present, we cannot at this time insist that a thermal process is always a critical factor. As stated above, preservatives may be used in lieu of a thermal process, but they can only be used to inhibit the growth of microorganisms not of health significance (i.e., molds and yeast).

The failure to destroy microorganisms not of health significance (spoilage microorganisms) with a heat treatment can also lead to product spoilage and subsequently product adulteration. There is also a concern that pathogens such as *E. coli* 0157:H7 and Yersinia may be able to survive in acid mediums with pH values below 4.6 for extended periods of time. This fact should be considered by the processor when choosing a scheduled process.

If the thermal process, as established by a qualified person, is not required to ensure public health protection, it need not be filed with the FDA.

Although not specifically required by these regulations (it is a requirement of the low-acid canned food regulations), if a thermal process is necessary for public health protection, a mercury-in-glass thermometer (or an equally accurate and reliable temperature measuring device) should be used as the reference instrument for indicating the processing temperature.

There may be situations where a mercury-in-glass thermometer is not practical or is unsafe to use, such as measuring the temperature of a solid particle or temperature measurements in a kettle. In these cases, a calibrated, accurate dial or digital thermometer, thermocouple, RTD, or other equally accurate and reliable temperature measuring device may be used.

Appropriate temperature recording devices should also be used to document thermal process delivery and should be calibrated or compared to the temperature indicating device.

C. Operation of Thermal Processing (Pasteurizing) Equipment

The specific thermal processing procedure for each food product in each size and type of container should be carefully detailed and made readily available to the supervisor in charge of the operation of the thermal processing equipment, provided the thermal process is indicated as a critical factor. It should be the supervisor's responsibility to ensure that each item receives the appropriate heat treatment, and this should be completely documented in the records. The thermal process equipment should be in good operating condition, the food should be properly packed, sealed, and at the correct temperature upon entering the equipment, and the correct temperatures should be achieved during the thermal process.

Check thermal processing equipment for

1. Incoming steam line controls.

Are pressure gauges functional?

Have pressure gauges been checked for accuracy within the last year?
Is the pressure reducer valve set properly to supply correct pressure and steam flow to the pasteurizer?

2. Conveying belt speed.

Many times belt speeds do not correspond to Q.C. specifications.
If belt speeds are faster or slower than specifications then it is likely the thermal process will differ from what is intended.

3. Steam line controls for individual zones.

Determine if automatic control valves are operating. Many times valves are not sequencing for various reasons.

Valves stuck due to corrosion problem.
Controls have been damaged and not repaired.
Valves are not sequencing due to overheating from adjacent zones. (This is a clue to look for problems in the adjacent zones.)

Check to see that the automatic controller is set at the desired temperature level.
Check to see if thermometers or other indicating devices are indicating the temperatures set on the control valve.

There should be two dial or digital thermometers, one above the conveyor and one below. Large differences between these readings may indicate poor control of temperature distribution.
The thermometers or other indicating devices must be routinely checked for accuracy.

Check to see that the temperature probe for the automatic controller is not submerged in water (steam thermal processing equipment).
If drains are blocked, water will fill individual zones.
If the temperature probe is submerged, it will record water temperature, not zone temperature, resulting in improper controller response.
For equipment where the product is heated in water or water spray, the temperature probe must be in the water.

4. Cooling sections.

Make sure fresh water valve is open.
Check to determine if tempering section water temperatures are correct.
Inspect cooling water pumps.
Inspect cooling water spray nozzles for proper cooling.

5. Curtains between zones.

Torn or missing curtains should be replaced.
Damaged or missing curtains can result in excessive heating or cooling of adjacent zones.
Improper temperature distribution makes control valves work harder trying to compensate.

6. Jars should be evenly distributed across the full width of the pasteurizer belt to insure best quality as related to cook time.

7. Determine how often the temperature distribution is checked.

D. Process Control

A manufacturer must control the processing of acidified foods by frequent testing to ensure that the finished equilibrium pH of each container is no higher than 4.6.

In most cases, the control of acidification should be monitored by measurements on both in-process samples and finished product. Proper control of such things as formulation, fill-in weight, and solid-to-liquid ratio, may be considered adequate to control acidification, in lieu of in-process pH control, if sufficient written documentation is available to warrant such consideration.

Formulation control would have to include consideration of such things as the raw material pH variability and the buffering capacity of raw materials, and other variables that could affect the pH of the finished product. In-process controls may also be considered adequate in lieu of extensive finished product testing if there is adequate written documentation that such control will ensure control of the finished equilibrium pH of all containers of the product. In most cases, some finished product testing must be conducted, since finished equilibrium pH is always a critical factor. One exception might be where a product is being packed in oil and the acidification takes place (as it should) prior to adding the oil. The pH of the food prior to adding the oil is the important factor since the oil will not affect the pH.

When products such as garlic, spices, herbs, or other naturally low-acid foods are packed in oil or the finished product is an oil emulsion, such as some sauces and dressings, assurance of proper pH control should be determined prior to adding the oil. In some cases, pH testing at this point might be considered as equivalent to finished product testing, as long as subsequent operations will not affect the pH. This is because of the difficulty of separating the oil phase from the water phase of the finished product get the pH of the water phase of the product. These procedures could result in erroneous pH values, which do not accurately reflect the actual pH of the water phase of the product.

The frequency of testing needed to ensure adequate pH control will depend on such things as the method of acidification, product characteristics (such as raw product pH variability), and control of other factors during processing. Processing procedures may dictate the frequency of in-process or finished product testing. For example, subjecting ingredients to high pH materials such as lye during lye peeling may affect the pH of an acid ingredient, which if not monitored could result in inadequate acidification.

Measurements of acidity may be made by potentiometric methods (pH meter), titratable acidity, or colorimetric methods (litmus or pH paper), depending on the finished equilibrium pH. If the finished equilibrium pH of a food is above 4.0, the measurement of the finished equilibrium pH must be made by a potentiometric method, and the in-process measurements by titration or colorimetry must be related to the finished equilibrium pH. If the finished equilibrium pH is 4.0 or below, any suitable method of measuring acidity may be used for determining both finished product and in-process pH levels.

E. Procedures for Acidification

1. Blanching of the Food Ingredients in Acidified Aqueous Solutions

Heating products before they are put into containers is often useful. Heating and acidification can be combined by blanching in a hot acid solution. If the blanch solution is the only source of acid in the final product, blanching times and temperatures must be established so the intended maximum equilibrium pH is not exceeded. If this technique is used for acidification, and the target equilibrium pH is close to 4.6, the product should be held until the equilibrium pH is at least below 4.6 before being placed into individual containers.

2. Immersion of the Blanched Food in Acid Solutions

This is a variation of the blanching of a low-acid food in an acidified solution. Blanching can make it easier for the acid to penetrate tissues, but it is sometimes more convenient to blanch in steam or water than in an acid bath. In that situation, the blanching can be done first and then the product immediately transferred to the acid solution. Again, if this technique is used for acidification and the target equilibrium pH is close to 4.6, the product should be held until the equilibrium pH is at least below 4.6 before being placed into individual containers. Although immersion of food in an acid solution is a satisfactory method for acidification, care must be taken to ensure that the acid concentration is properly maintained, because over time, as the food absorbs the acid, the low-acid product will dilute the acid in the solution.

3. Direct Batch Acidification

This can be achieved by adding a known amount of an acid solution to a specified amount of food during acidification. If an acidified food with a finished equilibrium pH of 4.0 or above is to be packed, all ingredients should be at or below 4.6 prior to packing into containers and the equilibrium pH of the product checked prior to packing.

4. Direct Addition of a Predetermined Amount of Acid to Individual Containers During Production

This is probably the most common method used for acidified vegetables. Jars are filled with product and a liquid packing medium from a brining machine. The packing media contains all the acid required to lower the finished equilibrium pH of the product, including all ingredients, to 4.6 or below. Sometimes individual containers are acidified with a pellet or tablet containing citric acid. When this is done, it is essential that the acid be completely dissolved in the container. In addition, proper storage of the pellets is important to ensure that the acid strength is not depleted. Pellets should be tested to be sure they are of the proper acid strength. Liquid acids are generally more effective than solid or pelleted acids, because the acid is already in solution.

There is one important caution concerning acidification in individual containers. Care should be taken to ensure that the proper amount of acid is added to each container. In addition to the variability that will occur in raw products and other ingredients in a formulation, additional container-to-container variation will occur owing to variations in the proportion of solids to liquid in individual containers, or to variations in the amount of solid product added to each container, as well as small variations in the volume of individual containers (especially jars). The equipment used to dispense tablets or liquid acids must be well maintained and must function in a manner that ensures that each container will receive the acid tablet or liquid acid component.

During inspections of manufacturers using this type of equipment, the operation of the equipment should be observed to determine that it is functioning as designed. With all of these unavoidable sources of variation, it is possible that an occasional container could have a finished equilibrium pH greater than 4.6 in those cases where the target maximum pH is between 4.0 and 4.6. Therefore the control of such things as solid-to-liquid ratio, raw product pH, brine pH, and acidity of pellets becomes very important and may in some cases be considered to be critical factors.

5. Addition of Acid Foods to Low-Acid Foods in Controlled Proportions to Conform to Specific Formulations

This method of acidification is used when acid foods, such as tomato products, with pH values less than 4.6, are added to low-acid foods. The product formulation should be developed to assure that the finished equilibrium pH is 4.6 or below.

When using this method of acidification, it is important to maintain control of the proportion of high-acid and low-acid ingredients in each container so that the finished equilibrium pH is 4.6 or below. Alternatively, the ingredients can be mixed in batches and allowed to equilibrate prior to filling the containers. The firm should have a written quantitative formula, which relates to the process establishment document so that any changes to the formula are well documented and can be related to a process source document. In addition, raw product specifications may be of importance.

For example, if the firm uses as an ingredient, an acidified food from another packer, they should have some means to ensure that the pH of that raw material is within the range upon which the process is based. There may also be occasions where a firm uses an acidified ingredient sometimes and a fresh unacidified ingredient at other times. In this case, there should be appropriate allowances in the formulation as well in the process source document to take into consideration the pH differences between the fresh and the previously acidified product. In most cases, the firm would be wise to file two process-filing forms, since the critical control factors and the amount of acid added will probably be different.

F. Container Closures

Container closure must be examined and tested often enough to ensure container integrity.

The tests and examinations considered by the FDA to be adequate will vary with container type. There are standard procedures for metal containers and glass containers. The container supplier should be contacted by the firm to obtain information on the appropriate inspection and testing procedures needed to ensure container integrity.

For glass containers, lids should be designed to make adequate closure with the particular finish of the glass jar being used (the finish is the very top of the jar). The lid should be adequately applied (by screwing, torquing, etc.) to the jar finish as recommended by the closure manufacturer. An applied lid should be seated well down on the finish and parallel to the transfer bead at the bottom of the finish. Removal of the lid should show an even furrow or impression in the gasket sealing compound around the periphery of the lid created by intimate contact between the lid and the finish.

Jars of finished product should have adequate vacuum to prevent the entry of microorganisms, help to hold the lid on the container, and maintain a tight seal. Presence of a vacuum will usually be noticeable by the concave appearance of the lid. If a steam flow capper is used, a cold water vacuum test should be performed to test the ability of the capper to form a vacuum. The cold water vacuum test is not required by these regulations but is required for LACF. Visual exams should note any container defects such as chips or cracks in the jars, especially in the finish area where the lid contacts the jar. Over or under application of the lid, tilted caps and any sign of leakage would be evidence that container integrity has been compromised.

Records of all testing should be maintained. (*Note:* the regulations do not require the maintenance of records of container closure tests, but without them it is not possible to determine whether a firm is in fact making the appropriate examinations.)

G. Coding

A manufacturer must mark each container with a permanently visible code delineating the processing establishment, the product, year, day, and packing period. The codes should be embossed or inked whenever possible; otherwise the labels may be legibly perforated or otherwise marked as long as the label is securely fixed to the container. The packing period code must be changed often enough to enable ready identification of lots during their sale and distribution. Changes may be made at intervals of 4 to 5 hours; personnel shift changes or batches as long as the containers constituting a batch do not represent those processed during more than one personnel shift.

H. Establishing Scheduled Processes

Scheduled processes must be established by a qualified person having expert knowledge acquired through appropriate training and experience in the acidification and processing of acidified foods.

The "qualified person" referred to is not necessarily limited to so-called processing authorities such as container and equipment suppliers or industry associations. A published paper or written document prepared by experts in acidified food processing may be a sufficient basis for a scheduled process. However, these documents may speak to the control of processing parameters that may not necessarily be essential to ensuring public health safety, but which would have to be filed with FDA since they are listed in the document.

The investigator should check the process source carefully and be sure all processing parameters discussed are filed with the FDA and controlled. If it appears that the process source delineates factors that may not be critical, suggest that they have the scheduled process reviewed by a qualified person and obtain a process that delineates only those critical factors necessary to ensure public health safety.

If published or written documents were used as the basis for developing the process, such documents should be listed as the process source, and copies of the documents must be kept at the firm. Any modifications to a process listed in a document or publication should be substantiated by a qualified person, and that person should be listed as the process source. The letter or document from the process source should list the critical factors and limits. If the thermal process is not listed as a critical factor and it has not been filed, and the investigator has reason to believe that it is critical, attempt to determine the basis for that determination.

I. Deviations from Scheduled Processes

Any product involved in a deviation from the scheduled process, including equilibrium pH values of the finished product above 4.6, must be set aside and evaluated by a competent processing authority, fully reprocessed by a process established by a competent processing authority as adequate to ensure a safe product, and thermally processed as a low-acid food under 21 CFR 113 (or destroyed). The "destroy" option does not appear in this part of this section of the regulations—it appears in the part describing the firm's options after evaluation.

However, the firm can decide to destroy the lot rather than choosing from the above three options.

A deviation below the filed thermal process may not represent a potential danger to public health if the finished equilibrium pH is 4.6 or below. However, if the thermal process is filed as a critical factor, a deviation below that process must still be evaluated. This is why it is important for the processor to check the process source to be sure that the critical factors delineated are only those that are necessary to inhibit the growth of microorganisms of public health significance. If

the process deviation is set aside for evaluation by a competent processing authority and the evaluation demonstrates that the food has not undergone a process, that would make it safe, it must be either reprocessed or destroyed. A record must be made of the evaluation procedures and the results.

If the processor decides to reprocess a lot where pH has been improperly controlled, the reprocessing (reacidifying) should be done immediately or the product should have been refrigerated until reprocessing occurred. The same applies if there is any other deviation from the filed process. If the product is set aside for evaluation by a competent processing authority, precautions, such as refrigeration, should have been taken to prevent microbial growth.

A pH of greater than 4.6 even in only a single container constitutes a process deviation. If a processor has selected a maximum pH below 4.6 for process control purposes (target pH), even though they have filed a maximum pH of 4.6, and that target pH is exceeded and is close to but not greater than 4.6, it would be prudent for them to conduct additional testing to be sure that no container has a pH greater than 4.6 and investigate the cause of the high pH values. This situation is not a process deviation, but if it occurs, additional records should be reviewed to determine if other similar situations have occurred. This kind of situation would be a good reason to collect samples of the suspect lot for pH determination. In some cases the manufacturer may file a scheduled process with a pH below 4.6 (e.g., a filed scheduled process of 4.4). If the pH of the product exceeds the pH of the filed process but not pH 4.6, this would be a process deviation. This process deviation must be handled in the manner as explained above. In some cases the process authority or process documentation may state a pH lower than 4.6 as a critical factor.

J. Methodology

This section deals with the methods, equipment, and procedures that may be used to measure pH or acidity. These are not the only methods that may be used. (Note that there is considerable emphasis placed on the proper maintenance of the equipment and sample preparation.) Erroneous results due to faulty equipment are essentially the same as no control of acidification. In order to determine if pH is controlled to meet the scheduled process, pH meters should be standardized often against known buffer solutions with sufficient frequency to ensure proper control. (*Note:* Standardization is not required by the regulations, but if the pH meter is not standardized properly and frequently, the firm cannot determine if pH is properly controlled.)

The frequency of standardization that is necessary will depend on such things as the frequency and number of samples tested, and the type of product. For example, if they are conducting tests at specific times throughout the day with a space of time between testing, the pH meter should be standardized prior to each testing period. If they are conducting tests every few minutes, it may be appropriate to standardize on a half-hour basis or less. The type of product will also dictate the frequency of standardization. A product containing oil or other substances can foul electrodes, and standardization should be conducted on a more frequent basis, possibly every third or fourth sample.

K. Sample Preparation

1. Most foods are mixtures of solids and liquid. In some products, like cucumber pickles, where pH equilibrium occurs readily, the equilibrated pH can be determined by blending to a slurry the entire contents of a container or sampling and blending a portion of the solids and liquid in the same proportions as is present in the product.

2. Products packed in oil or which have been marinated in marinade containing oil must be separated from the oil prior to pH measurement. This includes fat-containing products such as artichoke in oil. Oil can interfere with pH measurement. The FDA Compliance Program delineates a procedure for sample preparation for these kinds of products.

3. The pH meter should be standardized at 68–86°F (20–30°C) and the sample should be at the same temperature as the buffers used to standardize the pH meter. To the small extent that the pH changes with temperature, pH will decrease as temperature increases.

4. If a product is difficult to blend (low moisture level), distilled water up to 20 percent by weight of the sample can be added. Addition of small amounts of distilled water to food samples does not cause significant changes in pH. For certain products, the pH may need to be measured by probing the particle (e.g., stuffed peppers, stuffed grape leaves) of food to ensure that the pH of the inside of the particle has reached equilibrium. This relates to the necessity of determining the time necessary for all portions of a food particle to reach equilibrium and should have been addressed during the establishment of the process.

L. Measurement of pH

The pH is defined as the negative logarithm of the hydrogen ion concentration. The lower the pH the higher the hydrogen ion concentration. pH is a measure of the free hydrogen ions in solution.

1. The use of pH meters (potentiometric) is the preferred method for determining finished equilibrium pH at any pH level. Potentiometric methods are required by the regulations when the pH is greater than 4.0.

There are a variety of pH meters, from small handheld units to complex bench-top units. pH meters have either an analog (dial with points) or a digital readout. pH meters all function in a similar manner and require special care and attention to assure proper functioning. In general, the manufacture's instructions should be followed for maintenance, storage and use.

2. pH meters measure electrical potential difference in millivolts between a reference electrode and a measuring electrode. This millivolt reading is automatically converted to a pH value on the instrument display. The pH scale goes from 0 to 14 with 7 being neutral between acidic and basic. The reason pH meters work is that there is a linear relationship between pH and the potential difference measured by the electrodes.

3. Two electrodes are necessary for pH measurement. Most pH meters use combination electrodes—both electrodes are contained in a single glass or plastic electrode body.

The reference electrode contains a specially prepared metal wire immersed in a concentrated solution of potassium chloride. There is a porous ceramic or fiber junction that looks like a rough spot on the side of the combination electrode.

This junction must be immersed in the sample and not clogged so a very slow flow of potassium chloride solution goes into the sample. This establishes an electrical contact between the reference electrode and the sample.

The sensing electrode is completely sealed. At its tip there is a glass bulb with a thin membrane. When it is put in a water solution, it builds up an electrical potential on its surface that is proportional to the concentration of hydrogen ions in solutions. If the glass membrane is scratched or damaged, the electrode is ruined and must be replaced.

4. pH meters should be stored in low humidity areas and away from acids to prevent corrosion. If on-line pH measurements are being made, unbreakable epoxy, plastic, or ceramic electrodes should be used. Electrodes should be stored in a solution according to the manufacture's instructions.

5. Before making a pH measurement, the analyst should thoroughly rinse the electrode with distilled water using a squirt bottle or with the next sample. Blot, and don't wipe, excess

water with a soft tissue. The analyst should place the electrode in the sample deep enough so the reference electrode junction is immersed. It should take less than one minute for the pH reading to stabilize. If it takes much longer, the electrode may be fouled or be permanently damaged. An electrode fouled with fat or protein may be restored by gently wiping the tip with a tissue saturated with 75 percent methanol solution or by soaking for five minutes in 0.1 N HCl, rinsing with water, and soaking overnight in buffer solutions.

6. The colorimetric method (pH paper or indicator solutions) can only be used to measure finished product and in-process samples if the finished equilibrium pH of the product is below 4.0. Colored products, storage conditions (light, acid vapors), age, and other factors make this kind of pH measurement less desirable than a pH meter even for very high acid foods.

pH paper may, however, be used as a tool during inspections to make quick checks on acid ingredients, blended ingredients, and finished products. The results of these tests may need to be confirmed by sample collection and laboratory testing of samples with a pH meter. A narrow range pH paper (e.g. pH 2.8–4.6) should be used to provide the best results.

7. Titratable acidity is a different measurement from pH in that it measures both bound and free hydrogen ions. There is no fixed relationship between pH and titratable acidity, but it can be used as an indicator that pH is no higher than a maximum value for a particular product if that relationship is established by experience with that food. It is a useful tool for assuring that ingredients contain the expected amount of acid.

M. Standardization of pH Meters

It is necessary to standardize a pH meter to get an accurate pH measurement. The directions for standardization and storage supplied by the manufacturer of the equipment should be followed.

A pH meter should be standardized at least once a day. The pH of pH 4.0 standard buffer can be checked as often as necessary to ensure accurate readings. If the pH measurement on the standard buffer deviates significantly from pH 4.0, the meter should be restandardized. When samples contain oil or grease, which can coat the electrodes, standardization should be done every two or three samples. In a situation where the objective is to have a target equilibrated pH near the critical pH of 4.6, the pH meter should be standardized after each sample.

Standardization is normally done for acidified foods with pH 7.0 and pH 4.0 buffers. This gives an accurate reading within the pH region of interest, pH 4.6. If desired, the pH of a 9.18 standard buffer may then be measured. If the electrodes and pH meter are working properly, the pH reading on the pH 9.18 buffer should be between pH 8.88 and pH 9.48. The electrodes and meter should he checked out according to the manufacturer's instructions if the pH reading is outside this range.

Owing to the effect of temperature on pH, the temperature of the standard buffer solutions should be the same as the temperature of the samples that are to be measured. If a magnetic stirrer or other type of stirring device is used to mix samples while pH measurements are done, the standard buffers should be stirred in the same way during standardization. A backup electrode and sufficient standard buffers should always be available.

N. Records

Records are a necessary ingredient in any good quality control program.

1. Records must be maintained of examinations of raw materials, packaging materials, and finished product and of suppliers' guarantees or certifications that verify compliance with FDA regulations and guidelines or action levels. The types of records will vary with the product being processed. For example, if raw material pH is a determining factor in the amount of acid to

add to the acidifying brine, records of these determinations would be required. Records of tests conducted to assure alkali removal or neutralization may also be necessary in those instances where alkali preprocess treatment is used.

2. Processing and production records must also be kept to show adherence to the scheduled process, including pH measurements. For example, if the thermal process is a critical control factor, it must be controlled, and records of the time and temperature must be kept.

All critical factors listed on the filing form and determined by the process source to be critical must be controlled, and records of the tests or measurements conducted to control these factors must be kept. For example, if the solid-to-liquid ratio is listed as a critical factor, fill-in weight determinations would have to be made and recorded. Records of periodic verification of the accuracy of pH meters, thermometers, and other measuring devices used in the control of the process should he kept but are not specifically required by the regulation. All records must contain enough additional information such as product name, product code, date, and container size to permit public health hazard evaluations of the processes applied to any given production lot. Not only are the records an important management tool to assure adequate processing, they may also be of great importance if we find a code lot of product to be inadequately processed to such a degree as to necessitate a recall. Accurate and complete processing records can be used to limit the scope of a recall. If no records exist or the records are inadequate, it may be necessary to recall all production.

3. Records must be kept, in a separate file, of all departures from the scheduled process having a possible bearing on public health or the safety of the food. The records must delineate the action taken and the final disposition of the product involved. Records identifying the initial distribution of the finished product must also be kept to facilitate the segregation of specific lots that may have become contaminated or otherwise unfit for their intended purpose. Copies of all records must be retained at the processing plant or other reasonably accessible location for 3 years.

O. Reporting to the FDA

Any instance of spoilage, process deviation, or contamination with microorganisms having potential health-endangering significance must be promptly reported to the FDA when any or all of a lot has entered distribution channels.

P. Recall Procedures

A recall procedure must be prepared and on file at the process establishment. Procedures must include plans for recalling products that may be injurious to health; for identifying, collecting. warehousing, and controlling products; for determining the effectiveness of recalls; for notifying the FDA of any recalls; and for implementing recall programs.

Q. Schools for Supervisors

As discussed earlier in this chapter about appropriate schools, all plant personnel involved in acidification, pH control, heat treatment, or other critical factors of the operation must be under the operating supervision of a person who has attended an approved school and satisfactorily completed the prescribed course of instruction there. Persons may attend the approved schools that offer the Better Process Control school curriculum or an approved Acidified Food GMP school.

An operating supervisor is one who is routinely on duty during processing and packing. This person should be present or reasonably accessible on the premises during processing, packing operations, and container closing.

R. Records Retention, Inspection, Copying

All records of processing, deviations in processing, pH, and other records specified must be kept for 3 years and must be made available for inspection and copying by a duly authorized employee of the FDA upon written demand during the course of an inspection to verify the pH and the adequacy of processing.

S. State Regulations

If a state regulates processors of acidified foods under effective regulations specifying at least the requirements of the FDA, compliance with such regulations will constitute compliance with FDA's, as long as the state or each processor registers and files processing information with the FDA for each processing establishment. This does not exempt firms from complying with this regulation nor exempt them from inspection by the FDA.

T. Imports

This section applies to any foreign processor offering acidified foods in the U.S. except that, in lieu of providing for the issuance of an emergency permit, the agency will request the U.S. Customs to refuse admission of such foods into the United States. Any foods refused admission will not be admitted into the U.S. until the agency determines that the processor has complied with the FDA's requirements and that the food is not injurious to health. An inspection of the facility may be necessary before allowing entry of these foods.

U. Confidential Information

The following information submitted to the FDA is not available for public disclosure:

Manufacturing methods or processes, including quality control information
Production, sales distribution, and similar information
Quantitative or semiquantitative formulae

V. SPOILAGE OF ACIDIFIED FOODS

Fresh food should be handled quickly and carefully and be kept at low temperatures to prevent the build-up of microorganisms that can spoil the product or affect the efficiency of subsequent processing procedures.

For example, damaged products allow for the entry of microorganisms past their natural barrier (surfaces of fruits and vegetables). High numbers of microorganisms may affect the adequacy of the thermal process. Plant sanitation is also important. Mold can grow quickly on food contact surfaces if not kept clean. Molds and some bacteria can grow in an acid environment and actually utilize acid as one of their nutrients, thus raising the pH to a level above 4.6 where *C. botulinum* or other toxin-producing microorganisms could grow. Microbial spoilage can be detected by observing swollen lids on jars or swollen can ends. The liquid may be turbid, and a

whitish deposit may be visible on the product or in the bottom of the jar. If a product has received a heat treatment, spoilage is often caused by lactic acid bacteria, since yeasts are more sensitive to heat. When preservation is dependent on sugar and acid concentrations, yeasts are more commonly the cause of spoilage. Leakage after processing will usually be manifested with mold or filamentous yeasts, which grow on the surface. Exclusion of air in the headspace is therefore very important.

VI. SUMMARY GUIDE TO INSPECTIONS OF ACIDIFIED FOOD MANUFACTURERS

The following information has been compiled in an effort to obtain the minimum information necessary to make a valid assessment of a processor's operations.

A. Establishment Registration and Process Filing

1. Has the firm registered with the FDA?
2. Determine if the firm has filed scheduled processes for each of their acidified foods in each container size produced.

If there are questions as to whether a food is an acidified food, an acid food, or a formulated acid food, obtain the information needed (quantitative formula, pH of ingredients, processing steps, etc.) to determine the status of the food product.

Processors must furnish information concerning the adequacy of the Scheduled Process when requested in writing.

B. Recall Procedures

1. Determine if the firm has written recall procedures.
2. Describe the firms recall procedures.

C. Schooling for Supervisors

1. Determine which supervisors have been to a Better Process Control School or other school approved by the FDA for acidified foods.
2. Determine the duties of each supervisor who has attended an approved school.
3. In the case of foreign processors, where the supervisors have not attended an approved school, determine the type and extent of training provided to the supervisor.

D. Acidification Procedures

1. Describe the method(s) used to acidify the food products.
2. Describe the critical control points in the firm's process.
3. Make a flow diagram to explain the firm's process.
4. Describe how the firm controls equilibrium pH in the final product container.
5. Describe the firm's method for checking the pH of in-process and final product.
6. If a pH meter is used,
   a. Is it standardized correctly (as per manufacturer or regulations)?
   b. Is it used correctly to determine the pH of in-process and finished product?
7. Describe the records used to document pH control.

E. Thermal Process

1. Determine if the thermal process is a critical part of the established process to destroy microorganisms of public health significance.
2. Describe the thermal process.
3. Describe the records used to document the thermal process.
4. Determine if the instruments used to measure and control the thermal process are accurate and are routinely checked for accuracy.
5. Determine that pasteurization equipment is operating correctly.

F. Process Deviations

1. Determine if the firm has had any process deviations.
2. Describe how process deviations are handled by the firm.

G. Containers

1. Are container examinations made per the container manufacturer specifications and/or the FDA's regulations?
2. Describe the firm's container coding system. Are all the required elements present?

H. Processing Records

Acidified food manufacturers must permit the inspection and copying of processing, acidification, and other records required under FDA regulations. This includes records of initial distribution.

1. Remember that processing records are not required to be signed or initialed by the operator or reviewed by management.
2. Describe the firm's records covering the examination of raw materials, containers, processing, and finished products.
3. Determine if the firm can identify the initial distribution of the finished food product.

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New Technology, Vegetable Processing, and Microbial Inactivation

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On June 2, 2000, the U.S. Food and Drug Administration (FDA) released a report called "Kinetics of Microbial Inactivation for Alternative Food Processing Technologies." This report evaluates the scientific information available on a variety of alternative food processing technologies. The purpose of the report is to help the Food and Drug Administration evaluate each technology's effectiveness in reducing and inactivating pathogens of public health concern.

The information in this chapter has been completely derived from this report. For ease of reading, all references have been removed. Consult the original documents for unabridged data. This is a report by the Institute of Food Technologists, prepared for the Food and Drug Administration. It was submitted March 29, 2000 and revised June 2, 2000. It is referred to as IFT/FDA contract No. 223-98-2333. Task Order 1. How to Quantify the Destruction Kinetics of Alternative Processing Technologies.

I. OVERARCHING PRINCIPLES

Kinetic parameters and models are used for the development of food preservation processes to ensure safety. They also permit comparison of different processing technologies on reduction of microbial populations. The parameters, with their recognized limitations, are used to analyze and report the reduction of a microbial population as a function of process parameters and include empirical coefficients experimentally determined from microbial reduction kinetics. The models and kinetic parameters are used to present and compare microbial inactivation data from thermal, pressure, and electromagnetic processes. The parameters (D value and $z(T)$, $z(P)$, $z(E)$, E, k, K, and V) have been calculated from data previously reported and using the models for thermal, pressure, and pulse electric field (PEF) technologies. The thermal parameters apply to microwave energy and electrical resistance (ohmic) processes, as well as any other technology where temperature is the primary factor.

The parameters for pressure or PEF treatments should apply to any process where pressure or electricity is the primary critical factor in reducing microbial populations. Given the scarcity of data, these are estimated parameters, and there is an imminent need for more research in this area.

The quantity of data for several of the other technologies, describing the influence of the treatment on reduction of microbial populations, is insufficient for a comparison.

The basic model assumes a linear first-order relationship between microbial population and time. There are considerable discussions about the appropriateness of using a first-order model to describe the reduction in microbial population for all preservation technologies, but without strong evidence to support alternative needs, first-order kinetics were used.

Kinetic parameters for microbial populations exposed to thermal treatments have been assembled over a significant period of time. The published literature has included kinetic parameters needed to respond to most process, product, and microbial situations. Thermal parameters provide a sound basis for development of processes for the microwave energy and electrical resistance (ohmic) technologies.

There are limitations to interpreting these parameters. Care should be taken when the parameters are used to develop processes, to compare the resistance of different microbial populations, or to identify appropriate microorganisms.

Data used to determine the D value and/or k for pressure treatment of microbial populations appear useful. Identifying the key pathogens of concern and their surrogates continue to be an ongoing challenge. Limitations of these data are primarily associated with temperature control or temperature changes during the pressure treatments. Evidence suggesting a synergistic impact of pressure and temperature on microbial populations is too limited for use. Much of the data were collected at a single pressure. Only four studies have used three to five pressure levels, while controlling all other factors affecting the parameters.

Data available on the influence of PEF on microbial populations have many limitations. The kinetic parameters are based on two points on the survivor curve. No single report has measured the inactivation of microbial populations at several levels of electric field strength, leading to the quantification of the PEF coefficient, nor has the synergistic influence of temperature been quantified.

Electrothermal alternative technologies utilize the well-established thermal kinetic parameters for thermal inactivation of vegetative cells of *Salmonella*, *Escherichia coli*, *Yersinia enterocolitica*, *Vibrio* spp., *Aeromonas hydrophila*, *Campylobacter jejuni*, *Listeria monocytogenes*, and *Staphylococcus aureus*. In general, the thermal resistance constants $z(T)$ for the vegetative microorganisms fall between 4 and 7.7°C. The largest D value (smallest k value) reported at 110°C for toxin-producing, spore-forming microorganisms is 12.42 min (k value $= 0.185$/min) for *Clostridium botulinum* proteolytic Type B spores at 110°C in pureed peas.

An independent additional inactivation mechanism due to the electric current during ohmic heating may occur, but at this time evidence is not sufficient to consider the use of alternate kinetic parameters for development of ohmic heating processes. The nonthermal effects of microwave processes on microbial inactivation have not been confirmed and appear insufficient in magnitude to be considered during development of processes. For processes involving the use of pressure for reduction of microbial populations, the F value is the time the product needs to be exposed to the specified pressure and other conditions (that is, temperature) to accomplish the recommended amount of inactivation.

The combined influence of pressure and temperature on inactivation kinetics has been investigated on only a limited basis. Pressure appears significantly to inactivate *S. aureus*. However, in comparable experiments, inactivation rates of selected strains of various *Listeria* spp. with, for example, D values ranging from 1.48 min ($k = 1.556$/min) at 350 MPa to 15 min ($k = 0.154$/min) at 400 MPa being lower than the ones for *S. aureus*. These data were measured at ambient temperatures (20 to 25°C).

Comprehensive data on inactivation rates of *Clostridium sporogenes* spores show that the influence of pressure on inactivation rate, $z(P)$, is 725 MPa at 93°C, 962 MPa at 100°C, and 752 MPa at 108°C. Data for *C. botulinum* Type E Alaska and Type E Beluga indicate that their

D values were in the same range as *C. sporogenes*. The *D* values for *C. botulinum* Type A 62-A are generally higher than the values for *C. sporogenes*, even when considering the influence of temperature and pressure. In another study, high-pressure resistance was reported for *L. monocytogenes* and *S. aureus*. The most pressure-resistant pathogenic vegetative cell populations appear to be those of *E. coli* O157:H7 with a *D* value of 6 min ($k = 0.384$/min) at 600 MPa, and *S. aureus* with a *D* value of 7.14 min ($k = 0.323$/min) at 600 MPa. The most resistant pressure spores appear to be *C. sporogenes* with a *D* value of 16.772 min ($k = 0.138$/min) at 600 MPa ($T = 90°C$) and *C. botulinum* Type A 62-A with a *D* value of 6.7 min ($k = 0.344$/min) at 827 MPa ($T = 75°C$). The pressure coefficient $z(P)$ of 1524 MPa for *C. botulinum* Type A 62-A constitutes an additional indication of the pressure resistance of the spore populations. A recent report shows little if any inactivation after 30 min of *C. botulinum* 17B and Cap 9B exposure to 827 MPa at 75°C.

Adequate inactivation data for estimating the kinetic parameters for microbial populations exposed to PEF are scarce but in a form that fits the basic model. Even with major limitations, the models could be used to establish process time (F) in the short term, but a great effort would be needed to evaluate the outcome.

Parameters based on two-point curves allowed direct comparisons of the effectiveness of PEF in reducing different microbial populations and the influence of the media on microbial inactivation. The *D* values for *Bacillus cereus* spores are higher than for other microbial populations at the same field strength and temperature. The survivor data for PEF are too limited for definite conclusions. For instance, data based on the same field strength and temperature are lacking. In addition, only a few of the published reports provide information on the threshold field strengths needed to initiate inactivation.

For pasteurization purposes, one is mostly concerned with the inactivation of vegetative cells of djsease-producing microorganisms. However, to have a commercially sterile product, the process must control or inactivate any microbial life (usually targeting spores of *Clostridium botulinum* capable of germinating and growing in the food under normal storage conditions).

Efficacy of any preservation technology is influenced by a number of microorganism-related factors that are generally independent of the technology itself. These include the type and form of target microorganism, the genus, species, and strain of the microorganism, the growth stage, environmental stress selection mechanisms; and sublethal injury. Each influences the resistance independently of the apparent inactivation capacity of that particular process.

Extreme environments may select for forms resistant to severe conditions leading to a microbial population of greater resistance. An example of this is the higher heat resistance of acid- or salt-adapted, heat-shocked or starved *E. coli* O157:H7 cells. The questions relative to process design and verification are (a) Are the microorganisms and food environments likely to result in stress induction? (b) Would stress-induced resistance possibly occur? (c) If it did, would it significantly impact the inactivation?

II. PATHOGENS OF PUBLIC HEALTH CONCERN

The following bacteria are known to be responsible for causing food-borne disease: *A. hydrophila*, *B. cereus*, *C. jejuni*, *C. botulinum*, *Clostridium perfringens*, pathogenic *E. coli*, *L. monocytogenes*, *Salmonella serovars*, *Shigella* spp., *S. aureus*, *Vibrio* spp., and *Y. enterocolitica*. The primary virus of concern that is carried by foods is hepatitis A. *Cryptosporidium* and *Cyclospora* are protozoa of concern mainly because they produce resistant cysts. When exploring the new preservation technologies, their preservation level should be compared to that of classical pasteurization or commercial sterilization technologies.

Establishment of traditional thermal processes for foods has been based on two main factors: (a) knowledge of the thermal inactivation kinetics of the most heat-resistant pathogen of concern for each specific food product, and (b) determination of the nature of the heat transfer properties of the food system. The validity of the established process is often confirmed using an inoculated test pack study tested under actual plant conditions using surrogate microorganisms as biological indicators that can mimic the pathogen. Thus the two factors described above, which are well established for thermal processes, should be used for establishing and validating scheduled electrothermal processes.

For other preservation processes not based on heat inactivation, key pathogens of concern and nonpathogenic surrogates need to be identified and their significance evaluated. Surrogates are selected from the population of well-known organisms that have well-defined characteristics and a long history of being nonpathogenic. Surrogates need to be nonpathogenic organisms and not susceptible to injury, with nonreversible thermal or other inactivation characteristics that can be used to predict those of the target organism. The durability to food and processing parameters should be similar to the target organism. Population of surrogates should be constant and have stable thermal and growth characteristics from batch to batch. Enumeration of surrogates should be rapid and with inexpensive detection systems that easily differentiate them from natural flora. Genetic stability of surrogates is desirable to obtain reproducible results. It is recommended also that surrogates do not establish themselves as "spoilage" organisms on equipment or in the production area. The validation process should be designed so that the surrogate exhibits a predictable time-temperature process character profile that correlates to that of the target pathogen. Introduction of system modifications or variables, leading to inaccurate results (e.g., thermocouple probes changing heating rates, nutrients added to the product for surrogate growth altering viscosity) should be avoided.

III. MICROWAVE AND RADIO FREQUENCY PROCESSING

Microwave and radio frequency heating refers to the use of electromagnetic waves of certain frequencies to generate heat in a material through two mechanisms, dielectric and ionic. Microwave and radio frequency heating for pasteurization and sterilization are preferred to conventional heating because they require less time to come up to the desired process temperature, particularly for solid and semisolid foods. Industrial microwave pasteurization and sterilization systems have been reported on and off for over 30 years, but commercial radio frequency heating systems for the purpose of food pasteurization or sterilization are not known to be in use.

For a microwave sterilization process, unlike conventional heating, the design of the equipment can dramatically influence the critical process parameters—the location and temperature of the coldest point. This uncertainty makes it more difficult to make general conclusions about processes and process deviations and how to handle deviations.

Many techniques have been tried to improve the uniformity of heating. The critical process factor when combining conventional heating and microwave or any other novel processes most likely remains the temperature of the food at the cold point, primarily owing to the complexity of the energy absorption and heat transfer processes.

Since the thermal effect is presumably the sole lethal mechanism, the time–temperature history at the coldest location will determine the safety of the process and is a function of the composition, shape, and size of the food, the microwave frequency, and the applicator (oven) design. Time is also a factor in the sense that, as the food heats up, its microwave absorption properties can change significantly and the location of cold points can shift.

IV. OHMIC AND INDUCTIVE HEATING

Ohmic heating (sometimes also referred to as Joule heating, electrical resistance heating, direct electrical resistance heating, electroheating, and electroconductive heating) is defined as the process of passing electric currents through foods or other materials to heat them. Ohmic heating is distinguished from other electrical heating methods by the presence of electrodes contacting the food, or by frequency and waveform.

Inductive heating is a process wherein electric currents are induced within the food due to oscillating electromagnetic fields generated by electric coils. No data about microbial death kinetics under inductive heating have been published.

A large number of potential future applications exist for ohmic heating, including its use in blanching, evaporation, dehydration, fermentation, and extraction. The principal advantage claimed for ohmic heating is its ability to heat materials rapidly and uniformly, including products containing particulates. The principal mechanisms of microbial inactivation in ohmic heating are thermal. While some evidence exists for nonthermal effects of ohmic heating, for most ohmic processes, which rely on heat, it may be unnecessary for processors to claim this effect in their process filings.

V. HIGH-PRESSURE PROCESSING

High-pressure processing (HPP), also called high-hydrostatic-pressure (HHP) or ultra-high-pressure (UHP) processing, subjects liquid and solid foods, with or without packaging, to pressures between 100 and 800 MPa. The process temperature during pressure treatment can be specified from below 0°C to above 100°C. Commercial exposure times can range from a millisecond pulse to over 20 min. Chemical changes in the food generally will be a function of the process temperature and the treatment time.

HPP acts instantaneously and uniformly throughout a mass of food independent of size, shape, and food composition. Compression will uniformly increase the temperature of foods approximately 3°C per 100 MPa. The temperature of a homogenous food will increase uniformly due to compression. Compression of foods may shift the pH of the food as a function of imposed pressure and must be determined for each food treatment process. Water activity and pH are critical process factors in the inactivation of microbes by HPP. An increase in food temperature above room temperature and to a lesser extent a decrease below room temperature increase the inactivation rate of microorganisms during HPP treatment. Temperatures in the range of 45 to 50°C appear to increase the rate of inactivation of food pathogens and spoilage microbes. Temperatures ranging from 90 to 110°C in conjunction with pressures of 500 to 700 MPa have been used to inactivate spore-forming bacteria such as *Clostridium botulinum*. Current pressure processes include batch and semicontinuous systems, but no commercial continuous HPP systems are operating.

The critical process factors in HPP include pressure, time at pressure, time to achieve treatment pressure, decompression time, treatment temperature (including adiabatic heating), product initial temperature, vessel temperature distribution at pressure, product pH, product composition, product water activity, packaging material integrity, and concurrent processing aids. Other processing factors present in the process line before or after the pressure treatment were not included.

Because some types of spores of *C. botulinum* are capable of surviving even the most extreme pressures and temperatures of HPP, there is no absolute microbial indicator for sterility

by HPP. For vegetative bacteria, nonpathogenic *L. innocua* is a useful surrogate for the food-borne pathogen *L. monocytogenes*. A nonpathogenic strain of *Bacillus* may be useful as a surrogate for HPP-resistant *E. coli* O157:H7 isolates.

VI. PULSED ELECTRIC FIELDS

High-intensity pulsed electric field (PEF) processing involves the application of pulses of high voltage (typically 20–80 kV/cm) to foods placed between two electrodes. PEF may be applied in the form of exponentially decaying, square wave, bipolar, or oscillatory pulses and at ambient, subambient, or slightly above ambient temperature for less than 1 s. Energy loss due to heating of foods is minimized, reducing the detrimental changes of the sensory and physical properties of foods.

Some important aspects in pulsed electric field technology are the generation of high electric field intensities, the design of chambers that impart uniform treatment to foods with minimum increase in temperature, and the design of electrodes that minimize the effect of electrolysis.

Although different laboratory- and pilot-scale treatment chambers have been designed and used for PEF treatment of foods, only two industrial-scale PEF systems are available. The systems (including treatment chambers and power supply equipment) need to be scaled up to commercial systems.

To date, PEF has been applied mainly to improve the quality of foods. The application of PEF is restricted to food products that can withstand high electric fields, have low electrical conductivity, and do not contain or form bubbles. The particle size of the liquid food in both static and flow treatment modes is a limitation.

Several theories have been proposed to explain microbial inactivation by PEF. The most studied are electrical breakdown and electroporation.

Factors that affect the microbial inactivation with PEF are process factors (electric field intensity, pulse width, treatment time and temperature, and pulse wave shapes), microbial entity factors (type, concentration, and growth stage of the microorganism), and media factors (pH, antimicrobials and ionic compounds, conductivity, and medium ionic strength).

Although PEF has potential as a technology for food preservation, existing PEF systems and experimental conditions are diverse, and conclusions about the effects of critical process factors on pathogens of concern and kinetics of inactivation need to be further studied.

VII. HIGH-VOLTAGE ARC DISCHARGE

Arc discharge is an early application of electricity to pasteurize fluids by applying rapid discharge voltages through an electrode gap below the surface of aqueous suspensions of microorganisms. A multitude of physical effects (intense wave) and chemical compounds (electrolysis) are generated, inactivating the microorganisms. The use of arc discharge for liquid foods may be unsuitable largely because electrolysis and the formation of highly reactive chemicals occur during the discharge. More recent designs may show some promise for use in food preservation, although the reported results should be confirmed by independent researchers.

VIII. PULSED LIGHT TECHNOLOGY

Pulsed light is a method of food preservation that involves the use of intense and short-duration pulses of broad spectrum "white light" (ultraviolet to the near-infrared region). For most applications, a few flashes applied in a fraction of a second provide a high level of microbial inactivation.

This technology is applicable mainly in sterilizing or reducing the microbial population on packaging or food surfaces. Extensive independent research on the inactivation kinetics under a full spectrum of representative variables of food systems and surfaces is needed.

IX. OSCILLATING MAGNETIC FIELDS

Static (SMF) and oscillating (OMF) magnetic fields have been explored for their potential to inactivate microorganisms. For static magnetic fields, the magnetic field intensity is constant with time, while an oscillating magnetic field is applied in the form of constant amplitude or decaying amplitude sinusoidal waves. OMF applied in the form of pulses reverses the charge for each pulse. The intensity of each pulse decreases with time to about 10% of the initial intensity. Preservation of foods with OMF involves sealing food in a plastic bag and subjecting it to 1 to 100 pulses in an OMF with a frequency of between 5 and 500 kHz at temperature of 0 to 50°C for a total exposure time ranging from 25 to 100 ms.

The effects of magnetic fields on microbial populations have been controversial. Consistent results concerning the efficacy of this method are needed before considering this technology for food preservation purposes.

X. ULTRAVIOLET LIGHT

There is a particular interest in using ultraviolet (UV) light to treat fruit juices, especially apple juice and cider. Other applications include disinfection of water supplies and food contact surfaces. Ultraviolet processing involves the use of radiation from the ultraviolet region of the electromagnetic spectrum. The germicidal properties of UV irradiation (UVC 200–280 nm) are due to DNA mutations induced by DNA absorption of the UV light. This mechanism of inactivation results in a sigmoidal curve of microbial population reduction.

To achieve microbial inactivation, the UV radiant exposure must be at least $400\,J/m^2$ in all parts of the product. Critical factors include the transmissivity of the product, the geometric configuration of the reactor, the power, wavelength, and physical arrangement of the UV source(s), the product flow profile, and the radiation path length. UV may be used in combination with other alternative process technologies, including various powerful oxidizing agents such as ozone and hydrogen peroxide.

XI. ULTRASOUND

Ultrasound is energy generated by sound waves of 20,000 or more vibrations per second. Although ultrasound technology has a wide range of current and future applications in the food industry, including inactivation of microorganisms and enzymes, presently most developments for food applications are nonmicrobial.

Data on inactivation of food microorganisms by ultrasound in the food industry are scarce, and most applications use combinations with other preservation methods. The bactericidal effect of ultrasound is attributed to intracellular cavitation, that is, micromechanical shocks that disrupt cellular structural and functional components up to the point of cell lysis. The heterogeneous and protective nature of food with the inclusion of particulates and other interfering substances severely curtails the use of ultrasound as the only preservation method. Although these limitations make the current probability of commercial development low, the combination of ultrasound with other preservation processes (e.g., heat and mild pressure) appears to have the greatest potential for industrial applications.

Critical processing factors are assumed to be the amplitude of the ultrasonic waves, the exposure/contact time with the microorganisms, the type of microorganism, the volume of food to be processed, the composition of the food, and the temperature of treatment.

XII. PULSED X-RAYS

A number of studies have compared the effects of electron beams, gamma rays, and x-rays, but comparison between these technologies is inconclusive because of differences in the doses applied. Electrons have a limited penetration depth of about 5 cm in food, while x-rays have significantly higher penetration depths (60–400 cm) depending upon the energy used.

Pulsed x-ray technology is a new alternative technology that utilizes a solid-state opening switch to generate electron beam x-ray pulses of high intensity (opening times from 30 ns down to a few nanoseconds; repetition rates up to 1,000 pulses/s in burst mode operation). The specific effect of pulsed in contrast to non-pulsed x-rays has yet to be investigated.

The practical application of food irradiation by x-rays in conjunction with existing food processing equipment is further facilitated by (a) the possibility of controlling the direction of the electrically produced radiation, (b) the possibility of shaping the geometry of the radiation field to accommodate different package sizes, and (c) its high reproducibility and versatility.

Potentially, the negative effects of irradiation on the food quality can be reduced.

XIII. RESEARCH NEEDS

This is a summary of research needs applicable to all or most of the technologies.

1. Evaluate the adequacy of the linear first-order survivor curve model. Although there is evidence of various types of deviations from this historical model, a universally accepted alternative has not evolved. Future research on (an) appropriate model(s) would be beneficial to all preservation technologies.
2. Establish an experimental protocol for obtaining statistically reliable kinetic parameters to describe survivor curves for microbial populations exposed to various alternative technologies, especially pulsed electric fields, pulsed light, oscillating magnetic fields, and x-rays. For example, PEF studies should incorporate multiple levels of electric field intensity, as well as test the potential for synergy with temperature.
3. Identify differences of inactivation action/mechanism(s) among alternative technologies. For example, pulsed light and ultraviolet light, ohmic and microwave, PEF and thermal.
4. Determine the synergism or antagonism of one alternative process used with another and their combined effect on microbial inactivation efficiency.

5. Determine potential formation of unpalatable and toxic by-products due to processing.
6. Develop methods for measuring and monitoring temperatures or other treatment actions within individual, large, solid particulates.
7. Identify new or changing critical process factors and their effect on microbial inactivation.
8. Investigate the influence of pressure on reduction of microbial populations using the proper experimental design (statistically valid, collection of data at different pressures, and control of temperature and product), so that $z(P)$ and/or activation volumes (V) are quantified. Synergistic effects among pressure, temperature, and other variables also should be evaluated.

Table 1 describes the application status of alternative technologies.

Table 1 Application Status of Alternative Technologies

	Ohmic heating[a,b,c]	Microwave and radio frequency[a,b,c]	High voltage arc discharge	PEF	Pulsed light	OMF	Ultrasound	High pressure
Process description	Well described	Well described	Well described	Well described	Well described	Well described	Well described	Well described
Mechanism of inactivation	Well described	Well described	Well described	Well described	Described	Not identified	Described	Well described
Critical process factors and quantification	Well described; hard to predict cold zones	Well described; hard to predict cold zones	Not identified	Described; kinetic models proposed, need validation	Not well defined	Not well defined	Suggested	Well described; proposed models
Process deviations	As in conventional thermal processing	As in conventional thermal processing	Not identified[d]	Identified	Not identified[d]	Not identified[d]	Not identified[d]	Well described

Organisms of concern	As in conventional thermal processing	As in conventional thermal processing	Not identified	Not identified	Not identified	Not identified	Not identified	Identified
Indicator organisms	As in conventional thermal processing	As in conventional thermal processing	Not identified[e]	Not identified[e]	Not identified[e]	Not identified[e]	Not identified[e]	Suggested
Main research need	Prediction of cold zones	Prediction of cold zones and uniformity of heating	Independently conducted research	Treatment measurement and kinetic models validation	Independently conducted research	Consistent microbial effects	Multiple in combination with other technologies	Validation of kinetic models; influence of synergistic processing conditions

[a]Not enough information was available on pulsed x-ray processing to be presented in this table.
[b]UV not presented in this table because only recent studies were discussed, not a comprehensive review.
[c]Not enough information was available on inductive heating processing to be presented in this table.
[d]Lack of critical process factors quantification does not permit suggested responses to process deviations.
[e]Must identify pathogens of concern before indicators are finalized.

APPENDIX A

U.S. Standards for Grades of Canned Whole Kernel (Whole Grain) Corn: 7 CFR 52.881-891

§52.881 PRODUCT DESCRIPTION

Canned whole kernel (whole grain) corn, including vacuum packed corn, means the canned product property prepared from clean, sound, succulent kernels of sweet corn as defined in the Standard of identify for Canned Corn (21 CFR 155.130) issued pursuant to the Federal Food, Drug, and Cosmetic Act.

§52.882 VARIETAL TYPES OF CANNED WHOLE KERNEL CORN

(a) **Conventional** means kernels of sweet corn that convert sugars to starch by going through distinct stages of maturity—milk, cream, then dough stages.

(b) **Supersweet (shrunken 2)** means kernels (or grains) of corn that provide higher naturally occurring sugar, and/or crisper texture (may be yellow, white or combination of each) typical for the variety. These varieties may be slightly darker in color, and some varieties have slightly tougher pericarp (kernel skin) than conventional sweet corn.

§52.883 COLOR TYPES OF CANNED WHOLE KERNEL CORN

(a) **Golden (or yellow)** means kernels (or grains) of corn that are predominately golden (or yellow) and typical for the variety.

(b) **White** means kernels (or grains) of corn that are predominately light cream in color and typical for the variety.

(c) **Combination yellow and white** means any combination of the above varieties and color types or a bicolored variety.

§52.884 DEFINITION OF TERMS

(a) **Acceptable quality level (AQL)** means the maximum percent of defective units or the maximum number of defects per hundred units of product that, for the purpose of acceptance sampling, can be considered satisfactory as a process average.

(b) **Appearance.**

(1) **Good appearance** means the sample unit has a practically uniform color typical of the varietal of color type.

(2) **Reasonably good appearance** means the sample unit has a reasonably uniform color typical of the varietal or color type.

(3) **Fairly good appearance** means the sample unit has a fairly uniform color typical of the varietal or color type. Fairly good appearance limits the "Lot Grade" to Grade B.

(c) **Chaff** means bits of internal and external kernel parts.

(d) **Cob** means tough cellulose material that the kernels of corn grow upon. A portion of cob material means a piece of cob that may or may not be attached to kernel(s) of corn **(corn kernels are removed from cob tissue before making measurements)**.

(e) **Cut** means the degree of smoothness of the cut surface of the kernels, uniformity of depth of cut, chaff, and the degree of freedom from adhering cob tissue.

(1) **Well cut** means the product is more than slightly affected by the presence of ragged cut kernels, torn kernels, chaff, and irregular cut kernels.

(2) **Reasonably well cut** means the product is not materially affected by the presence of ragged cut kernels, torn kernels and irregular cut kernels.

(3) **Fairly well cut** means the product is not seriously affected by the presence of ragged cut kernels, torn kernels, chaff, and irregular cut kernels.

(f) **Damaged kernel** means any kernel affected by insect injury, discoloration, pathological injury, or by other means to the extent that the appearance or eating quality is materially affected. **Seriously damaged kernel** means any kernel affected by insect injury, discoloration, pathological injury, or by other means to the extent that the appearance or eating quality is seriously affected.

(g) **Defect** means any nonconformance of a unit of product from a specified requirement of a signal quality characteristic.

(h) **Extraneous vegetable material (EVM)** means any harmless vegetable material, to include, but not limited to: cob; husk; shank and stalk; or silk **(any color)**.

(i) **Flavor and odor** refers to the palatability of the product. The natural flavor of the sweet corn for the varietal type and/or the effect of added natural sweeteners, salt, or other suitable optional ingredients (Standard of Identity 155.130) are considered in evaluating this factor.

(1) **Good flavor and odor** means the product has a good characteristic flavor and odor for the varietal type of canned sweet corn and is free from objectionable flavors and odors. The number of sample units in a lot that have "fairly good flavor" shall not exceed the applicable acceptance number specified in the sample plan contained in the "Regulations Governing Inspection and Certification of Processed Fruits and Vegetables and Related Products."

(2) **Fairly good flavor and odor** means the product may be lacking in good flavor and odor, may have a flavor typical of very mature corn, may have an overcooked flavor or an atypical flavor caused by processing or postharvest conditions, but is free from objectionable flavors and odors.

(j) **Husk** means the fibrous vegetable sheath that surrounds the ear of the corn.

(k) **Pulled kernel** means a kernel of corn that has been removed from the cob (with cob tissue attached) such that the appearance or eating quality is materially affected as shown in examples 5, 6, and 7 of the USDA Photo-Guide for Classifying "Cut" and "Pulled" Kernels in Canned and Frozen Whole Kernel Corn.

(l) **Sample unit** means the amount of product specified to be used for grading. For appearance, cut, flavor and odor, tenderness and maturity, and varietal characteristics this

includes the entire drained contents of the container. For grading EVM this includes 850 grams (30 oz drained weight); for seriously damaged kernels, damaged kernels and pulled kernels the sample unit is 1000 kemels. The sample unit may be:

(1) The entire contents of a container;

(2) A portion of the contents of a container; or

(3) A combination of the contents of two or more containers.

(m) **Shank** means the tough stem that attaches the ear of corn to the stalk. Shank material includes the tough basal portion that is attached to the husk.

(n) **Silk** means the silky hair-like filament of any color.

(o) **Stalk** means the tough woody main support stem of the corn plant.

(p) **Tolerance** means the percentage of defective units allowed for a specific sample size.

(q) **Tenderness and maturity** means tender in texture with characteristics typical of early stage of development of the kernels for the varietal type(s).

(1) Good tenderness and maturity.

For conventional sweet corn—corn is tender with a cream texture a pericarp that chews easily. The kernels are full and tender, typical of the milk and early cream stage of maturity. There are three levels of quality within "good tenderness and maturity": very tender, tender, moderately tender.

For supersweet corn—corn is crisp and may have slightly tough pericarp, compact internal flesh, that is associated with plump or full kernels. There are three levels of quality within "good tenderness and maturity:" very tender and crisp; tender and crisp; and moderately tender and crisp.

(2) Reasonably good tenderness and maturity.

For conventional sweet corn—is typical of the cream stage of maturity but lacks the attributes for "good tenderness and maturity." Some pericarp residue may be evident upon chewing. There are two levels of quality within "reasonably good tenderness and maturity": cream stage and moderate cream stage.

Far supersweet corn—is corn that lacks tenderness and maybe moderately dry. Kernels may have a reasonably tough pericarp and occasionally are dented. There are two levels of quality within "reasonably good tenderness and maturity": not crisp, not moist; and not crisp, moderately dry, and may include occasionaldented kernels. The number of sample units in a lot that fail to meet "reasonably good tenderness and maturity" shall not exceed the applicable acceptance number specified in the sample plan contained in the "Regulations Governing Inspection and Certification of Processed Fruits and Vegetables and Related Products" (Reference 109-A-1, 52.38).

(3) Fairly tough.

For conventional sweet corn—is corn that is in the dough stage "dry and chewy." Kernels may be dented, but not woody. Pericarp may be tough but not very tough.

For supersweet corn—is corn that is dry, chewy corn, with tough but not very tough pericarp. The number of sample units in a lot that fail to meet "tough" shall not exceed the applicable acceptance number specified in the sample plan contained in the "Regulations Governing Inspection and Certification of Processed Fruits and Vegetables and Related Products."

(r) **Unit** means a kernel of corn or a significant portion thereof.

§52.885 RECOMMENDED FILL OF CONTAINER

The standard for fill of container is not incorporated in the grades of the finished product, since fill of container, as such, is not a factor of quality for the purposes of these grades. It is

recommended that each container of canned corn be filled as full as practicable without impairment of quality and that, except for vacuum pack, the product and packing medium occupy not less than 90 percent of the capacity of the container. The product is considered "Vacuum Packed" when the liquid in the container [as outlined in 21 CFR 155.130 (a)] is not more than 20 percent of the netweight and the container is closed under conditions creating a high vacuum.

§52.886 RECOMMENDED MINIMUM DRAINED WEIGHT

The minimum drained weight recommendations found in the Grading Manual for Canned Whole Kernel Corn are not incorporated in the grades of the finished product, since drained weight, as such, is not a factor of quality for the purpose of these grades.

§52.887 GRADES

(a) **U.S. Grade A** is the quality of canned corn that:
- **(1)** Meets the following prerequisites (Table 1) in which the canned corn:
  - **(i)** Has similar varietal characteristics;
  - **(ii)** Has a good appearance;
  - **(iii)** Is well cut;
  - **(iv)** Has a good flavor and odor; and
  - **(v)** Has good tenderness and maturity for the varietal type.
- **(2)** Is within the limits for defects as specified in Tables 2 and 3 as applicable for the varietal type.

(b) **U.S. Grade B** is the quality of canned corn that:
- **(1)** Meets the following prerequisites (Table 1) in which the canned corn:
  - **(i)** Has similar varietal characteristics;
  - **(ii)** Has a reasonably good appearance;
  - **(iii)** Is reasonably well cut;
  - **(iv)** Has a good flavor and odor; and
  - **(v)** Has reasonably good tenderness and maturity for the varietal type.
- **(2)** Is within the limits for defects as specified in Tables 2 and 3 as applicable for the varietal type.

Table 1 Prerequisites Requirements

Prerequisite	Grade A	Grade B	Grade C
Varietal characteristics	Similar	Similar	Similar
Appearance	Good	Reasonably good	Fairly good
Cut	Well	Reasonably well	Fairly well
Flavor and odor	Good	Good	Fairly good
Tenderness and maturity	Good	Reasonably good	Fairly tough

Table 2 AQL's, Tolerances, and Acceptance Numbers for EVM Based on 850 Grams (30.0 oz.)

Sample units × sample unit size			1 × 850	3 × 850	6 × 850	13 × 850	21 × 850	29 × 850
Units of product in grams			850	2550	5100	11,050	17,850	24,650
Extraneous vegetable material (EVM)	TOL 1[a]	AQL	Acceptance numbers					
			Grade A					
Cob each cc (0.061 cu in)[b]	1.41	1.25	0.80	2.05	3.85	7.85	12.35	16.85
Husk each cm^2 (0.155 sq. in)[b]	0.57	0.47	7	17	32	64	99	133
Silk, each 2.54 cm, recorded in inches	3.5	3.2	36	96	184	384	611	835
			Grade B					
Cob each cc (0.061 cu in)[b]	3.5	3.2	1.8	4.8	9.2	19.2	30.6	41.8
Husk each cm^2 (0.155 sq. in)[b]	1.14	0.99	13	33	62	126	198	270
Silk, each 2.54 cm, recorded in inches	7.0	6.6	68	189	367	774	1235	1693
			Grade C					
Cob each cc (0.061 cu in)[b]	4.94	4.6	2.45	6.75	13.0	27.3	43.4	59.5
Husk each cm^2 (0.155 sq. in)[b]	1.71	1.5	18	48	91	187	244	402
Silk, each 2.54 cm, recorded in inches	24.5	23.8	222	642	1264	2703	4342	5976

[a]Tolerance for cob is based on each 0.55 cc; for husk—each cm^2; and silk—each 9 cm at 11,050 grams.
[b]Corn stalk and shank: If hard and tough, count as cob; if less severe, count as husk.

Table 3 AQL's, Tolerances, and Acceptance Numbers for Other Defects[a]

Sample units × sample unit size			1 × 1000	3 × 1000	6 × 1000	13 × 1000	21 × 1000	29 × 1000
Units of product by count			1000	3000	6000	13,000	21,000	29,000
Defects other than EVM	TOL[a]	AQL	Acceptance numbers					
			Grade A					
Seriously damaged kernels	0.08	0.047	1	3	5	10	15	20
Damaged kernels	0.25	0.192	4	10	17	33	51	68
Pulled kernels	0.25	0.192	4	10	17	33	51	68
			Grade B					
Seriously damaged kernels	0.25	0.192	4	10	17	33	51	68
Damaged kernels	0.50	0.409	7	18	33	65	101	136
Pulled kernels	0.42	0.34	6	15	28	55	85	115
			Grade C					
Seriously damaged kernels	0.42	0.34	6	15	28	55	85	115
Damaged kernels	1.00	0.867	13	34	64	130	204	277
Pulled kernels	0.67	0.562	9	23	43	87	136	184

[a]Based on 1,000 × 13 (13,000) kernels.

(c) **U.S. Grade C** is the quality of canned corn that:
- **(1)** Meets the following prerequisites (Table 1) in which the canned corn:
  - **(i)** Has similar varietal characteristics;
  - **(ii)** Has a fairly good appearance;
  - **(iii)** Is fairly well cut;
  - **(iv)** Has a fairly good flavor and odor; and
  - **(v)** Is fairly tough for the varietal type.
- **(2)** Is within the limits for defects as specified in Tables 2 and 3 as applicable for the varietal type.

(d) **Substandard** is the quality of canned corn that fails to meet the requirements of U.S. Grade C.

§52.888 FACTORS OF QUALITY

The grade of canned corn is based on requirements for the following quality factors:

(a) Prerequisite quality factors:
- **(1)** Varietal characteristics;
- **(2)** Appearance;
- **(3)** Cut;
- **(4)** Flavor and odor; and
- **(5)** Tenderness and maturity.

(b) Classified quality factors:
- **(1)** Extraneous vegetable material (EVM);
- **(2)** Seriously damaged kernels;
- **(3)** Damaged kernels; and
- **(4)** Pulled kernels.

§52.889 ALLOWANCES FOR DEFECTS

§52.890 SAMPLE SIZE

The sample size used to determine whether the requirements of these standards are met shall be as specified in the sampling plans and procedures in the "Regulations Governing Inspection and Certification of Processed Fruits and Vegetables, Processed Products Thereof, and Certain Other Processed Food Products" (7 CFR 52.1 through 52.83).

§52.891 QUALITY REQUIREMENTS

(a) A lot of canned corn is considered as meeting the requirements for quality if:
- **(1)** The prerequisite requirements specified in Section 52.887 are met; and
- **(2)** None of the allowances for the individual quality factors, specified in Section 52.889 in Tables 2 and 3, as applicable are exceeded.

(b) Single sample unit. Each unofficial sample unit submitted for quality evaluation will be treated individually and is considered as meeting the requirements for quality if:
- **(1)** The prerequisites requirements specified in Section 52.887 are met;
- **(2)** The acceptable quality levels (AQL's) in Section 52.889 in Tables 2 and 3, as applicable for the style, are not exceeded.

APPENDIX B

FDA Standard for Frozen Vegetables: 21 CFR 158. Definitions: 21 CFR 158.3; FDA Standard for Frozen Vegetables: 21 CFR 158. Frozen Peas: 21 CFR 158.170

I. FDA STANDARD FOR FROZEN VEGETABLES: 21CFR 158. DEFINITIONS: 21 CFR 158.3

For the purposes of this part the following definitions shall apply:

(a) Lot. A collection of primary containers or units of the same size, type and style manufactured or packed under similar conditions and handled as a single unit of trade.
(b) Lot size. The number of primary containers or units (pounds when in bulk) in the lot.
(c) Sample size. The total number of sample units drawn for examination from a lot.
(d) Sample unit. A container, a portion of the contents of a container, or a composite mixture of product from small containers that is sufficient for the examination or testing as a single unit.
(e) Defective. Any sample unit shall be regarded as defective when the sample unit does not meet the criteria set forth in the standards.
(f) Acceptance number. The maximum number of defective sample units permitted in the sample in order to consider the lot as meeting the specified requirements. The following acceptance numbers shall apply:

	Size container	
Lot size (primary container)	n[a]	c[b]
Net weight equal to or less than 1 kg (2.2 lb) (lb)		
4800 or less	13	2
4801 to 24,000	21	3
24,001 to 48,000	29	4
48,001 to 84,000	48	6
84,001 to 144,000	84	9
144,001 to 240,000	126	13
Over 240,000	200	19
Net weight greater than 1 kg (2.2 lb) (lb)		
20,000 or less	13	2
More than 20,000 to 100,000	21	3

Lot size (primary container)	Size container	
	n[a]	c[b]
More than 100,000 to 200,000	29	4
More than 200,000 to 400,000	48	6
More than 400,000 to 600,000	84	9
More than 600,000 to 1,000,000	126	13
More than 1,000,000	200	19

[a]n = number of sample units.
[b]c = acceptance number.

(g) Acceptable quality level (AQL). The maximum percentage of defective sample units permitted in a lot that will be accepted approximately 95 percent of the time.

II. FDA STANDARD FOR FROZEN VEGETABLES: 21 CFR 158. FROZEN PEAS: 21 CFR 158.170

(a) Identity—(1) Product definition. Frozen peas is the food in "package" form as that term is defined in Sec. 1.20 of this chapter, prepared from the succulent seed of the pea plant of the species *Pisum sativum* L. Any suitable variety of pea may be used. It is blanched, drained, and preserved by freezing in such a way that the range of temperature of maximum crystallization is passed quickly. The freezing process shall not be regarded as complete until the product temperature has reached $-18^{\circ}C$ ($0^{\circ}F$) or lower at the thermal center, after thermal stabilization. Such food may contain one, or any combination of two or more, of the following safe and suitable optional ingredients:

(i) Natural and artificial flavors.
(ii) Condiments such as spices and mint leaves.
(iii) Dry nutritive carbohydrate sweeteners.
(iv) Salt.
(v) Monosodium glutamate and other glutamic acid salts.

(2) Size specifications. If size graded, frozen peas shall contain not less than 80% by weight of peas of the size declared or of smaller sizes. The sample unit may not contain more than 20% by weight of peas of the next two larger sizes, of which not more than one quarter by weight of such peas may be of the larger of these two sizes, and may contain no peas larger than the next two larger sizes, if such there be. The following sizes and designations shall apply:

Size designation	Round hole sieve size through which peas will pass	
	Millimeters	Inch
Extra small	Up to 7.5	0.295
Very small	Up to 8.2	0.32
Small	Up to 8.75	0.34
Medium	Up to 10.2	0.40
Large	Over 10.2	0.40

(3) Labeling. The name of the product is "peas." The term "early," "June," or "early June" shall precede or follow the name in the case of smooth-skin or substantially smooth-skin peas, such as Alaska-type peas. Where the peas are of sweet green wrinkled varieties, the name may include the designation "sweet," "green," "wrinkled," or any combination thereof. The label shall contain the words "frozen" or "quick frozen." The name of the food shall include a declaration of any flavoring that characterizes the product as specified in Sec. 101.22 of this chapter and a declaration of any condiment such as spices and mint leaves that characterizes the product, e.g., "Spice added." Where a statement of pea size is made, such statement shall indicate either the size designation as specified in paragraph (a) (2) of this section or the applicable sieve size. However, the optional descriptive words "petite" or "tiny" may be used in conjunction with the product name when an average of 80% or more of the peas, will pass through a circular opening of a diameter of 8.75 mm (0.34 in.) or less for sweet green wrinkled peas and 8.2 mm (0.32 in.) for smooth-skin or substantially smooth-skin peas, such as Alaska-type peas.

(4) Label declaration. Each of the ingredients used in the food shall be declared on the label as required by the applicable sections of parts 101 and 130 of this chapter.

(b) Quality. (1) The standard of quality for frozen peas is as follows:

(i) Not more than 4 percent by weight blond peas, i.e., yellow or white but edible peas;

(ii) Not more than 10 percent by weight blemished peas, i.e., slightly stained or spotted peas;

(iii) Not more than 2 percent by weight seriously blemished peas, i.e., peas that are hard, shrivelled, spotted, discolored or otherwise blemished to an extent that the appearance or eating quality is seriously affected.

(iv) Not more than 15 percent by weight pea fragments, i.e., portions of peas, separated or individual cotyledons, crushed, partial or broken cotyledons and loose skins, but excluding entire intact peas with skins detached;

(v) Not more than 0.5 percent by weight, or more than 12 sq cm (2 sq in.) in area, extraneous vegetable material, i.e., vine or leaf or pod material from the pea plant or other such material per sample unit as defined in paragraph (b) of this section.

(vi) The sum of the pea material described in paragraphs (b) (1) (i), (ii), (iii), and (iv) of this section shall not exceed 15 percent.

(vii) For peas that meet the organoleptic and analytical characteristics of sweet green wrinkled varieties:

(a) The alcohol-insoluble solids may not be more than 19 percent based on the procedure set forth in paragraph (b) (3) of this section.

(b) Not more than 15 percent by count of the peas may sink in a solution containing 16 percent salt by weight according to the brine flotation test set forth in paragraph (b) (4) of this section;

(viii) For smooth-skin or substantially smooth-skin varieties the alcohol-insoluble solids may not be more than 23 percent based on the procedure set forth in paragraph (b) (3) of this section.

(ix) The quality of a lot shall be considered acceptable when the number of defectives does not exceed the acceptance number in the sampling plans set forth in Sec. 158.3 (f).

(2) The sample unit for determining compliance with the requirements of paragraph (b) (1) of this section other than those of paragraphs (b) (1) (vii) (a) and (b) (1) (viii) of this section, shall be 500 g (17.6 oz). For the determination of alcohol-insoluble solids as specified in paragraph (b) (3) of this section, the container may be the sample unit.

(3) Alcohol-insoluble solids determination. (i) Extracting solutions:

(a) One hundred parts of ethanol denatured with five parts of methanol volume to volume (formula 3A denatured alcohol), or

(b) A mixture of 95 parts of formula 3A denatured alcohol and five parts of isopropanol v/v.

(ii) Eighty percent alcohol (8 liters of extracting solutions, specified in paragraph (b) (3) (i) (a) or (b) of this section, diluted to 9.5 liters with water).

(iii) Drying dish—a flat-bottom dish with a tight fitting cover.

(iv) Drying oven—a properly ventilated oven thermostatically controlled at 100 ± 2°C.

(v) Procedure—Transfer frozen contents of package to plastic bag; tie bag securely and immerse in water bath with continuous flow at room temperature. Avoid agitation of bag during thawing by using clamps or weights. When sample completely thaws, remove bag, blot off adhering water, and transfer peas to U.S. No. 8 sieve, using (20 cm) size for container of less than 3 lb net weight and (30.5 cm) for larger quantities. Without shifting peas, incline sieve to aid drainage, drain 2 minutes. With cloth wipe surplus water from lower screen surface. Weigh 250 g of peas into high-speed blender, add 250 g of water and blend to smooth paste. For less than 250 g sample, use entire sample with equal weight of water. Weight 20 g ± 10 mg the paste into 250 mL distillation flask, add 120 mL of extracting solutions specified in paragraph (b) (3) (i) (a) or (b) of this section, and reflux 30 minutes on steam or water bath or hotplate. Fit into a buchner funnel a filter paper of appropriate size (previously prepared by drying in flat-bottom dish for 2 hours in drying oven, covering, cooling in desiccator, and weighing). Apply vacuum to buchner funnel and transfer contents of beaker so as to avoid running over edge of paper. Aspirate to dryness and wash material on filter with 80 percent alcohol until washings are clear and colorless. Transfer paper and alcohol-insoluble solids to drying dish used to prepare paper, dry uncovered for 2 hours in drying oven, cover, cool in desiccator, and weigh at once. From this weight deduct weight of dish, cover, and paper. Calculate percent by weight of alcohol-insoluble solids.

(4) Brine flotation test. (i) Explanation—The brine flotation test utilizes salt solutions of various specific gravities to separate the peas according to maturity. The brine solutions are based on the percentage by weight of pure salt (NaCl) in solution at 20°C. In making the test the brine solutions are standardized to the proper specific gravity equivalent to the specified "percent of salt solutions at 20°C" by using a salometer spindle accurately calibrated at 20°C. A 250 mL glass beaker or similar receptacle is filled with the brine solution to a depth of approximately 50 mm. The brine solution and sample (100 peas per container) must be at the same temperature and should closely approximate 20°C.

(ii) Procedure—After carefully removing the skins from the peas, place the peas into the solution. Pieces of peas and loose skins should not be used in making the brine flotation test. If cotyledons divide, use both cotyledons in the test and consider the two separated cotyledons as 1 pea; and, if an odd cotyledon sinks, consider it as one pea. Only peas that sink to the bottom of the receptacle within 10 seconds after immersion are counted as "peas that sink."

(5) If the quality of the frozen peas falls below the standard prescribed in paragraph (b) (1) of this section, the label shall bear the general statement of substandard quality specified in the Code of Federal Regulations but in lieu of the words prescribed in the second line of the rectangle the following words may be used where the frozen peas fall below the standard in only one respect: "Below standard in quality ___," the blank to be filled in with the specific reason for substandard quality as listed in the standard.

APPENDIX C

Approximate pH of Vegetables and Vegetable Products

The pH and/or acidity of a food are generally used to determine processing requirements and the applicability of GMP regulations for regulatory purposes. Methods and conditions for determining the pH and acidity of foods are also summarized in 21 CFR 114.90. Methodology for pH is generally available from pH meter and electrode manufacturers.

To assist readers in determining the product pH levels, the approximate ranges of pH values are complied here. Considerable variation exists between varieties, conditions of growing, and processing methods, etc. Data is presented for the edible portion of foods in their normal and natural state, unless otherwise designated. We solicit your input to this matter. This list will be updated when new information is available.

The references have been omitted from this appendix. Please consult the original document for details.

Item	Approximate pH
Artichokes	5.60
Artichokes, canned, acidified	4.30–4.60
Artichokes, French, cooked	5.60–6.00
Artichokes, Jerusalem, cooked	5.93–6.00
Asparagus	6.00–6.70
Buds	6.70
Stalks	6.10
Asparagus, cooked	6.03–6.16
Asparagus, canned	5.00–5.80
Asparagus, frozen, cooked	6.35–6.48
Asparagus, green, canned	5.20–5.32
Asparagus, strained	4.80–5.09
Bamboo shoots	6.20
Bamboo shoots, preserved	3.50–4.60
Beans	5.60–6.50
Lima	6.50
String	5.60
Kidney	5.40–6.00
Boston style	5.05–5.42
Black, cooked	5.78–6.02
Soy	6.00–6.60

(*continued*)

Source: Approximate pH of Foods and Food Products, FDA, June 2000.

Item	Approximate pH
Wax, cooked	5.30–5.70
Beans, pork and tomato sauce, canned	5.10–5.80
Beans, vegetarian, tomato sauce, canned	5.32
Beets	5.30–6.60
Beets, cooked	5.23–6.50
Beets, canned, acidified	4.30–4.60
Beets, canned	4.90–5.80
Beets, chopped	5.32–5.56
Beets, strained	5.32–5.56
Broccoli, cooked	6.30–6.52
Broccoli, frozen, cooked	6.30–6.85
Broccoli, canned	5.20–6.00
Brussels sprouts	6.00–6.30
Brussels sprouts, cooked	6.00–6.15
Cabbage	5.20–6.80
Green	5.50–6.75
White	6.20
Red	5.60–6.00
Savoy	6.30
Carrots, juice	6.40
Carrots	5.88–6.10
Carrots, cooked	5.58–6.03
Carrots, canned	5.18–5.22
Carrots, chopped	5.30–5.56
Carrots, pureed	4.55–5.80
Carrots, strained	5.10–5.10
Cauliflower	5.60
Cauliflower, cooked	6.45–6.80
Celery	5.70–6.00
Celery, cooked	5.37–5.92
Celery knob, cooked	5.71–5.85
Chicory	5.90–6.05
Chili sauce, acidified	2.77–3.70
Chives	5.20–6.31
Corn	5.90–7.30
Corn, Golden Bantam, cooked on cob	6.22–7.04
Corn, frozen, cooked	7.33–7.68
Corn, canned	5.90–6.50
Corn flakes	4.90–5.38
Cucumbers	5.12–5.78
Cucumbers, dill pickles	3.20–3.70
Cucumbers, pickled	4.20–4.60
Eggplant	4.75–5.50
Escarolle	5.70–6.00
Fennel (anise)	5.48–5.88
Fennel, cooked	5.80–6.02
Greens, mixed, chopped	5.05–5.22
Greens, mixed, strained	5.22–5.30
Horseradish, freshly ground	5.35

(*continued*)

Item	Approximate pH
Horseradish	3.56
Kale, cooked	6.36–6.80
Ketchup	3.89–3.92
Kohlrabi, cooked	5.72–5.82
Leeks	5.52–6.17
Leeks, cooked	5.49–6.10
Lentils, cooked	6.30–6.83
Lettuce	5.80–6.15
Lettuce, Boston	5.89–6.05
Lettuce, Iceberg	5.70–6.13
Mushrooms	6.00–6.70
Mushrooms, cooked	6.15–6.22
Mushroom soup, cream of, canned	5.95–6.40
Okra, cooked	5.50–6.60
Olives, green, fermented	3.60–4.60
Olives, ripe	6.00–7.30
Onions, white	5.40–5.80
Onions, red	5.30–5.80
Onions, red	5.32–5.52
Onions, white	5.37–5.85
Onions, yellow	5.32–5.60
Onions, pickled	3.70–4.60
Onions, yellow	5.40–5.60
Parsley	5.70–6.03
Parsnip	5.30–5.70
Parsnips, cooked	5.45–5.65
Pea soup, cream of, canned	5.70
Peas, cooked	6.22–6.88
Peas, frozen, cooked	6.40–6.70
Peas, canned	5.70–6.00
Peas, pureed	4.90–5.85
Peas, strained	5.91–6.12
Peas, dried (split green), cooked	6.45–6.80
Peas, dried (split yellow), cooked	6.43–6.62
Peas, chick, garbanzo	6.48–6.80
Peppers	4.65–5.45
Peppers, green	5.20–5.93
Pickles, fresh pack	5.10–5.40
Pimiento	4.40–4.90
Persimmons	4.42–4.70
Pimento, canned, acidified	4.40–4.60
Potatoes	5.40–5.90
Tubers	5.70
Sweet	5.30–5.60
Mashed	5.10
Pumpkin	4.90–5.50
Radishes, red	5.85–6.05
Radishes, white	5.52–5.69
Red pepper relish	3.10–3.62

(*continued*)

Item	Approximate pH
Rhubarb, California, stewed	3.20–3.34
Rhubarb	3.10–3.40
Canned	3.40
Sauce, enchilada	5.50
Sauerkraut	3.30–3.60
Spinach	5.50–6.80
Frozen	6.30–6.50
Squash (all cooked)	
Yellow	5.80–6.00
White	5.50–5.70
Hubbard	6.00–6.20
Romaine	5.78–6.06
Sauerkraut, cooked	3.16–3.50
Shallots, cooked	5.30–5.70
Spinach, cooked	6.60–7.18
Spinach, frozen, cooked	6.30–6.52
Spinach, chopped	5.38–5.52
Spinach, pureed	5.50–6.22
Spinach, strained	5.63–5.79
Squash, acorn, cooked	5.18–6.49
Squash, Hubbard, cooked	6.00–6.20
Squash, white, cooked	5.52–5.80
Squash, yellow, summer, cooked	5.79–6.00
Swiss chard, cooked	6.17–6.78
Taro syrup	4.50
Tomatoes, whole	4.30–4.90
Paste	3.50–4.70
Canned	3.50–4.70
Juice	4.10–4.60
Tomatoes, wine ripened	4.42–4.65
Tomatoes, strained	4.32–4.58
Tomato puree	4.30–4.47
Tomato soup, cream of, canned	4.62
Turnips	5.29–5.90
Turnip, greens, cooked	5.40–6.20
Turnip, white, cooked	5.76–5.85
Turnip, yellow, cooked	5.57–5.82
Vegetable juice	3.90–4.30
Vegetable soup, canned	5.16
Vegetable soup, chopped	4.98–5.02
Vegetable soup, strained	4.99–5.00
Water chestnut	6.20
Watercress	5.88–6.18
Yams, cooked	5.79–6.81
Yeast	5.65
Zucchini, cooked	5.69–6.10

APPENDIX D

Pathogens: Vegetables and Vegetable Products

The information in this appendix has been adapted from "Analysis and Evaluation of Preventive Control Measures for the Control and Reduction/Elimination of Microbial Hazards on Fresh and Fresh-Cut Produce," FDA, September 30, 2001. All references have been removed. Please consult the original document for details.

Table D-1 Examination of Lettuce or Salad Greens for the Presence of Pathogens

Pathogen	Type	Country[a]	Place of sampling	Incidence	Percentage	Comments
Aeromonas hydrophila	Chicory salads	Italy	Retail	12/12	100	Presumptive *A. hydrophila*
A. hydrophila or *A. caviae*	Lettuce, cut	Australia	Retail or production	66/120	55	Cut and packaged lettuce samples obtained over an 8-month period
A. hydrophila	Salad mix (various)	Italy	Retail	12/12	100	Presumptive *A. hydrophila*
Clostridium botulinum	Salad mix (various)	United States	Retail	2/350	0.6	MAP samples from three different producers
Campylobacter	Lettuce	Canada	Outdoor markets and supermarkets	2/165	1.2	Samples from farmers' markets and supermarkets; positives only from farmers' markets
Campylobacter	Lettuce	United Kingdom	Retail	0/151	0	Imported whole lettuce
Cryptosporidium	Lettuce	Costa Rica	Open markets	2/80	2.5	Samples from eight open markets during the dry and rainy season
Escherichia coli O157:H7	Lettuce	United Kingdom	Retail	0/151	0	Imported whole lettuce
E. coli O157:H7	Salad mix (various)	United States	Retail and food service	0/63	0	Samples from 31 retail and food service facilities
Listeria monocytogenes	Chopped lettuce	Canada	Hospitals	5/39	13	Samples stored at 4 or 10°C for up to 11 days
L. monocytogenes	Lettuce	Canada	Retail	0/50	0	Samples were grown in the US or Canada. Outer leaves tested
L. monocytogenes	Lettuce	France	Production	0/35	0	Lettuce samples from the packing plant before they were cleaned and packaged
L. monocytogenes	Lettuce	Malaysia	NR[b]	1/28	3.6	—
L. monocytogenes	Lettuce	Sri Lanka	NR	10/20	50	—
L. monocytogenes	Lettuce	United Kingdom	Retail	0/151	0	Imported whole lettuce
L. monocytogenes	Lettuce	United States	Retail	1/92	1.1	Samples obtained from two supermarkets

L. monocytogenes	Lettuce, cut	Australia	Retail or production	3/120	2.5	Cut and packaged lettuce samples obtained over an 8-month period
L. monocytogenes	Lettuce, iceberg	United States	—	1/297	0.3	Sample collection from December 1992 to February 1993
L. monocytogenes	Lettuce, Romaine	United States	—	0/320	0	Sample collection from December 1992 to February 1993
L. monocytogenes	Prepacked salads	Northern Ireland	From processor	3/40	7.5	Samples collected from 2 food processors
L. monocytogenes	Prepacked salads	United Kingdom	Retail	4/60	6.7	*Listeria* isolated from two salad varieties; serotype 1/2 (4 isolates) and serotype 4b (1 isolate); ten salad varieties sampled
L. monocytogenes	Salad mix (various)	Germany	NR	6/263	2.3	—
L. monocytogenes	Salad mix (various)	Netherlands	NR	11/25	44	—
L. monocytogenes	Salad mix (various)	Northern Ireland	At production	4/45	9.0	Samples collected from 12 food processors at 6-week intervals
L. monocytogenes	Salad mix (various)	United Kingdom	NR	2/108	1.8	—
L. monocytogenes	Salad mix (various)	Canada	Hospitals	9/39	23	Samples stored at 4 or 10°C for up to 11 days
L. monocytogenes	Salad mix (various)	United States	Retail and food service	1/63	1.6	Samples taken from 31 retail and food service facilities
Staphylococcus aureus	Salad greens	United Kingdom	NR	13/256	5.1	—
S. aureus	Salad mix (various)	Egypt	Retail/food service	3/36	8.3	—
Salmonella	Lettuce	Various	—	1/116	0.9	Produce imported into the US. Samples collected from 11 countries

(*continued*)

Table D-1 Continued

Pathogen	Type	Country[a]	Place of sampling	Incidence	Percentage	Comments
Salmonella	Lettuce	Italy	Retail	82/120	68	Samples taken from five retail outlets and sampled at monthly intervals for 1 year
Salmonella	Lettuce	Netherlands	Various	2/28	7.1	*Salmonella* tested only when *E. coli* present
Salmonella	Lettuce	United Kingdom	Retail	0/151	0	Imported whole lettuce
Salmonella	Salad greens	Egypt	Retail/food service	2/57	3.5	—
Salmonella	Salad mix (various)	Egypt	Retail/food service	1/159	0.6	—
Salmonella	Salad mix (various)	United States	Retail and food service	0/63	0	Samples taken from 31 retail and food service facilities
Salmonella	Lettuce	Spain	Farms, wholesale markets, and retail	5/80	6.3	Samples collected during the four seasons and from different sources. Possible use of contaminated irrigation water
Shigella	Lettuce	Various	—	1/116	1.0	Produce imported into the US. Samples collected and analyzed from 11 countries
Shigella	Lettuce	United Kingdom	Retail	0/151	0	Imported whole lettuce
Shigella	Salad greens	Egypt	Retail/food service	1/157	1.8	—
Shigella	Salad mix (various)	Egypt	Retail/food service	3/159	1.9	—
Vibrio cholerae	Lettuce	United Kingdom	Retail	0/151	0	Imported whole lettuce
Yersinia enterocolitica	Lettuce, cut	Australia	Retail or production	71/120	59	Cut and packaged lettuce samples obtained over an 8-month period
Yersinia	Prepacked salads	United Kingdom	Retail	3/3	100	Subsamples from same batch. Predominantly environmental strains of *Y. enterocolitica*

[a]Country where produce samples were collected and tested.
[b]Not reported.

Table D-2 Examination of Mixed Raw Vegetables for the Presence of Pathogens

Pathogen	Country[a]	Place of sampling	Incidence	Percentage	Comments
Aeromonas spp.	Brazil	Retail	43/90	48	Samples with vegetables like lettuce, watercress, and endive
Clostridium botulinum	United States	Retail	1/144	0.7	MAP samples obtained from three different producers
C. perfringens	United Kingdom	Retail	34/100	34	—
Escherichia coli (enteropathogenic)	United States	Retail	0/49	0	Samples taken from various chain stores. Raw and frozen vegetables
E. coli O157:H7	Mexico	—	17/89	19	—
Giardia spp.	Brazil	Gardens	NR[b]	13	—
Listeria monocytogenes	Germany	Retail	2/103	1.9	—
L. monocytogenes	Italy	—	7/102	6.9	—
L. monocytogenes	Spain	Markets	8/103	7.8	Samples included a variety of vegetables
L. monocytogenes	Taiwan	Markets	6/49	12	Organism isolated from lettuce, Chinese cabbage, and green onions
L. monocytogenes	United Kingdom	Retail	4/64	6.3	Samples taken year round from 4 supermarkets
L. monocytogenes	United Kingdom	Unknown	8/42	19	Prepared mixed vegetables
Salmonella	United States	Wholesale and retail	4/50	8.0	Samples obtained over a 2-year survey. Various vegetables evaluated
Salmonella	Iraq	Various	3/43	7.0	—
Salmonella	Spain	Various	46/849	5.4	Irrigation water samples also taken. Results indicate a close relationship between isolates obtained from water and produce samples

(*continued*)

Table D-2 Continued

Pathogen	Country[a]	Place of sampling	Incidence	Percentage	Comments
Yersinia enterocolitica	Brazil	Retail	1/30	3.3	Samples included lettuce, spinach, watercress, and chicory
Y. enterocolitica	France	NR	4/58	7.0	—
Y. enterocolitica	France	NR	15/30	50	—
Y. enterocolitica	Italy	NR	1/102	1.0	—

[a]Country where produce samples were collected and tested.
[b]Not reported.

Table D-3 Examination of Raw Herbs or Spices for the Presence of Pathogens

Pathogen	Type	Country[a]	Place of sampling	Incidence	Percentage	Comments
Campylobacter	Parsley	Canada	Outdoor markets and supermarkets	1/177	0.6	Samples from farmers' markets and supermarkets. Positives only from farmers' markets
Cryptosporidium	Cilantro (leaves)	Costa Rica	Open markets	4/80	5.0	Samples obtained from eight open markets during the rainy and dry season
Cryptosporidium	Cilantro (roots)	Costa Rica	Open markets	7/80	8.7	Samples obtained from eight open markets during the rainy and dry season
Escherichia coli O157:H7	Cilantro	Mexico	NR[b]	8/41	20	—
E. coli O157:H7	Coriander	Mexico	NR	2/10	20	—
Salmonella	Parsley	Spain	Farm, wholesale, and retail	1/23	4.3	Samples collected all four seasons at different sources. Possible contamination from contaminated irrigation water
Salmonella	Chili	Netherlands	Various	5/16	31	—
Salmonella	Chili	Surinam	NR	5/16	31	—
Salmonella	Cilantro	Various	Various	16/177	9.0	Produce imported into the US. Samples collected from 6 countries
Salmonella	Culantro	Various	Various	6/12	50	Produce imported into the US. Samples collected from 2 countries
Salmonella	Parsley	Various	Various	1/84	1.2	Produce imported into the US. Samples collected from 7 countries
Shigella	Cilantro	Various	Various	0/177	0	Produce imported into the US. Samples collected from 6 countries

(*continued*)

Table D-3 Continued

Pathogen	Type	Country[a]	Place of sampling	Incidence	Percentage	Comments
Shigella	Culantro	Various	Various	0/12	0	Produce imported into the US. Samples collected from 7 countries
Shigella	Parsley	Various	Various	1/84	1.2	Produce imported into the US. Samples collected from 6 countries
Staphylococcus	Parsley	Lebanon	NR	NR	7.7	—

[a]Country where produce samples were collected and tested.
[b]Not reported.

Table D-4 Examination of Raw Vegetables Other than Lettuce and Salad Greens for the Presence of Pathogens

Pathogen	Type	Country[a]	Place of sampling	Incidence	Percentage	Comments
Aeromonas hydrophila	Carrots	Italy	Retail	12/12	100	Presumptive *A. hydrophila*
Clostridium botulinum	Cabbage	United States	Retail	1/337	0.3	MAP[b] samples of shredded cabbage obtained from three different companies
C. botulinum	Coleslaw	United States	Retail	0/72	0	MAP[b] samples of shredded cabbage obtained from three different companies
C. botulinum	Green pepper	United States	Retail	1/201	0.5	MAP[b] samples of shredded cabbage obtained from three different companies
C. botulinum	Mushrooms	Netherlands	Farm auctions	0/5	0	Samples obtained from 5 different auctions. At least 10 different production farms sampled from each auction
Campylobacter jejuni	Mushrooms	United States	Retail	3/200	1.5	Samples obtained from local grocery stores between March and August 1985
Campylobacter	Cabbage	Canada	Outdoor markets and supermarkets	0/130	0	—
Campylobacter	Carrots	Canada	Outdoor markets and supermarkets	0/149	0	—
Campylobacter	Celery	Canada	Outdoor markets and supermarkets	0/150	0	—
Campylobacter	Cucumber	Canada	Outdoor markets and supermarkets	0/123	0	—
Campylobacter	Green onion	Canada	Outdoor markets and supermarkets	1/180	0.6	Samples from farmers' markets and supermarkets. Positives only from farmers markets

(*continued*)

Table D-4 Continued

Pathogen	Type	Country[a]	Place of sampling	Incidence	Percentage	Comments
Campylobacter	Potatoes	Canada	Outdoor markets and supermarkets	1/153	0.7	Samples from farmers markets and supermarkets. Positives only from farmers markets
Campylobacter	Spinach	Canada	Outdoor markets and supermarkets	2/183	1.1	Samples from farmers markets and supermarkets. Positives only from farmers markets
Campylobacter	Radish	Canada	Outdoor markets and supermarkets	2/174	1.1	Samples from farmers markets and supermarkets. Positives only from farmers markets
Cryptosporidium	Cabbage	Costa Rica	Open markets	0/80	0	Samples obtained from eight open markets during the rainy and dry season
Cryptosporidium	Carrots	Costa Rica	Open markets	1/80	1.3	Samples obtained from eight open markets during the rainy and dry season
Cryptosporidium	Cucumber	Costa Rica	Open markets	1/80	1.3	Samples obtained from eight open markets during the rainy and dry season
Cryptosporidium	Radish	Costa Rica	Open markets	1/80	1.3	Samples obtained from eight open markets during the rainy and dry season
Cryptosporidium	Tomato	Costa Rica	Open markets	1/80	1.3	Samples obtained from eight open markets during the dry and rainy season
E. coli O157:H7	Celery	Mexico	NR[c]	6/34	18	—
Listeria monocytogenes	Broccoli	Canada	Hospital	2/35	5.7	Samples stored at 10°C prior to testing
L. monocytogenes	Broccoli	United States	Retail	0/92	0	Samples obtained from two supermarkets
L. monocytogenes	Cabbage	United States	Retail	1/92	1.1	Samples obtained from two supermarkets

L. monocytogenes	Cabbage, green	United States	Processing facility	73/1016	7.2	Samples collected between December 1992 and February 1993
L. monocytogenes	Cabbage, red	United States	Processing facility	10/399	2.5	Samples collected between December 1992 and February 1993
L. monocytogenes	Carrots	Canada	Hospital	0/35	0	Samples stored at 10°C prior to testing
L. monocytogenes	Carrots	United States	Retail	1/92	0	Samples obtained from two supermarkets
L. monocytogenes	Cauliflower	Canada	Hospital	0/39	0	Samples stored at 10°C prior to testing
L. monocytogenes	Cauliflower	United States	Retail	0/92	0	Samples obtained from two supermarkets
L. monocytogenes	Celery	Canada	Retail	0/30	0	Produce grown either in the US or in Canada
L. monocytogenes	Celery	Canada	Hospital	0/39	0	Samples stored at 10°C prior to testing
L. monocytogenes	Coleslaw	Canada	Hospital	1/35	2.9	Samples obtained from stored conditions of 10°C
L. monocytogenes	Coleslaw	Singapore	NR	2/50	4.0	—
L. monocytogenes	Coleslaw	United Kingdom	Retail	3/39	7.7	Samples taken year round from four supermarkets
L. monocytogenes	Cucumber	Malaysia	Restaurants	4/5	80	Samples taken from street vendors. Samples sliced
L. monocytogenes	Cucumber	Pakistan	Retail	1/15	6.7	—
L. monocytogenes	Cucumber	United States	Retail	2/92	2.2	Samples obtained from two supermarkets
L. monocytogenes	Green pepper	Canada	Hospital	1/35	2.9	Samples stored at 10°C prior to testing
L. monocytogenes	Leafy vegetables	Malaysia	Retail	5/22	23	Samples taken from refrigerated supermarkets and open wet markets

(*continued*)

Table D-4 Continued

Pathogen	Type	Country[a]	Place of sampling	Incidence	Percentage	Comments
L. monocytogenes	Mushrooms	United States	Retail	10/92	11	Samples obtained from two supermarkets
L. monocytogenes	Potatoes	United States	Retail	21/132	16	Samples obtained from two supermarkets
L. monocytogenes	Raddiccio	United States	Processing facility	0/180	0	Samples collected between December 1992 and February 1993
L. monocytogenes	Radish	Canada	Retail	0/10	0	Produce grown either in the US or in Canada
L. monocytogenes	Radish	United States	Retail	19/132	14	Samples obtained from two supermarkets
L. monocytogenes	Tomato	Canada	Retail	0/20	0	Produce grown either in the US or in Canada
L. monocytogenes	Tomato	Pakistan	NR	2/15	13	—
L. monocytogenes	Tomato	United States	Retail	0/92	0	Samples obtained from two supermarkets
L. monocytogenes	Unspecified vegetables	United Kingdom	Retail	5/90	5.6	Samples taken year round from four supermarkets
Salmonella	Artichoke	Spain	Farm, wholesale, and retail	3/25	12	Samples collected all four seasons at different sources. Possible contamination from contaminated irrigation water
Salmonella	Cabbage	Netherlands	Various	0/18	0	—
Salmonella	Cabbage	Spain	Various	7/41	17	Samples collected all four seasons at different sources. Possible contamination from contaminated irrigation water
Salmonella	Cardoon	Spain	Farm, wholesale, and retail	1/4	20	Samples collected all four seasons at different sources. Possible contamination from contaminated irrigation water

Salmonella	Cauliflower	Netherlands	Various	1/13	7.7	Salmonella tested only when *E. coli* present
Salmonella	Cauliflower	Spain	Farm, wholesale, and retail	1/23	4.3	Samples collected all four seasons at different sources. Possible contamination from contaminated irrigation water
Salmonella	Celery	Netherlands	Various	0/20	0	—
Salmonella	Celery	Various	Various	1/84	1.2	Produce imported into the US. Samples collected from 2 countries
Salmonella	Eggplant	Netherlands	Various	2/13	1.5	Salmonella tested only when *E. coli* present
Salmonella	Endive	Netherlands	Various	2/26	7.7	Samples either locally grown or imported from Italy
Salmonella	Fennel	Italy	Retail	64/89	72	Samples taken from five retail outlets and sampled monthly for 1 year
Salmonella	Fennel	Netherlands	Various	0/15	0	Samples either locally grown or imported from Italy
Salmonella	Green onion	Various	Various	1/180	0.6	Produce imported into the US. Samples collected from 5 countries
Salmonella	Pepper	Netherlands	Various	0/20	0	—
Salmonella	Spinach	Spain	Various	2/38	5.2	Samples collected all four seasons at different sources. Possible contamination from contaminated irrigation water
Salmonella	Zuchini	Netherlands	Various	0/11	0	—
Salmonella	Beet leaves	Spain	Various	4/52	7.7	Samples collected all four seasons at different sources. Possible contamination from contaminated irrigation water

(*continued*)

Table D-4 Continued

Pathogen	Type	Country[a]	Place of sampling	Incidence	Percentage	Comments
Salmonella	Celery	Spain	Farm, wholesale, and retail	2/26	7.7	Samples collected all four seasons at different sources. Possible contamination from contaminated irrigation water
Shigella	Celery	Various	Various	2/84	2.4	Produce imported into the US. Samples collected from 2 countries
Shigella	Green onion	Various	Various	2/180	1.1	Produce imported into the US. Samples collected from 5 countries
Staphylococcus	Carrots	Lebanon	NR	NR	14	—
Staphylococcus	Radish	Lebanon	NR	NR	6.3	—
Yersinia enterolitica	Watercress	Brazil	Retail	1/5	20	—

[a]Country where produce samples were collected and tested.
[b]Modified atmosphere packaging.
[c]Not reported.

Table D-5 Examination of Seed Sprouts for the Presence of Pathogens

Pathogen	Type	Country[a]	Place of sampling	Incidence	Percentage	Comments
Bacillus cereus	Alfalfa	United States	Health food stores	13/14	92.9	Seeds sprouted in the lab using a home sprouting kit
B. cereus	Mung bean	United States	Health food stores	33/40	83	Seeds sprouted in the lab using a home sprouting kit
B. cereus	Mung bean	United States	At production	2/16	12	Ten surveys conducted over a six-month period
B. cereus	Wheat	United States	Health food stores	15/24	63	Seeds sprouted in the lab using a home sprouting kit
Listeria monocytogenes	Mung bean	France	At production	1/31	3.1	—
L. monocytogenes	Mung bean	France	Retail	19/102	19	—
L. monocytogenes	Mung bean	Malaysia	Retail	6/7	86	Samples taken from refrigerated supermarkets and open wet markets
Salmonella	Mung bean	United States	At production	0/13	0	Ten surveys conducted over a six-month period
Salmonella	Mung bean	Sweeden	NR[b]	NR	NR	—
Salmonella	Mung bean	Thailand	Open markets	30/344	8.7	Samples collected monthly for seven months
Staphylococcus aureus	Alfalfa	Canada	Retail	4/18	22	Sprouts produced by a single processor. Samples obtained from three retail outlets
S. aureus	Mixed sprouts	Canada	Retail	5/18	28	Sprouts produced by a single processor. Samples obtained from three retail outlets
S. aureus	Onion	Canada	Retail	4/18	22	Sprouts produced by a single processor. Samples obtained from three retail outlets

[a]Country where produce samples were collected and tested.
[b]Not reported.

Table D-6 Examination of Unsprouted Seeds for the Presence of *Salmonella*

Type	Country[a]	Place of sampling	Incidence	Percentage	Comments
Alfalfa	United States	Production	0/4	0	Seeds from a local processor
Alfalfa	United States	Health food stores	1/10	10	Seeds labeled as organic
Mixed seeds	United States	Production	0/4	0	Seeds from a local processor
Onion	United States	Production	0/4	0	Seeds from a local processor

[a]Country where produce samples were collected and tested.

Table D-7 Survival and Growth of Pathogenic Bacteria on Raw Tomatoes

Pathogen	Produce type	pH	Method of inoculation	Storage conditions	Temperature (°C)	Initial counts (log_{10} CFU)	Incubation time	Final counts (log_{10} CFU)	Unit	Comments
Listeria monocytogenes (2 strains)	Tomato (chopped)	4.1	Cells suspended in 0.1 M phosphate buffer, 10 mL mixed in 1000 g of tomatoes	Stored in sealed bags with 3% O_2 and 97% N_2 or ambient air. Tomatoes either unwashed or washed in 210–280 ppm chlorine prior to chopping	10	4.5–4.8	10 d	~3.5–4.2	CFU/g	Subjectively judged to be inedible after 10 days due to deterioration
L. monocytogenes (2 strains)	Tomato (chopped)	4.1	Cell suspension in 0.1 M phosphate buffer, 10 mL mixed in 1000 g of tomatoes	Stored in sealed bags with 3% O_2 and 97% N_2 or ambient air. Tomatoes either unwashed or washed in 210–280 ppm chlorine prior to chopping	21	5	8 d	1.0–3.5	CFU/g	Survival slightly better in chlorine treated samples
L. monocytogenes (2 strains)	Tomato (whole, cherry)	Nra	Dip inoculation, inoculum suspended in 0.1 M phosphate buffer	Stored in sealed bags with 3% O_2 and 97% N_2 or ambient air. Tomatoes either not washed or washed in 210–280 ppm chlorine	10	3.5–3.7	20 d	3.5–5.0	CFU/g	Significant growth observed only for Scott A inoculated onto chlorine treated tomatoes stored in air. Little difference between strains, tomato treatments, or storage conditions

(*continued*)

Table D-7 Continued

Pathogen	Produce type	pH	Method of inoculation	Storage conditions	Temperature (°C)	Initial counts (log_{10} CFU)	Incubation time	Final counts (log_{10} CFU)	Unit	Comments
L. monocytogenes (2 strains)	Tomato (whole, cherry)	NR	Dip inoculation, inoculum suspended in 0.1 M phosphate buffer	Stored in sealed bags with 3% O_2 and 97% N_2 or ambient air. Tomatoes either not washed or washed in 210–280 ppm chlorine	21	3.4–3.6	2–8 d	4.8–5.5	CFU/g	Significant growth observed only for Scott A inoculated onto chlorine treated tomatoes stored in air. Little difference between strains, tomato treatments, or storage conditions
Salmonella baildon	Tomato (diced)	4.50–4.52	Cells suspended in deionized water; 30 mL mixed with 2270 g of tomatoes	Tomatoes (450 g) sealed in plastic bags. Stored for up to 12 d	4	0.4	12 d	<1.0	CFU/g	Not detected in 6 enriched 25 g samples analyzed each day (0, 2, 5, 8, 12 d)
S. baildon	Tomato (diced)	4.50–4.52	Cells suspended in deionized water; 30 mL mixed with 2270 g of tomatoes	Tomatoes (450 g) sealed in plastic bags. Stored for up to 12 d	4	3.4	12 d	1.8	CFU/g	Counts reduced by 0.40, 0.67, and 0.75 log_{10} CFU/g after 2, 5, and 8 d respectively
S. baildon	Tomato (diced)	4.39–4.41	Cell suspended in deionized water; 20 mL mixed with 600 g of tomatoes	Tomatoes (100 g) sealed in plastic bags. Stored for up to 72 h	21	0.79	72 h	8.1	CFU/g	Counts 5.32 and 7.60 log_{10} CFU/g after 24 and 48 h, respectively
S. baildon	Tomato (diced)	4.39–4.41	Cells suspended in deionized water; 20 mL mixed with 600 g of tomatoes	Tomatoes (100 g) sealed in plastic bags. Stored for up to 72 h	30	0.79	72 h	7.94	CFU/g	Counts 7.30 and 7.90 log_{10} CFU/g after 24 and 48 h, respectively
S. montevideo	Tomato (cut slices)	4.31–4.52	Spot inoculation, inoculum suspended in distilled water. 25 μL inoculated onto each slice	Tomato sliced into quarters	25	3.4 4.4 7.4	12 h 12 h 12 h	~7.5 ~8.0 ~9.5	CFU/slice	—

S. montevideo	Tomato (mature green, wounded)	4.33–4.52	Spot inoculation, inoculum suspended in distilled water. 25 μL inoculated onto each wounded area	Tomatoes punctured to a depth of 1 mm and 0.6 cm in diameter in eight separate areas	25 25 25	3.0 4.0 7.0	24 h	~4.8 ~5.5 ~7.0	CFU per wounded area	—
S. montevideo	Tomato (ripe, chopped)	4.1	Cell suspension in 0.05 M potassium phosphate buffer. 1 mL inoculated into 50 g sample	1 cm cubes. Stored in stomacher bags	5 20 30	4.4	96 h 22 h 22 h	~4.2 ~6.0 ~7.0	CFU/g CFU/g CFU/g	Tomatoes inedible after 22 h at 20 or 30°C and after 96 h at 5°C
S. montevideo	Tomato (stem scar)	NR	Spot inoculation inoculum suspended in distilled water. 25 μL inoculated onto stem scar	—	20 25	8.0 8.0	7 d 7 d	6.5 5.8	CFU/stem scar	—
S. montevideo	Tomato (stem scar)	NR	Spot inoculation, inoculum suspended in TSB. 25 μL inoculated onto stem scar	—	20 25	7.2 7.2	7 d 7 d	4.6 6.3	CFU/stem scar	—
S. montevideo	Tomato (whole, mature green)	NR	Dip inoculation, inoculum suspended in 0.1 M phosphate buffer	Stored individually in open plastic bags with relative humidity 45–60%	10 20 30	~1.4	1–18 d 7 d 2 d	~2.2 ~4.0 ~5.0	CFU/cm^2	Populations declined at 20 and 30°C after day 7
S. montevideo	Tomato, skin	NR	Spot inoculation, cells suspended in distilled water. Sterile filter discs submerged in inoculum and placed on tomatoes	Filter discs dried at room temperature for 2 h and removed from tomatoes. Tomatoes stored at 83% (20°C) or 72% (25°C) relative humidity	20 25	5.8 5.8	5 d 3 d	<1 <1	CFU/area inoculated	—

(*continued*)

Table D-7 Continued

Pathogen	Produce type	pH	Method of inoculation	Storage conditions	Temperature (°C)	Initial counts (log_{10} CFU)	Incubation time	Final counts (log_{10} CFU)	Unit	Comments
S. montevideo	Tomato, skin	NR	Spot inoculation, cells suspended in TSR. Sterile filter discs submerged in inoculum and placed on tomatoes	Filter discs dried at room temperature for 2 h and removed from tomatoes. Tomatoes stored at 83% (20°C) or 72% (25°C) relative humidity	20 25	5.5 5.5	7 d 7 d	2.6 4.1	CFU/area inoculated	—
Salmonella (3 serotypes)	Tomato (cut, small pieces)	4.0–4.40	Cell suspension in saline, 0.1 mL, inoculated into 20 g of sample	Inoculated samples sealed in polyethylene plastic bags	22 30	1.1	24 h	6.3–6.9 7.2–8.4	CFU/g CFU/g	Final pH 3.90–4.36. *S.* Enteriditis, *S.* Infantis, and *S.* Typhimurium

[a]Not reported.

Table D-8 Survival and Growth of Pathogenic Bacteria on Raw Vegetables Other than Tomatoes, Sprouts, Lettuce, and Salads

Pathogen	Produce type	pH	Mode of inoculation	Storage conditions	Temperature (°C)	Initial counts (log_{10} CFU)	Incubation time	Final counts (log_{10} CFU)	Unit	Comments
Aeromonas hydrophila (2 strains)	Asparagus	NR[a]	Dip inoculation, 1 min. Cells suspended in 0.1 M potassium phosphate buffer	Samples stored in 6% CO_2, 79% N_2, and 15% O_2 in glass jars	15 4	4.5 4.5	4 d 14 d	~8.0 ~7.5	CFU/g CFU/g	Asparagus first became unacceptable for consumption on day 6 (15°C) or day 21 (4°C)
A. hydrophila (2 strains)	Asparagus	NR	Dip inoculation, 1 min. Cells suspended in 0.1 M potassium phosphate buffer	Samples stored in ambient air in glass jars	15 4	4.5 4.5	4 d 21 d	~8.0 ~7.5	CFU/g CFU/g	Asparagus first became unacceptable for consumption on day 4 (15°C) or day 15 (4°C)
A. hydrophila (2 strains)	Broccoli	NR	Dip inoculation, 1 min. Cells suspended in 0.1 M potassium phosphate buffer	Samples stored in 10% CO_2, 79% N_2, and 11% O_2 in glass jars	15 4	5.1 4.0	4 d 14 d	~8.2 ~6.0	CFU/g CFU/g	Broccoli first became unacceptable for consumption on day 10 (15°C) or day 21 (4°C)
A. hydrophila (2 strains)	Broccoli	NR	Dip inoculation, 1 min. Cells suspended in 0.1 M potassium phosphate buffer	Samples stored in ambient air in glass jars	15 4	5.1 4.0	4 d 14 d	~8.2 ~6.0	CFU/g CFU/g	Broccoli first became unacceptable for consumption on day 6 (15°C) or day 21 (4°C)
A. hydrophila (2 strains)	Cauliflower	NR	Dip inoculation, 1 min. Cells suspended in 0.1 M potassium phosphate buffer	Samples stored in ambient air in glass jars	15 4	4.0 3.5	4 d 14 d	~8.5 ~5.9	CFU/g CFU/g	Cauliflower first became unacceptable for consumption on day 6 (15°C) or day 21 (4°C)

(*continued*)

Table D-8 Continued

Pathogen	Produce type	pH	Mode of inoculation	Storage conditions	Temperature (°C)	Initial counts (log_{10} CFU)	Incubation time	Final counts (log_{10} CFU)	Unit	Comments
A. hydrophila (2 strains)	Cauliflower	NR	Dip inoculation, 1 min. Cells suspended in 0.1 M potassium phosphate buffer	Samples stored in 3% CO_2, 79% N_2, and 18% O_2 in glass jars	15 4	4.0 3.5	4 d 14 d	~8.5 ~6.0	CFU/g CFU/g	Cauliflower first became unacceptable for consumption on day 8 (15°C) or day 21 (4°C)
A. hydrophila (1 strain)	Endive (chicory)	NR	Cell suspension added to samples	Stored in moderate vacuum packaging containers under moderate vacuum	6.5	3.2	3–7 d	~7.0	CFU/g	—
A. hydrophila (1 strain)	Endive (chicory)	NR	Cell suspension added to samples	Stored in moderate vacuum packaging container in ambient air	6.5	3.2	3 d	6.5	CFU/g	Populations declined to log 1.0 CFU/g by day 7
A. hydrophila	Vegetable salads (mixed vegetables)	6.0	Cell suspension injected through a silicone septum. Cells suspended in brain heart infusion broth	Samples sealed and stored in polypropylene plastic film	4 15	3.0 3.0	9 d 24 h	~3.5 ~7.9	CFU/g	Population at 15°C steadily declined from 24 h to 6 d
Clostridium botulinum (10 strains)	Broccoli	6.9	Spot inoculation, spores prepared in broth, heat shocked, and diluted in distilled water	Samples loosely packaged and stored in sealed polyethylene bags	21	2.0	3 d	NR	spores/g	6/6 samples toxic. Spoilage observed
C. botulinum (10 strains)	Broccoli	6.9	Spot inoculation, spores prepared in broth, heat shocked, and diluted in distilled water	Samples loosely packaged and stored in sealed polyethylene bags	12	2.0	9 d	NR	spores/g	3/6 samples toxic. Gross spoilage observed

C. botulinum (10 strains)	Broccoli	6.9	Spot inoculation, spores prepared in broth, heat shocked, and diluted in distilled water	Samples loosely packaged and stored in sealed polyethylene bags	4	2.0	30 d	NR	spores/g	0/6 samples toxic. Gross spoilage observed
C. botulinum nonproteolytic (8 strains)	Butternut squash	NR	Spore suspension (2.5 mL) added to 500 g sample	1-inch cubes, inoculated and sealed in a polystyrene tray	10 5	3.0 3.0	7 d 21 d	NR	spores/g	Toxin detected at 7 d (10°C) or 21 d (5°C). No change in appearance. Final pH 6.4 (5°C), 6.7 (10°C)
C. botulinum proteolytic (10 strains)	Butternut squash	NR	Spore suspension (2.5 mL) added to 500 g sample	1-inch cubes, inoculated and sealed in a polystyrene tray	15 25	2.0 2.0	14 d 3 d	NR	spores/g	Toxin detected at 14 d (15°C) or 3 d (25°C). 15°C samples dry and moldy. Swelling of package observed in 25°C samples. Final pH 6.5 (15°C), 6.2 (25°C)
C. botulinum (12 strains)	Cabbage (shredded)	NR	Spore suspension (1 mL), heat shocked, sprayed onto sample. Spores suspended in gel-phosphate buffer	Samples were sealed in 3-qt pouches and stored vented or not vented. Vented bags were placed with space between samples so that air could circulate	4.4 12.7 21	2.1 2.1 2.1	28 d 28 d 28 d	2.2 2.0 ND[b]	MPN spores/g	No toxin detected in samples stored at 4.4°C or 12.7°C. Toxin detected in nonvented samples stored at 21°C after 7 d. Samples judged to be inedible prior to toxin detection
C. botulinum (10 strains, 5 type A and 5 type B)	Cabbage (shredded)	6.2	Spore suspended in water, 1 mL heat shocked suspension added to sample	Stored in ethylene vinyl alcohol bags. Sealed in MAP of 70% CO_2 and 30% N_2	22–25	0.8–1.8	6 d	NR	spores/g	No toxin detected

(*continued*)

Table D-8 Continued

Pathogen	Produce type	pH	Mode of inoculation	Storage conditions	Temperature (°C)	Initial counts (log_{10} CFU)	Incubation time	Final counts (log_{10} CFU)	Unit	Comments
C. botulinum (10 strains, 5 type A and 5 type B)	Cabbage (shredded)	6.2	Spore suspended in water, 1 mL heat shocked suspension added to sample	Stored in ethylene vinyl alcohol bags. Sealed in MAP of 70% CO_2 and 30% N_2	22–25	2–2.3	4 d	NR	spores/g	5/6 bags toxic. Cabbage acceptable. Only type A grew and produced toxin
C. botulinum (10 strains, 5 type A and 5 type B)	Cabbage (shredded)	6.2	Spore suspended in water, 1 mL heat shocked suspension added to sample	Stored in ethylene vinyl alcohol bags. Sealed in MAP of 70% CO_2 and 30% N_2	22–25	2.9	4 d	NR	spores/g	2/2 bags toxic. Cabbage acceptable. Only type A grew and produced toxin
C. botulinum (5 strains, type A)	Cabbage (shredded)	6.2	Spore suspended in water, 1 mL heat shocked suspension added to sample	Stored in ethylene vinyl alcohol bags. Sealed in MAP of 70% CO_2 and 30% N_2	22–25	1.6–2.1	6 d	NR	spores/g	No toxin detected
C. botulinum (5 strains, type A)	Cabbage (shredded)	6.2	Spore suspended in water, 1 mL heat shocked suspension added to sample	Stored in ethylene vinyl alcohol bags. Sealed in MAP of 70% CO_2 and 30% N_2	22–25	2.5–3.0	4 d 5 d 6 d	NR	spores/g	5/10 bags toxic at 4 d, 8/10 bags toxic at 5 d, and 9/10 bags toxic at 6 d. Cabbage acceptable
C. botulinum (10 strains)	Cabbage (shredded)	6.4	Spot inoculation, spores prepared in broth, heat shocked, and diluted in distilled water	Samples stored in polyethylene bags and vacuum sealed	4 12 21	2.0	37 8 4	NR	spores/g	0/6 samples were toxic at end of storage for all three temperatures. Gross spoilage observed

C. botulinum (10 strains)	Carrots (sliced)	6.3	Spot inoculation, spores prepared in broth, heat shocked, and diluted in distilled water	Samples stored in polyethylene bags and vacuum sealed	4 12 21	2.0	78 d 14 d 4 d	NR	spores/g	0/6 samples were toxic at end of storage for all three temperatures. Gross spoilage observed
C. botulinum nonproteolytic (8 strains)	Coleslaw	NR	Spore suspension (1 mL) injected through gas-tight septum	Samples in original package	5 10	3.0	21 d	NR	spores/g	No toxin detected after 21 d. No change in appearance
C. botulinum proteolytic (10 strains)	Coleslaw	NR	Spore suspension (1 mL) injected through gas-tight septum	Samples in original package	15 25	2.0	21 d	NR	spores/g	No toxin detected after 21 d. No change in appearance
C. botulinum (10 strains)	Green beans	6.3	Spot inoculation, spores prepared in broth, heat shocked, and diluted in distilled water	Samples loosely packaged and stored in sealed polyethylene bags	4 12 21	2.0	35 9 7	NR	spores/g	0/6 samples toxic at end of storage for all three temperatures. Gross spoilage observed
C. botulinum proteolytic (10 strains)	Mushroom (enoki)	NR	Spores suspended in trypticase peptone glucose yeast extract, 0.1 mL inoculated per package	Stored under anaerobic conditions in sealed bags	6 15 15 27	3.0	21 d 7 d 14 d 2 d	No toxin No toxin Toxin Toxin	spores/ package	Spoilage evident when toxin detected
C. botulinum proteolytic (10 strains)	Mushroom (enoki)	NR	Spores suspended in trypticase peptone glucose yeast extract, 0.1 mL inoculated per package	Stored under anaerobic conditions in sealed bags	15 27 27	2.0	14 d 2 d 4 d	Toxin No toxin Toxin	spores/ package	Spoilage evident when toxin detected
C. botulinum proteolytic (10 strains)	Mushroom (enoki)	NR	Spores suspended in trypticase peptone glucose yeast extract, 0.1 mL inoculated per package	Stored under anaerobic conditions in sealed bags	15 21 27 27	1.0	14 d 21 d 2 d 4 d	No toxin Toxin No toxin Toxin	spores/ package	Spoilage evident when toxin detected

(*continued*)

Table D-8 Continued

Pathogen	Produce type	pH	Mode of inoculation	Storage conditions	Temperature (°C)	Initial counts ($\log_{10}$ CFU)	Incubation time	Final counts ($\log_{10}$ CFU)	Unit	Comments
C. botulinum proteolytic (10 strains)	Onion	NR	Spore suspension (2.5 mL) added to 500 g sample	5-mm slices, inoculated and sealed in polystyrene trays	25	3.0	6 d	—	spores/g	Toxin detected at 6 d. Swelling of package observed but no change in appearance of onions
C. botulinum nonproteolytic (8 strains)	Rutabaga	NR	Spore suspension (2.5 mL) added to 500 g sample	1-inch cubes, inoculated and sealed in polystyrene tray	5 10	3.0 3.0	21 d	NR	spores/g	No toxin detected after 21 d. No change in appearance
C. botulinum proteolytic (10 strains)	Rutabaga	NR	Spore suspension (2.5 mL) added to 500 g sample	1-inch cubes, inoculated and sealed in polystyrene tray	15 25	2.0 2.0	21 d	NR	spores/g	No toxin detected after 21 d (15°C). No change in appearance. At 25°C toxin detected at 7 d. Decay evident. Final pH 5.9
C. botulinum nonproteolytic (8 strains)	Stir fry vegetables	NR	Spore suspension (1 mL) injected into sealed bags through gas-tight septum	Stored in plastic film	5 10	3.0 3.0	21 d	3.0 3.3	CFU/g	No toxin detected after 21 d. No change in appearance
C. botulinum proteolytic (10 strains)	Stir fry vegetables	NR	Spore suspension (1 mL) injected into sealed bags through gas-tight septum	Stored in plastic film	15	2.0	21 d	2.8	CFU/g	No toxin detected at 21 d. No change in appearance
C. botulinum proteolytic (10 strains)	Stir fry vegetables	NR	Spore suspension (1 mL) injected into sealed bags through gas-tight septum	Stored in plastic film	25	2.0	11 d	>4.5	CFU/g	Toxin detected at 11 d. Soft appearance. Final pH 4.2

Escherichia coli O157:H7 (5 strains)	Carrot (shredded)	7.1	Dip inoculation, 1 min. Cells suspended in deionized water	Stored in polyolefin L-bags consisting of 3% O_2 and 97% N_2	5 12 21	2.5	3 d 3 d 7 d	<1 <1 4.2	CFU/g	Samples held at 5°C and 12°C positive upon enrichment through day 14
E. coli O157:H7 (5 strains)	Carrot (shredded)	7.1	Dip inoculation, 1 min. Cells suspended in deionized water	Stored in air in polyolefin L-bags	5 12 21	5.3	3 d 14 d 7 d	4.6 6.3 6.0	CFU/g	Samples held at 5°C positive upon enrichment through day 14
E. coli O157:H7 (5 strains)	Carrot (shredded)	7.1	Dip inoculation, 1 min. Cells suspended in deionized water	Stored in air in polyolefin L-bags	5 12 21	2.5	3 d 3 d 7 d	<1 <1 3.8	CFU/g	Samples held at 5°C and 12°C positive upon enrichment through day 14
E. coli O157:H7 (5 strains)	Carrot (shredded)	7.1	Dip inoculation, 1 min. Cells suspended in deionized water	Stored in polyolefin L-bags consisting of 3% O_2 and 97% N_2	5 12 21	5.3	3 d 14 d 7 d	4.1 6.6 6.5	CFU/g	Samples held at 5°C positive upon enrichment through day 14
E. coli O157:H7 (5 strains)	Cucumber (sliced)	7.3	Dip inoculation, 1 min. Cells suspended in deionized water	5-mm discs, stored in 3% O_2 and 97% N_2 in polyolefin L-bags	5 12 21	5.1	10 d 10 d 7 d	2.3 5.4 4.6	CFU/g	—
E. coli O157:H7 (5 strains)	Cucumber (sliced)	7.3	Dip inoculation, 1 min. Cells suspended in deionized water	5-mm discs, stored in 3% O_2 and 97% N_2 in polyolefin L-bags	5 12 21	2.3	3 d 3 d 7 d	<1 <1 2.6	CFU/g	Samples stored at 5 and 12°C positive upon enrichment through day 3 and day 7, respectively
E. coli O157:H7 (5 strains)	Cucumber (sliced)	7.3	Dip inoculation, 1 min. Cells suspended in deionized water	5-mm discs, stored in air in polyolefin L-bags	5 12 21	5.1	10 d 10 d 7 d	3.4 5.7 2.6	CFU/g	—

(*continued*)

Table D-8 Continued

Pathogen	Produce type	pH	Mode of inoculation	Storage conditions	Temperature (°C)	Initial counts (log_{10} CFU)	Incubation time	Final counts (log_{10} CFU)	Unit	Comments
E. coli O157:H7 (5 strains)	Cucumber (sliced)	7.3	Dip inoculation, 1 min. Cells suspended in deionized water	5-mm discs, stored in air in polyolefin L-bags	5 12 21	2.3	3 d 3 d 7 d	<1 <1 3.1	CFU/g	Samples stored at 5 and 12°C positive upon enrichment through day 3 and day 10, respectively
Listeria monocytogenes (1 strain)	Asparagus	NR	Cells injected into samples	Stored in hemetically sealed bags	2 4 8 12 20	5.0 5.0 5.0 5.0 5.0	6–24 d 6–24 d 3–24 d 3–15 d 3–6 d	4.5 5.0 7.0 9.0 9.0	CFU/g CFU/g CFU/g CFU/g CFU/g	Approximately 1 log increase at 2 and 4°C within 3 d followed by decrease
L. monocytogenes (2 strains)	Asparagus	NR	Dip inoculation, 1 min. Cells suspended in 0.1 M potassium phosphate buffer	Samples stored in 6% CO_2, 79% N_2, and 15% O_2 in glass jars	15 4	4.0/4.8 4.2/4.8	6 d 21 d	~7.3 ~5.8/6.5	CFU/g CFU/g	Asparagus first became unacceptable for consumption on day 6 (15°C) or day 21 (4°C)
L. monocytogenes (2 strains)	Asparagus	NR	Dip inoculation, 1 min. Cells suspended in 0.1 M potassium phosphate buffer	Samples stored in ambient air in glass jars	15 4	4.0/4.8 4.2/4.8	4 d 14 d	~7.0 ~5.0/5.5	CFU/g CFU/g	Asparagus first became unacceptable for consumption on day 4 (15°C) or day 14 (4°C)
L. monocytogenes (2 strains)	Broccoli	NR	Dip inoculation, 1 min. Cells suspended in 0.1 M potassium phosphate buffer	Samples stored in 10% CO_2, 79% N_2, and 11% O_2 in glass jars	15 4	5.0/5.5 4.0	10 d 21 d	~8.8 ~4.0/4.5	CFU/g CFU/g	Broccoli first became unacceptable for consumption on day 10 (15°C) or day 21 (4°C)

L. monocytogenes (2 strains)	Broccoli	NR	Dip inoculation, 1 min. Cells suspended in 0.1 M potassium phosphate buffer	Samples stored in ambient air in glass jars	15 4	5.6 4.0	10 d 21 d	~8.7 ~3.8/4.0	CFU/g CFU/g	Broccoli first became unacceptable for consumption on day 6 (15°C) or day 14 (4°C)
L. monocytogenes (5 strains)	Butternut squash	6.3	Cell suspension, 10 mL of cells added to sample. Cells suspended in 0.1% peptone	2.5 cm cubes, inoculated, and transferred to a foam tray. Sealed and stored in a bag	4 10	3.0	9 d	~6.5 ~8.5	CFU/g	—
L. monocytogenes (1 strain)	Cabbage (shredded)	NR	Cells suspended in Butterfield's phosphate buffer, 1 mL added to sample	Samples in stored gas impermeable plastic bags and sealed in ambient atmosphere	5	3.6	13 d/17 d	4.6/2.1	CFU/g	—
L. monocytogenes (1 strain)	Cabbage (shredded)	NR	Cells suspended in Butterfield's phosphate buffer, 1 mL added to sample	Samples in stored gas impermeable plastic bags and sealed in 70% CO_2 and 30% N_2, held refrigerated for first 24 h	5	3.0	17 d	~4.9	CFU/g	—
L. monocytogenes (1 strain)	Cabbage (shredded)	6.32 (day 1)	Cells suspended in Butterfield's phosphate buffer, 1 mL added to sample	Samples in stored gas impermeable plastic bags and sealed in ambient atmosphere, held refrigerated for first 24 h	25	4.1	2 d/6–9 d	~6.0/<1.3	CFU/g	—

(*continued*)

Table D-8 Continued

Pathogen	Produce type	pH	Mode of inoculation	Storage conditions	Temperature (°C)	Initial counts (log_{10} CFU)	Incubation time	Final counts (log_{10} CFU)	Unit	Comments
L. monocytogenes (1 strain)	Cabbage (shredded)	6.32 (day 1)	Cells suspended in Butterfield's phosphate buffer, 1 mL added to sample	Samples stored in gas impermeable plastic bags and sealed in 70% CO_2 and 30% N_2	25	4.0	2 d/6–9 d	~4.5/<1.3	CFU/g	—
L. monocytogenes (1 strain)	Cabbage (shredded)	NR	Cells suspended in 0.1 M potassium phosphate buffer and added to sample	Samples mixed, drained, and adjusted to incubation temperature within 3 h	5	4.0	25–64 d	~8.0	CFU/g	—
L. monocytogenes (5 strains)	Carrot	NR	Cell suspension, 1 to 1.6 mL of inoculum injected through a gas-tight septum. Cells suspended in 0.1% peptone	Samples purchased from the store, stored in original packaging	4 10	2.3 2.3	9 d 9 d	1.0 <1.0	CFU/g	—
L. monocytogenes (2 strains)	Carrot (shredded)	—	Dip inoculation, cells suspended in 0.1 M potassium phosphate buffer	Carrots washed or unwashed in 200–250 ppm prior to shredding. Stored in ambient air or in 3% O_2 and 97% N_2	5 15	1.1–2.6 < 1.0	24 d 7 d	3.8–4.6 3.4–5.8	CFU/g	Similar results obtained for unwashed carrots stored at 5°C. Population declined to <1 log CFU/g (day 7) in unwashed carrots stored at 15°C

L. monocytogenes (2 strains)	Carrot (whole)	—	Dip inoculation, cells suspended in 0.1 M potassium phosphate buffer	Carrots washed or unwashed in 200–250 ppm. Stored in ambient air or in 3% O_2 and 97% N_2	5 15	1.8–2.4 2.5–3.0	18 d 7 d	<1.0 <1.0	CFU/g	—
L. monocytogenes (2 strains)	Cauliflower	NR	Dip inoculation, 1 min. Cells suspended in 0.1 M potassium phosphate buffer	Samples stored in 3% CO_2, 79% N_2, and 18% O_2 in glass jars	15 4	3.4/4.0 2.8/3.0	8 d 21 d	~6.8/7.1 ~3.0/3.6	CFU/g CFU/g	Cauliflower first became unacceptable for consumption on day 8 (15°C) or day 21 (4°C)
L. monocytogenes (2 strains)	Cauliflower	NR	Dip inoculation, 1 min. Cells suspended in 0.1 M potassium phosphate buffer	Samples stored in ambient air in glass jars	15 4	3.4/4.0 2.8/3.0	8 d 14 d	~6.2/6.8 ~2.3/3.6	CFU/g CFU/g	Cauliflower first became unacceptable for consumption on day 6 (15°C) or day 14 (4°C)
L. monocytogenes (5 strains)	Coleslaw	6.6	Cell suspension, 1 to 1.6 mL of inoculum injected through a gas-tight septum. Cells suspended in 0.1% peptone	Samples purchased from the store. Stored in original packaging	4 10	2.5 2.5	9 d	~4.0 ~5.0	CFU/g	—
L. monocytogenes (1 strain)	Endive (chicory)	NR	Cell suspension added to samples	Stored in moderate vacuum packaging containers under moderate vacuum	6.5	3.3	7 d	~2.5	CFU/g	—
L. monocytogenes (1 strain)	Endive (chicory)	NR	Cell suspension added to samples	Stored in moderate vacuum packaging container in ambient air	6.5	3.3	7 d	~5.2	CFU/g	—

(*continued*)

Table D-8 Continued

Pathogen	Produce type	pH	Mode of inoculation	Storage conditions	Temperature (°C)	Initial counts (log_{10} CFU)	Incubation time	Final counts (log_{10} CFU)	Unit	Comments
L. monocytogenes (1 strain)	Endive (broad leaved)	—	Dip inoculation, 10 min. Cells suspended in sterile distilled water	Samples inoculated, drained, sealed, and stored in polypropylene pouches	10	4.5	7 d	5.2	CFU/g	—
L. monocytogenes (1 strain)	Endive (curly leaved)	—	Dip inoculation, 10 min. Cells suspended in sterile distilled water	Samples were inoculated, drained, sealed, and stored in polypropylene pouches	10	4.2	7 d	4.5	CFU/g	—
L. monocytogenes (3 strains)	Endive (broad leaved)	NR	Dip inoculation, 10 min. Cells suspended in sterile distilled water. Strains inoculated independently	Samples were inoculated, drained, sealed, and stored in polypropylene pouches	10	4.1–4.8	7 d	6.1–7.0	CFU/g	When lower inoculation levels were used, populations increased faster during initial storage but final populations lower
L. monocytogenes (3 strains)	Endive (broad leaved)	NR	Dip inoculation, 10 min. Cells suspended in sterile distilled water	Stored in 90-mm diameter petri dishes and placed in plastic boxes. Boxes contained wet absorbent paper. Stored in modified atmosphere of 10% CO_2, 10% O_2	3 10	~3.9–4.0 ~4.1–4.2	10 d 8 d	~3.5–4.5 ~6.2–6.7	CFU/g	Higher initial CO_2 levels caused significant spoilage

L. monocytogenes (3 strains)	Endive (broad leaved)	NR	Dip inoculation, 10 min. Cells suspended in sterile distilled water	Stored in 90-mm diameter petri dishes and placed in plastic boxes. Boxes contained wet absorbent paper. Stored in ambient air	3 10	~3.6–3.9 ~4.1–4.2	10 d 8 d	~4.0–5.0 ~6.2–6.7	CFU/g	—
L. monocytogenes (5 strains)	Onion	5.8	Cell suspension, 10 mL of cells added to sample. Cells suspended in 0.1% peptone	1-cm slices, inoculated and transferred to foam trays. Sealed and stored in bags	4 10	4.0 3.5	9 d	~3.0 ~4.8	CFU/g	—
L. monocytogenes (5 strains)	Rutabaga	6.3	Cell suspension, 10 mL of cells added to sample. Cells suspended in 0.1% peptone	0.5 by 0.5 by 7.5 cm sticks, inoculated and transferred to foam trays. Stored and sealed in bags	4 10	3.0 3.0	9 d	~4.0 ~6.0	CFU/g	—
L. monocytogenes (5 strains)	Stir fry vegetables	6.8	Cell suspension, 1–1.6 mL of inoculum injected through a gas-tight septum. Cells suspended in 0.1% peptone	Samples purchased from store. Stored in original packaging	4 10	2.5 2.5	9 d	~3.0 ~5.5	CFU/g	—
Samonella Typhi	Jicama (cubes)	3.30	Spot inoculation, cells suspended in saline. 1 drop (Pasteur pipette) inoculated per cube	12 cm^2 cubes, 0.05 mL lemon juice added, inoculated, and stored in covered glass trays	25–27	3.1	6 h	3.4	CFU/cube	—

(*continued*)

Table D-8 Continued

Pathogen	Produce type	pH	Mode of inoculation	Storage conditions	Temperature (°C)	Initial counts (log_{10} CFU)	Incubation time	Final counts (log_{10} CFU)	Unit	Comments
S. Typhi	Jicama (cubes)	5.97	Spot inoculation, cells suspended in saline. 1 drop (Pasteur pipette) inoculated per cube	12 cm^2 cubes, inoculated and stored in covered glass trays	25–27	3.2	6 h	4.7	CFU/cube	—
Shigella dysenteriae (1 strain)	Jicama (cubes)	5.97	Spot inoculation, cells suspended in saline. 1 drop (Pasteur pipette) inoculated per cube	12 cm^2 cubes, inoculated and stored in covered glass trays	25–27	1.5	6 h	2.2	CFU/cm^2	—
S. flexneri (1 strain)	Carrot salad	NR	Cells suspended in water and added to sample	Samples stored in 50 mL polypropylene centrifuge tubes	5	~6.7	11 d	~2.5	CFU/g	—
S. flexneri (1 strain)	Green pepper (chopped)	NR	Cells suspended in water and added directly to sample	Samples stored in 50 mL polypropylene centrifuge tubes	4	6.7	12 d	4.3	CFU/g	—
S. flexneri (1 strain)	Coleslaw	NR	Cells suspended in water, added directly to sample	Samples stored in 50 mL polypropylene centrifuge tubes	4	~5.1	16 d	~4.3	CFU/g	—
S. flexneri (1 strain)	Cabbage (chopped)	NR	Cells suspended in water, added directly to sample	Samples stored in 50 mL polypropylene centrifuge tubes	4	6.5	26 d	3.1	CFU/g	—

S. flexneri (1 strain)	Onion (chopped)	NR	Cells suspended in water and added to sample	Samples stored in 50 mL polypropylene centrifuge tubes	4	6.7	12 d	5.3	CFU/g	—
S. sonnei	Parsley (chopped leaves)	NR	Parsley was immersed in suspension of cells in 0.05 M potassium phosphate buffer (pH 6.8) for 1 min while being agitated, then dried at 21°C for 1 h	Leaves (300 g) placed in 9-liter pans	21	3.5	1 d	6.2	CFU/g	Subjective examination revealed that parsley was edible
S. sonnei	Parsley (whole leaves)	NR	Parsley was immersed in suspension of cells in 0.05 M potassium phosphate buffer (pH 6.8) for 1 min while being agitated, then dried at 21°C for 1 h	Leaves (300 g) placed in 9-liter pans	21	3.2	7 d	3.8	CFU/g	Subjective examination revealed that parsley was edible
S. sonnei	Parsley (whole or chopped leaves)	NR	Parsley was immersed in suspension of cells in 0.05 M potassium phosphate buffer (pH 6.8) for 1 min while being agitated, then dried at 21°C for 1 h	Leaves (300 g) placed in 9-liter pans	4	3.2–3.5	14 d	0.4–0.8	CFU/g	Subjective examination revealed that parsley was edible

(*continued*)

Table D-8 Continued

Pathogen	Produce type	pH	Mode of inoculation	Storage conditions	Temperature (°C)	Initial counts (log_{10} CFU)	Incubation time	Final counts (log_{10} CFU)	Unit	Comments
S. sonnei (3 strains)	Parsley (chopped)	—	Dip inoculation, cells suspended in 0.05 M potassium phosphate-buffered saline. 1200 g sample inoculated and dried. Chopped after drying	Stored in 9-liter plastic pans	4 21	6.48/3.49	2 d	~9.2/~6.3	CFU/g	The pathogen grew to 9.2 and 6.3 log CFU/g within 2 d at 21°C, followed by a decline. Inoculated chopped parsley stored at 4°C declined throughout a 14 day storage period
S. sonnei (3 strains)	Parsley (whole leaves)	—	Dip inoculation, cells suspended in 0.05 M potassium phosphate-buffered saline. 1200 g sample inoculated and dried.	Stored in 9-liter plastic pans	21	3.23/6.19	7 d/7 d	~3.0/~6.5	CFU/g	An increase of <1 log within 1 day at 21°C, followed by a decline in population after 2 d. Inoculated parsley stored at 4°C declined throughout the 14 day storage period
S. sonnei (1 strain)	Cabbage (shredded)	6.8	Dip inoculation, cells suspended in Butterfield's phosphate buffer	Stored under vacuum in gas-impermeable bags	24 ± 2 0–6	3.2 3.5	1 d/7 d 7 d	7.0/ < -0.52 3.5	MPN/g	—
S. sonnei (1 strain)	Cabbage (shredded)	6.8	Dip inoculation, cells suspended in Butterfield's phosphate buffer	Stored in modified atmosphere (30% N_2, 70% CO_2) in gas-impermeable bags	24 ± 2 0–6	3.4 2.6	1 d/7 d 7 d	7.0/3.7 2.5	MPN/g	—

Table D-9 Survival and Growth of Pathogenic Bacteria on Raw Lettuce and Salads

Pathogen	Produce type	pH	Mode of inoculation	Storage conditions	Temperature (°C)	Initial counts (log_{10} CFU)	Incubation time	Final counts (log_{10} CFU)	Unit	Comments
Clostridium botulinum (10 strains)	Lettuce (intact)	6.2	Spot inoculation, spores prepared in broth, heat shocked, and diluted in distilled water	Samples stored in polyethylene bags and vacuum sealed	4 12 21	2.0	50 d 13 d 6 d	NR	NR	At 4°C, 0/6 toxic. At 12°C, 0/6 toxic. At 21°C, 2/6 toxic. Gross spoilage observed when toxin detected
C. botulinum nonproteolytic (8 strains)	Mixed salad	NR[a]	Spore suspension, 1 mL injected through gas-tight septum	Samples in original package	5 10 15 25	3.0	21 d 21 d 14 d 4 d	3.7 3.7 >4.5 >4.4	spores/g	No toxin at 5 or 10°C. Toxin detected at 14 d (15°C) and 4 d (25°C). Moderate browning at time of toxin detection. Final pH 5.3–5.9
C. botulinum proteolytic (10 strains)	Mixed salad	NR	Spore suspension, 1 mL injected through gas-tight septum	Samples in original package	15 15 25	1.0 2.0	21 d 21 d 7 d	NR NR >4.5	spores/g	No toxin at 15°C. Extensively decay observed when toxin detected (7 d at 24°C)
C. botulinum (12 strains)	Romaine lettuce (shredded)	NR	Spore suspension (1 mL), heat shocked, sprayed onto sample. Spores suspended in gel-phosphate buffer	Samples sealed in 3-qt pouches and stored vented or not vented. Vented bags placed with space between samples so that air could circulate	4.4 12.7 21	2.0 2.0 2.0	28 d 28 d 28 d	2.0 2.1 ND[b]	MPN spores/g	No toxin detected in samples stored at 4.4°C or 12.7°C. Toxin detected in nonvented samples stored at 21°C after 14 d and in vented samples after 21 d. Samples were judged to be inedible prior to toxin detection

(*continued*)

Table D-9 Continued

Pathogen	Produce type	pH	Mode of inoculation	Storage conditions	Temperature (°C)	Initial counts (log_{10} CFU)	Incubation time	Final counts (log_{10} CFU)	Unit	Comments
C. botulinum nonproteolytic (8 strains)	Romaine lettuce	NR	Spore suspension, 1 mL injected through gas-tight septum	Samples in original package	5 10	3.0	21 d	NR	spores/g	Toxin not detected. No change in appearance
C. botulinum proteolytic (10 strains)	Romaine lettuce	NR	Spore suspension, 1 mL injected through gas-tight septum	Samples packaged in film	15 15 25	1.0 2.0	21 d 21 d 9 d	NR NR >4.5	spores/g	Toxin not detected at 15°C. No change in appearance. Extensive decay observed when toxin detected at 25°C
Escherichia coli O157:H7	Lettuce (shredded)	~7.4	Dip inoculation, 1 min. Cells suspended in deionized water	Stored in polyolefin L-bags consisting 3% O_2 and 97% N_2	5 12 21	5.3	14 d 3 d/14 d 3 d/7 d	3.1 7.0/8.0 8.5/8.7	CFU/g	—
E. coli O157:H7	Lettuce (shredded)	~7.4	Dip inoculation, 1 min. Cells suspended in deionized water	Stored in air in polyolefin L-bags	5 12 21	5.3	14 d 3 d/14 d 3 d/7 d	4.2 6.8/7.5 8.5/8.8	CFU/g	—
E. coli O157:H7	Iceberg lettuce (shredded)	NR	Dip inoculation (1 min) in 0.1 M phosphate buffer (pH 7.0) suspension before mild heat treatment (50°C, 90 s)	Stored in plastic bags for up to 18 d	5	3.4	18 d	2.9	CFU/g	Counts on heated lettuce were similar to counts on unheated lettuce.
E. coli O157:H7	Iceberg lettuce (shredded)	NR	Dip inoculation (1 min) in 0.1 M phosphate buffer (pH 7.0) suspension before mild heat treatment (50°C, 90 s)	Stored in plastic bags for up to 7 d	15	3.4	7 d	7.6	CFU/g	Counts on heated lettuce were significantly higher than counts on unheated lettuce stored for 4 and 7 d

E. coli O157:H7	Iceberg lettuce (pieces)	—	Dip inoculation 30 s. Cells suspended in trypticase soy broth	Stored in sealed plastic bags	4	~3.9	4	~3.7	CFU/g	—
Listeria monocytogenes (1 strain)	Butterhead lettuce	NR	Dip inoculation 10 min. Cells suspended in sterile distilled water	Samples were drained on absorbent paper, sealed, and stored in polypropylene pouches	10	4.4	7 d	5.3	CFU/g	—
L. monocytogenes (5 strains)	Ceasar salad	6.3	Cells suspended in 0.1% peptone, 1–1.6 mL injected through a gas-tight septum	Samples purchased from store, inoculated, and stored in original packaging	4 10	~3.0 ~3.0	9 d	~3.0 ~6.0	CFU/g	—
L. monocytogenes (1 strain)	Lettuce (pieces)	NR	Inoculated with contaminated gloved hands. Inoculum diluted in sterile water	Stored in sealed plastic bags	5 12 25	5.4 3.8 4.6	14 d 14 d 14 d	6.5 6.9 5.9	CFU/g	Levels of *L. monocytogenes* estimated by randomly selecting 5 colonies from plate count agar and streaking onto McBride Listeria Agar
L. monocytogenes (2 strains)	Lettuce (shredded)	NR	Dip inoculation, 1 min. Cells suspended in 0.1 M phosphate buffer	Produce washed in 200–250 ppm chlorine and stored in Cryvovac L-bags in 3% O_2 and 97% N_2	5 10	4.1 4.2	15 d 10 d	~5.0 ~8.0	CFU/g	—
L. monocytogenes (2 strains)	Lettuce (shredded)	NR	Dip inoculation 1 min. Cells suspended in 0.1 M phosphate buffer	Produce not washed and stored in Cryvovac L-bags in 3% O_2 and 97% N_2	5 10	4.8 4.8	15 d 10 d	~4.8 ~7.7	CFU/g	—

(*continued*)

Table D-9 Continued

Pathogen	Produce type	pH	Mode of inoculation	Storage conditions	Temperature (°C)	Initial counts ($\log_{10}$ CFU)	Incubation time	Final counts ($\log_{10}$ CFU)	Unit	Comments
L. monocytogenes (2 strains)	Lettuce, whole leaves	NR	Dip inoculation, 1 min. Cells suspended in 0.1 M phosphate buffer	Produce not washed and stored in Cryvovac L-bags in 3% O_2 and 97% N_2	5 10	4.6 4.7	15 d 10 d	5.4 6.8	CFU/g	—
L. monocytogenes (2 strains)	Lettuce, whole leaves	NR	Dip inoculation, 1 min. Cells suspended in 0.1 M phosphate buffer	Produce washed in 200–250 ppm chlorine and stored in Cryvovac L-bags in 3% O_2 and 97% N_2	5 10	4.3 4.7	15 d 10 d	4.9 6.8	CFU/g	—
L. monocytogenes (1 strain)	Lamb's lettuce	NR	Dip inoculation, 10 min. Cells suspended in sterile distilled water	Samples drained on absorbent paper, sealed, and stored in polypropylene pouches	10	4.1	7 d	4.0	CFU/g	—
L. monocytogenes	Iceberg lettuce (pieces)	—	Dip inoculation, 30 s. Cells suspended in trypticase soy broth	Stored in sealed plastic bags	4	~4.1	4	~4.4	CFU/g	—

Salmonella Baildon	Iceberg lettuce (shredded)	6.06–7.00	Cells suspended in deionized water, 30 mL mixed with 2270 g of lettuce	Lettuce (450 g) was sealed in plastic bags. Stored for up to 12 d	4	0.3	12 d	< 1.0	CFU/g	Detected in 6 of 6 enriched samples (25 g) after 2, 5, and 8 d, and 1 of 6 samples after 12 d
S. Baildon	Iceberg lettuce (shredded)	6.06–7.00	Cells suspended in deionized water; 30 mL mixed with 2270 g of lettuce	Lettuce (450 g) was sealed in plastic bags. Stored for up to 12 d	4	3.3	12 d	1.8	CFU/g	Counts were 3.24, 3.07, and 2.69 $\log_{10}$ CFU/g after 2,5, and 8 d, respectively
S. Montevideo	Icerbeg lettuce (pieces)	—	Dip inoculation 30 s. Cells suspended in trypticase soy broth	Stored in sealed plastic bags	4	~4.1	4	~4.4	CFU/g	—
Shigella sonnei	Lettuce (shredded)	NR	Spot inoculated	Strain isolated from outbreak and inoculaed onto lettuce	5	NR	7 d	1 log decrease	CFU/g	—
S. sonnei	Lettuce (shredded)	NR	Spot inoculated	Strain isolated from outbreak and inoculated onto lettuce	15	3.1	—	—	CFU/g	5 h generation time
S. sonnei (1 strain)	Lettuce (shredded)	NR	Spot inoculated	Strain isolated from outbreak and inoculated onto lettuce	22	3.1	12 h	6.3	CFU/g	*S. sonnei* survived but did not grow at 5 and 15°C

[a]Not reported.
[b]Not determined.

Table D-10 Survival of Pathogenic Viruses on Raw Produce

Pathogen	Produce type	Mode of inoculation	Storage conditions	Temperature (°C)	Initial counts (log_{10} CFU)	Incubation time	Final counts (log_{10} CFU)	Unit	Comments
Coxsackie virus B5	Carrot, whole	0.05 mL spot inoculated onto sample. Virus suspended in water	Samples left uncovered	4	~2.6	1 d 5 d	~1.6 <0.6	PFU/sample	Presence of moisture improved survival. Survival significantly better in closed containers with high humidity. Presence of feces improval survival
Coxsackie virus B5	Carrot, whole	0.05 mL spot inoculated onto sample. Virus suspended in dilute feces (1%)	Samples were left uncovered	4	~2.6	1 d 5 d	~1.7 ~1.2	PFU/sample	Presence of moisture improved survival. Survival significantly better in closed containers with high humidity. Presence of feces improved survival
Coxsackie virus B5	Carrot, whole	Spot inoculation, 0.05 mL inoculated onto sample. Virus suspended in undiluted feces	Samples left uncovered	4	~2.6	1 d 5 d	~1.9 ~1.4	PFU/sample	Presence of moisture improved survival. Survival significantly better in closed containers with high humidity. Presence of feces improved survival
Coxsackie virus B5	Celery	0.05 mL spot inoculated onto sample. Virus suspended in water or dilute feces (1%)	Sample enclosed in polyethylene bags which contained a dish of water to maintain humidity	4	~2.6	8 d	~2.6	PFU/sample	Presence of moisture improved survival. Survival significantly better in closed containers with high humidity. Presence of feces improved survival
Coxsackie virus B5	Celery	0.05 mL spot inoculated onto sample. Virus suspended in water or dilute feces (1%)	Samples left uncovered	4	~2.6	1 d	~2.0	PFU/sample	Presence of moisture improved survival. Survival significantly better in closed containers with high humidity. Presence of feces improved survival
Coxsackie virus B5	Lettuce, pieces	Spot inoculation, 0.1 mL inoculated onto each 16-mm disc. Virus grown in hep-2 cells, diluted in phosphate buffered saline	Lettuce discs stored in capped storage flasks with no moisture	4	2.0	7 d	~1.9	—	—

Coxsackie virus B5	Lettuce, pieces	Spot inoculation, 0.1 mL inoculated onto each 16-mm disc. Virus grown in hep-2 cells, diluted in phosphate buffered saline	Lettuce discs stored in capped storage flasks with low moisture levels	4	2.0	7 d	~1.6	—	—
Coxsackie virus B5	Lettuce, pieces	Spot inoculation, 0.1 mL inoculated onto each 16-mm disc. Virus grown in hep-2 cells, diluted in phosphate buffered saline	Lettuce discs stored in capped storage flasks with high moisture levles	4	2.0	7 d	~1.9	PFU/sample	—
Coxsackie virus B5	Radish, whole root	0.05 mL spot inoculated onto sample. Virus suspended in water	Samples left uncovered	4	~2.6	1 d 5 d	~1.6 <0.6	PFU/sample	Presence of moisture improved survival. Survival significantly better in closed containers with high humidity. Presence of feces improved survival
Coxsackie virus B5	Radish, whole root	0.05 mL spot inoculated onto sample. Virus suspended in dilute feces (1%)	Samples left uncovered	4	~2.6	1 d 5 d	~1.8 ~1.3	PFU/sample	Presence of moisture improved survival. Survival significantly better in closed containers with high humidity. Presence of feces improved survival
Coxsackie virus B5	Radish, whole root	0.05 mL spot inoculated onto sample. Virus suspended in undiluted feces	Samples left uncovered	4	~2.6	1 d 5 d	~2.0 ~1.7	PFU/sample	Presence of moisture improved survival. Survival significantly better in closed containers with high humidity. Presence of feces improved survival
Enteroviruses (5 strains)	Lettuce	Virus suspended in saline, 1 mL inoculated per 100 g sample	Samples kept in 150–200 mL beakers	3.1	Unknown	11 d	—	TCD_{50}/mL	0.5 log decrease observed
Enteroviruses (5 strains)	Tomato, whole	Virus suspended in saline, 1 mL inoculated per 100 g sample	Samples kept in 150–200 mL beakers	3–8	Unknown	15 d	—	TCD_{50}/mL	1 log decrease observed

(*continued*)

Table D-10 Continued

Pathogen	Produce type	Mode of inoculation	Storage conditions	Temperature (°C)	Initial counts (log_{10} CFU)	Incubation time	Final counts (log_{10} CFU)	Unit	Comments
Enteroviruses (5 strains)	Tomato, whole	Virus suspended in saline, 1 mL inoculated per 100 g sample	Samples kept in 150–200 mL beakers	3.1	Unknown	15 d	—	TCD_{50}/mL	1 to 2.5 log decrease observed
Hepatitis A virus (strain hM 175)	Lettuce (pieces)	Inoculum contained 5% fetal bovine serum	Samples held in loosely covered petri dishes to allow air flow	4 22	7.3 7.3	12 d 12 d	6.9 3.3	PFU/mL	—
Hepatitis A virus (strain hM 175)	Lettuce (pieces)	Inoculum contained 5% fetal bovine serum	Samples held inside heat sealed plastic bag	4 22	7.3 7.3	12 d 12 d	7.1 6.1	PFU/mL	—
Hepatitis A virus (strain hM 175)	Lettuce (pieces)	Inoculum contained 5% fetal bovine serum	Samples held in heat sealed plastic bags containing 70% CO_2 and 30% N_2	4 22	7.3 7.3	12 d 12 d	7.2 6.9	PFU/mL	—
Rotavirus SA-11	Carrot, pieces	0.1 mL spot inoculated onto sample. Virus grown on MA-104 cells. Virus suspended in Tris-buffered saline	Samples stored in uncovered containers	4 25	4.5 4.5	25 d 15 d	~1.2 ~1.0	PFU/mL	—
Rotavirus SA-11	Carrot, pieces	Immersion inoculation, 200 mL of 10^5 PFU/mL. Virus grown on MA-104 cells. Virus suspended in Tris-buffered saline	Samples stored in uncovered containers	4 25	3.0 2.8	4 d 2 d	<1.0 <1.0	PFU/mL	—

Rotavirus SA-11	Lettuce, pieces	0.1 mL spot inoculated onto sample. Virus grown on MA-104 cells. Virus suspended in Tris-buffered saline	Samples stored in uncovered containers	4 25	4.5	30 d 25 d	2.5 1.1	PFU/mL	—
Rotavirus SA-11	Lettuce, pieces	Immersion inoculation, 200 mL of 10^5 PFU/mL. Virus grown on MA-104 cells. Virus suspended in Tris-buffered saline	Samples stored in uncovered containers	4 25	4.5	25 d 15 d	~1.2 ~1.2	PFU/mL	—
Rotavirus SA-11	Radish, whole root	0.1 mL spot inoculated onto sample. Virus grown on MA-104 cells. Virus suspended in Tris-buffered saline	Samples stored in covered containers	4 25	4.5 4.5	30 d 4 d	~1.5 ~2.5	PFU/mL	—
Rotavirus SA-11	Radish, whole root	Immersion inoculation, 200 mL of 10^5 PFU/mL. Virus grown on MA-104 cells. Virus suspended in Tris-buffered saline	Samples stored in uncovered containers	4 25	3.6 3.6	5 d 4 d	~1.0 ~2.0	PFU/mL	—

Table D-11 Survival and Growth of Pathogenic Organism on Sprout Seeds or Raw Sprouts

Pathogen	Produce type	Mode of inoculation	Storage conditions	Temperature (°C)	Initial counts (log_{10} CFU)	Incubation time	Final counts (log_{10} CFU)	Unit	Comments
Aeromonas hydrophila	Sprouts, mung bean	Diluted suspension inoculated onto sprouts	Stored in rigid plastic containers, 400 mB	6.5	5.0	5 d	~6.8	CFU/g	Sprouts obtained from local retail market
A. hydrophila	Sprouts, mung bean	Diluted suspension inoculated onto sprouts	Stored in rigid plastic containers	6.5	5.0	7 d	~9.2	CFU/g	Sprouts obtained from local retail market
Escherichia coli O157:H7 (5 strains)	Seeds, alfalfa	Dip inoculation, 1 min. Cells suspended in deionized water	Inoculated seeds dried (5.1–6.2% moisture) before storage in sealed containers	5	3	54 weeks	<0.3	CFU/g	Counts decreased to 1.5 log_{10} CFU/g within 38 weeks. Detected by enrichment at 54 weeks
E. coli O157:H7 (5 strains)	Seeds, alfalfa	Dip inoculation, 1 min. Cells suspended in deionized water	Inoculated seeds dried (5.1–6.2% moisture) before storage in sealed containers	25	3	54 weeks	<0.3	—	Counts decreased to 0.74 and <0.3 log_{10} CFU/g after 8 and 12 weeks, respectively. Detected by enrichment after 38 weeks but not 54 weeks
E. coli O157:H7 (5 strains)	Seeds, alfalfa	Dip inoculation, 1 min. Cells suspended in deionized water	Inoculated seeds dried (5.1–6.2% moisture) before storage in sealed containers	37	3	54 weeks	<0.3	—	Counts decreased to <0.3 log_{10} CFU/g within 8 weeks. Detected by enrichment after 38 weeks but not 54 weeks
E. coli O157:H7 (5 strains)	Sprouts, alfalfa	Dip inoculation of seeds, 1 min. Cells suspended in Butterfield's phosphate buffer	Counts monitored during sprout production in glass jars	25	NR	5 d	7.1–8.0	CFU/g	Seeds treated with disinfectants before sprouting

E. coli O157:H7 (5 strains)	Sprouts, alfalfa	Dip inoculation of seeds, 1 min. Cells suspended in deionized water. Sprouts produced from inoculated, dried seeds	Counts monitored during sprout production in plastic boxes	21	2.3	72 h	7.1	CFU/g	Sprouts contained 7.4 and 7.2 $\log_{10}$ CFU/g after 24 and 48 h, respectively
E. coli O157:H7	Sprouts, alfalfa	Dip inoculation of seeds, 10 min. Cells suspended in 0.1% peptone	Counts monitored during sprout production in covered trays	22	3.1	10 d	5.7	CFU/g	Counts reached ca. 5.8 $\log_{10}$ CFU/g within 2 d
E. coli O157:H7 (5 strains)	Sprouts, alfalfa	Sprouts produced at 21°C from inoculated seeds containing 2.7 $\log_{10}$ CFU/g	Stored in closed plastic boxes	9	6.0–6.9	12 d	5.6–6.5	CFU/g	Subjective evaluation revealed sprouts were edible
Salmonella (5 serotypes)	Sprouts, alfalfa	Spot inoculation (0.1 mL) of 10 g of sprouts. Cells suspended in 0.05 M phosphate buffer (pH 6.8)	Stored in closed clear plastic boxes	10	7.7	11 d	6.9	CFU/g	Sprouts subjectively judged to be edible after 11 d
S. Stanley	Seeds, alfalfa	Dip inoculation, 1 min. Cells suspended in deionized water	Inoculated seeds dried before storage in sealed containers	8, 21	2.5	9 weeks	1.81	CFU/g	Seeds stored at 8°C for 9 weeks, then 21°C for 8 weeks contained 0.92 $\log_{10}$ CFU/g
S. Stanley	Alfalfa seeds	Dip inoculation, cells suspended in 30 mL deionized water, seeds added to suspension and mixed for 1 min	Seeds placed on wire screens, dried under a laminar flow hood for 24 h. Seeds stored in plastic bags at 21°C for 48 h and then stored at 8°C	21	2.5	8 weeks	0.9	CFU/g	—

(*continued*)

Table D-11 Continued

Pathogen	Produce type	Mode of inoculation	Storage conditions	Temperature (°C)	Initial counts ($\log_{10}$ CFU)	Incubation time	Final counts ($\log_{10}$ CFU)	Unit	Comments
S. Typhi	Sprouts, alfalfa	Dip inoculation of seeds, 10 min. Cells suspended in 0.1% peptone	Counts monitored during sprout production in covered trays	22	2.5	6 d	3.7	CFU/g	Counts increased to ca. 6.1 $\log_{10}$ CFU/g within 1 d, then decreased through 6 d
S. Typhi	Sprouts, alfalfa	Dip inoculation of seeds, 10 min. Cells suspended in 0.1% peptone. Sprouts produced at 22°C for 7 d	Stored in closed trays	4–7	4.8	15 d	4.5	CFU/g	Decreases have no practical significance to safety
S. Typhi	Sprouts, alfalfa	Seeds germinated for 24 h, then inoculated with cells suspended in 0.1% peptone	Counts monitored during sprout production in covered trays	22	3.4	8 d	2.4	CFU/g	Counts decreased by ca. 1 $\log_{10}$, suggesting inability to compete with aerobic microorganisms, which were present at 7.5 $\log_{10}$ CFU/g when sprouts were inoculated with *S.* Typhi

Vibrio cholerae	Sprouts, alfalfa	Dip inoculation of seeds, 10 min. Cells suspended in 0.1% peptone	Counts monitored during sprout production in covered trays	22	2.5	6 d	3.7	CFU/g	Counts increased to ca. 5.8 $\log_{10}$ CFU/g within 1 d, then decreased through 6 d
V. cholerae	Sprouts, alfalfa	Seeds germinated for 24 h, then inoculated with cells suspended in 0.1% peptone	Counts monitored during sprout production in covered trays	22	2.5	8 d	0.5	CFU/g	Counts decreased by ca. 2 $\log_{10}$, suggesting inability to compete with aerobic microorganisms, which were at 7.5 $\log_{10}$ CFU/g when sprouts were inoculated with *V. cholerae*
V. cholerae	Sprouts, alfalfa	Dip inoculation of seeds, 10 min. Cells suspended in 0.1% peptone. Sprouts produced at 22°C for 7 d	Stored in closed trays	4–7	3.1	15 d	2.1	CFU/g	Decreases have no practical significance to safety

APPENDIX E

Reference Tables for Modified Atmosphere Packaging (MAP) and Controlled Atmosphere Systems (CAS)

The information in this appendix has been adapted from "Analysis and Evaluation of Preventive Control Measures for the Control and Reduction/Elimination of Microbial Hazards on Fresh and Fresh-Cut Produce," FDA, September 30, 2001. All references have been removed. Please consult the original document for details.

Table E-1 Commercially Available Controlled Atmosphere Systems

System	Description
O_2 control External gas generator	Oxygen is removed from incoming air by external gas generators which operate on the open-flame or catalytic burner principles. Fuel as well as CO_2 scrubbers are required; however, the system operation is very flexible and O_2 is rapidly removed.
O_2 control Liquid nitrogen atmospheric generators	The controlled atmosphere is maintained by flushing with sprayed liquid nitrogen placed in front of the evaporator blowers. Excess CO_2 is absorbed by lime bags; a sensor detects rising O_2 levels and corrects them by spraying more liquid nitrogen.
O_2 control Gas separator systems	Pressure-swing adsorption (PSA) system. The absorption of O_2 is mediated by a filtering system where it is contained in a membrane; N_2 rich gas is exported, and the bound O_2 is flushed by depressurization of the vessel. Hollow fibre membrane (HFM) system. Compressed air is heated and forced through hollow fibers made of semipermeable membranes; the CO_2 and O_2 are selectively removed by the membrane, and the N_2 continues into the storage space.
O_2 control Hypobaric storage	This form of low-pressure storage is mediated by a vacuum pump which evacuates the container until the desired pressure is reached. All gas levels are reduced and ethylene diffusion from the product is enhanced. Moisture loss is also reduced. Recommended for the curing of onions.
Carbon dioxide control	These systems are based on scrubbing action where one of the following 5 reagents is used: caustic soda, water, hydrated lime, activated charcoal, or molecular sieves. All involve the removal of CO_2.
Ethylene control	Ethylene can be removed by means of a scrubber-heated catalyst system where ethylene is oxidized to yield CO_2 and water vapor, which is then removed from the room, or by means of an absorbent bead scrubber where ethylene is bound to aluminum silicate spheres mixed with potassium permanganate. In the latter, as bead saturation occurs, they turn from purple ($KMnO_4$) to brown.

Table E-2a Polymers, Film Types, and Permeability Available for Packaging of MAP Produce

Film	Permeability ($cm^3/m^2 \cdot d \cdot atm$ for 25 μ film at 25°C)			Water vapor transmission, $g/m^2/day/atm$ (38°C and 90% relative humidity)
	Oxygen	Nitrogen	Carbon dioxide	
Ethylene vinyl alcohol (EVOH)	3–5	NA	—	16–18
Polyvinylidene chloride coated (PVdC)	9–15	—	20–30	—
Polyethylene, LD	7,800	2,800	42,000	18
Polyethylene, HD	2,600	650	7,600	7–10
Polypropylene cast	3,700	680	10,000	10–12
Polypropylene, oriented	2,000	400	8,000	6–7
Polypropylene, oriented, PvdC coated	10–20	8–13	35–50	4–5
Rigid PVC	150–350	60–150	450–1,000	30–40
Plasticized PVC	500–30,000	300–10,000	1,500–46,000	15–40
Ethylene vinyl acetate (EVA)	12,500	4,900	50,000	40–60
Polystyrene, oriented	5,000	800	18,000	100–125
Polyurethane (polyester)	800–1,500	600–1,200	7,000–25,000	400–600
PvdC-PVC copolymer (Saran)	8–25	2–2.6	50–150	1.5–5.0
Polyamide (Nylon-6)	40	14	150–190	84–3,100
Microperforated (MP)	>15,000[d]	—	—	—
Microporous (MPOR)	>15,000[d]	—	—	Variable

Table E-2b

Edible films	O_2 permeability ($mL \cdot mm/m^2 \cdot d \cdot atm$)	—	CO_2 permeability ($mL \cdot mm/m^2 \cdot d \cdot atm$)	Relative humidity
Pectin	57.5	—	—	87
Chitosan	91.4	—	1,553	93
Wheat (gluten)	190/250	—	4,750/7,100	91/94.5
Na caseinate	77	—	462	77
Gluten-DATEM	153	—	1,705	94.5
Gluten-beeswax	133	—	1,282	91
Na casenate/Myvacet	83	—	154	48
MC/MPMC/fatty acids	46.6	—	180	52
MC and beeswax	4	—	27	42
Gluten-DATEM and beeswax	<3	—	15	56
Gluten-Beeswax and beeswax	<3	—	13	56
Methylcellulose-palmitic acid	78.8	—	—	100
Zein	0.36[b]	—	2.67[b]	0.116[c]
Cozeen	0.89[b]	—	5.25[b]	0.407[c]
Polyethylene	8.3[b]	—	26.1[b]	—
Polypropylene	0.55[b]	—	—	0.00065[c]
Sucrose polyester	2.10[b]	—	—	0.00042[c]

Table E-2c

Smart Films

O_2 scavengers with O_2 indicators
Antibody-based detection systems for detection of microbial pathogen

Antimicrobial films

(i) Edible
Chlorinated phenoxy compound with biocide incorporated into the polymer layer (that is, nisin, lysozyme)
Chlorine dioxide with biocide incorporated into polymer layer
Edible films with sorbic acid, sodium benzoate, benzoic acid, and potassium sorbate
Pine-based volatiles added to edible film
Horseradish extract added to edible film

(ii) Nonedible films/products
Propyl paraben dispersed in a polymer emulsion (Permax 801 or Carboset)
LDPE with Imazalil
LDPE with grapefruit seed extract
Gas, as produced by sachets or other materials to produce sodium metabisulfite to obtain the production of sulfite

NA = information not available. HPMC = hydroxypropyl-methylcellulose; MC = methylcellulose; DATEM = diacety-diacetylated tartaric ester of monoglycerides; AM = acetylated monoglycerides.
[a]Dependent on moisture.
[b]Unit of permeability is in $fl \cdot m/m^2 \cdot s \cdot Pa$; f is abbreviation for femto (10^{-15}).
[c]Unit of permeability is $ng \cdot m/m^2 \cdot s \cdot Pa$; n is the abbreviation for nano (10^{-9}).
[d]Oxygen transmission rate, dependent on film and degree of microperforation or microporosity.

Table E-3 Commercially Available Modified Atmosphere Packaging Systems for Small and Large Quantities of Vegetables

Product[a]	Description	Use
Pallet Package System	Pallet box wrapped in heavy gauge polyethylene, with a silicone membrane window to allow gas exchange regulation and a calibrated hole for pressure regulation.	Various perishables
Marcellin System	For room storage: regulates the atmospheric composition via a parallel series of rectangular bags of silicone rubber; can be installed in or out of storage area and maintains a fairly consistent atmosphere.	Various perishables
Atmolysair System	System of gas diffusion panels enclosed in an airtight container, having two separate airflow paths and a control panel, allowing the potential for automation.	Cabbage in Canada, other perishables
Tom-Ah-Toes (Natural Pak Produce)	Long, narrow box overwrapped with gas permeable film; contains a sachet containing calcium chloride and activated lime to absorb CO_2.	Tomatoes
FreshSpan™ (SunBlush Technologies Inc.)	Consists of a breathable plastic membrane in the liner of the walls of a corrugated paperboard FreshSpan™ box, which can be hermetically sealed.	Fresh-cut asparagus, broccoli, cauliflower
MaptekFresh™ (SunBlush Technologies Inc.)	Maptek Fresh™ is a postharvest biotechnology where specific features and conditions are applied for each type of product to stabilize the produce and place it in a state of hibernation.	Fresh-cut produce
Fresh*flex*™ (Curwood)	Curwood provides a variety of films for produce packaging and can add a variety of features to the package such as antifog, EZ Peel®, Peel-Reseal, Integra Tear®, and Magic Cut®	Produce
MAPAX® (AGA, Sweden)	This system incorporates the optimal atmosphere by testing, to choose the exact gas mixture and the best film for each product considering respiration rate, temperature, packaging film, pack volume, fill weight, and light.	Fresh-cut produce, lettuce, mushrooms, prepeeled potatoes
FreshHold (Hercules Chemical Co.)	Polypropylene label with calcium carbonate embedded in it.	Broccoli, asparagus, cauliflower
Cryovac (W.R. Grace and Co.)	0.75, 1.25, 2.5 mm thick bag made of several layers of polyethylene related polymers.	Cut lettuce, broccoli, cauliflower, spinach, peeled potatoes, and other vegetables
Propafilm CR and CK (Imperial Chemical Industries PLC)	Polypropylene-based films.	Fresh-cut lettuce and other vegetables

(*continued*)

Table E-3 Continued

Product[a]	Description	Use
P-Plus films (Courtaulds Packaging)	Spark perforated films which result in nonuniform perforations throughout the film to facilitate gas exchange.	Brussels sprouts, lettuce, broccoli, fresh mushrooms, and bean sprouts
T-grade (CVP Systems)	Films are coextruded bilayer films in 1.0, 1.25, 1.5, and 1.75 mm thickness.	
Clysar EHC, EH, ECL, LLP (DuPont)	Biaxially oriented, heat shrinkable polyethylene or polyolefin films.	
Laminated boxes (Georgia Pacific, Weyerhaeuser and Tamfresh Ltd.)	Cartons with films laminated within the cardboard or coated on the inside of the cardboard liner. Reduces moisture loss and potentiates air flow.	Broccoli and other perishables
Film Convertors	The converters (companies) buy resin or film and adapt it to attractive specifications. Converters are often more flexible with respect to specific applications of the requested film.	Variable/product specific
Edible films[a]		
Semperfresh, Nu-Coat Fo, Ban-seel, Brilloshine, Snow-White, and White Wash products (Surface Systems Intl. Ltd.)	Sucrose-ester-based fruit coatings with sodium carboxymethyl cellulose products manufactured exclusively from food ingredients available in dip or spray.	Most vegetables, processed and whole potatoes (Snow-White and White-Wash)
PacRite products (American Machinery Corp.)	Variety of products, water-based carnauba-shellac emulsions, shellac and resin water emulsions, water-based mineral oil fatty acid emulsions, and so forth.	Tomatoes, cucumbers, green peppers, squash
Fresh-Cote product line (Agri-Tech Inc.)	Variety of products including shellac-based, carnauba-based, and oil emulsion edible films.	Eggplant, tomatoes, cucumbers
Sta-Fresh Products (Food Machinery Corp.)	Natural, synthetic, and modified natural resin products and combinations thereof.	Tomatoes, and sweet potatoes
Fresh Wax products (Fresh Mark Corp.)	Shellac and wood resin, oxidized polyethylene wax, white oil/paraffin wax products.	Sweet potatoes, cucumbers, tomatoes, and other vegetables
Nature-Seal™, AgriCoat (Mantrose Bradshaw Zinsser Group)	Composite polysaccharide-based coating using cellulose derivatives as film formers.	Carrots, peppers, onions, lettuce

Table E-3 Continued

Product[a]	Description	Use
Intelligent systems		
Activated Earth Films	Typically polyethylene bags with powdered clay material made of powdered aluminum silicates, incorporated into the film matrix. Possibly reduces ethylene concentration by facilitating its diffusion out of the bag.	Variable
Temperature Responsive Films (Landec Labs)	Films increase their gas permeabilities in response to temperature increases as well as increases in respiration. Stabilizes the modified atmosphere so it remains the same under various temperatures.	Specific for each product
CO_2 Scavengers FreshLock (Mitsubishi Gas Chemical Co.), Verifrais (Codimer Tournessi, Gujan-Mestras)	Sachet type product which is placed directly in the package and absorbs both carbon dioxide and oxygen.	Vegetables
Ethylene absorbents Ethysorb (StayFresh Ltd), Ageless C (Mitsubishi Gas Chemical Company), Freshkeep (Kurarey), Acepack (nippon Greener), Peakfresh (Klerk Plastic Industrie, Chantler Packaging Inc.)	Sachet type product which is placed directly in the package and absorbs ethylene. They are composed of a variety of products such as aluminum oxide, potassium permanganate, activated carbon, and silicon dioxide.	Vegetables
Antimicrobial films of uncertain commercial availability		

[a]Different film types discussed in another table.

Table E-4 Some Characteristics and Optimum Storage Conditions of Vegetables for MAP

Commodity	Respiration rate (at 5°C, mg CO_2/kg/h)	Tolerance		Optimum		Recommended storage temperature	Approximate storage life
		Maximum CO_2 (%)	Minimum O_2 (%)	CO_2 (%)	O_2 (%)		
Artichoke	—	2	3	2–3	2–3	0–5	29 d
Asparagus	>60	14	5	10–14	Air	1–5	21 d
Beans, snap	40–60	10?	2	5–10	2–3	5–10	7–10 d
Broccoli	>60	10	1	5–10	1–2	0–5	2–3 m
Brussels sprouts	40–60	5	2	5–7	1–2	0–5	2–3 m
Cabbage	10–20	5	2	3–6	2–3	0–5	6–12 m
Carrot	10–20	5	5	3–4	5	0–5	4–5 m
Cauliflower	20–40	5	2	2–5	2–5	0–5	2–3 m
Chili peppers	10–20	2	3	5	3	8–12	—
Corn, sweet	>60	15	2	10–20	2–4	0–5	—
Cucumber	4[b]	10	3	0	3–5	8–12	14–21 d
Lettuce (leaf)	10–20	2	2	0	1–3	0–5	3–4 wks
Mushrooms	>60	15	1	5–15	3–21	0–5	3–4 d
Bell peppers	10–20	2	3	0	3–5	8–12	2–3 wks
Spinach	>60	15	—	10–20	Air	0–5	2–3 wks
Tomatoes (mature)	10–20	2	3	0	3–5	12–20	2 wks
Tomatoes (partly ripe)	10–20	2	3	3–5	3–5	10–15	—
Potato	5–10	—	—	none	none	4–12	—

Table E-5 Properties and Characteristics of Edible Films

Film	Film preparation	Advantages	Disadvantages
General films			
Natural biopolymer films: composed of polysaccharides, polyester proteins, lipids and derivatives	Simple coacervation[a] Complex coacervation[a] Gelatin or thermal coagulation[a]	*Polysaccharide/protein* Biodegradable and renewable Used to replace short shelf life plastics Suitable overall mechanical and optical properties Good for high-moisture foods *Lipids/polyesters* Biodegradable and renewable Good water vapor barrier properties	*Polysaccharide/protein* Highly sensitive to moisture and has poor water vapor barrier properties *Lipids/polyesters* Reduction of moisture transport Opaque and relatively inflexible Can be fragile and unstable
Lipid-based coatings			
Emulsions	Nonlipid support matrix required to reduce brittleness Lipid added to an emulsion barrier when cellulose within support matrix is dissolved When mixed (lipid/support matrix), the barrier is cast using impenetrable glass or metal level plate Water and ethanol are removed, and the barrier dried to moisture content of 2–5%, and then peeled from plate	Lower water vapor permeability than laminate barriers	Requires nonliquid support matrix
Laminates	Molten lipid is painted, sprayed, or poured to form a distinct layer on the dry support matrix Laminate is then dried/cooled, peeled off, and stored until use	Easier to apply than emulsions	Required nonlipid support matrix

(*continued*)

Table E-5 Continued

Film	Film preparation	Advantages	Disadvantages
Casein, collagen, corn zein, gelatin, soy protein, wheat gluten, gelatin, WPI[b]	Obtained from aqueous or ethanolic solution	Biodegradable Reduces moisture loss Adds nutritional value Does not require support matrix	More permeable to water vapor than lipid barriers
Wheat (gluten)	Obtained from aqueous solution	Effective oxygen barrier at low relative humidity High gluten content Increased puncture strength and extensibility	Vapor barrier ability limited High gluten content may also be a disadvantage for those intolerant to gluten
Polysaccharide barriers			
Pectin Most effective on low-moisture products	Generally made from low-methoxyl pectin, calcium chloride (cross-linker), a plasticizer, and sometimes organic acids	Can retard water loss from food Can improve handling and appearance of foods	Not adequate moisture barriers Low oxygen permeability
Chitosan Nutri-Save (NovaChem), used for whole apples and pears	Methylation of the chitosan polymer results in increased resistance to CO_2 Permeability use of chitosan with lipids may solve moisture barrier problems	Natural preservative, inhibits growth of fungi Impermeable to gases at 70% RH[c]	At 100% RH, permeability to CO_2 and O_2 due to diffusion with water
Derivatives of cellulose Tal pro-long (Courtaulds Group) Semperfresh (Surface Systems Intl., Ltd.)	Used mainly for composite coatings comprised of the sodium salt of carboxymethyl cellulose (CMC) as the film former, with sucrose fatty acid ester as the emulsifiers	Good film formers due to linear structure of polymer backbone O_2 is limited in entering the fruit more than CO_2 is from escaping; limiting buildup of harmful CO_2 and maintenance of reduced O_2	Not good barriers to movement of water; however, the film can retain a moisture layer which will delay moisture loss from the fruit by being the first layer of moisture lost
Carrageenan coatings Successfully used on cut grapefruit halves Bryan 1972) Not yet approved by FDA for coatings	Extracted from several species of red seaweeds and used in food systems as a gel	Can reduce moisture loss, oxidation or disintegration of the product	Not yet approved by the FDA for food coatings

[a]See glossary for definition of molding techniques.
[b]Wheat protein isolate.
[c]Relative humidity.

Table E-6 Edible Coating Applications and Functions

Type of edible coating	Function
Polysaccharide coatings	
I. Cellulose	
Carboxymethyl cellulose	
Fresh vegetables	O_2 and CO_2
Freshly cut celery	Moisture barrier
Tomatoes	O_2 and CO_2 barrier
II. Chitin/Chitosan	
Fresh cucumbers, bell peppers	Postharvest decay control
Protein Coatings	
I. Corn Zein	
Zein	

Table E-7 Conditions Supporting Growth and Toxin Production by *Clostridium botulinum* on Fresh-Cut MAP Vegetables

Product	Initial modified atmosphere	Film gas permeability ($cm^3/m^2/24h$ at 23°C)		Final modified atmosphere		Challenge level	Temperature (°C)	Days to toxin production (d)	Appearance
		O_2	CO_2	O_2 (%)	CO_2 (%)				
Onion[a]	Air	2,100	—	0.67	81.5	P,[b] 1,000/g	25	6	No change, swelling
Butternut squash[a]	Air	2,100	—	1.10	22.6	NP,[c] 1,000/g	5	21	
Butternut squash[a]	Air	2,100	—	1.10	64.7	P, 100/g	25	3	No change, swelling
Rutabaga[a]	Air	2,100	—	0.97	25.3	P, 100/g	25	7	Decay
Broccoli[a]	Air	13,013	32,306	<2	10	P & NP, 100/g	12	9	Gross spoilage
Broccoli	Air	7,000	20,500	3.68	10.59	P, 10^2/g	13	21	Spoiled
Broccoli	Air	7,000	20,500	1.3	13.47	P, 10^2/g	21	10	Spoiled
Broccoli	Air	16,000	36,000	1.34	7.16	P, 10^2/g	21	10	Spoiled/poor
Carrot[a]	Vacuum −70 kPa	3,000	9,800	—	—	P & NP, 100/g	21	4 No toxin	Gross spoilage
Carrot[a]	Vacuum −70 kPa	6,000–8,000	19,000–22,000	—	—	P & NP, 100/g	21	4 No toxin	Gross spoilage
Broccoli[a]	Air	16,544	35,175	<2	10	P & NP, 100/g	12	9	Gross spoilage
Stir-fry[d]	UK	80–100	—	0	17.7	P, 100/g	25	11	Soft
Stir-fry[d]	UK	80–100	—	0	24.2	P, 10/g	15	21	Soft
Green bean[a]	Air	5,500–7,500	20,000–24,000	—	—	P & NP, 100	21	7 No toxin	Gross spoilage
Green bean[a]	Air	16,544	35,175	—	—	P & NP, 100	21	7 No toxin	Gross spoilage
Romaine lettuce[d]	UK	40	—	1.37	25.2	P, 100/g	25	9	Extensive decay

Romaine lettuce[d]	Air	Vented package		—	—	P & NP, 100/g	21	28	Extensive decay
Romaine lettuce[d]	Air	Unvented package		—	—	P & NP, 100/g	21	17	Extensive decay
Lettuce[a]	Vacuum −60 kPa	3,000	9,800	<2	10	P & NP, 100/g	21	6	Gross spoilage
Lettuce[a]	Vacuum −60 kPa	6,000	17,000	<2	10	P & NP, 100/g	21	6	Gross spoilage
Mixed salad[d]	UK	80–100	—	1.0	39.0	P, 100/g	25	7	Extensive decay
Mixed salad[d]	UK	80–100	—	0.0	45.8	NP, 1,000/g	25	4	Moderate browning
Mixed salad[d]	UK	80–100	—	0.0	35.0	NP, 1,000/g	15	14	Moderate browning
Shredded cabbage[a]	70 : 30 $O_2 : N_2$	Unknown	—	—	—	P, 96–184/g	22–25	4	Acceptable
Shredded cabbage[a]	Air	Vented package		—	—	P & NP, 100/g	21	No toxin	Inedible
Shredded cabbage[a]	Air	Unvented package		—	—	P & NP, 100/g	21	10	Extensive decay
Chopped cabbage[a]	Vacuum −60 kPa	3,000	9,800	—	—	P & NP, 100/g	21	No toxin	Spoiled 3 d
Chopped cabbage[a]	Vacuum −60 kPa	6,000–8,000	19,000–22,000	—	—	P & NP, 100/g	21	No toxin	Spoiled 3 d
Mushrooms[a]	Air	800 $cm^3/100\,in^2$	6,000 $cm^3/100\,in^2$	1–2	—	P, 10^4/ mushroom	20	4	Fair
Tomato	1 (O_2)	PVC[e] trays with packet of 15 g NaCl and sealed with EVA[f]		1.6	21.6	P & NP, 4,100	13	42–46	Not acceptable

[a]Noncommercial, prepared by researcher.
[b]P = proteolytic *C. botulinum.*
[c]NP = nonproteolytic *C. botulinum.*
[d]Commercially obtained.
[e]Polyvinyl chloride.
[f]Ethylene-vinyl acetate.

APPENDIX F

FDA Food Defect Action Levels for Vegetables and Vegetable Products

I. INTRODUCTION

Title 21, Code of Federal Regulations, Part 110.110 allows the Food and Drug Administration (FDA) to establish maximum levels of natural or unavoidable defects in foods for human use that present no health hazard. These "Food Defect Action Levels" listed in this booklet are set on this premise—that they pose no inherent hazard to health.

Poor manufacturing practices may result in enforcement action without regard to the action level. Likewise, the mixing or blending of food with a defect at or above the current defect action level with another lot of the same or another food is not permitted. That practice renders the final food unlawful regardless of the defect level of the finished food.

The FDA set these action levels because it is economically impractical to grow, harvest, or process raw products that are totally free of nonhazardous, naturally occurring, unavoidable defects. Products harmful to consumers are subject to regulatory action whether or not they exceed the action levels.

It is incorrect to assume that because the FDA has an established defect action level for a food commodity, the food manufacturer need only stay just below that level. The defect levels do not represent an average of the defects that occur in any of the products—the averages are actually much lower. The levels represent limits at which FDA will regard the food product as "adulterated" and subject to enforcement action under Section 402(a)(3) of the Food, Drug, and Cosmetics Act.

As technology improves, the FDA may review and change defect action levels on this list. Also, products may be added to the list. The FDA publishes these revisions as *Notices* in the *Federal Register*. It is the responsibility of the user of this booklet to stay current with any changes to this list.

II. PRODUCTS WITHOUT DEFECT LEVELS

If there is no defect action level for a product, or when findings show levels or types of defects that do not appear to fit the action level criteria, FDA evaluates the samples and decides on a case-by-case basis. In this procedure, FDA's technical and regulatory experts in filth and extraneous materials use a variety of criteria, often in combination, in determining the significance and regulatory impact of the findings.

Source: The Food Defect Action Levels: Levels of Natural or Unavoidable Defects in Food That Present No Health Hazards for Humans, FDA May 1995; revised March 1997; revised May 1998.

The criteria considered are based on the reported findings (e.g., lengths of hairs, sizes of insect fragments, distribution of filth in the sample, and combinations of filth types found). Moreover, FDA interprets the findings considering available scientific information (e.g., ecology of animal species represented) and the knowledge of how a product is grown, harvested, and processed.

III. USE OF CHEMICAL SUBSTANCES TO ELIMINATE DEFECT LEVELS

It is FDA's position that pesticides are not the alternative to preventing food defects. The use of chemical substances to control insects, rodents, and other natural contaminants has little if any impact on natural and unavoidable defects in foods. The primary use of pesticides in the field is to protect food plants from being ravaged by destructive plant pests (leaf feeders, stem borers, etc.).

A secondary use of pesticides is for cosmetic purposes—to prevent some food products from becoming so severely damaged by pests that they become unfit to eat.

IV. USING THIS FOOD DEFECT ACTION LEVEL BOOKLET

This edition of *The Food Defect Action Level* includes the source of each defect and the significance of it (i.e., how the defect affects the food). Food processors may find this information helpful as a quality control tool in their operation.

Vegetable and vegetable products are listed alphabetically. Each listing indicates the analytical methodology (Defect Method) used, as well as the parameters for the defect (Defect Action Level).

AOAC refers to the Association of Official Analytical Chemists. The reference number following AOAC refers to its official method of analysis.

The glossary describes terms used throughout this booklet.

V. GLOSSARY

ABUSE Improper handling.

AESTHETIC Offensive to the senses.

CONTAMINATION Addition of foreign material, (e.g., dirt, hair, excreta, noninvasive insects, machinery mold) to a product.

COPEPODS Small free-swimming marine crustaceans, many of which are fish parasites. In some species the females enter the tissues of the host fish and may form pus pockets.

DAMAGE Refers to the condition of the product which shows the evidence of the pest habitation or feeding, (e.g., tunneling, gnawing, egg cases).

DECOMPOSED Consists of the bacterial breakdown of the normal product tissues and the subsequent enzyme induced chemical changes. These changes are manifested by abnormal odors, taste, texture, color, etc.

DECOMPOSITION METABOLITES Compounds such as histamines and diamines.

ECONOMIC ADULTERATION Intentional failure to remove inedible materials from the finished product, or the intentional addition or substitution of cheaper food or ingredient to a product.

EXTRANEOUS MATERIALS Any foreign matter in a product associated with objectionable conditions or practices in production, storage, or distribution. Includes objectionable matter

contributed by insects, rodents, and birds; decomposed material; and miscellaneous matter such as sand, soil, glass, rust, or other foreign substances.

FOREIGN MATTER Includes objectionable matter such as sticks, stones, burlap bagging, cigarette butts. Also includes the valueless parts of the raw plant material, such as stems.

GUMMY A resinous glaze on an almond kernel that is induced by an insect injury or mechanical damage.

HARVEST Occurs during the harvesting process.

HISTAMINE A chemical compound formed by the bacterial decomposition of seafood.

INDOLE A chemical compound formed by the bacterial decomposition of seafood.

INFECTION A condition due to the growth of an organism in a host (e.g., rot or decay, visible mold mycelia).

INFESTATION The presence of any live or dead life cycle stages of insects in a host product (e.g., weevils in pecans, fly eggs and maggots in tomato products); or evidence of their presence (i.e., excreta, cast skins, chewed product residues, urine, etc.); or the establishment of an active breeding population, (e.g., rodents in a grain silo).

MILDEW Refers to downy mildew, which is a fungus infection that causes yellow-brown spots on the leaves of edible greens in the mustard family.

MOLD COUNT Refers to the results of the Howard mold count method, which is reported as the percentage of positive microscopic fields that have been scored as either positive or negative based on the presence or absence of a minimum amount of mold hyphae. Performed only on comminuted fruits and vegetables, and some ground spices. The source of the mold hyphae is rotten raw material that is processed along with sound raw material but is no longer visible due to the comminution process.

MOLDY Evidenced by the presence of mold (mold hyphae and/or spore forming structures) that are visible to the unaided eye. Microscopic examination may be used to confirm the presence of characteristic hyphal filaments and fruiting structures.

POSTHARVEST Occurs after harvest, for example,

Field holding of the harvested crop prior to transit
Farm storage of harvested crop
During transit by truck, ship, rail, etc.
At the processing facility, awaiting processing, or proper storage.

PREHARVEST Occurs while product is in the field, during growth, or awaiting harvest.

PROCESSING Occurs while in the processing facility, in storage, or during processing.

RANCID A condition where a product has a disagreable odor or taste of decomposed oils or fat. For example, rancid nuts frequently are soft, with a yellow, dark, or oily appearance, a bitter taste, and a stale odor.

ROT Plant tissue that is visibly decomposed, usually discolored with disagreeable odors and taste. The plant tissue has been invaded and is being digested by microorganisms. Although rot can also be caused by bacteria and yeasts, these organisms are secondary invaders. Molds are the primary organisms of decomposition, and the presence of mold hyphae in the tissue is used to confirm rot.

SHRIVELED A condition where the nut kernel is shrunken and not fully developed, commonly a result of climatic stress or infection by certain molds.

SIGNIFICANCE OF DEFECT Refers to the real or potential impact on the consumer due to the presence of a particular defect. A listed defect can have more than one significance to the consumer (e.g., the mold defect of whole cassia has an aesthetic significance, whereas the mold defect of green coffee beans has a potential health hazard significance due to the threat of mold toxins produced by the mold species known to infect coffee beans).

SOUR In fruits, consists of the bacterial breakdown of the product and the formation of lactic acid and subsequent sour taste.

WATER INSOLUBLE INORGANIC MATTER A contaminant of the finished product that consists of fine grit that originates from the sand, dirt, and stones that contaminate the raw agricultural product at the time of harvest.

WHOLE OR EQUIVALNET INSECT A whole insect, separate head, or body portions with head attached.

WORTHLESS Any condition where the product has been affected by organisms or the environment so that it has no food value.

VI. COMMODITIES AND DEFECT ACTION LEVELS

Product	Defect (method)	Action level
ALLSPICE, GROUND	Insect Filth (AOAC 981.21)	Average of 30 or more insect fragments per 10 grams
	Rodent filth (AOAC 981.21)	Average of 1 or more rodent hairs per 10 grams
DEFECT SOURCE: *Insect fragments—pre/postharvest and processing insect infestation. Rodent hair—post harvest and/or processing contamination with animal hair or excreta*		
SIGNIFICANCE: *Aesthetic*		
ALLSPICE, WHOLE	Mold (MPM-V32)	Average of 5% or more berries by weight are moldy
DEFECT SOURCE: *Preharvest and/or postharvest infection*		
SIGNIFICANCE: *Potential health hazard—may contain mycotoxin producing fungi*		
ASPARAGUS, CANNED OR FROZEN	Insect filth (MPM-V93)	10% by count of spears or pieces are infested with 6 or more attached asparagus beetle eggs and/or sacs
	Insects (MPM-V93)	Asparagus contains an average of 40 or more thrips per 100 grams OR Insects (whole or equivalent) of 3 mm or longer have an average aggregate length of 7 mm or longer per 100 grams of asparagus
DEFECT SOURCE: *Preharvest insect infestation*		
SIGNIFICANCE: *Aesthetic*		

Product	Defect (method)	Action level
BAY (LAUREL) LEAVES	Mold (MPM-V92)	Average of 5% or more pieces by weight are moldy
	Insect filth (MPM-V32)	Average of 5% or more pieces by weight are insect infested
	Mammalian excreta (MPM-V32)	Average of 1 mg or more mammalian excreta per pound after processing
DEFECT SOURCE: *Mold—preharvest infection. Insect infestation—preharvest and/or postharvest and/or processing insect infestation. Mammalian excreta—postharvest and/or processing animal contamination*		
SIGNIFICANCE: *Aesthetic*		
BEETS, CANNED	Rot	Average of 5% or more pieces by weight with dry rot
DEFECT SOURCE: *Preharvest mold infection*		
SIGNIFICANCE: *Aesthetic*		
BROCCOLI, FROZEN	Insects and mites (AOAC 945.82)	Average of 60 or more aphids and/or thrips and/or mites per 100 grams
DEFECT SOURCE: *Preharvest insect infestation*		
SIGNIFICANCE: *Aesthetic*		
BRUSSELS SPROUTS, FROZEN	Insects (MPM-V95)	Average of 30 or more aphids and/or thrips per 100 grams
DEFECT SOURCE: *Preharvest insect infestation*		
SIGNIFICANCE: *Aesthetic*		
CAPSICUM		
Pods	Insect filth and/or mold (MPM-V32)	Average of more than 3% of pods by weight are insect-infested and/or moldy
	Mammalian excreta (MPM-V32)	Average of more than 1 mg mammalian excreta per pound
DEFECT SOURCE: *Insect infested—preharvest and/or postharvest insect infestation. Mold—preharvest and/or postharvest infection. Mammalian excreta—postharvest and/or processing animal contamination*		
SIGNIFICANCE: *Aesthetic; potential health hazard—mold may contain mycotoxin producing fungi*		
Ground Capsicum (excluding paprika)	Mold (AOAC 945.94)	Average mold count is more than 20%
	Insect filth (AOAC 978.22)	Average of more than 50 insect fragments per 25 grams
	Rodent filth (AOAC 978.22)	Average of more than 6 rodent hairs per 25 grams
DEFECT SOURCE: *Mold—preharvest and/or postharvest mold infection. Insect fragments—preharvest and/or postharvest and/or processing insect infestation. Rodent hair—preharvest and/or postharvest and/or processing contamination with animal hair or excreta*		
SIGNIFICANCE: *Aesthetic; mold may contain mycotoxin producing fungi*		
Ground Paprika	Mold (AOAC 945.94)	Average mold count is more than 20%
	Insect filth (AOAC 977.25B)	Average of more than 75 insect fragments per 25 grams
	Rodent filth (AOAC 977.25B)	Average of more than 11 rodent hairs per 25 grams
DEFECT SOURCE: *Mold—preharvest and/or postharvest mold infection. Insect fragments—preharvest and/or postharvest and/or processing insect infestation. Rodent hair—preharvest and/or postharvest and/or processing contamination with animal hair or excreta*		
SIGNIFICANCE: *Aesthetic; potential health hazard—mold may contain mycotoxin producing fungi*		

(*continued*)

Product	Defect (method)	Action level
CASSIA (OR) CINNAMON BARK, WHOLE	Mold (MPM-V32)	Average of 5% or more pieces by weight are moldy
	Insect filth (MPM-V32)	Average of 5% or more pieces by weight are insect infested
	Mammalian excreta (MPM-V32)	Average of 1 mg or more mammalian excreta per pound
DEFECT SOURCE: *Mold—postharvest mold infection. Insect infestation—postharvest and/or processing. Mammalian excreta—postharvest and/or processing animal contamination*		
SIGNIFICANCE: *Aesthetic*		
CINNAMON, GROUND	Insect filth (AOAC 968.38b)	Average of 400 or more insect fragments per 50 grams
	Rodent filth (AOAC 968.38b)	Average of 11 or more rodent hairs per 50 grams
DEFECT SOURCE: *Insect fragments—postharvest and/or processing insect infestation. Rodent hair—postharvest and/or processing contamination with animal hair or excreta*		
SIGNIFICANCE: *Aesthetic*		
CLOVES	Stems (MPM-V32)	Average of 5% or more stems by weight
DEFECT SOURCE: *Harvest*		
SIGNIFICANCE: *Aesthetic; economic adulteration*		
CORN: SWEET CORN, CANNED	Insect larvae (AOAC 973.61)	Insect larvae (corn ear worms, corn borers) 2 or more 3 mm or longer larvae, cast skins, larval or cast skin fragments of corn ear worms or corn borer and the aggregate length of such larvae, cast skins, larval or cast skin fragments exceeds 12 mm in 24 pounds (24 No. 303 cans or equivalent)
DEFECT SOURCE: *Preharvest insect infestation*		
SIGNIFICANCE: *Aesthetic*		
CORN HUSKS FOR TAMALES	Insect filth (MPM-V115)	Average of 5% or more husks by weight are insect infested (including insect damaged)
	Mold (MPM-V115)	Average of 5% or more husks by weight are moldy
DEFECT SOURCE: *Insect infested—preharvest and/or processing insect infestation. Mold—preharvest and/or postharvest and/or processing infection*		
SIGNIFICANCE: *Aesthetic*		
CORNMEAL	Insects (AOAC 981.19)	Average of 1 or more whole insects (or equivalent) per 50 grams
	Insect filth (AOAC 981.19)	Average of 25 or more insect fragments per 25 grams
	Rodent filth (AOAC 981.19)	Average of 1 or more rodent hairs per 25 grams OR Average of 1 or more rodent excreta fragment per 50 grams

Product	Defect (method)	Action level
DEFECT SOURCE: *Insects and insect fragments—preharvest and/or postharvest and/or processing insect infestation. Rodent hair and excreta fragments—postharvest and/or processing contamination with animal hair or excreta*		
SIGNIFICANCE: *Aesthetic*		
FENNEL SEED	Insects (MPM-V32)	20% or more of subsamples contain insects
	Mammalian excreta (MPM-V32)	20% or more of subsamples contain mammalian excreta OR average of more than 3 mg of mammalian excreta per pound
DEFECT SOURCE: *Insects—preharvest and/or postharvest insect infestation. Excreta—postharvest and/or processing animal contamination*		
SIGNIFICANCE: *Aesthetic*		
GINGER, WHOLE	Insect filth and/or mold (MPM-V32)	Average of 3% or more pieces by weight are insect infested and/or moldy
	Mammalian excreta (MPM-V32)	Average of 3 mg or more of mammalian excreta per pound
DEFECT SOURCE: *Insect infestation—postharvest and/or processing. Mold—postharvest and/or processing infection. Mammalian excreta—postharvest and/or processing animal contamination*		
SIGNIFICANCE: *Aesthetic; potential health hazard—may contain mycotoxin producing fungi*		
GREENS, CANNED	Mildew (AOAC 967.23)	Average of 10% or more of leaves, by count or weight, showing mildew over 1/2″ in diameter
DEFECT SOURCE: *Preharvest infection*		
SIGNIFICANCE: *Aesthetic*		
MACE	Insect filth and/or mold (MPM-V32)	Average of 3% or more pieces by weight are insect infested and/or moldy
	Mammalian excreta (MPM-V32)	Average of 3 mg or more of mammalian excreta per pound
	Foreign matter (MPM-V32)	Average of 1.5% or more of foreign matter through a 20-mesh sieve
DEFECT SOURCE: *Insect infestation—preharvest and/or postharvest and/or processing. Mold—preharvest and/or postharvest infection. Mammalian excreta—postharvest and/or processing animal contamination. Foreign matter—postharvest contamination*		
SIGNIFICANCE: *Aesthetic*		
MARJORAM, WHOLE PLANT, UNPROCESSED	Insect filth and/or mold (MPM-V32)	Average of 5% or more pieces by weight are insect infested or moldy
	Mammalian excreta (MPM-V32)	Average of 1 mg or more mammalian excreta per pound
DEFECT SOURCE: *Insect infestation—preharvest and/or postharvest and/or processing. Mold—postharvest and/or processing infection. Mammalian excreta—postharvest and/or processing animal contamination*		
SIGNIFICANCE: *Aesthetic*		
MARJORAM, GROUND	Insect filth (AOAC 975.49)	Average of 1175 or more insect fragments per 10 grams
	Rodent filth (AOAC 975.49)	Average of 8 or more rodent hairs per 10 grams
DEFECT SOURCE: *Insect fragments—preharvest and/or postharvest and/or processing insect infestation. Rodent hair—postharvest and/or processing contamination with animal hair or excreta*		

Product	Defect (method)	Action level
MARJORAM, UNGROUND	Insect filth (AOAC 985.39)	Average of 250 or more insect fragments per 10 grams
	Rodent filth (AOAC 985.39)	Average of 2 or more rodent hairs per 10 grams
DEFECT SOURCE: *Insect fragments—preharvest and/or postharvest and/or processing insect infestation. Rodent hair—processing contamination with animal hair or excreta*		
SIGNIFICANCE: *Aesthetic*		
MUSHROOMS, CANNED AND DRIED	Insects (AOAC 967.24)	Average of over 20 or more maggots of any size per 100 grams of drained mushrooms and proportionate liquid or 15 grams of dried mushrooms OR Average of 5 or more maggots 2 mm or longer per 100 grams of drained mushrooms and proportionate liquid or 15 grams of dried mushrooms
	Mites (AOAC 967.24)	Average of 75 mites per 100 grams drained mushrooms and proportionate liquid or 15 grams of dried mushrooms
	Decomposition (MPM-V100)	Average of more than 10% of mushrooms are decomposed
DEFECT SOURCE: *Insects—preharvest insect infestation. Mites—preharvest and/or postharvest infestation. Decomposition—preharvest infection*		
SIGNIFICANCE: *Aesthetic*		
NUTMEG, WHOLE	Insect filth and/or mold (MPM-V41)	Average of 10% or more pieces by count are insect infested and/or moldy
DEFECT SOURCE: *Insect infestation—preharvest and/or postharvest and/or processing. Mold—preharvest and/or postharvest infection*		
SIGNIFICANCE: *Aesthetic; potential health hazard—may contain mycotoxin producing fungi*		
NUTMEG, GROUND	Insect filth (AOAC 979.26)	Average of 100 or more insect fragments per 10 grams
	Rodent filth (AOAC 979.26)	Average of 1 or more rodent hairs per 10 grams
DEFECT SOURCE: *Insect fragments—postharvest and/or processing insect infestation. Rodent hair—postharvest and/or processing contamination with animal hair or excreta*		
SIGNIFICANCE: *Aesthetic*		
OLIVES		
Pitted olives	Pits (MPM-V67)	Average of 1.3 percent or more by count of olives with whole pits and/or pit fragments 2 mm or longer measured in the longest dimension
DEFECT SOURCE: *Processing*		
SIGNIFICANCE: *Mouth/tooth injury*		
Imported Green olives	Insect damage (MPM-V67)	7% or more olives by count showing damage by olive fruit fly

Product	Defect (method)	Action level
DEFECT SOURCE: *Preharvest insect infestation* SIGNIFICANCE: *Aesthetic*		
Salad olives	Pits (MPM-V67)	Average of 1.3 or more olives by count of olives with whole pits and/or pit fragments 2 mm or longer measured in the longest dimension
	Insect damage (MPM-V67)	9% or more olives by weight showing damage by olive fruit fly
DEFECT SOURCE: *Pits—processing. Insect damage—preharvest insect infestation* SIGNIFICANCE: *Pits—mouth/tooth injury. Insect damage—aesthetic*		
Salt-cured olives	Insects (MPM-V67)	Average of 10% or more olives by count with 10 or more scale insects each
	Mold (MPM-V67)	Average of 25% or more olives by count are moldy
DEFECT SOURCE: *Scale insects—preharvest infestation. Mold—postharvest and/or processing infection* SIGNIFICANCE: *Aesthetic*		
Imported Black olives	Insect damage (MPM-V67)	10% or more olives by count showing damage by olive fruit fly
DEFECT SOURCE: *Preharvest insect infestation* SIGNIFICANCE: *Aesthetic*		
OREGANO, WHOLE PLANT, UNPROCESSED	Insect filth and/or mold weight (MPM-V32)	Average of 5% or more insect infested and/or moldy pieces by weight
	Mammalian excreta (MPM-V32)	Average of 1 mg or more mammalian excreta per pound
DEFECT SOURCE: *Insect infested—preharvest and/or postharvest and/or processing. Mold—postharvest and/or processing infection. Mammalian excreta—postharvest and/or processing animal contamination* SIGNIFICANCE: *Aesthetic*		
OREGANO, GROUND	Insect filth (AOAC 975.49)	Average of 1250 or more insect fragments per 10 grams
	Rodent filth (AOAC 975.49)	Average of 5 or more rodent hairs per 10 grams
DEFECT SOURCE: *Insect fragments—preharvest and/or postharvest and/or processing insect infestation. Rodent hair—postharvest and/or processing contamination with animal hair or excreta* SIGNIFICANCE: *Aesthetic*		
OREGANO, CRUSHED	Insect filth (AOAC 969.44)	Average of 300 or more insect fragments per 10 grams
	Rodent filth (AOAC 969.44)	Average of 2 or more rodent hairs per 10 grams
DEFECT SOURCE: *Insect fragments—preharvest and/or postharvest and/or processing insect infestation. Rodent hair—postharvest and/or processing contamination with animal hair or excreta* SIGNIFICANCE: *Aesthetic*		
PEAS: BLACK-EYED, COWPEAS, FIELD PEAS, DRIED	Insect damage (MPM-V104)	Average of 10% or more by count of class 6 damage or higher in minimum of 12 subsamples
DEFECT SOURCE: *Preharvest and/or postharvest insect infestation* SIGNIFICANCE: *Aesthetic*		

(*continued*)

Product	Defect (method)	Action level
PEAS, COWPEAS, BLACK-EYED PEAS (SUCCULENT), CANNED	Insect larvae (MPM-V104)	Average of 5 or more cowpea curculio larvae or the equivalent per No. 2 can
DEFECT SOURCE: *Preharvest and/or postharvest insect infestation*		
SIGNIFICANCE: *Aesthetic*		
PEAS AND BEANS, DRIED	Insect filth (MPM-V104)	Average of 5% or more by count insect infested and/or insect damaged by storage insects in a minimum of 12 subsamples
DEFECT SOURCE: *Preharvest and/or postharvest and/or processing infestation*		
SIGNIFICANCE: *Aesthetic*		
PEPPER, WHOLE (BLACK & WHITE)	Insect filth and/or insect-mold (MPM-V39)	Average of 1% or more pieces by weight are infested and/or moldy
	Mammalian excreta (MPM-V39)	Average of 1 mg or more mammalian excreta per pound
	Foreign matter (MPM-V39)	Average of 1% or more pickings and siftings by weight
DEFECT SOURCE: *Insect infested—postharvest and/or processing infestation. Moldy—postharvest and/or processing infection. Mammalian excreta—postharvest and/or processing animal contamination. Foreign material—postharvest contamination*		
SIGNIFICANCE: *Aesthetic; potential health hazard—mammalian excreta may contain salmonella*		
PEPPER, GROUND	Insect filth (AOAC 972.40)	Average of 475 or more insect fragments per 50 grams
	Rodent filth (AOAC 972.40)	Average of 2 or more rodent hairs per 50 grams
DEFECT SOURCE: *Insect fragments—postharvest and/or processing insect infestation. Rodent hair—postharvest and/or processing contamination with animal hair or excreta*		
SIGNIFICANCE: *Aesthetic*		
POTATO CHIPS	Rot (MPM-V113)	Average of 6% or more pieces by weight contain rot
DEFECT SOURCE: *Preharvest and/or postharvest infection*		
SIGNIFICANCE: *Aesthetic*		
SAGE, WHOLE PLANT, UNPROCESSED	Insect filth (MPM-V32)	Average of 5% or more pieces by weight are insect infested
	Mammalian excreta (MPM-V32)	Average of 1 mg or more per pound after processing
DEFECT SOURCE: *Insect infested—preharvest and/or postharvest and/or processing infestation. Mammalian excreta—postharvest and/or processing animal contamination*		
SIGNIFICANCE: *Aesthetic*		
SAGE, GROUND	Insect filth (AOAC 985.38)	Average of 200 or more insect fragments per 10 grams
	Rodent filth (AOAC 985.38)	Average of 9 or more rodent hairs per 10 grams
DEFECT SOURCE: *Insect fragments—preharvest and/or postharvest and/or processing infestation. Rodent hair—post harvest and/or processing contamination with animal hair or excreta*		
SIGNIFICANCE: *Aesthetic*		

Product	Defect (method)	Action level
SAUERKRAUT	Insects (AOAC 955.45)	Average of more than 50 thrips per 100 grams
DEFECT SOURCE: *Preharvest insect infestation* SIGNIFICANCE: *Aesthetic*		
SPICES, LEAFY, OTHER THAN BAY LEAVES	Insect filth and/or mold (MPM-V32)	Average of 5% or more pieces by weight are insect infested and/or moldy
	Mammalian excreta (MPM-V32)	Average of 1 mg or more of mammalian excreta per pound after processing
DEFECT SOURCE: *Insect infested—preharvest and/or postharvest and/or processing infestation. Mold—preharvest and/or postharvest and/or processing infection. Mammalian excreta—postharvest and/or processing animal contamination* SIGNIFICANCE: *Aesthetic*		
SPINACH, CANNED OR FROZEN	Insects and mites (AOAC 974.33)	Average of 50 or more aphids, thrips, and/or mites per 100 grams OR 2 or more 3 mm or longer larvae and/or larval fragments or spinach worms (caterpillars) whose aggregate length exceeds 12 mm are present in 24 pounds OR Leaf miners of any size average 8 or more per 100 grams or leaf miners 3 mm or longer average 4 or more per 100 grams
DEFECT SOURCE: *Preharvest infestation* SIGNIFICANCE: *Aesthetic*		
THYME, WHOLE PLANT, UNPROCESSED	Insect filth (MPM-V32)	Average of 5% or more pieces by weight are insect infested and/or moldy
	Mammalian excreta (MPM-V32)	Average of 1 mg or more mammalian excreta per pound after processing
DEFECT SOURCE: *Insect infested—preharvest and/or postharvest and/or processing infestation. Mold—preharvest and/or postharvest and/or processing infection. Mammalian excreta—postharvest and/or processing animal contamination* SIGNIFICANCE: *Aesthetic*		
THYME, GROUND	Insect filth (AOAC 975.49)	Average of 925 or more insect fragments per 10 grams
	Rodent filth (AOAC 975.49)	Average of 2 or more rodent hairs per 10 grams
DEFECT SOURCE: *Insect fragments—preharvest and/or postharvest and/or processing infestation. Rodent hair—postharvest and/or processing contamination with animal hair or excreta* SIGNIFICANCE: *Aesthetic*		
THYME, UNGROUND, PROCESSED	Insect filth (AOAC 975.49)	Average of 325 insect fragments or more per 10 grams
	Rodent filth (AOAC 975.49)	Average of 2 rodent hairs or more per 10 grams
DEFECT SOURCE: *Insect fragments—preharvest and/or postharvest and/or processing insect infestations. Rodent hair—postharvest and/or processing contamination with animal hair or excreta* SIGNIFICANCE: *Aesthetic*		
TOMATOES, CANNED	Drosophila fly (AOAC 955.46)	Average of 10 or more fly eggs per 500 grams

(*continued*)

Product	Defect (method)	Action level
		OR 5 or more fly eggs and 1 or more maggots per 500 grams OR 2 or more maggots per 500 grams
DEFECT SOURCE: *Preharvest and/or postharvest and/or processing insect infestation* SIGNIFICANCE: *Aesthetic*		
TOMATOES, CANNED, WITH (OR) WITHOUT JUICE (BASED ON DRAINED JUICE)	Mold (AOAC 945.90)	Average mold count in 6 subsamples is 15% or more and the counts of all of the subsamples are more than 12%
DEFECT SOURCE: *Preharvest and/or postharvest and/or processing infection* SIGNIFICANCE: *Aesthetic*		
TOMATOES, CANNED, PACKED IN TOMATO PUREE (BASED ON DRAINED LIQUID)	Mold (AOAC 945.90)	Average mold count in 6 subsamples is 29% or more and the counts of all of the subsamples are more than 25%
DEFECT SOURCE: *Preharvest and/or postharvest and/or processing infection* SIGNIFICANCE: *Aesthetic*		
TOMATO JUICE	Drosophila fly (AOAC 955.46)	Average of 10 or more fly eggs per 100 grams OR 5 or more fly eggs and 1 or more maggots per 100 grams OR 2 or more maggots per 100 grams, in a minimum of 12 subsamples
	Mold (AOAC 965.41)	Average mold count in 6 subsamples is 24% or more and the counts of all of the subsamples are more than 20%
DEFECT SOURCE: *Fly eggs and maggots—preharvest and/or postharvest and/or processing insect infestation. Mold—preharvest and/or postharvest and/or processing infection* SIGNIFICANCE: *Aesthetic*		
TOMATO PASTE, PIZZA, AND OTHER SAUCES	Drosophila fly (AOAC 955.46)	Average of 30 or more fly eggs per 100 grams OR 15 or more fly eggs and 1 or more maggots per 100 grams OR 2 or more maggots per 100 grams in a minimum of 12 subsamples
DEFECT SOURCE: *Preharvest and/or postharvest and/or processing insect infestation* SIGNIFICANCE: *Aesthetic*		

Product	Defect (method)	Action level
TOMATO PUREE	Drosophila fly (AOAC 955.46)	Average of 20 or more fly eggs per 100 grams OR 10 or more fly eggs and 1 or more maggots per 100 grams OR 2 or more maggots per 100 grams in a minimum of 12 subsamples
DEFECT SOURCE: *Preharvest and/or postharvest and/or processing insect infestation* SIGNIFICANCE: *Aesthetic*		
TOMATO PASTE (OR) PUREE	Mold (AOAC 955.46)	Average mold count in 6 subsamples is 45% or more and the mold counts of all of the subsamples are more than 40%
DEFECT SOURCE: *Preharvest and/or postharvest and/or processing infection* SIGNIFICANCE: *Aesthetic*		
PIZZA AND OTHER TOMATO SAUCES	Mold (AOAC 945.92)	Average mold count in 6 subsamples is 34% or more and the counts of all of the subsamples are more than 30%
DEFECT SOURCE: *Preharvest and/or postharvest and/or processing infection* SIGNIFICANCE: *Aesthetic*		
TOMATO SAUCE, UNDILUTED	Mold (AOAC 965.41)	Average mold count in 6 subsamples is 45% or more and the mold counts of all of the subsamples are more than 40%
DEFECT SOURCE: *Preharvest and/or postharvest and/or processing infection* SIGNIFICANCE: *Aesthetic*		
TOMATO CATSUP	Mold (AOAC 965.41)	Average mold count in 6 subsamples is 55% or more
DEFECT SOURCE: *Preharvest and/or postharvest and/or processing infection* SIGNIFICANCE: *Aesthetic*		
TOMATO POWDER, EXCEPT SPRAY-DRIED	Mold (AOAC 972.42)	Average mold count in 6 subsamples is 45% or more and the mold counts of all of the subsamples are more than 40%
DEFECT SOURCE: *Preharvest and/or postharvest and/or processing infection* SIGNIFICANCE: *Aesthetic*		
TOMATO POWDER, SPRAY-DRIED	Mold (AOAC 972.42)	Average mold count in 6 subsamples is 67% or more
DEFECT SOURCE: *Preharvest and/or postharvest and/or processing infection* SIGNIFICANCE: *Aesthetic*		
TOMATO SOUP AND TOMATO PRODUCTS	Mold (AOAC 945.91)	Average mold count in 6 subsamples is 45% or more and the mold counts of all of the subsamples are more than 40%
DEFECT SOURCE: *Preharvest and/or postharvest and/or processing infection* SIGNIFICANCE: *Aesthetic*		

APPENDIX G

FDA Action Levels for Poisonous or Deleterious Substances in Vegetables and Vegetable Products

This appendix lists action levels established by the Food and Drug Administration (FDA) for poisonous or deleterious substances in human food and animal feed. Action levels for poisonous or deleterious substances are established by the FDA to control levels of contaminants in human food and animal feed.

Action levels and tolerances are established based on the unavoidability of the poisonous or deleterious substances and do not represent permissible levels of contaminantion where it is avoidable. The blending of a food or feed containing a substance in excess of an action level or tolerance with another food or feed is not permitted, and the final product resulting from blending is unlawful, regardless of the level of the contaminant.

Action levels and tolerances represent limits at or above which FDA will take legal action to remove products from the market. Where no established action level or tolerance exists, FDA may take legal action against the product at the minimal detectable level of the contaminant.

The action levels are established and revised according to criteria specified in Title 21, Code of Federal Regulations, Parts 109 and 509 and are revoked when a regulation establishing a tolerance for the same substance and use becomes effective.

This appendix is arranged by substance, listing the applicable human and animal feed products.

This list is current as of August, 2000. Notices will be published in the *Federal Register* as new action levels are established or as existing action levels are revised or revoked. It is the responsibility of the user of the list to keep up to date on changes in the action levels.

Only vegetable and vegetable products are included in this appendix.

The reference CPG refers to FDA's Compliance Policy Guide.

Aldrin and Dieldrin

Commodity[a]	Action level (ppm)	Reference
Alfalfa	0.03	CPG 575.100
Animal feed, processed	0.03	CPG 575.100
Artichokes	0.05	CPG 575.100

(*continued*)

Source: Adapted from "Action Levels for Poisonous or Deleterious Substances in Human Food and Animal Feed," U. S. Food and Drug Administration Industry Activities Staff Booklet, August 2000.

Aldrin and Dieldrin (continued)

Commodity[a]	Action level (ppm)	Reference
Asparagus	0.03	CPG 575.100
Bananas	0.02	CPG 575.100
Beets (garden and sugar)	0.1	CPG 575.100
Beet tops (garden and sugar)	0.05	CPG 575.100
Broccoli	0.03	CPG 575.100
Brussels sprouts	0.03	CPG 575.100
Bulb vegetables	0.1	CPG 575.100
Cabbage	0.03	CPG 575.100
Carrots	0.1	CPG 575.100
Cauliflower	0.03	CPG 575.100
Celery	0.03	CPG 575.100
Clover	0.03	CPG 575.100
Collards	0.05	CPG 575.100
Cowpea hay	0.03	CPG 575.100
Cucumbers	0.1	CPG 575.100
Eggplant	0.05	CPG 575.100
Endive (escarole)	0.05	CPG 575.100
Horseradish	0.1	CPG 575.100
Kale	0.05	CPG 575.100
Kohlrabi	0.05	CPG 575.100
Legume vegetables (except guar, jackbeans, lablab beans, and lentils)	0.05	CPG 575.100
Lettuce	0.03	CPG 575.100
Mustard greens	0.05	CPG 575.100
Parsnips	0.1	CPG 575.100
Pea hay	0.03	CPG 575.100
Peppers	0.05	CPG 575.100
Pimentos	0.05	CPG 575.100
Potatoes	0.1	CPG 575.100
Radishes	0.1	CPG 575.100
Radish tops	0.03	CPG 575.100
Rutabagas	0.1	CPG 575.100
Salsify roots	0.1	CPG 575.100
Salsify tops	0.05	CPG 575.100
Spinach	0.05	CPG 575.100
Squash	0.1	CPG 575.100
Sweet potatoes	0.1	CPG 575.100
Swiss chard	0.05	CPG 575.100
Tomatoes	0.05	CPG 575.100
Turnips	0.1	CPG 575.100
Turnip tops	0.05	CPG 575.100

[a]Action levels for crop groups cover all commodities specified in 40 CFR 108.34(f), unless an exception is noted.

Benzene Hexachloride (BHC)

Commodity[a]	Action level (ppm)	Reference
Asparagus	0.05	CPG 575.100
Beans	0.05	CPG 575.100
Brassica (cole) leafy vegetables (except broccoli raab, and rape greens)	0.05	CPG 575.100
Celery	0.05	CPG 575.100
Carrots	0.3	CPG 575.100
Cereal grains (except buckwheat, millet, popcorn, teosinte, and wild rice)	0.05	CPG 575.100
Cucurbit vegetables (except Balsam pears, Chinese waxgourds, gherkins, and gourds)	0.05	CPG 575.100
Eggplant	0.05	CPG 575.100
Endive	0.05	CPG 575.100
Lettuce	0.05	CPG 575.100
Okra	0.05	CPG 575.100
Onions	0.05	CPG 575.100
Paprika	1.0	CPG 575.100
Peas	0.05	CPG 575.100
Peppers	0.05	CPG 575.100
Root and tuber vegetables (except carrots)	0.05	CPG 575.100
Spinach	0.05	CPG 575.100
Swiss chard	0.05	CPG 575.100
Stone fruits (except Chickasaw, Damson, and Japanese plums)	0.05	CPG 575.100
Tomatoes	0.05	CPG 575.100
Turnip Greens	0.05	CPG 575.100

The figures listed are for residues of total BHC. However, in adding amounts of individual isomers, do not count alpha, gamma, or delta BHC at a level below 0.02 ppm in milk and rabbits, and 0.01 ppm for all other commodities listed. Do not count beta BHC at a level below 0.05 ppm for milk and rabbits, and 0.02 ppm for all other commodities listed.
[a]Action levels for crop groups cover all commodities specified in 40 CFR 180.34(f), unless an exception is noted.

Chlordane

Commodity[a]	Action level (ppm)	Reference
Asparagus	0.1	CPG 575.100
Beans	0.1	CPG 575.100
Beets (with or without tops)	0.1	CPG 575.100
Beet greens	0.1	CPG 575.100
Brassica (cole) leafy vegetables (except broccoli raab, Chinese mustard cabbage, and rape greens)	0.1	CPG 575.100
Carrots	0.1	CPG 575.100

(*continued*)

Chlordane (continued)

Commodity[a]	Action level (ppm)	Reference
Celery	0.1	CPG 575.100
Corn	0.1	CPG 575.100
Cucumbers	0.1	CPG 575.100
Eggplant	0.1	CPG 575.100
Lettuce	0.1	CPG 575.100
Okra	0.1	CPG 575.100
Onions	0.1	CPG 575.100
Parsnips	0.1	CPG 575.100
Peas	0.1	CPG 575.100
Peppers	0.1	CPG 575.100
Potatoes	0.1	CPG 575.100
Radishes (with or without tops)	0.1	CPG 575.100
Radish tops	0.1	CPG 575.100
Rutabagas (with or without tops)	0.1	CPG 575.100
Rutabaga tops	0.1	CPG 575.100
Spinach	0.1	CPG 575.100
Squash	0.1	CPG 575.100
Stone fruits (except Chicasaw, Damson, and Japanese plums)	0.1	CPG 575.100
Sweet potatoes	0.1	CPG 575.100
Swiss chard	0.1	CPG 575.100
Tomatoes	0.1	CPG 575.100
Turnips (with or without tops)	0.1	CPG 575.100
Turnips greens	0.1	CPG 575.100

The listed action levels are for residues of chlordane, including *cis*- and *trans*-chlordane, *cis*- and *trans*-nonachlor, oxychlordane, alpha-, beta-, and gamma-chlordene, and chlordene. Levels of individual components must be quantitated at 0.02 ppm or above and confirmed in order to be added into the "chlordane" total value.

The GLC pattern of the residue determines which reference standard(s) will be used for quantitation. If the residue pattern matches that of technical chlordane, quantitate against a technical chlordane reference standard. If the residue consists of identifiable individual components (i.e., *cis*- and *trans*-chlordane, *cis*- and *trans*-nonachlor, oxychlordane, alpha-, beta-, and gamma-chlordene, and chlordene), quantitate individual components against their respective standards. Sum individual values to obtain the total "chlordane" level. Do not include levels of heptachlor epoxide in the summation.

APPENDIX H

FDA Macroanalytical Methods for Vegetables and Vegetable Products

A. Method for Asparagus (V-93)

1. Scope

This method covers procedures for visual examination of individual shoots or pieces of asparagus to detect damage due to the asparagus beetle and other insects.

The succulent young shoots of this widely cultivated vegetable, *Asparagus officinalis* L., are cooked and consumed in a variety of recipes. The color of the shoots varies from white to dark green.

2. Applicable Documents

a. CPG 7114.02 Defect Action Levels
b. 21 CFR 155.200 Standard of Identity

3. Defects

Asparagus beetles are major pests of asparagus. There are two species, the asparagus beetle [*Crioceris asparagi* (L.)] and the spotted asparagus beetle [*Crioceris duodecimpunctata* (L.)]. The asparagus beetles emerge in the spring about the time asparagus shoots appear. The young tips are damaged by beetle feeding and egg laying. The eggs are normally dark in color and attached singly on end by a secretion which forms a hardened base between the egg and the spear or shoot. The base may remain after the egg sac has been removed. After the egg has hatched, the egg sac may remain attached and appear as a dark spot on the spear.

Larvae of the armyworm [*Pseudaletia unipuncta* (Haworth)] have been found on imported frozen asparagus. The larvae range in size from 2 to 3 mm in length and have been reported to reach a maximum length of 35 mm.

Thrips have also been reported to be a pest of asparagus.

4. Procedure: Determination of Asparagus Beetle Eggs and Egg Sacs in Asparagus

a. Sample Preparation Determine drained weight of canned asparagus and net weight of frozen product. For canned asparagus, pour contents of can evenly over a weighed No. 2 sieve. Use 8-in. sieve for containers of less than 3 lb net weight and 12-in. sieve for larger containers. Drain for 2 min and reweigh sieve and asparagus to determine drained weight of asparagus. Rinse container. Combine drained liquid with rinsing and set aside for use in Procedure (5)a.

b. Visual Examination and Classification of Rejects Place contents of can or thawed frozen package in a shallow white pan and cover with water. Roll each spear or piece and count the beetle eggs and egg sacs attached to it. Magnification may be used if needed. Class as a reject any spear or piece having six or more attached beetle eggs and/or egg sacs.

Any whole insects or equivalent, including thrips, detected by this examination, should be counted and combined with the results obtained in (5).

c. Report Report the percentage of reject spears or pieces by count.

5. Procedure: Determination of Insects in Asparagus

a. Examination of Drained Liquid Filter drained liquid and rinsing from (4)a through ruled filter paper; examine and record separately "whole insects and equivalent" and thrips. Do not count cast skins of thrips.

b. Examination of Drained Asparagus Insert 7-in. funnel containing a 5-in. No. 12 sieve into a 2 L Wildman trap flask. Decant liquid contents of pan containing asparagus from (4)b through sieve into trap flask. Cover asparagus in pan with water and wash by stirring to release any insects. Decant liquid again through sieve to trap, flask. Repeat washing and decantation to trap flask. Extract, trap, and filter, using water and 25 and 15 mL portions of *n*-heptane (III.(7)). If pieces of asparagus float in the heptane, remove with forceps and rinse over the filter with water. Examine papers microscopically and record the number of whole insects or equivalent according to categories in AOAC 970.66B(i) and the number of thrips. Do not count cast skins of thrips. Calculate the number of thrips per 100 g of asparagus as follows:

$$\left(\begin{array}{c}\text{No. thrips in}\\ \text{drained liquid ((5)a.)}\end{array} + \begin{array}{c}\text{No. thrips in drained}\\ \text{asparagus ((5)b.)}\end{array}\right) \times \frac{\text{100 wt (g)}}{\text{drained asparagus}}$$

c. Report Report total number and breakdown of whole insects and equivalent for each container or subsample and the average of the subsamples. Report also the number of thrips in 100 g asparagus from each container or subsample examined. Also report the average of the subsamples.

B. Method for Brussels Sprouts (V-95)

1. Scope

Brussels sprouts are prepared from the clean, sound, succulent heads of the brussels sprouts plant (*Brassica oleracea* L. var. *gemmifera*). This method contains a procedure for determination of whole insects and equivalent by visual examination of a representative sample after cutting the sprouts to expose the presence of aphids, thrips, or other insects.

2. Applicable Documents

a. CPG 7114.07 Defect Action Level

3. Defects

The major defects associated with brussels sprouts are contamination by insects such as aphids and thrips.

4. Procedure: Determination of Insects in Brussels Sprouts

a. Sample Preparation and Visual Examination If frozen, thaw the sample and weigh at least 100 g per subsample. Cut heads longitudinally into quarters and immerse in water in a white pan. Spread leaves to expose insects. Count all aphids and thrips on the heads and those loose in the water that are visible without magnification. Magnification may be used to distinguish between whole aphids and thrips and cast skins. Do not count cast skins of aphids and thrips.

b. Report Report the number of aphids and thrips in each subsample and the average number per 100 g. Report separately other types of insects.

C. Method for Microscopic Detection of Substitute Vegetable Tissues in Ground Horseradish (V-96)

1. Scope

This method describes a microscopic procedure for detecting and estimating the amount of foreign tissues or adulterants added to or substituted for horseradish root in the preparation of horseradish sauce.

Horseradish sauce is prepared by crushing, mincing, or powdering the root of *Armoracia rusticana* Gaertn., Mey. & Scherb., a member of the Cruciferae family. In processing horseradish, the roots are washed in a tumbler or rotary washer, and either scraped to remove the brown outer skin, or cleaned in an automatic vegetable peeler prior to grinding.

2. Applicable Documents

a. CPG 7109.20 Horseradish-Definition

3. Defects

A few manufacturers have occasionally prepared imitation horseradish products from cheaper substitutes without declaring such on the label. Parsnip and turnip roots have been encountered most frequently as substitutes for the genuine horseradish root. The microscope offers a ready means for detecting such adulterants, based on diagnostic histological characteristics which distinguish horseradish root tissues from substitute materials.

4. Procedure: Microscopic Determination of Substitute Vegetable Tissues in Ground Horseradish

a. Diagnostic Microscopic Features of Ground Materials

(i) *Horseradish*—Horseradish starch grains are elliptical to nearly spherical with indistinct central hilum. The grains are generally 3–15 micrometers in diameter, with some grains occasionally reaching 25 micrometers. Elongated xylem and phloem parenchyma cells measure 100 to 150 micrometers in length and have pointed ends that lock together with the adjacent cells. Irregularly rounded to greatly elongated stone cells are scattered throughout the cortex.

(ii) *Parsnip*—Parsnip starch grains are irregularly rounded and polygonal. The grains are 3 to 7 micrometers in diameter. Some grains occasionally reach a diameter of 15 micrometers. A cross-hatched appearance of the xylem rays is quite characteristic in longitudinal sections. Oil is especially vivid after staining with Sudan III and warming in acidified chloral hydrate glycerol solution.

(iii) *Turnip*—Turnip cells are large, thin-walled, and isodiametric. They are devoid of starch. The cells appear in cobweblike groups.

b. Microscopic Examination Mount a small portion of the subsample in water and examine microscopically for foreign starch. Place about 5 g of the subsample in a 50 mL test tube, add 5 mL I-KI solution, and shake until thoroughly mixed. Let soak for 5 min to stain the horseradish starch thoroughly. Place in a No. 60 sieve and rinse with a stream of water to remove excessive I-KI solution. Transfer the stained material to a petri dish, cover with a small amount of water, and examine with a widefield binocular microscope. Horseradish tissues are stained a deep blue. Parsnip roots may stain either a light or dark blue since the amount of starch present will vary depending on whether roots used were dug in the spring or fall. Turnip and other starch-free roots will stain yellow. If a considerable number of yellow-stained fragments are present, one may suspect the addition of turnip or parsnip to the product. Make microscopic mounts in acidified chloral hydrate–glycerol solution of several fragments and check identity from the diagnostic characteristics listed in (4)a above. Estimate the approximate percent of foreign tissues present by determining identity of 25 or more pieces of tissue selected at random. More accurate estimates of amounts of foreign tissues present may be made by comparing the subsample material with authentic mixtures containing known percentages of each ingredient in the mixture.

c. Report State the presence and approximate percent (by weight) of tissues other than horseradish found.

REFERENCES

Ballard, Chas. W., and F. J. Pokorny. "Histological Study of Horseradish Root and Some Common Adulterants." J. Am. Pharm. Assoc. *28*:376–381, June 1939.

Winton, A. L., and K. B. Winton. "Vegetables, Legumes and Fruits." *Structure and Composition of Foods*, Vol. 2, pp. 72–75, John Wiley and Sons Inc., New York, 1935.

D. Method for lettuce (V-98)

1. Scope

This method covers a procedure for the visual examination of lettuce to determine the percentage of leaves in the head that are either decomposed and/or contaminated with insects. The method employs a washing and separation process to determine numbers of insects in a representative sample.

Numerous varieties of lettuce are under cultivation; they are grouped as either

Common
COS or romaine.

Garden lettuce is derived from *Lactuca sativa* L. and is used primarily as a salad ingredient. Leaves of common lettuce vary in color from light to dark green. Leaves of some species are mottled with brown or purple.

2. Applicable Documents

3. Defects

Bacterial spot of lettuce is caused by *Xanthomonas vitians*, a bacterium which forms raised, pale-yellow colonies on nutrient dextrose agar. Infestation takes place through stomata during periods

of high humidity, dew, and rain. The disease is characterized by circular or irregular translucent water-soaked leaf lesions which become dark brown with age. If the infection is severe it may render the crop unmarketable.

Bacterial soft rot, often called "slime," is the most serious market disease of lettuce. The common causative agents are *Pseudomonas* spp. and *Erwinia* spp. In the early stages of infection the tissue appears to be water-soaked and may develop a russet or brown color. As the decay progresses the lettuce becomes soft and slimy. Under dry conditions, decayed areas of the outer leaves may become papery in texture.

Aphids and other insects such as leaf miners also may infest lettuce.

4. Procedure: Examination of Lettuce for Decomposition and Insect Contamination

a. Sample Preparation Select at least three heads from each subsample or select a minimum of nine heads from each sample. Weigh the heads from each subsample. Strip off and discard any obviously worthless outside leaves.

b. Visual Examination and Report Examine the prepared heads by stripping off single leaves and examining each for decomposed areas, aphids, and other insects. For each head, report the total number of leaves and the number showing rot spots in. or greater in diameter.

Calculate and report the percentage by number of leaves with rot.

Report the percentage by number of leaves in each subsample (three or more heads) showing aphid or other insect infestation and state whether the insects are alive or dead. Wash each insect-infested leaf with water, using an aerator [AOAC, 945.75B(a)]. Pour the combined washings from each subsample through an 8 in. No. 80 sieve. Transfer residue from sieve to ruled filter. Examine at about 15×. Report the total number of aphids, aphid heads, and other insects, and calculate the number of each per 100 g of each subsample.

State whether the rot and/or insect infestation is general throughout the head or confined to the outer leaves.

REFERENCE

U.S. Department of Agriculture Handbook No. 155, Washington, DC, April 1959.

E. Method for Mushroom Products (V-100)

1. Scope

The common cultivated mushroom (*Agaricus bisporus*) is sold commercially as a fresh, canned, frozen, and dried product. A method for the determination of maggots and mites in canned, fresh, frozen, freeze-dried, and dehydrated mushrooms is specified in AOAC 967.24A. In addition, AOAC 967.24B provides a procedure for detecting light and heavy filth in dried (not powdered) mushrooms. To supplement the foregoing, this method includes procedures for mushroom products which cover

Determination of damage by decomposition (mold, etc.) in individual canned, dried, and fresh mushrooms

Determination of light filth and maggots in mushroom soup

2. Applicable Documents

a. CPG 7114.13 Defect Action Levels

3. Defects

a. Insect Infestation and Damage Two insects commonly infest mushrooms. The mushroom fly larva (*Lycoriella* spp.) is a black-headed maggot which tunnels through the stem and cap of the mushroom. The larvae of the Cecidomyiid or cecid fly, which feed primarily around the mushroom gills, are pointed at both ends, and reach a length of 3 mm. Less commonly, maggots of the phorid fly have also been found in canned mushrooms. In addition, several species of mites also attack mushrooms. Of these, the mold mite (*Tyrophagus putrescentiae* (Schrank)) is the most serious pest.

b. Mold and Other Microbial Deterioration Several species of bacteria and fungi produce discolored rot areas on the mushrooms. These areas appear as dark brown or black spots, streaks, blotches, or pits. *Verticillium* mold infection can be recognized by the gray bloom which develops in the centers of the older spots or pits as a result of the growth of conidiophores. The mold *Trichoderma* is a much less common cause of spotting and pitting. Typically, *Verticellium* grows close to the surface of the mushroom, while *Trichoderma* penetrates more deeply into the tissues, often causing large portions of the mushroom to become discolored and rotten.

4. Procedure: Determination of Damage by Decomposition in Canned, Dried, and Fresh Mushrooms

a. Sample Preparation For canned mushrooms, pour contents of can evenly over No. 8 sieve. Use an 8-in. sieve for containers of net weight less than 3 lb and a 12-in. sieve for larger containers. Drain 2 min or longer. For dried mushrooms, place about 20 g from each subsample into a suitable size container and add sufficient water to immerse the mushrooms. Soften mushrooms by soaking for several hr or, alternately, by heating on a steam bath or boiling 1.5 to 2 hr as necessary. Drain 2 min or longer on a No. 8 sieve. Use fresh mushrooms as is.

b. Visual Examination Weigh 100 g of the drained canned or dehydrated mushrooms and 200 g fresh mushrooms to be used as analytical units. Examine each mushroom or piece under good lighting for evidence of decomposition. Classify as a reject any mushroom or piece which contains at least one decomposed area 1/4 in. or more in average diameter. These areas will appear as dark brown or black spots, streaks, blotches, or pits (see (3)b above). Examine the tissue from discolored areas microscopically for the presence of pathogens. If microscopic examination shows characteristic conidiophores of *Verticillium*, consisting of a central stalk with whorls of branches, the presence of *Verticillium* is confirmed. Separate and weigh the reject mushrooms and pieces.

c. Report Report the percent (by weight) of reject decomposed mushrooms in each analytical unit. Also report the average percent (by weight) of rejects for all units examined.

5. Procedure: Determination of Light Filth by Flotation in Mushroom Soup

a. Sample Preparation and Microscopic Examination Use the entire contents of a can (about 10 3/4 oz.) as the analytical unit. Weigh and pour the entire contents of the can into 1.5 L beaker. Bring the volume to 900 mL with hot tap water. Add the following and stir well:

100 mL HCl
1 sec spray of Antifoam A [AOAC 945.75C(e)]
10 mL Igepal CO-730 [AOAC 945.75C(j)]

Bring to a boil and continue boiling with rapid magnetic stirring for 30 min. Pour a small portion at a time onto a No. 230 sieve and wet-sieve with hot tap water. Wash each portion on the sieve with 40% isopropanol and transfer to a 2 L trap flask. Bring the volume to 1 L with 40%

isopropanol, add 50 mL HCl, and boil 10 min with gentle magnetic stirring. Transfer the trap flask to a cool magnetic stirrer, add 40 mL light mineral oil, and stir at maximum speed (without visible or audible splashing) for 3 min. Fill with water and trap off into a beaker. Stir 30 mL light mineral oil into the flask and perform second trapping after 10 min. Filter combined trappings from beaker and examine microscopically. Retain the trap flask contents for further analysis as in (6) below.

b. Report Report, using the applicable categories in AOAC 970.66B(i).

6. Procedure: Determination of Maggots in Mushroom Soup

a. Sample Preparation and Microscopic Examination Pour the settled residue in trap flask from (5)a above onto a No. 230 sieve and rinse thoroughly with isopropanol and hot tap water. Quantitatively transfer residue on sieve to a 600 mL beaker. Proceed as in AOAC 967.24A(a), paragraph 3, beginning with, "Pour mixt. into nested set of 8" Nos. 20, 40, and 140 sieves . . . ."

b. Report Report the number of maggots for each analytical unit and the average number per unit weight.

F. Method for the Preservation and Identification of Mushrooms (V-102)

1. Scope

This method describes a procedure for preserving specimens of mushrooms and related fungal products for specific identification by a qualified taxonomist. This is important when toxic or nonedible species may be suspected as contaminants in a product.

At present, there are at least 17 edible species of fungi being cultivated commercially. The "mushroom" most familiar to the American consumer is *Agaricus bisporus*. Another species, *Agaricus bitorquis*, which closely resembles *A. bisporus*, is rapidly gaining in world economic importance. The tolerance of *A. bitorquis* for higher cultivation temperatures permits its widespread cultivation above ground. Other cultivated mushrooms available to the consumer include

Volvariella volvacea—the padi straw mushroom
Lentinus edodes—the shiitake mushroom
Pleurotus ostreatus (Jacq) Fr.—the oyster mushroom.

Wild European mushrooms available in either canned or dried form include

Morchella spp.—morels
Cantharellus cibarius Fr.—chanterelles
Boletus spp.—cepe or steinpiltz

2. Applicable Documents

a. Import Alert 25-02-Morels

3. Defects

Several toxic and potentially lethal species of fungi have been found as contaminants in imported products. Among these are

Verpa Bohemica (false morels)
Gyromitra spp. (false morels)
Helvella spp.

4. Procedure: Method for Preserving Mushrooms for Taxonomic Identification

Mushroom identification requires extensive training and experience and should not be attempted by an inexperienced analyst. There are a variety of pictorial keys and handbooks available on mushroom identification; however, these are useful only to the specialist or experienced taxonomist. A combination of authentic specimens, direct microscopic examination, spore prints, and microchemical tests are sometimes necessary to differentiate edible and toxic mushrooms.

To preserve specimens, dry them with forced warm air (40–50°C). Chemical preservatives such as alcohol or formalin may be used, but a portion of the unknown mushroom or sample should also be dried.

REFERENCES

1. Miller, Orson K. *Mushrooms of North America*. Dutton, New York, 1979.
2. Singer, Rolf. *The Agaricales in Modern Taxonomy*, 3rd ed. J. Cramer Verlag, Braunscheig, Germany, 1975.

G. Method for Peas and Beans (Canned, Frozen, and Dried) (V-104)

1. Scope

This method covers procedures for the preparation and visual examination of canned, frozen, and dried peas and beans for mold and insect damage. Legumes or pulses (family Leguminosae) are grown for their edible seeds. While many varieties of legumes are referred to as beans and peas, there is at least one variety of legumes, lentils, which is not. Types of peas and beans covered by this method include but are not limited to

Beans of the genus *Phaseolus*, such as French, "string," "snap," or kidney beans (*Phaseolus vulgaris* L.); the lima or butter bean (*P. lunatus* L.);* and the scarlet runner bean (*P. coccineus* L.)

Beans of the genus *Vigna* such as mung beans [*Vigna radiata* (L.) Wilczek], the species from which bean sprouts are produced; the adzuki bean [*Vigna angularis* (Willd.) Ohwi and Ohashi], similar but with larger seeds than the mung bean, and which is red, cream, lilac, or mottled in color

The large podded or broad bean (*Vicia faba* L.) also called "lupini bean"

Soybeans and soya seeds [*Glycine max* (L.) Merr.] used in such products as processed soybeans, processed soybean oil, soy flours, fermented soy products, soy mills, bean cake, and tofu

The true pea (*Pisum sativum* L.)

Cowpeas, black-eyed peas, crowder peas, field peas, and southern peas [*Vigna unguiculata* (L.) Walp. subsp. *unguiculata*]

Yard-long bean (*Vigna unguiculata* subsp. *sesquipedalis* (L.) Verdc.)

Pigeon pea (*Cajanus cajan* (L.) Huth)

Chick pea, garbanzo, or Bengal gram (*Cicer arietenum* L.), which are rounded seeds with a characteristic "beak" resembling the head of a baby chicken

Lentil (*Lens culinaris* Medik.)

*White seeded types are usually grown because colored seeds often have a relatively high cyanogenic glycoside level, which can be dangerous.

2. Applicable Documents

a. CPG7114.05 Lygus bug damage in dried cowpeas
b. CPG7114.11 Cowpea curculio in canned cowpeas
c. CPG7114.15 Insect damage and rocks in dried peas and beans

3. Defects

a. Insect Damage in Canned and Frozen Peas and Beans Peas and beans may become infested by various types of insects, their eggs, and larvae. Such infestation may be found in the finished product.

Pea weevil infestation [*Bruchus pisorum* (L.)], by far the most commonly encountered defect in peas, occurs in the fields prior to harvesting. Adult weevils lay their eggs on the tiny pods, and after hatching, the larvae perforate the skins and enter the peas. Infestation is evidenced by the presence of small round holes on the peas. These holes are usually accompanied by discolorations around the openings. The larvae may be found under the skin embedded in the cotyledon.

The bean weevil [*Acanthoscelides obtectus* (Say)] may infest beans in the field, although it is also a serious pest of dry beans in storage. The larvae attack the seeds of several varieties of beans (including kidney beans, limas, and cowpeas) in the field and in storage. It also attacks faba beans, peas, lentils, and others in storage only.

Cowpea curculio [*Chalcodermus aeneus* (Boheman)] is a common defect in field peas and black-eyed peas. Some variety of crowder peas and the California black-eye are more susceptible than other varieties. The greatest damage from this insect is done by the larvae feeding on the seed within the green pods. Shelled peas with curculio damage have small dark spots present, which may or may not contain an egg or larva. These small dark spots are commonly called "weevil stings." The curculio is legless and C-shaped. Its body is pale yellow and the head is brown. The larva is less than 1/4-in. in length when full grown.

b. Weevil and Moth Damage in Dried Peas and Beans There are five major insect species that attack dried peas and beans. They are the bean weevil (*Acanthoscelides obtectus* (Say)), the cowpea weevil (*Callosobruchus maculatus* (Fabricius)), the Indianmeal moth (*Plodia interpunctella* (HØbner)), the tobacco moth (*Ephestia elutella* (HØbner)), and the almond moth (*Cadra cautella* (Walker)).

The bean weevil and the cowpea weevil are the most destructive. They attack beans and peas while they are in the field, where they may become heavily infested before they are taken to the warehouse. These species will breed continuously in the dry seeds if stored in a warn place. The insect eggs of the bean weevil are smooth and white, and are laid singly or in clusters among or near the beans. The eggs hatch into tiny white larvae, which eat their way into the beans. The entrance holes are small and easily overlooked. In warm weather, the larvae develop rapidly within the beans and soon reach the pupal, or resting, stage from which the adults are formed. The adults then chew a round opening through the seed coat and emerge. The bean weevil is capable of developing in all varieties of common beans and cowpeas. The life cycle of the cowpea weevil is similar to that of the bean weevil, except that the eggs are glued to the pods or exposed seeds. The hatching larvae chew from the egg through the seed coat and into the seed.

The damage caused by the three species of moths that attack dry peas and beans results chiefly from the webbing and frass that is deposited among the beans and peas while the larvae are feeding. The larvae can feed only on beans and peas that are split or have cracked seed coats.

c. Lygus and Aphid Damage in Dried Peas and Beans In the field, peas and beans may also be damaged by sucking insects. The lygus bug (*Lygus* spp.) and the aphid may damage legumes by the insertion of the proboscis into the growing seed to inject a digestive juice and to

suck out plant substances such as protein. This results in an area of dead tissue which appears as a brown spot or in some cases a chalky pit surrounded by brown scar tissue. In some instances the damage does not penetrate the cotyledons; however, in other instances there is extensive inner damage while only a small amount of damage can be detected on the exterior. [See http://www.cfsan.fda.gov/~dms for figure showing the type of interior damage done to black-eyed peas by the lygus bug and aphid. The illustrations have been arranged to show increasingly greater aphid and lygus bug type of damage.]

d. Mold Damage in Dried Peas and Beans Dried beans with no visible external damage and an apparently intact integument (seed coat) may have extensive internal mold and require splitting of the cotyledons to detect.

4. Procedure: Determination of Insect-Damaged Peas or Beans in the Canned or Frozen

Examine at least 200 peas or beans. In canned beans and peas, the insect plug or exit hole shows as a hole in the bean which is often light brown or black. In frozen beans, the insect damage is mainly due to the insect's egg being laid in the bean. This can often be seen in beans by staining them with a dilute iodine solution. The insect egg plug shows up as a small dot which is dark blue or black. Classify as insect-damaged any pea or bean containing an insect(s) or showing definite evidence of tunneling or frass. Report percent by number of insect-damaged peas or beans. If any appreciable amount of weevil damage is noted, proceed as in (5)c below, as necessary.

5. Procedure: Determination of Insect-Damaged Peas or Beans in the Dried Product

a. Visual Examination for Weevil Damage Examine at least 12 subsamples. Cowpea weevil eggs appear as white oblong mounds approximately 0.4×0.7 mm that are firmly glued to the outer surface of the seed. Weevil egg punctures are very small but can occasionally be seen. Weevil exit holes are about 1 mm in diameter and show little or no discoloration. Classify as insect-damaged any pea or bean containing an insect(s) or showing evidence of tunneling or frass. Report percent by number of insect-damaged peas or beans. If any appreciable amount of weevil damage is noted, proceed as in (5)c below, as necessary.

b. Visual Examination for Lygus or Aphid Damage Examine at least 12 subsamples. In the case of lygus or aphid type of damage, classify as rejects all peas or beans which have exterior damage equal to or greater than No. 6 in Fig. V-9. Split open those beans or peas having less exterior damage than No. 6, and examine for interior damage. When the interior and exterior areas of damage (as judged from the figure) are added together and the total divided by two is equal to or greater than No. 6, classify the bean or pea as a reject. Report number of beans or peas examined and number and percentage of rejects.

c. Examination for Internal Weevil Damage Proceed as in AOAC 945.81.

6. Procedure: Determination of Moldy Peas or Beans in the Dried Product

a. Sample Preparation Examine at least 200 peas or beans. Soak beans 15–30 min in 70% alcohol or until seed coat separates from the cotyledons as evidenced by wrinkles in the seed coat. Remove beans or peas from the alcohol solution and place on absorbent paper. Gently split beans or peas with scalpel, hilum side down. The seed coat and the cotyledons will separate. Using a #5 or #7 jeweler's forceps, separate cotyledons and seed coat and place them in 100% isopropanol. Remove cotyledons and seed coat and place on a spot plate. They should dry in about 2 min.

b. Visual Examination and Classification of Rejects Examine the internal surface of the seed coat for the presence of mold hyphae. In cases of extensive invasion, hyphae and fruiting bodies may be present between the cotyledons, and the cotyledons may be discolored.

Suspected hyphae and fruiting bodies may be confirmed by removing them with forceps, mounting in glycerol–alcohol (1 + 1 v/v) solution, and examining with the compound microscope at 100–200×. The characteristics of mold hyphae used in the Howard mold count method should be applied in confirming mold hyphae (AOAC Fig. 984.29B). Classify any pea or bean in which 1/4 or more of the internal surface of the cotyledons is affected by mold as mold damaged.

c. Report Report percent by number of mold-damaged peas or beans.

H. Method for Pickled Vegetables and Relish

1. Scope

This method covers procedures for detection of insects, grit, and mold in individual pickles and pickled vegetables.

The cucumber (*Cucumis sativus* L.) is commonly eaten raw or pickled, and is eaten less often as a cooked vegetable. Characteristics of the fruit are

The elongated, rounded triangular form
The three locules
The more or less prominent spiny warts
A hard green rind
Succulent flesh

Cucumbers are processed commercially into a variety of pickle products and relish.

2. Applicable Documents

3. Defects

Cucumbers may be contaminated by insects which enter the crop in the field. The pickleworm [*Diaphania nitidalis* (Stoll)], which is an internal feeder in cucumbers, may not be eliminated during the processing steps unless the pickle stock is adequately sorted or trimmed. Cucumbers may contain excessive grit, sand, or soil when delivered for processing. These contaminants may not be entirely removed by washing unless special care is taken.

Cucumbers and other vegetables are frequently pickled in open tanks; use of this method may allow insects and other animal filth to get into the finished product tank unless care is exercised to prevent contamination. Outdoor salt tanks may accumulate large numbers of various types of flying insects in the surface brine. Insects and other debris may also be found below the surface, due to periodic addition and circulation of brine. Indoor sweetening tanks are particularly attractive to drosophilids which breed on any exposed product and on the inner sides of the tanks above the level of the liquid.

Moldy cucumbers or other vegetables are sometimes used in pickled and chopped vegetable relishes. The moldy condition of the cucumbers or vegetables is concealed in the product by grinding or chopping.

4. Procedure: Determination of Grit, Sand, and Soil in Pickled Vegetables

a. Sample Preparation Examine at least 6 containers to provide a minimum of 100 pickles. Drain entire contents of each container on a No. 10 screen. Collect the brine and set aside for (4)c.

b. Organoleptic Examination Count and examine contents of each jar separately. Cut pickles other than gherkins and midgets into approximately three equal cross sections. Score grittiness of each pickle according to the number of thirds showing grittiness and report as in (4)d. In scoring the grittiness of each section, do not include grittiness that is slight and unobjectionable to the taste. Do not section midget and gherkin size pickles but record these as whole units.

c. Analysis for Grit, Sand, and Soil in Brine Filter brine onto paper and examine residue microscopically for presence of sand or soil particles. If appreciable amount is present, ash the filter paper and record weight of ash in mg per unit size jar.

d. Report Tabulate results as follows:

	Subsample no.			
	1	2	etc.	Totals
Pickles gritty in all thirds No.: Percent:				
Pickles gritty in two thirds No.: Percent:				
Pickles gritty in one thirds No.: Percent:				
Midgets or gherkins gritty No.: Percent:				
Grit, sand, and soil in brine Wt. of ash (mg/jar)				

5. Procedure: Determination of Moldy Material in Pickle Relish

Stain 10 g of the well-mixed relish with a few drops of crystal violet solution [III.(3)] for 3 min. Both relish fragments and mold filaments take the stain readily. Wash out excess stain on a No. 20 sieve with water. Transfer the stained relish a small portion at a time to a petri dish and examine under water with a wide field microscope equipped with a substage light at 30–40×. To verify rotten or moldy relish fragments, check suspect fragments for mold with compound microscope if necessary, and report weight of moldy fragments. Decay caused by bacteria or yeasts will not be detected by this method.

I. Method for Pimientos (V-111)

1. Scope

This method describes procedures for determination of rot in pimientos. The term "pimento" or "pimiento" (*Capsicum annuum* L.) is used rather loosely for nonpungent, fleshy varieties of red pepper. There are two distinct types of pimiento fruit:

Oblate fruit of the tomato type
Conically shaped fruit

Pimientos are used in salads, in cooking, and as a stuffing for green olives.

2. Applicable Documents

3. Defects

Pimientos in jars or cans may have decayed portions resulting from the growth of mold. These moldy areas are found more frequently on the inner surfaces of the pimiento than on the outer. They are distinguished by a brown or black discoloration. Dark-colored areas due to charring during the fire flaming process for removal of the skin may also be present, but they are easily distinguished from areas containing mold.

4. Procedure: Determination of Rot in Whole Pimientos

a. Sample Preparation Tare a No. 8 sieve with a lightweight drip pan. For containers of 3 lb net weight or less, use a sieve 8 in. in diameter. For containers of more than 3 lb, use a 12 in. sieve. With screen tilted about 17–20, drain contents of can or jar 2 min. Place sieve on drip pan and determine drained weight and total number of fruits. Transfer pimientos to a pan of suitable size and examine under good light.

b. Visual Examination Open each pimiento and examine both inner and outer surfaces for suspected moldy areas. Confirm the presence of mold by microscopic examination of a small portion of tissue. Count and weigh the fruits containing rot. Report size of each rotten area by averaging the lengths of the longest diameter and its bisect. Dissect out decayed portions, cutting completely through the flesh, even if the rot shows on only one side. Weigh the cut-out rotten pieces. Determine and report percentage of rot by weight, using the following formula:

$$\% \text{ rot} = \left(\frac{\text{wt cut-out rot}}{\text{drained wt}} \right) \times 100$$

c. Report Tabulate results as follows:

	Subsample no.				
Code no.	1	2	3	etc.	Average
Pimientos per can					
Drained wt (g)					
No. of whole pimientos					
Pimentos with rot					
Drained wt (g)					
No.					
Average diameter of rot in each piece (mm)[a]					
Cut out rot					
Drained wt (g)					
Percent rot by weight					
Remarks					

[a]If a piece contains more than one moldy area, record the average diameter of each area in the tabulation.

5. Procedure: Determination of Rot in Pimiento Pieces (Sliced, Diced, or Chopped)

Proceed as for whole pimientos (a count of total number of pieces per can is not necessary).

J. Method for Potato Chips (V-113)

1. Scope

This method contains a procedure for the examination of individual potato chips to determine the percent of chips that are affected by rot as demonstrated by the presence of mold filaments. Potato chips arc thin slices of potato [*Solanum tuberosum*] fried in deep fat and then salted. Potato chips are produced in the home kitchen and on a commercial basis.

2. Applicable Documents

a. CPG 7114.20 Defect Action Level for Rot

3. Defects

Many of the rots encountered in potatoes are of bacterial origin, with molds occurring as secondary rotting agents. In a number of instances, therefore, molds may not be detected in the finished rotten chip, even though the chip shows an apparently discolored, decayed area. The finding of mold in the decayed area is a definite proof of the existence of rot.

4. Procedure: Examination for Rot in Potato Chips

a. Sample Preparation and Visual Examination Examine 8 oz. of potato chips per subsample for rot spots. Weigh subsample and count the number of chips. Rot spots are characterized by a discolored gray area. If the rot spot is large the interior may have dropped out, leaving a hole with a greyish rim. Separate the suspected rotten chips as an aliquot (a proportionate part of the subsample) for confirmation of mold. Weigh and count the number of chips in the aliquot.

b. Microscopic Confirmation Confirm the rot in the separated pieces as follows. Transfer the chips to a suitably sized beaker and add petroleum ether (at room temperature) to cover the chips and allow to remain for 15 min. Decant petroleum ether, wash with additional petroleum ether, and dry. Wet a portion from the dark spot in water until soft. Mount on a microscopic slide and tease apart. Add Hertwig's solution [AOAC 44.003(v)] as a clearing agent. Warm and cover with a cover slip. Search for mold filaments at $100-200\times$. Calculate the weight and number of rotten chips based on the proportion of chips in the aliquot showing mold.

c. Report Tabulate results as follows:

		Subsample no.				
		1	2	3	4	etc.
Subsample size	Wt					
	No.					
Rotten chips	Wt					
	No.					
	% by wt.					
Remarks:						

K. Method for Corn Husks (V-115)

1. Scope

This method covers a procedure for the visual examination of corn husks to determine the percent of husks that are insect and/or mite damaged and/or affected by mildew or molds.

Dried corn husks (foliaceous bracts or spathes enclosing the ear of corn, *Zea mays* L.) are used as wrappers for tamales. The husks are usually imported in one of three forms:

Unprocessed husks—these consist of the aggregates of husks and silk, as they are taken from the field following removal of the ear.

Partially processed husks—these consist of individual bracts with the silk partially removed and the butt portion removed, or of naturally layered groups of a small number of bracts with the butt portion removed.

Processed husks—these consist of individual bracts with the worm-eaten tips and silk removed.

2. Applicable Documents

a. CPG 7114.10 Defect Action Level

3. Defects

The most commonly encountered type of insect contamination is that of the corn earworm. Corn husks may contain excreta, webbing, and fragments of this insect. Spiders, spider droppings, earwigs, beetles, psocids, aphids, thrips, and mites also have been found. Occasionally corn husks are heavily mildew-stained near the tips. Other mold is usually negligible.

4. Procedure: Determination of Reject Corn Husks

a. Sample Preparation and Visual Examination Weigh 200 g husks from a subsample and examine all individual bracts visually for rejects due to insect infestation, mites, and/or mold. Verify findings microscopically (10–30×), if necessary. The presence of mold filaments in decomposed tissue may be verified by macerating the area in water and examining at 100×. Classify according to (4)b below and weigh each category of rejects.

b. Classification of Reject Corn Husks

(i) *Insect-infested*—Classify as insect-infested any husk containing insects, mites, insect parts, webbing, excreta, or definite evidence of insect feeding, with the following limitations:

Do not classify as a reject any bract containing insect-cut holes unless the tissue around one or more of the holes, over 1 mm in diameter, is obviously discolored or the bract contains a number of holes whose combined diameters exceed 1 cm (each hole measured at its greatest diameter).

Do not classify as a reject any bract containing aphids, mites, psocids, or thrips unless these pests are so numerous that the bract is obviously unfit for its intended use.

Do not classify as a reject any bract containing less than five insect excreta pellets without other definite evidence of insect infestation.

(ii) *Moldy*—Classify as moldy any husk or bract which contains staining mildew or other mold damage over more than 10% of its area.

c. Report Tabulate percent (by weight) of corn husks in each reject category and total percent rejects.

L. Method for Garlic Bulbs (V-117)

1. Scope

This method covers a procedure for the visual examination of individual garlic bulbs to determine percent of reject bulbs due to damage by insects, molds, or other means. Garlic (*Allium sativum* L.) is a perennial bulbous plant. It is marketed as a compound bulb consisting of approximately 10–20 small bulbils or cloves contained within whitish membranous scales.

2. Applicable Documents

3. Defects

Garlic is susceptible to insect and mite infestation, and to several types of decomposition, including bulb rot (caused by *Aspergillus alliaceus*), blue mold rot (*Penicillium* spp.), and white rot (*Sclerotia cepivorum*).

A nonparasitic disease known as "waxy breakdown" may be due to heat, sunscald, or physiological breakdown. In the early stages, small, sunken, light-yellow areas are seen in the flesh of the clove. As breakdown progresses, these areas become deep yellow or amber throughout. The clove is usually somewhat sticky or waxy to the touch but not soft, as is the case of tissue affected by parasitic fungi. Waxy breakdown is classified in the "otherwise unfit" category.

4. Procedure: Determination of Insect-Damaged, Moldy, and Otherwise Decomposed Garlic Bulbs

a. Sample Preparation and Visual Examination Examine at least 50 bulbs, taking a representative number from each subsample. Examine each compound bulb separately and class it as either reject or passable. Remove the outer scales from the bulb and examine each clove by peeling and cutting as necessary. Classify the reject bulbs according to the defect definitions below. If a bulb is both insect-infested and moldy or otherwise decomposed, class it as insect-infested. Describe the decomposition.

b. Classification of Reject Bulbs

(i) *Insect-infested*—Classify as insect-infested any bulb containing live or dead insects, webbing, excreta, or definite evidence of insect feeding.

(ii) *Moldy*—Classify as moldy any bulb containing

Conspicuous fruiting mold or sclerotia
Inconspicuous mold affecting an aggregate area larger than 1 cm^2. The presence of inconspicuous mold may be verified by magnification after identifying the affected area without magnification.

(iii) *Otherwise unfit*—Classify as otherwise unfit any bulb not classed as moldy but which is otherwise decomposed as evidenced by discoloration or other abnormal appearance affecting an aggregate area equivalent to a circle 3/4 in. or more in diameter.

c. Report Report number and percent of bulbs in each reject category. Also report total percent rejects.

REFERENCE

Market Diseases of Asparagus, Onions, Beans, Peas, Carrots, Celery, and Related Vegetables. Agriculture Handbook No. 303, Market Quality Research Division, USDA/ARS, Sept. 1966.

APPENDIX I
Safety of Vegetable Juices

FOOD LABELING WARNING AND NOTICE STATEMENTS: 21 CFR 101.17

(g) Juices that have not been specifically processed to prevent, reduce, or eliminate the presence of pathogens.

(1) For purposes of this paragraph (g), "juice" means the aqueous liquid expressed or extracted from one or more fruits or vegetables, purees of the edible portions of one or more fruits or vegetables, or any concentrate of such liquid or puree.

(2) The label of:

(i) Any juice that has not been processed in the manner described in paragraph (g) (7) of this section; or

(ii) Any beverage containing juice where neither the juice ingredient nor the beverage has been processed in the manner described in paragraph (g) (7) of this section, shall bear the following warning statement:

WARNING: This product has not been pasteurized and, therefore, may contain harmful bacteria that can cause serious illness in children, the elderly, and persons with weakened immune systems.

(3) The warning statement required by this paragraph (g) shall not apply to juice that is not for distribution to retail consumers in the form shipped and that is for use solely in the manufacture of other foods or that is to be processed, labeled, or repacked at a site other than originally processed, provided that for juice that has not been processed in the manner described in paragraph (g) (7) of this section, the lack of such processing is disclosed in documents accompanying the juice, in accordance with the practice of the trade.

FDA HAZARD ANALYSIS AND CRITICAL CONTROL POINT (HACCP) SYSTEMS: 21 CFR 120

Subpart A—General Provisions

Sec.

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Subpart A—General Provisions

Sec. 120.1 Applicability

(a) Any juice sold as such or used as an ingredient in beverages shall be processed in accordance with the requirements of this part. Juice means the aqueous liquid expressed or extracted from one or more fruits or vegetables, purees of the edible portions of one or more fruits or vegetables, or any concentrates of such liquid or puree. The requirements of this part shall apply to any juice regardless of whether the juice, or any of its ingredients, is or has been shipped in interstate commerce (as defined in section 201(b) of the Federal Food, Drug, and Cosmetic Act, 21 U.S.C. 321(b)). Raw agricultural ingredients of juice are not subject to the requirements of this part. Processors should apply existing agency guidance to minimize microbial food safety hazards for fresh fruits and vegetables in handling raw agricultural products.

(b) The regulations in this part shall be effective January 22, 2002. However, by its terms, this part is not binding on small and very small businesses until the dates listed in paragraphs (b) (1) and (b) (2) of this section.

(1) For small businesses employing fewer than 500 persons the regulations in this part are binding on January 21, 2003.

(2) For very small businesses that have either total annual sales of less than $500,000, or if their total annual sales are greater than $500,000 but their total food sales are less than $50,000; or the person claiming this exemption employed fewer than an average of 100 full-time equivalent employees and fewer than 100,000 units of juice were sold in the United States, the regulations are binding on January 20, 2004.

Sec. 120.3 Definitions

The definitions of terms in section 201 of the Federal Food, Drug, and Cosmetic Act, Sec. 101.9(j) (18) (vi), and part 110 of this chapter are applicable to such terms when used in this part, except where redefined in this part. The following definitions shall also apply:

(a) Cleaned means washed with water of adequate sanitary quality.
(b) Control means to prevent, eliminate, or reduce.
(c) Control measure means any action or activity to prevent, reduce to acceptable levels, or eliminate a hazard.

(d) Critical control point means a point, step, or procedure in a food process at which a control measure can be applied and at which control is essential to reduce an identified food hazard to an acceptable level.

(e) Critical limit means the maximum or minimum value to which a physical, biological, or chemical parameter must be controlled at a critical control point to prevent, eliminate, or reduce to an acceptable level the occurrence of the identified food hazard.

(f) Culled means separation of damaged fruit from undamaged fruit. For processors of citrus juices using treatments to fruit surfaces to comply with Sec. 120.24, culled means undamaged, tree-picked fruit that is U.S. Department of Agriculture choice or higher quality.

(g) Food hazard means any biological, chemical, or physical agent that is reasonably likely to cause illness or injury in the absence of its control.

(h) Importer means either the U.S. owner or consignee at the time of entry of a food product into the United States, or the U.S. agent or representative of the foreign owner or consignee at the time of entry into the United States. The importer is responsible for ensuring that goods being offered for entry into the United States are in compliance with all applicable laws. For the purposes of this definition, the importer is ordinarily not the custom house broker, the freight forwarder, the carrier, or the steamship representative.

(i) Monitor means to conduct a planned sequence of observations or measurements to assess whether a process, point, or procedure is under control and to produce an accurate record for use in verification.

(j) (1) Processing means activities that are directly related to the production of juice products.

(2) For purposes of this part, processing does not include:

(i) Harvesting, picking, or transporting raw agricultural ingredients of juice products, without otherwise engaging in processing; and

(ii) The operation of a retail establishment.

(k) Processor means any person engaged in commercial, custom, or institutional processing of juice products, either in the United States or in a foreign country, including any person engaged in the processing of juice products that are intended for use in market or consumer tests.

(l) Retail establishment is an operation that provides juice directly to the consumers and does not include an establishment that sells or distributes juice to other business entities as well as directly to consumers. “Provides” includes storing, preparing, packaging, serving, and vending.

(m) Shall is used to state mandatory requirements.

(n) Shelf-stable product means a product that is hermetically sealed and, when stored at room temperature, should not demonstrate any microbial growth.

(o) Should is used to state recommended or advisory procedures or to identify recommended equipment.

(p) Validation means that element of verification focused on collecting and evaluating scientific and technical information to determine whether the HACCP plan, when properly implemented, will effectively control the identified food hazards.

(q) Verification means those activities, other than monitoring, that establish the validity of the HACCP plan and that the system is operating according to the plan.

Sec. 120.5 Current Good Manufacturing Practice

Part 110 of this chapter applies in determining whether the facilities, methods, practices, and controls used to process juice are safe, and whether the food has been processed under sanitary conditions.

Sec. 120.6 Sanitation Standard Operating Procedures

(a) Sanitation controls. Each processor shall have and implement a sanitation standard operating procedure (SSOP) that addresses sanitation conditions and practices before, during, and after processing. The SSOP shall address:
  (1) Safety of the water that comes into contact with food or food contact surfaces or that is used in the manufacture of ice;
  (2) Condition and cleanliness of food contact surfaces, including utensils, gloves, and outer garments;
  (3) Prevention of cross contamination from insanitary objects to food, food packaging material, and other food contact surfaces, including utensils, gloves, and outer garments, and from raw product to processed product;
  (4) Maintenance of hand washing, hand sanitizing, and toilet facilities;
  (5) Protection of food, food packaging material, and food contact surfaces from adulteration with lubricants, fuel, pesticides, cleaning compounds, sanitizing agents, condensate, and other chemical, physical, and biological contaminants;
  (6) Proper labeling, storage, and use of toxic compounds;
  (7) Control of employee health conditions that could result in the microbiological contamination of food, food packaging materials, and food contact surfaces; and
  (8) Exclusion of pests from the food plant.

(b) Monitoring. The processor shall monitor the conditions and practices during processing with sufficient frequency to ensure, at a minimum, conformance with those conditions and practices specified in part 110 of this chapter that are appropriate both to the plant and to the food being processed. Each processor shall correct, in a timely manner, those conditions and practices that are not met.

(c) Records. Each processor shall maintain SSOP records that, at a minimum, document the monitoring and corrections prescribed by paragraph (b) of this section. These records are subject to the recordkeeping requirements of Sec. 120.12.

(d) Relationship to Hazard Analysis and Critical Control Point (HACCP) plan. Sanitation standard operating procedure controls may be included in the HACCP plan required under Sec. 120.8(b). However, to the extent that they are implemented in accordance with this section, they need not be included in the HACCP plan.

Sec. 120.7 Hazard Analysis

(a) Each processor shall develop, or have developed for it, a written hazard analysis to determine whether there are food hazards that are reasonably likely to occur for each type of juice processed by that processor and to identify control measures that the processor can apply to control those hazards. The written hazard analysis shall consist of at least the following:
  (1) Identification of food hazards;
  (2) An evaluation of each food hazard identified to determine if the hazard is reasonably likely to occur and thus constitutes a food hazard that must be

addressed in the HACCP plan. A food hazard that is reasonably likely to occur is one for which a prudent processor would establish controls because experience, illness data, scientific reports, or other information provide a basis to conclude that there is a reasonable possibility that, in the absence of those controls, the food hazard will occur in the particular type of product being processed. This evaluation shall include an assessment of the severity of the illness or injury if the food hazard occurs;

(3) Identification of the control measures that the processor can apply to control the food hazards identified as reasonably likely to occur in paragraph (a) (2) of this section;

(4) Review of the current process to determine whether modifications are necessary; and

(5) Identification of critical control points.

(b) The hazard analysis shall include food hazards that can be introduced both within and outside the processing plant environment, including food hazards that can occur before, during, and after harvest. The hazard analysis shall be developed by an individual or individuals who have been trained in accordance with Sec. 120.13 and shall be subject to the recordkeeping requirements of Sec. 120.12.

(c) In evaluating what food hazards are reasonably likely to occur, consideration should be given, at a minimum, to the following:

(1) Microbiological contamination;

(2) Parasites;

(3) Chemical contamination;

(4) Unlawful pesticides residues;

(5) Decomposition in food where a food hazard has been associated with decomposition;

(6) Natural toxins;

(7) Unapproved use of food or color additives;

(8) Presence of undeclared ingredients that may be allergens; and

(9) Physical hazards.

(d) Processors should evaluate product ingredients, processing procedures, packaging, storage, and intended use; facility and equipment function and design; and plant sanitation, including employee hygiene, to determine the potential effect of each on the safety of the finished food for the intended consumer.

(e) HACCP plans for juice need not address the food hazards associated with microorganisms and microbial toxins that are controlled by the requirements of part 113 or part 114 of this chapter. A HACCP plan for such juice shall address any other food hazards that are reasonably likely to occur.

Sec. 120.8 Hazard Analysis and Critical Control Point (HACCP) Plan

(a) HACCP plan. Each processor shall have and implement a written HACCP plan whenever a hazard analysis reveals one or more food hazards that are reasonably likely to occur during processing, as described in Sec. 120.7. The HACCP plan shall be developed by an individual or individuals who have been trained in accordance with Sec. 120.13 and shall be subject to the recordkeeping requirements of Sec. 120.12. A HACCP plan shall be specific to:

(1) Each location where juice is processed by that processor; and

(2) Each type of juice processed by the processor. The plan may group types of juice products together, or group types of production methods together, if the food hazards, critical control points, critical limits, and procedures required to be identified and performed by paragraph (b) of this section are essentially identical, provided that any required features of the plan that are unique to a specific product or method are clearly delineated in the plan and are observed in practice.

(b) The contents of the HACCP plan. The HACCP plan shall, at a minimum:

(1) List all food hazards that are reasonably likely to occur as identified in accordance with Sec. 120.7, and that thus must be controlled for each type of product;

(2) List the critical control points for each of the identified food hazards that is reasonably likely to occur, including as appropriate:

(i) Critical control points designed to control food hazards that are reasonably likely to occur and could be introduced inside the processing plant environment; and

(ii) Critical control points designed to control food hazards introduced outside the processing plant environment, including food hazards that occur before, during, and after harvest;

(3) List the critical limits that shall be met at each of the critical control points;

(4) List the procedures, and the frequency with which they are to be performed, that will be used to monitor each of the critical control points to ensure compliance with the critical limits;

(5) Include any corrective action plans that have been developed in accordance with Sec. 120.10(a), and that are to be followed in response to deviations from critical limits at critical control points;

(6) List the validation and verification procedures, and the frequency with which they are to be performed, that the processor will use in accordance with Sec. 120.11; and

(7) Provide for a recordkeeping system that documents the monitoring of the critical control points in accordance with Sec. 120.12. The records shall contain the actual values and observations obtained during monitoring.

(c) Sanitation. Sanitation controls may be included in the HACCP plan. However, to the extent that they are monitored in accordance with Sec. 120.6, they are not required to be included in the HACCP plan.

Sec. 120.9 Legal Basis

Failure of a processor to have and to implement a Hazard Analysis and Critical Control Point (HACCP) system that complies with Secs. 120.6, 120.7, and 120.8, or otherwise to operate in accordance with the requirements of this part, shall render the juice products of that processor adulterated under section 402(a) (4) of the Federal Food, Drug, and Cosmetic Act. Whether a processor's actions are consistent with ensuring the safety of juice will be determined through an evaluation of the processor's overall implementation of its HACCP system.

Sec. 120.10 Corrective Actions

Whenever a deviation from a critical limit occurs, a processor shall take corrective action by following the procedures set forth in paragraph (a) or paragraph (b) of this section.

(a) Processors may develop written corrective action plans, which become part of their HACCP plans in accordance with Sec. 120.8(b) (5), by which processors predetermine the corrective actions that they will take whenever there is a deviation from a critical limit. A corrective action plan that is appropriate for a particular deviation is one that describes the steps to be taken and assigns responsibility for taking those steps, to ensure that:
  (1) No product enters commerce that is either injurious to health or is otherwise adulterated as a result of the deviation; and
  (2) The cause of the deviation is corrected.

(b) When a deviation from a critical limit occurs, and the processor does not have a corrective action plan that is appropriate for that deviation, the processor shall:
  (1) Segregate and hold the affected product, at least until the requirements of paragraphs (b) (2) and (b) (3) of this section are met;
  (2) Perform or obtain a review to determine the acceptability of the affected product for distribution. The review shall be performed by an individual or individuals who have adequate training or experience to perform such review;
  (3) Take corrective action, when necessary, with respect to the affected product to ensure that no product enters commerce that is either injurious to health or is otherwise adulterated as a result of the deviation;
  (4) Take corrective action, when necessary, to correct the cause of the deviation; and
  (5) Perform or obtain timely verification in accordance with Sec. 120.11, by an individual or individuals who have been trained in accordance with Sec. 120.13, to determine whether modification of the HACCP plan is required to reduce the risk of recurrence of the deviation, and to modify the HACCP plan as necessary.

(c) All corrective actions taken in accordance with this section shall be fully documented in records that are subject to verification in accordance with Sec. 120.11(a) (1) (iv) (B) and the recordkeeping requirements of Sec. 120.12.

Sec. 120.11 Verification and Validation

(a) Verification. Each processor shall verify that the Hazard Analysis and Critical Control Point (HACCP) system is being implemented according to design.
  (1) Verification activities shall include:
    (i) A review of any consumer complaints that have been received by the processor to determine whether such complaints relate to the performance of the HACCP plan or reveal previously unidentified critical control points;
    (ii) The calibration of process monitoring instruments;
    (iii) At the option of the processor, the performance of periodic end-product or in-process testing; except that processors of citrus juice that rely in whole or in part on surface treatment of fruit shall perform end-product testing in accordance with Sec. 120.25.
    (iv) A review, including signing and dating, by an individual who has been trained in accordance with Sec. 120.13, of the records that document:
      (A) The monitoring of critical control points. The purpose of this review shall be, at a minimum, to ensure that the records are complete and to verify that the records document values that are within the critical limits. This review shall occur within 1 week (7 days) of the day that the records are made;

(B) The taking of corrective actions. The purpose of this review shall be, at a minimum, to ensure that the records are complete and to verify that appropriate corrective actions were taken in accordance with Sec. 120.10. This review shall occur within 1 week (7 days) of the day that the records are made; and

(C) The calibrating of any process monitoring instruments used at critical control points and the performance of any periodic end-product or in-process testing that is part of the processor's verification activities. The purpose of these reviews shall be, at a minimum, to ensure that the records are complete and that these activities occurred in accordance with the processor's written procedures. These reviews shall occur within a reasonable time after the records are made; and

(v) The following of procedures in Sec. 120.10 whenever any verification procedure, including the review of consumer complaints, establishes the need to take a corrective action; and

(vi) Additional process verification if required by Sec. 120.25.

(2) Records that document the calibration of process monitoring instruments, in accordance with paragraph (a) (1) (iv) (B) of this section, and the performance of any periodic end-product and in-process testing, in accordance with paragraph (a) (1) (iv) (C) of this section, are subject to the recordkeeping requirements of Sec. 120.12.

(b) Validation of the HACCP plan. Each processor shall validate that the HACCP plan is adequate to control food hazards that are reasonably likely to occur; this validation shall occur at least once within 12 months after implementation and at least annually thereafter or whenever any changes in the process occur that could affect the hazard analysis or alter the HACCP plan in any way. Such changes may include changes in the following: Raw materials or source of raw materials; product formulation; processing methods or systems, including computers and their software; packaging; finished product distribution systems; or the intended use or consumers of the finished product. The validation shall be performed by an individual or individuals who have been trained in accordance with Sec. 120.13 and shall be subject to the recordkeeping requirements of Sec. 120.12. The HACCP plan shall be modified immediately whenever a validation reveals that the plan is no longer adequate to fully meet the requirements of this part.

(c) Validation of the hazard analysis. Whenever a juice processor has no HACCP plan because a hazard analysis has revealed no food hazards that are reasonably likely to occur, the processor shall reassess the adequacy of that hazard analysis whenever there are any changes in the process that could reasonably affect whether a food hazard exists. Such changes may include changes in the following: Raw materials or source of raw materials; product formulation; processing methods or systems, including computers and their software; packaging; finished product distribution systems; or the intended use or intended consumers of the finished product. The validation of the hazard analysis shall be performed by an individual or individuals who have been trained in accordance with Sec. 120.13, and, records documenting the validation shall be subject to the recordkeeping requirements of Sec. 120.12.

Sec. 120.12 Records

(a) Required records. Each processor shall maintain the following records documenting the processor's Hazard Analysis and Critical Control Point (HACCP) system:
  (1) Records documenting the implementation of the sanitation standard operating procedures (SSOP's) (see Sec. 120.6);
  (2) The written hazard analysis required by Sec. 120.7;
  (3) The written HACCP plan required by Sec. 120.8;
  (4) Records documenting the ongoing application of the HACCP plan that include:
    (i) Monitoring of critical control points and their critical limits, including the recording of actual times, temperatures, or other measurements, as prescribed in the HACCP plan; and
    (ii) Corrective actions, including all actions taken in response to a deviation; and
  (5) Records documenting verification of the HACCP system and validation of the HACCP plan or hazard analysis, as appropriate.

(b) General requirements. All records required by this part shall include:
  (1) The name of the processor or importer and the location of the processor or importer, if the processor or importer has more than one location;
  (2) The date and time of the activity that the record reflects, except that records required by paragraphs (a) (2), (a) (3), and (a) (5) of this section need not include the time;
  (3) The signature or initials of the person performing the operation or creating the record; and
  (4) Where appropriate, the identity of the product and the production code, if any. Processing and other information shall be entered on records at the time that it is observed. The records shall contain the actual values and observations obtained during monitoring.

(c) Documentation.
  (1) The records in paragraphs (a) (2) and (a) (3) of this section shall be signed and dated by the most responsible individual onsite at the processing facility or by a higher level official of the processor. These signatures shall signify that these records have been accepted by the firm.
  (2) The records in paragraphs (a) (2) and (a) (3) of this section shall be signed and dated:
    (i) Upon initial acceptance;
    (ii) Upon any modification; and
    (iii) Upon verification and validation in accordance with Sec. 120.11.

(d) Record retention.
  (1) All records required by this part shall be retained at the processing facility or at the importer's place of business in the United States for, in the case of perishable or refrigerated juices, at least 1 year after the date that such products were prepared, and for, in the case of frozen, preserved, or shelf stable products, 2 years or the shelf life of the product, whichever is greater, after the date that the products were prepared.
  (2) Offsite storage of processing records required by paragraphs (a) (1) and (a) (4) of this section is permitted after 6 months following the date that the monitoring occurred, if such records can be retrieved and provided onsite within 24 hours of

request for official review. Electronic records are considered to be onsite if they are accessible from an onsite location and comply with paragraph (g) of this section.

(3) If the processing facility is closed for a prolonged period between seasonal packs, the records may be transferred to some other reasonably accessible location at the end of the seasonal pack but shall be immediately returned to the processing facility for official review upon request.

(e) Official review. All records required by this part shall be available for review and copying at reasonable times.

(f) Public disclosure.

(1) All records required by this part are not available for public disclosure unless they have been previously disclosed to the public, as defined in Sec. 20.81 of this chapter, or unless they relate to a product or ingredient that has been abandoned and no longer represents a trade secret or confidential commercial or financial information as defined in Sec. 20.61 of this chapter.

(2) Records required to be maintained by this part are subject to disclosure to the extent that they are otherwise publicly available, or that disclosure could not reasonably be expected to cause a competitive hardship, such as generic type HACCP plans that reflect standard industry practices.

(g) Records maintained on computers. The maintenance of computerized records, in accordance with part 11 of this chapter, is acceptable. Sec. 120.13 Training.

(a) Only an individual who has met the requirements of paragraph (b) of this section shall be responsible for the following functions:

(1) Developing the hazard analysis, including delineating control measures, as required by Sec. 120.7.

(2) Developing a Hazard Analysis and Critical Control Point (HACCP) plan that is appropriate for a specific processor, in order to meet the requirements of Sec. 120.8;

(3) Verifying and modifying the HACCP plan in accordance with the corrective action procedures specified in Sec. 120.10(b) (5) and the validation activities specified in Sec. 120.11(b) and (c); and Sec. 120.7;

(4) Performing the record review required by Sec. 120.11(a) (1) (iv).

(b) The individual performing the functions listed in paragraph (a) of this section shall have successfully completed training in the application of HACCP principles to juice processing at least equivalent to that received under standardized curriculum recognized as adequate by the Food and Drug Administration, or shall be otherwise qualified through job experience to perform these functions. Job experience may qualify an individual to perform these functions if such experience has provided knowledge at least equivalent to that provided through the standardized curriculum. The trained individual need not be an employee of the processor.

Sec. 120.14 Application of Requirements to Imported Products

This section sets forth specific requirements for imported juice.

(a) Importer requirements. Every importer of juice shall either:

(1) Obtain the juice from a country that has an active memorandum of understanding (MOU) or similar agreement with the Food and Drug Administration, that covers the food and documents the equivalency or compliance of the inspection system of the foreign country with the U.S. system, accurately reflects the relationship between the signing parties, and is functioning and enforceable in its entirety; or

(2) Have and implement written procedures for ensuring that the juice that such importer receives for import into the United States was processed in accordance with the requirements of this part. The procedures shall provide, at a minimum:

(i) Product specifications that are designed to ensure that the juice is not adulterated under section 402 of the Federal Food, Drug, and Cosmetic Act because it may be injurious to health or because it may have been processed under insanitary conditions; and

(ii) Affirmative steps to ensure that the products being offered for entry were processed under controls that meet the requirements of this part. These steps may include any of the following:

(A) Obtaining from the foreign processor the Hazard Analysis and Critical Control Point (HACCP) plan and prerequisite program of the standard operating procedure records required by this part that relate to the specific lot of food being offered for import;

(B) Obtaining either a continuing or lot specific certificate from an appropriate foreign government inspection authority or competent third party certifying that the imported food has been processed in accordance with the requirements of this part;

(C) Regularly inspecting the foreign processor's facilities to ensure that the imported food is being processed in accordance with the requirements of this part;

(D) Maintaining on file a copy, in English, of the foreign processor's hazard analysis and HACCP plan, and a written guarantee from the foreign processor that the imported food is processed in accordance with the requirements of this part;

(E) Periodically testing the imported food, and maintaining on file a copy, in English, of a written guarantee from the foreign processor that the imported food is processed in accordance with the requirements of this part; or

(F) Other such verification measures as appropriate that provide an equivalent level of assurance of compliance with the requirements of this part.

(b) Competent third party. An importer may hire a competent third party to assist with or perform any or all of the verification activities specified in paragraph (a) (2) of this section, including writing the importer's verification procedures on the importer's behalf.

(c) Records. The importer shall maintain records, in English, that document the performance and results of the affirmative steps specified in paragraph (a) (2) (ii) of this section. These records shall be subject to the applicable provisions of Sec. 120.12.

(d) Determination of compliance. The importer shall provide evidence that all juice offered for entry into the United States has been processed under conditions that comply with this part. If assurances do not exist that an imported juice has been

processed under conditions that are equivalent to those required of domestic processors under this part, the product will appear to be adulterated and will be denied entry.

SUBPART B—PATHOGEN REDUCTION

Sec. 120.20 General

This subpart augments subpart A of this part by setting forth specific requirements for process controls.

Sec. 120.24 Process Controls

(a) In order to meet the requirements of subpart A of this part, processors of juice products shall include in their Hazard Analysis and Critical Control Point (HACCP) plans control measures that will consistently produce, at a minimum, a 5-log (i.e., 10/5/) reduction, for a period at least as long as the shelf life of the product when stored under normal and moderate abuse conditions, in the pertinent microorganism. For the purposes of this regulation, the "pertinent microorganism" is the most resistant microorganism of public health significance that is likely to occur in the juice. The following juice processors are exempt from this paragraph:
   (1) A juice processor that is subject to the requirements of part 113 or part 114 of this chapter; and
   (2) A juice processor using a single thermal processing step sufficient to achieve shelf-stability of the juice or a thermal concentration process that includes thermal treatment of all ingredients, provided that the processor includes a copy of the thermal process used to achieve shelf-stability or concentration in its written hazard analysis required by Sec. 120.7.

(b) All juice processors shall meet the requirements of paragraph (a) of this section through treatments that are applied directly to the juice, except that citrus juice processors may use treatments to fruit surfaces, provided that the 5-log reduction process begins after culling and cleaning as defined in Sec. 120.3(a) and (f) and the reduction is accomplished within a single production facility.

(c) All juice processors shall meet the requirements of paragraphs (a) and (b) of this section and perform final product packaging within a single production facility operating under current good manufacturing practices. Processors claiming an exemption under paragraph (a) (1) or (a) (2) of this section shall also process and perform final product packaging of all juice subject to the claimed exemption within a single production facility operating under current good manufacturing practices.

Sec. 120.25 Process Verification for Certain Processors

Each juice processor that relies on treatments that do not come into direct contact with all parts of the juice to achieve the requirements of Sec. 120.24 shall analyze the finished product for biotype I *Escherichia coli* as follows:

(a) One 20 milliliter (mL) sample (consisting of two 10 mL subsamples) for each 1,000 gallons of juice produced shall be sampled each production day. If less than 1,000 gallons of juice is produced per day, the sample must be taken for each 1,000 gallons produced but not less than once every 5 working days that the facility is producing that juice. Each subsample shall be taken by randomly selecting a package of juice ready for distribution to consumers.

(b) If the facility is producing more than one type of juice covered by this section, processors shall take subsamples according to paragraph (a) of this section for each of the covered juice products produced.

(c) Processors shall analyze each subsample for the presence of *E. coli* by the method entitled "Analysis for *Escherichia coli* in Citrus Juices—Modification of AOAC Official Method 992.30" or another method that is at least equivalent to this method in terms of accuracy, precision, and sensitivity in detecting *E. coli*. This method is designed to detect the presence or absence of *E. coli* in a 20 mL sample of juice (consisting of two 10 mL subsamples). The method is as follows:

(1) Sample size. Total—20 mL of juice; perform analysis using two 10 mL aliquots.

(2) Media. Universal Preenrichment Broth (Difco, Detroit, MI), EC Broth (various manufacturers).

(3) Method. ColiComplete (AOAC Official Method 992.30—modified).

(4) Procedure. Perform the following procedure two times:

(i) Aseptically inoculate 10 mL of juice into 90 mL of Universal Preenrichment Broth (Difco) and incubate at 35 deg C for 18 to 24 hours.

(ii) Next day, transfer 1 mL of preenriched sample into 10 mL of EC Broth, without durham gas vials. After inoculation, aseptically add a ColiComplete SSD disc into each tube.

(iii) Incubate at 44.5 deg C for 18 to 24 hours.

(iv) Examine the tubes under longwave ultraviolet light (366 nm). Fluorescent tubes indicate presence of *E. coli.*

(v) MUG positive and negative controls should be used as reference in interpreting fluorescence reactions. Use an *E. coli* for positive control and 2 negative controls—a MUG negative strain and an uninoculated tube media.

(d) If either 10 mL subsample is positive for *E. coli*, the 20 mL sample is recorded as positive and the processor shall:

(1) Review monitoring records for the control measures to attain the 5-log reduction standard and correct those conditions and practices that are not met. In addition, the processor may choose to test the sample for the presence of pathogens of concern.

(2) If the review of monitoring records or the additional testing indicates that the 5-log reduction standard was not achieved (e.g., a sample is found to be positive for the presence of a pathogen or a deviation in the process or its delivery is identified), the processor shall take corrective action as set forth in Sec. 120.10.

(e) If two samples in a series of seven tests are positive for *E. coli*, the control measures to attain the 5-log reduction standard shall be deemed to be inadequate and the processor shall immediately:

(1) Until corrective actions are completed, use an alternative process or processes that achieve the 5-log reduction after the juice has been expressed;

(2) Perform a review of the monitoring records for control measures to attain the 5-log reduction standard. The review shall be sufficiently extensive to determine that there are no trends toward loss of control;
   (i) If the conditions and practices are not being met, correct those that do not conform to the HACCP plan; or
   (ii) If the conditions and practices are being met, the processor shall validate the HACCP plan in relation to the 5-log reduction standard; and

(3) Take corrective action as set forth in Sec. 120.10. Corrective actions shall include ensuring no product enters commerce that is injurious to health as set forth in Sec. 120.10(a) (1).

FDA STANDARD FOR VEGETABLE JUICES: 21 CFR 156. DEFINITIONS: 21 CFR 156.3

For the purpose of this part:

(a) Strength and redness of color means at least as much red as obtained by comparison of the prepared product, with the blended color produced by spinning a combination of the following concentric Munsell color discs of equal diameter, or the color equivalent of such discs:
Disc 1—Red (5R 2.6/13) (glossy finish)
Disc 2—Yellow (2.5 YR 5/12) (glossy finish)
Disc 3—Black (N1) (glossy finish)
Disc 4—Grey (N4) (mat finish)

Such comparison is to be made in full diffused daylight or under a diffused light source of approximately 2,691 lux (250 footcandles) and having a spectral quality approximating that of daylight under a moderately overcast sky, with a correlated color temperature of 7,500 degrees Kelvin ⟨plus-minus⟩ 200 degrees. With the light source directly over the disc and product, observation is made at an angle of 45 degrees from a distance of about 24 inches from the product. Electronic color meters may be used as an alternate means of determining the color of tomato juice. Such meters shall be calibrated to indicate that the color of the product is as red or more red than that produced by spinning the Munsell color discs in the combination as set out above.

(b) Tomato soluble solids means the sucrose value as determined by the method prescribed in "Official Methods of Analysis of the Association of Official Analytical Chemists," 13th ed., 1980, sections 32.014 to 32.016 and 52.012, under the headings "Soluble Solids in Tomato Products Official Final Action" and "Refractive Indices (n) of Sucrose Solutions at 20 deg.," which is incorporated by reference. Copies are available from the Association of Official Analytical Chemists International, 481 North Frederick Ave., Suite 500, Gaithersburg, MD 20877-2504, or available for inspection at the Office of the Federal Register, 800 North Capitol Street, NW, Suite 700, Washington, DC. If no salt has been added, the sucrose value obtained from the referenced tables shall be considered the percent of tomato soluble solids. If salt has been added, either intentionally or through the application of the acidified break, determine the percent of such added sodium chloride as specified in paragraph (c) of this section. Subtract the percentage so found from the percentage of tomato soluble

solids found (sucrose value from the refractive index tables) and multiply the difference by 1.016. The resultant value is considered the percent of "tomato soluble solids."

(c) Salt means sodium chloride, determined as chloride and calculated as percent sodium chloride, by the method prescribed in "Official Methods of Analysis of the Association of Official Analytical Chemists," 13th ed., 1980, sections 32.025 to 32.030, under the heading "Method III (Potentiometric Method)," which is incorporated by reference.

(d) Compliance means the following: Unless otherwise provided in a standard, a lot of canned vegetable juice shall be deemed in compliance for the following factors, to be determined by the sampling and acceptance procedure as provided in paragraph (e) of this section, namely:

(1) Quality. The quality of a lot shall be considered acceptable when the number of defectives does not exceed the acceptance number (*c*) in the sampling plans.

(2) Fill of container. A lot shall be deemed to be in compliance for fill of container when the number of defectives does not exceed the acceptance number (*c*) in the sampling plans.

(e) Sampling and acceptance procedure means the following:

(1) Definitions

(i) Lot. A collection of primary containers or units of the same size, type, and style manufactured or packed under similar conditions and handled as a single unit of trade.

(ii) Lot size. The number of primary containers or units in the lot.

(iii) Sample size (*n*). The total number of sample units drawn for examination from a lot.

(iv) Sample unit. A container, a portion of the contents of a container, or a composite mixture of product from small containers that is sufficient for the examination or testing as a single unit. For fill of container, the sample unit shall be the entire contents of the container.

(v) Defective. Any sample unit shall be regarded as defective when the sample unit does not meet the criteria set forth in the standards.

(vi) Acceptance number (*c*). The maximum number of defective sample units permitted in the sample in order to consider the lot as meeting the specified requirements.

(vii) Acceptable quality level (AQL). The maximum percent of defective sample units permitted in a lot that will be accepted approximately 95 percent of the time.

(2) Sampling plans:

Acceptable Quality Level (AQL) 6.5

	Size of container	
Lot size (primary containers)	*n*	*c*
Net weight equal to or less than 1 kg (2.2 lb)		
4,800 or less	13	2
4,801 to 24,000	21	3
24,001 to 48,000	29	4
48,001 to 84,000	48	6

(*continued*)

Continued

Lot size (primary containers)	Size of container	
	n	*c*
84,001 to 144,000	84	9
144,001 to 240,000	126	13
Over 240,000	200	19
Net weight greater than 1 kg (2.2 lb) but not more than 4.5 kg (10 lb)		
2,400 or less	13	2
2,401 to 15,000	21	3
15,001 to 24,000	29	4
24,001 to 42,000	48	6
42,001 to 72,000	84	9
72,001 to 120,000	126	13
Over 120,000	200	19
Net weight greater than 4.5 kg (10 lb)		
600 or less	13	2
601 to 2,000	21	3
2,001 to 7,200	29	4
7,201 to 15,000	48	6
15,001 to 24,000	84	9
24,001 to 42,000	126	13
Over 42,000	200	19

n = number of primary containers in sample.
c = acceptance number.

FDA STANDARD FOR VEGETABLE JUICES: 21 CFR 156. TOMATO JUICE: 21 CFR 156.145

(a) Identity

(1) Definition. Tomato juice is the food intended for direct consumption, obtained from the unfermented liquid extracted from mature tomatoes of the red or reddish varieties of *Lycopersicum esculentum* P. Mill, with or without scalding followed by draining. In the extraction of such liquid, heat may be applied by any method which does not add water thereto. Such juice is strained free from peel, seeds, and other coarse or hard substances, but contains finely divided insoluble solids from the flesh of the tomato in accordance with current good manufacturing practice. Such juice may be homogenized, may be seasoned with salt, and may be acidified with any safe and suitable organic acid. The juice may have been concentrated and later reconstituted with water and/or tomato juice to a tomato soluble solids content of not less than 5.0 percent by weight as determined by the method prescribed in Sec. 156.3(b). The food is preserved by heat sterilization (canning), refrigeration, or freezing. When sealed in a container to be held at ambient temperatures, it is so processed by heat, before or after sealing, as to prevent spoilage.

(2) Labeling.

(i) The name of the food is:

(a) "Tomato juice" if it is prepared from unconcentrated undiluted liquid extracted from mature tomatoes of reddish varieties.

(b) "Tomato juice from concentrate" if the finished juice has been prepared from concentrated tomato juice as specified in paragraph (a) (1) of this section or if the finished juice is a mixture of tomato juice and tomato juice from concentrate.

(ii) Label declaration. Each of the ingredients used in the food shall be declared on the label as required by the applicable sections of parts 101 and 130 of this chapter.

(b) Quality.

(1) The standard of quality for tomato juice is as follows:

(i) The strength and redness of color is not less than the composite color produced by spinning the Munsell color discs in the following combination: 53 percent of the area of Disc 1; 28 percent of the area of Disc 2; and 19 percent of the area of either Disc 3 or Disc 4; or 91/2 percent of the area of Disc 3 and 91/2 percent of the area of Disc 4, whichever most nearly matches the appearance of the tomato juice.

(ii) Not more than two defects for peel and blemishes, either singly or in combination, in addition to three defects for seeds or pieces of seeds, defined as follows, per 500 milliliters (16.9 fluid ounces):

(a) Pieces of peel 3.2 millimeters (0.125 inch) or greater in length.

(b) Blemishes such as dark brown or black particles (specks) greater than 1.6 millimeters (0.0625 inch) in length.

(c) Seeds or pieces of seeds 3.2 millimeters (0.125 inch) or greater in length.

(2) Methodology.

(i) Determine strength and redness of color as specified in Sec. 156.3(a).

(ii) Examine a total of 500 milliliters for peel, blemishes, and seeds. Divide the 500-milliliter sample into two 250-milliliter aliquots and pour each aliquot onto separate 30.5 × 45.7 centimeters (12 × 18 inches) white grading trays. Remove defects and evaluate for color and size as defined in paragraph (b) (1) (ii) of this section.

(3) Determine compliance as specified in Sec. 156.3(d).

(4) If the quality of the tomato juice falls below the standard prescribed in paragraph (b) (1) and (3) of this section, the label shall bear the general statement of substandard quality specified in Sec. 130.14(a) of this chapter, in the manner and form therein specified, but in lieu of such general statement of substandard quality when the quality of the tomato juice falls below the standard in one or more respects, the label may bear the alternative statement, "Below Standard in Quality—," the blank to be filled in with the words specified after the corresponding paragraph (s) under paragraph (b) (1) of this section which such tomato juice fails to meet, as follows:

(i) "Poor color."

(ii) (a) "Excessive pieces of peel."

(b) "Excessive blemishes."

(c) "Excessive seeds" or "excessive pieces of seed."

(c) Fill of container.

(1) The standard of fill of container for tomato juice, as determined by the general method for fill of container prescribed in Sec. 130.12(b) of this chapter, is not less than 90 percent of the total capacity, except when the food is frozen.
(2) Determine compliance as specified in Sec. 156.3(d).
(3) If the tomato juice falls below the standard of fill prescribed in paragraph (c) (1) and (2) of this section, the label shall bear the general statement of substandard fill specified in Sec. 130.14(b) of this chapter, in the manner and form therein prescribed.

APPENDIX J

Vegetables, Vegetable Products, and Disease Outbreaks

The information in this appendix has been adapted from "Analysis and Evaluation of Preventive Control Measures for the Control and Reduction/Elimination of Microbial Hazards on Fresh and Fresh-Cut Produce," FDA, September 30, 2001. All references have been removed. Please consult original document for details.

Table J-1 Examples of Reported Outbreaks of Foodborne Disease Associated with Raw Lettuce or Salads

Pathogen	Year	Location	Produce source	Venue	Type of lettuce or salad	No. of cases	No. of deaths	Isolated from produce	Comments
Campylobacter jejuni	1984	British Columbia, Canada	NR[a]	University cafeteria	Salad	330	0	No	Possible cross contamination during food preparation and poor food storage practices. Salad appeared to initiate outbreak.
C. jejuni	1996	Oklahoma	NR	Restaurant	Lettuce	14	0	NR	Probable cross contamination of lettuce with raw chicken juices.
Clostridium perfringens	1993	Ontario, Canada	Unknown	Wedding reception	Salad	48	0	No	Salad implicated but epidemiology weak.
Cyclospora cayatenesis	1997	Florida	Possibly Peru	Restaurant, cruise ship	Baby lettuce leaves (mesclun)	>91	0	NR	Possibly related outbreaks traced to cruise ship sailing out of Florida and several Florida restaurants. Lettuce originated from Peru and US, purchased from the same distributor.
Calicivirus	1992	Ontario, Canada	NR	Catered event	Salad	27	0	NR	Salad served at a potluck. Vegetables may have been improperly washed or cross contaminated by an infected food handler.

Escherichia coli O157:H7	1995	Idaho	Unknown	Unknown	Lettuce (romaine)	21	0	NR	Possibly infected food handler.
E. coli O157:H7	1995	Maine	California	Scout camp	Lettuce (iceberg)	30	0	NR	Cross contamination with raw hamburger juice.
E. coli O157:H7	1995	Ontario, Canada	NR	Acute care hospital	Iceberg lettuce	23	0	NR	Outbreak occurred in an acute care hospital. Lettuce received was heavily spoiled.
E. coli O157:H7	1995	Alberta, Canada	NR	Restaurant	Caesar salad	37	0	NR	—
E. coli O157:H7	1995	Montana	Montana and Washington	Retail	Lettuce	70	0	No	Possible contamination from irrigation runoff or compost used to fertilize the fields. Cattle had access to the stream above the pond used for irrigation.
E. coli O157:H7	1996	Connecticut and Illinois	US	Various	Mesclun lettuce	49	0	Yes	The implicated lettuce was traced to a single grower processor. Cattle were found near the lettuce fields.
E. coli O157:H7	1998	California	NR	Restaurant	Salad	2	0	No	—
Giardia	1989	New Mexico	NR	Church dinner	Lettuce and onions	21	0	NR	Possible contamination from potable water used in washing the vegetables. Possible cross contamination from using the same cutting board to cut all vegetables.

(*continued*)

Table J-1 Continued

Pathogen	Year	Location	Produce source	Venue	Type of lettuce or salad	No. of cases	No. of deaths	Isolated from produce	Comments
Hepatitis A	1986	Florida	NR	Restaurant	Lettuce salad	103	0	No	The probable source for the outbreak was an infected foodhandler with poor hygiene practices. The lettuce was shredded with hands.
Hepatitis A	1988	Kentucky	US but possibly Mexico	Restaurants	Iceberg lettuce	202	0	No	Three restaurants received lettuce from the same produce distributor. Contamination suspected to have occurred before distribution.

Shigella sonnei	1983	Texas	Arizona, California, New Mexico	University cafeteria	Lettuce	140	0	No	Two concurrent outbreaks at separate universities. Both universities purchased lettuce from the same supplier. Supplier purchased lettuce from three states. Farm source could not be determined.
S. sonnei	1986	Texas	Texas	Restaurants	Shredded lettuce	347	0	No	Implicated restaurants received shredded lettuce from one source. Possible contamination from food handler at the shredding facility.
S. sonnei	1994	Norway, Sweden, and UK	Spain	Various	Lettuce (iceberg)	110 (Norway), 8 (Sweden), NR (UK)	0	No	Fecal coliforms and *Salmonella* were detected in iceberg lettuce obtained from patients' homes.
Vibrio cholerae	1970	Israel	NR	NR	Mixed vegetables	176	0	NR	Possible contamination from waste water irrigation.

[a]NR, not reported.

Table J-2 Examples of Reported Outbreaks of Foodborne Disease Associated with Raw Vegetables Other than Seed Sprouts, and Lettuce or Salads

Pathogen	Year	Location	Produce source	Venue	Type of produce	No. of cases	No. of deaths	Isolated from produce	Comments
Clostridium botulinum (type A)	1987	Florida	NR[a]	Home	Cabbage salad	4	0	Yes	Performed toxin and spores were found in coleslaw dressing which contained cabbage and carrot pieces. Possible growth of *C. botulinum* in the cabbage.
C. botulinum (type A)	1989	New York	NR	Home	Chopped garlic in oil	3	0	Yes	Product was made from chopped garlic, ice water, and olive oil sometime between 1985 and 1987. Chemical or acid additives not used. "Keep refrigerated" in small print. Jar was stored at room temperature for approximately 3 months prior to opening. Refrigerated after opening. Same processor as 1988 outbreak.

C. botulinum (type B)	1985	British Columbia, Canada	US	Restaurants	Chopped garlic in oil	37	0	Yes	The product was made from dehydrated and rehydrated and soybean oil. Chemical or acid additives not used. "Keep refrigerated" in small print. Jar was stored at room temperature at the restaurant.
Cryptosporidium parvum	1997	Washington	US	Restaurants	Green onions (inconclusive association)	54	0	No	Green onions were not washed before delivery to the restaurant and not washed before serving to customers. Possible contamination by a food handler.
Cyclospora cayatenansis	1997	Multistate, US	US	Retail/Catered events	Basil	>308	0	Yes	Suspected fresh basil. Mode of contamination unknown.
Escherichia coli (enterotoxigenic)	1993	Rhode Island, New Hampshire	US	Airline, hotel	Shredded carrots	47,121	0	NR	Possible contamination of carrots used in salads. Carrots used came from same state.
E. coli O157:H7	1998	Indianapolis	NR	Restaurant	Coleslaw	33	0	Yes	—
E. coli O157:H7	1998	Wisconsin	NR	Catered event	Fruit salad	47 (3 HUS)	0	No	—
Giardia lamblia	1989	US	NR	NR	Lettuce, tomatoes, onions	21	NR	NR	—

(*continued*)

Table J-2 Continued

Pathogen	Year	Location	Produce source	Venue	Type of produce	No. of cases	No. of deaths	Isolated from produce	Comments
Hepatitis A	1971	Tennessee	Tennessee	Home	Raw watercress	129	0	No	Watercress harvested from small streams near farm. Specimen cultures revealed gross contamination with fecal organisms. Several abandoned septic tanks were seen near the stream.
Hepatitis A	1994	Arkansas	NR	NR	Diced tomatoes	92	0	NR	Suspected contamination by food handler.
Listeria monocytogenes	1979	Boston	NR	Hospitals	Raw tomatoes, lettuce and celery suspected	20	5	NR	Multiple hospitals involved. Tuna fish, chicken salad, and cheese sandwiches epidemiologically linked to listeriosis. All served with tomatoes, raw vegetables such as celery and lettuce.
L. monocytogenes	1981	Nova Scotia, Canada	Nova Scotia, Canada	Various	Vegetable mix for coleslaw	41	17	Yes	Cabbage was grown on farm where two sheep had died of listeriosis. Raw and composed manure was used to fertilize the fields. Cold storage may have allowed for *Listeria* growth.

Norwalk virus	1982	Minnesota	NR	Hotel restaurant	Fruit salad, coleslaw, and tossed salad	233	0	NR	Outbreak traced to three separate banquets. Fruit salad and coleslaw prepared by one worker during her acute illness and up to 48 hours following her recovery. A second worker prepared implicated tossed salad 24 hours following her recovery.
Norwalk virus	1990	Hawaii	NR	Cruise ship	Fresh cut fruit	>217	0	NR	Possible contamination occurred during preparation. Fresh cut fruits included pineapple, papaya, watermelon, cantaloupe, and honeydew melon.
Salmonella Baildon	1998–1999	Multistate, US	Florida	Various	Tomatoes	85	3	NR	Tomatoes traced to two packers in Florida. Possible field contamination by domesticated of wild animals.
S. Javiana	1990	Multistate, US	South Carolina	Various	Tomatoes	174	0	NR	Contamination of water bath used by packer.
S. Montevideo	1993	Multistate, US	South Carolina	Various	Tomatoes	84	0	No	Contamination of water bath used by packer.
S. Typhi	1998–1999	US	Brazil	Unknown	Mamey	13	0	Unknown	Imported frozen mamey. Source of contamination not known.

(*continued*)

Table J-2 Continued

Pathogen	Year	Location	Produce source	Venue	Type of produce	No. of cases	No. of deaths	Isolated from produce	Comments
Shigella flexneri 6A	1994	Multistate, US	Mexico	Various	Green onions	72	0	ND	Possible contamination during harvest or packaging in Mexico.
S. sonnei	1998	Multistate, US and Canada	Mexico	Restaurants	Parsley	310	0	No	Municipal water supplied to packing shed was unchlorinated. Water was used in hydrocooler where it was recirculated. Also used to make ice for packing the parsley. Workers had limited hygiene education and sanitary facilities. In restaurants, parsley was often chopped and left at room temperature for several hours prior to serving.

Vibrio cholerae	1970	Israel	NR	NR	Various raw vegetables	176	NR	NR	Contamination by irrigation and untreated waste water.
V. cholerae	1991	Peru	Peru	Various	Cabbage	Unknown	71	NR	Several factors were associated with cholera transmission including contaminated drinking water, going to fiestas, and eating raw or lightly cooked cabbage. Farmer in region commonly used untreated sewage to irrigate crops.

[a]NR, not reported.

Table J-3 Examples of Reported Outbreaks of Food-borne Disease Associated with Raw Vegetables Due to Contamination During Final Preparation

Pathogen	Year	Location	Venue	Type of produce	No. of cases	No. of deaths	Isolated from produce	Comments
Campylobacter jejuni	1984	British Columbia, Canada	University cafeteria	Salad	330	0	No	Possible cross contamination during food preparation and poor food storage practices. The salad appeared to initiate outbreak.
C. jejuni	1996	Oklahoma	Restaurant	Lettuce	14	0	NR	Probable cross contamination of lettuce with raw chicken juices.
Crytosporidium parvum	1997	Washington	Restaurants	Green onions (inconclusive association)	54	0	No	Green onions were not washed before delivery to the restaurant and not washed before serving to customers. Possible contamination by a food handler.

Calicivirus	1992	Ontario, Canada	Catered event	Salad	27	0	NR	Salad served at a potluck. Vegetables may have been improperly washed or cross contaminated by an infected food handler.
E. coli O157:H7	1995	Idaho	Unknown	Lettuce (romaine)	21	0	NR	Possibly contaminated by food handler.
E. coli O157:H7	1995	Maine	Scout camp	Lettuce (iceberg)	30	0	NR	Cross contamination with raw hamburger juice.
Giardia	1989	New Mexico	Church dinner	Lettuce and onions	21	0	NR	Possible contamination from potable water used in washing the vegetables. Possible cross contamination from using the same cutting board to cut all vegetables.

(*continued*)

Table J-3 Continued

Pathogen	Year	Location	Venue	Type of produce	No. of cases	No. of deaths	Isolated from produce	Comments
Hepatitis A	1986	Florida	Restaurant	Lettuce salad	103	0	No	The probable source for the outbreak was an infected food handler with poor hygiene practices. Lettuce was shredded by hand.
Hepatitis A	1994	Arkansas	Unknown	Diced tomatoes	92	0	Unknown	Suspected contamination by food handler.

[a]NR, not reported.

Table J-4 Examples of Reported Outbreaks of Foodborne Disease Associated with Seed Sprouts

Pathogen	Year	Location	Seed source	Type of sprout	No. of cases	No. of deaths	Isolated from sprouts/seeds	Comments
Bacillus cereus	1973	Texas	Uganda (soy), Holland (cress), and Denmark (mustard)	Soy, mustard, and cress	4	0	Yes/yes	Sprouted from a home seed sprouting kit.
Escherichia coli O157:H7	1996	Japan	NR[a]	Radish	6561 (101 with HUS[b]), 160 secondary cases	2	No/no	Contamination route unknown.
E. coli O157:H7	1997	Japan	NR	Radish	126	0	Yes/no	The pathogen was isolated from leftover sprouts in the refrigerator but not the seeds from the same seed lots.
E. coli O157:H7	1997	Michigan and Virginia	NR	Alfalfa	108	0	NR/NR	Sprouts were sprouted from same seed lot in both states.
E. coli O157:NM	1998	California	California and Nevada	Clover/alfalfa	8	0	Yes/no	Sprouts were traced to a single sprouter. Contaminated seeds suspected (same sprouter as 1997–1998 *S.* Senftenberg outbreak).
Salmonella Bovismorbificans	1994	Sweden and Finland	Australia	Alfalfa	595	0	Yes/no	Contaminated seeds came from the same seed lot and importer.

(*continued*)

Table J-4 Continued

Pathogen	Year	Location	Seed source	Type of sprout	No. of cases	No. of deaths	Isolated from sprouts/seeds	Comments
S. Enteriditis	2000	Alberta and Saskatchewan, Canada	China	Alfalfa	8	0	NR/NR	Outbreaks occurred at 5 Vietnamese restaurants. Sprouts came from 2 growers who received seeds imported from China.
S. Enteriditis	2000	California	China	Mung	45	0	No/no	Cluster of illness linked to 3 Vietnamese restaurants. *S.* Enteriditis isolated from environment at sprouter.
S. Gold-Coast	1989	UK	The Netherlands	Cress	31	0	Yes/no	Contaminated seed and/or sprouter.
S. Havana	1998	California and Arizona	NR	Alfalfa	14 (California) 4 (Arizona)	1	No/yes	Sprouts were traced to a single producer. Seeds obtained from the same lot yielded sprouts from which *S.* Havana was cultured.
S. Havana/Cubana/ Tennessee	1998	California	California	Alfalfa	34	0	Yes/yes	Contaminated seeds were suspected.
S. Infantis and *S.* Anatum	1997	Kansas and Missouri	Unknown	Alfalfa	109	0	NR/NR	Seeds were believed to be contaminated.
S. Mbandaka	1999	Oregon, California, Idaho, and Washington	California	Alfalfa	Appx. 68	0	Yes/yes	Seeds were believed to come from the same lot and distributed to various growers in California, Florida, and Washington. No cases in Florida.

S. Meleagridis	1997	Canada	Unknown	Alfalfa	124	0	NR/NR	Sprouts were organically grown with no chlorine presoak.
S. Montevideo and *S.* Meleagridis	1996	California	California	Alfalfa	>500	1	Yes/no	The sprouts were traced to a specific sprouter. Seeds traced to single California seed grower. Contaminated seeds suspected.
S. Newport	1995	Denmark (probably US and Canada)	The Netherlands	Alfalfa	154	0	Yes/yes	Seeds came from the same shipper as US/Canada outbreak (see below). Source of contamination unknown.
S. Newport	1995–1996	British Columbia, Canada, Oregon (probably Georgia and Vermont), and Denmark	The Netherlands	Alfalfa	133	0	Yes/yes	Organisms isolated were indistinguishable from the Denmark outbreak (see above).
S. Paratyphi B var. Java	1999	Alberta, British Columbia, and Saskatchewan, Canada	Unknown	Alfalfa	46	0	NR/NR	Spouts were from the same brand or common seed source.
S. Saint-Paul	1988	UK	Thailand and Australia	Mung	143	0	Yes/yes	Multiple serovars isolated from bean spouts, seeds, and environmental samples (from producer waste materials).

(*continued*)

Table J-4 Continued

Pathogen	Year	Location	Seed source	Type of sprout	No. of cases	No. of deaths	Isolated from sprouts/seeds	Comments
S. Saint-Paul *S.* Havana *S.* Muenchen	1988	Sweden	NR	Mung	148	0	Yes/NR	Probably same seeds as UK outbreak. *S.* Havana and *S.* Muenchen but not S. Saint-Paul isolated from sprouts.
S. Senftenberg	1997–1998	California	5 US states	Alfalfa and clover sprouts	52	0	Yes/no	Sprouts were traced to a specific sprouter. Contaminated seeds suspected. Same sprouter as 1998 *E. coli* O157:NM outbreak.
S. Stanley	1995	Multistate, US, Canada, and Finland	The Netherlands	Alfalfa	>272	0	No/no	Seeds came from the same sprouter. At least 4 seed lots involved. Possible contamination occurred prior to shipping.
S. Virchow	1988	UK	Thailand and Australia	Mung	7	0	Yes/NR	Probably from the same outbreak as *S.* Saint-Paul in UK.
Yersinia enterolitica	1982	Pennsylvania	Unknown	Bean sprouts	16	0	NR/NR	Bean sprouts were immersed at home in well water contaminated with *Yersinia.*

[a]NR, not reported.
[b]Hemolytic uremic syndrome.