POST-HARVEST TECHNOLOGY OF HORTICULTURAL CROPS

Sharon Pastor Simson
Martha C. Straus

Post-harvest Technology
of
Horticultural Crops

"This page is Intentionally Left Blank"

Post-harvest Technology
of
Horticultural Crops

Sharon Pastor Simson
Martha C. Straus

Oxford Book Company
Jaipur, India

ISBN : 978-93-80179-25-4

Edition 2010

Oxford Book Company
267, 10-B-Scheme, Opp. Narayan Niwas,
Gopalpura By Pass Road, Jaipur-302018
Phone: 0141-2594705, Fax: 0141-2597527
e-mail: oxfordbook@sify.com
website: www.oxfordbookcompany.com

Typeset by :
Shivangi Computers
267, 10-B-Scheme, Opp. Narayan Niwas,
Gopalpura By Pass Road, Jaipur-302018

Printed at :
Mehra Offset Press, Delhi

Preface

Post-harvest handling is the stage of crop production immediately following harvest, including cooling, cleaning, sorting and packing. The instant a crop is removed from the ground, or separated from its parent plant, it begins to deteriorate. Post-harvest treatment largely determines final quality, whether a crop is sold for fresh consumption, or used as an ingredient in a processed food product.

The most important goals of post-harvest handling are keeping the product cool, to avoid moisture loss and slow down undesirable chemical changes, and avoiding physical damage such as bruising, to delay spoilage. Sanitation is also an important factor, to reduce the possibility of pathogens that could be carried by fresh produce. After the field, post-harvest processing is usually continued in a packing house. This can be a simple shed, providing shade and running water, or a large-scale, sophisticated, mechanised facility, with conveyor belts, automated sorting and packing stations, walk-in coolers and the like. In mechanised harvesting, processing may also begin as part of the actual harvest process, with initial cleaning and sorting performed by harvesting machinery.

Initial post-harvest storage conditions are critical to maintaining quality. Each crop has an optimum range for storage temperature and humidity. Also, certain crops cannot be effectively stored together, as unwanted chemical interactions can result. Various methods of high-speed cooling, and sophisticated refrigerated and atmosphere-controlled environments, are employed to prolong freshness, particularly in large-scale operations. Regardless of the scale of harvest, from domestic garden to industrialised farm, the basic principles of post-harvest handling for most crops are the same: handle with care to avoid damage, cool immediately and maintain in cool conditions, and cull.

This book covers post-harvest factors affecting fruit and vegetable quality, waste management, safety factors, and processing methods. The conventional as well as modern post-harvest technologies are described it detail. This book will be an invaluable resource for research professionals, quality control personnel and postharvest biology students anyone involved in the technology for handling and storing fresh fruits, vegetables, and ornamentals.

Sharon Pastor Simson
Martha C. Straus

"This page is Intentionally Left Blank"

Contents

"This page is Intentionally Left Blank"

1

Horticulture Production: Global Trends

Recently, the Food Agricultural Organisation of the United Nations (FAO) predicted that the world population would top eight billion by the year 2030. Therefore, the demand for food would increase dramatically. As stated in the FAO report, "Agriculture: Towards 2015/30", remarkable progress has been made over thc last three decades towards feeding the world. While global population has increased over 70 percent, per capita food consumption has been almost 20 percent higher. In developing countries, despite a doubling of population, the proportion of those living in chronic states of under nourishment was cut in half, falling to 18 percent in 1995/97. According to the report, crop output is projected to be 70 percent higher in 2030 than current output. Fruits and vegetables will play an important role in providing essential vitamins, minerals, and dietary fibre to the world, feeding populations in both developed and developing countries.

In developed countries, the U.S. continues to dominate the international trade of fruits and vegetables, and is ranked number one as both importer and exporter, accounting for approximately 18 percent of the $40 billion (USD) in fresh produce world trade. As a group, the European Union (EU) constitutes the largest player, with 15 additional export and import commodities contributing about 20 percent to total fresh fruit and vegetable trade. Within Europe, Germany is the principal exporter; Spain is the principal supplier; and the Netherlands plays an important role in the physical distribution process. In the Southern Hemisphere, Chile, South Africa, and New Zealand have become major suppliers in the international trade of fresh fruit commodities, although they remain insignificant in vegetable trade.

FAO estimated that the world production of fruits and vegetables over a three-year period was 489 million tons for vegetables and 448 million tons for fruits. This trend increased as expected, reaching a global production of 508 million tons for vegetables and 469 tons for fruits in 1996. This trend in production is expected to increase at a rate of 3.2 percent per year for vegetables and 1.6 percent per year for fruits. However, this trend is not uniform worldwide, especially in developing countries where the lack of adequate infrastructure and technology constitutes the major drawback to competing with industrialised countries. Nevertheless, developing countries will continue to be the leaders in providing fresh exotic fruits and vegetables to developed countries. Most developing countries have experienced a high increase in fruit and vegetable production, as in the case of Asia and South America.

Asia is the leading producer of vegetables with a 61 percent total volume output and a yearly growth of 51 percent. However, the U.S. continues to lead in the export of fresh fruits and vegetables worldwide with orange, grapes, and tomatoes. Brazil dominates the international trade of frozen orange juice concentrate, while Chile has become the major fresh fruit exporter with a production volume of 45 percent. Despite the large growth in exports in the 1990s, the U.S. remains a net importer of horticultural products.

As U.S. consumers have become more willing to try new fruit and vegetable varieties, the imported share of the domestic market has increased. According to a USDA report, the total value of horticultural products imported into the U.S. has grown by more than 50 percent since 1990. If long-term projections hold for the next decade, the U.S. could achieve a trade balance surplus in horticultural products, due mainly to a global increase in the market. While the import value of horticultural products is projected to grow at a steady rate of 4 percent per year, between 1998 and 2007, the USDA's baseline projection period for exports are projected to grow by 5 to 7 percent per year.

The top six fruit producers, in declining order of importance, are China, India, Brazil, USA, Italy, and Mexico. China, India, and Brazil account for almost 30 percent of the world's fruit supply, but since most of this production is destined for domestic consumption its impact on world trade is minimal.

TRADITIONAL CONSUMPTION

Fruit and vegetable consumption per capita showed an increase of 0.38 percent for fresh fruits and 0.92 percent for vegetables per capita from 1986 to 1995. The highest consumption of fresh fruits was registered in China (6.4%), as the apparent per capita consumption of vegetables in China went from 68.7 kg per capita in 1986 to 146 kg in 1995 (53.8% growth rate), while African and Near East Asian countries showed a decrease in fresh fruit consumption. The lowest consumption of vegetables per capita was registered in Sub-Saharan Africa. According to trade sources, Chinese customers purchased most of their fresh fruit at street retail shops and market places where imported fresh fruits are available and U.S. and European brand names have received recognition. Products such as Red Delicious apples, Sunkist oranges, and Red Globe table grapes are especially popular. Sunkist is one of the few brands of oranges consumers recognise. The trend toward fresh vegetable consumption in developing countries is one indication of the population's standard of living, but generally, fresh vegetables lose their market share to processed products. Many vegetables can be processed into canned products that cater to local tastes. Easy to carry and convenient to serve, they can be stored for a long time, reducing losses incurred from the seasonal supply of surplus vegetables marketed yearly at the same time. Urban population is exploding in developing countries, having risen from 35 percent of the total population in 1990, and projected to rise 54 percent in 2020. With increasing urban populations, more free markets and wholesale markets will be required to increase the supply of fresh fruits and vegetables. For example, the growth of consumption in the U.S. has been stimulated partly by increasing demand for tropical and exotic fruits and vegetables.

ECONOMIC AND SOCIAL IMPACT

Ongoing consumer demand for new fruits and vegetables in developed countries has contributed to an increase in trade volume of fresh produce in developing countries. This, in turn, has promoted the growth of small farms and the addition of new products, creating more rural and urban jobs and reduced the disparities in income levels among farms of different sizes. As countries become wealthier, their demand for high-valued commodities increases. The effect of income growth on consumption is more pronounced in developing countries, compared to developed countries, they are expected to spend larger shares of extra income on food items like meat and fruit and vegetable products. The implementation of international trade agreements, such as NAFTA (USA and Canada) and MERCOSUR (Argentina, Brazil, Paraguay and Uruguay), has significantly impacted the economy of the signatory countries by increasing the trade volumes and trade flows, particularly through general areas such as market access, tarification, limits on export subsidies, cuts in domestic supports, phyto-sanitary measures, and safeguard clauses.

COMMERCIAL CONSTRAINTS

According to the USDA economic report, the commercial constraints on fruits and vegetables include:

- *Trade barriers:* Natural and artificial barriers. Natural trade barriers include high transportation costs to distant markets, and artificial barriers include legal measures such as protectionist policies. Liberalisation of trade through international agreements has been instrumental in relaxing many legal trade barriers by reducing tariffs and by harmonising the technical barriers to trade.
- *Scientific phyto-sanitary requirements:* Importing countries set the standards that potential trade partners must meet in order to protect human health or prevent the

spread of pests and diseases. For instance, Japanese imports of U.S. apples are limited to Red and Golden Delicious apples from Washington and Oregon. The Japanese, who are mainly concerned with the spread of fire blight, impose rigorous and costly import requirements on the U.S. apple shippers. The apples must be subjected to a cold treatment and fumigation with methyl bromide before shipment to Japan, and three inspections of U.S. apple orchards during the production stage. Infestation by fruit flies (*Tepbritidae: Diptera*), common in the tropics, is a major constraint to the production and export of tropical fruits.

— *Technological innovations:* Countries can increase their competitiveness and world market shares by providing higher quality products and promoting lower prices through technological innovations.

Trade liberalisation, negotiated through the Uruguay Round Agreement (URA) (of the GATT and implemented under WTO), as well as through regional agreements, such as NAFTA and MERCOSUR, has expanded market access and provided strengthened mechanisms for combating non-tariff trade barriers such as scientifically unfounded phyto-sanitary restrictions. Future prospects of fruits and vegetables exported from developing countries will largely depend on the growth of import demand, mostly in the developed countries. Developed countries are expected to diversify their consumption of fruits and vegetables. This will increase the concern about health and nutrition; the consumer's familiarity with more fruits and vegetables because of wider availability, increased travel, and improved communications will lead to an increase in the ratio of imports to domestic products.

POST-HARVEST LOSSES AND RESOURCE UNDER-UTILISATION IN DEVELOPING COUNTRIES

Postharvest losses of fruits and vegetables are difficult to predict; the major agents producing deterioration are those attributed to physiological damage and combinations of several organisms. Flores described postharvest losses due to various causes as follows:

Food Losses after Harvesting

These include losses from technological origin such as deterioration by biological or microbiological agents, and mechanical damage. Losses due to technological origin include: unfavourable climate, cultural practices, poor storage conditions, and inadequate handling during transportation, all of which can lead to accelerated product decay.

Physiological deterioration of fruits and vegetables refers to the aging of products during storage due to natural reactions. Deterioration caused by biochemical or chemical agents refers to reactions, of which intermediate and final products are undesirable.

These can result in significant loss of nutritional value and in many cases the whole fruit or vegetable is lost.

Deterioration by biological or microbiological agents refers to losses caused by insects, bacteria, moulds, yeasts, viruses, rodents, and other animals. When fruits and vegetables are gathered into boxes, crates, baskets, or trucks after harvesting, they may be subject to cross-contamination by spoilage microorganisms from other fruits and vegetables and from containers.

Most of the microorganisms present in fresh vegetables are saprophytes, such as *coryniforms*, lactic acid bacteria, spore-formers, *coliforms, micrococci,* and pseudomonas, derived from the soil, air, and water. *Pseudomonas* and the group of *Klebsiella-Enterobacter-Serratia* from the enterobacteriaceae are the most frequent. Fungi, including *Aureobasidium, Fusarium,* and *Alternaria,* are often present but in relatively lower numbers than bacteria. Due to the acidity of raw fruits, the primary spoilage organisms are fungi, predominantly moulds and yeasts, such as *Sacharomyces cerevisiae, Aspergillus niger, Penicillum spp., Byssochlamys fulva, B. nivea, Clostridium pasteurianum, Coletotrichum gloesporoides, Clostridium perfringes,* and *Lactobacillus spp.* Psychrotrophic bacteria are able to grow in vegetable products; some of them are *Erwina carotovora, Pseudomonas fluorescens, P. auriginosa, P. luteola, Bacillus species, Cytophaga jhonsonae, Xantomonas campestri,* and *Vibrio fluvialis.*

The existence of pathogenic bacteria in fresh fruit and vegetable products has been reported by Alzamora et al., which include *Listeria monocytogenes, Aeromonas hydrophila,* and *Escherichia coli* O157: H7. These bacteria are found in both fresh and minimally processed fruit and vegetable products. *Listeria monocytogenes* is able to survive and grow at refrigeration temperatures on many raw and processed vegetables, such as ready-to-eat fresh salad vegetables, including cabbage, celery, raisins, fennel, watercress, leek salad, asparagus, broccoli, cauliflower, lettuce, lettuce juice, minimally-processed lettuce, butterhead lettuce salad, broad-leaved and curly-leaved endive, fresh peeled hamlin oranges, and vacuum-packaged potatoes.

Aeromonas hydrophila is a characteristic concern in vegetables; it is a psychrotrophic and facultative anaerobe. *Aeromonas* strains are susceptible to disinfectants, including chlorine, although recovery of *Aeromonas* from chlorinated water has been reported. Challenging studies inoculating *A. hydrophila* in minimally processed fruit salads showed that *A. hydrophila* was able to grow at 5°C during the first 6 days, however, the pathogen decreased after 8 days of storage.

E. coli O157H:7 has emerged as a highly significant food borne pathogen. The principal reservoir of E. *coli O157H:7* is believed to be the bovine gastrointestinal tract. Thus, contamination of associated food products with faeces is a significant risk factor, particularly if untreated contaminated water is consumed directly or used to wash uncooked foods.

Mechanical damage is caused by inappropriate methods used during harvesting, packaging, and inadequate transporting, which can lead to tissue wounds, abrasion, breakage, squeezing, and escape of fruits or vegetables. Mechanical damage may increase susceptibility to decay and growth of microorganisms. Some operations, such as washing, can reduce the microbial load; however, they may also help to distribute spoilage microorganisms and moisten surfaces enough to permit growth of microorganisms during holding periods. All methods of harvesting cause bruising and damage to the cellular and tissue structure, in which enzyme activity is greatly enhanced as cellular components are dislocated.

Besides the above issues, most post-harvest losses in developing countries occur during transport, handling, storage, and processing. Rough handling during preparation for market will increase bruising and mechanical damage, and limits the benefits of cooling.

By-products from fruit and vegetable processing are not wholly utilised in developing countries due to lack of machinery and infrastructure to process waste. The easiest way to dispose of by-products is to dump the waste or use it directly as animal feed. Waste materials such as leaves and tissues could be used in animal feed formulations and plant fertilisers.

In general, it is estimated that between 49 to 80% goes to consumers in the production of a particular commodity, and the difference is lost during the varied steps that comprise the harvest-consumption system.

Food Losses due to Social and Economic Reasons

- *Policies:* This involves political conditions under which a technological solution is inappropriate or difficult to put in to practice, for example, lack of a clear policy capable of facilitating and encouraging utilisation and administration of human, economic, technical, and scientific resources to prevent the deterioration of commodities.
- *Resources:* This is related to human, economic, and technical resources for developing programs aimed at prevention and reduction of post-harvest food losses.
- *Education:* This includes unknown knowledge of technical and scientific technologies associated with preservation, processing, packaging, transporting, and distribution of food products.

- *Services:* This refers to inefficient commercialisation systems, and absent or inefficient government agencies in the production and marketing of commodities, as well as a lack of credit policies that address the needs of the country and participants.
- *Transportation:* This is a serious problem faced by fruit growers in developing countries, where vehicles used in transporting bulk raw fruits to markets are not equipped with good refrigeration systems. Raw fruits exposed to high temperatures during transportation soften in tissue and bruise easily, causing rapid microbial deterioration.

Pre-processing to Add Value

Rapid cooling of produce following harvest is essential for crops intended for transport in refrigerated ships, land vehicles, and containers not designed to handle the full load of field heat but capable of maintaining precooled produce at a selected carriage temperature. The selected method of cooling will depend greatly on the anticipated storage life of the commodity. Rapidly respiring commodities with short post-harvest life should be cooled immediately after harvest. Therefore, added value is achieved in precooling the produce immediately after harvest, which will restrict deterioration and maintain the produce in a condition acceptable to the consumer.

Blanching of fruits as a pre-treatment method may also be applied before freezing and juicing, or in some cases, before dehydration. The fruit may be blanched either by exposure to near boiling water, steam, or hot air for 1 to 10 minutes. Blanching inactivates those enzyme systems that degrade flavcur and colour and cause vitamin loss during subsequent processing and storage.

Pre-processing to Avoid Losses

Pre-processing of fruits and vegetables includes: blanching to inactivate enzymes and microorganisms, curing of root and tubers to extend shelf life, pre-treatment of produce with cold or high temperatures, and chemical preservatives to control pests after harvest. Storage of produce under controlled temperature and relative humidity conditions will extend its perishability and reduce decay. Packaging of produce in appropriate material enhances colour appearance and marketability.

Alternative Processing Methods

A variety of alternative methods to preserve fruits and vegetables can be used in rural areas, such as fermentation, sun drying, osmotic dehydration, and refrigeration.

Fruits and vegetables can be pre-processed via scalding to eliminate enzymes and microorganisms. Fermentation of fruits and vegetables is a preservation method used in rural areas, and due to the simplicity of the process, there is no need for sophisticated equipment; pickled produce, sauerkraut, and wine are examples of this process. A general schematic diagram of the different alternative processes for fruits and vegetables is presented in Figure 1, and described as follows:

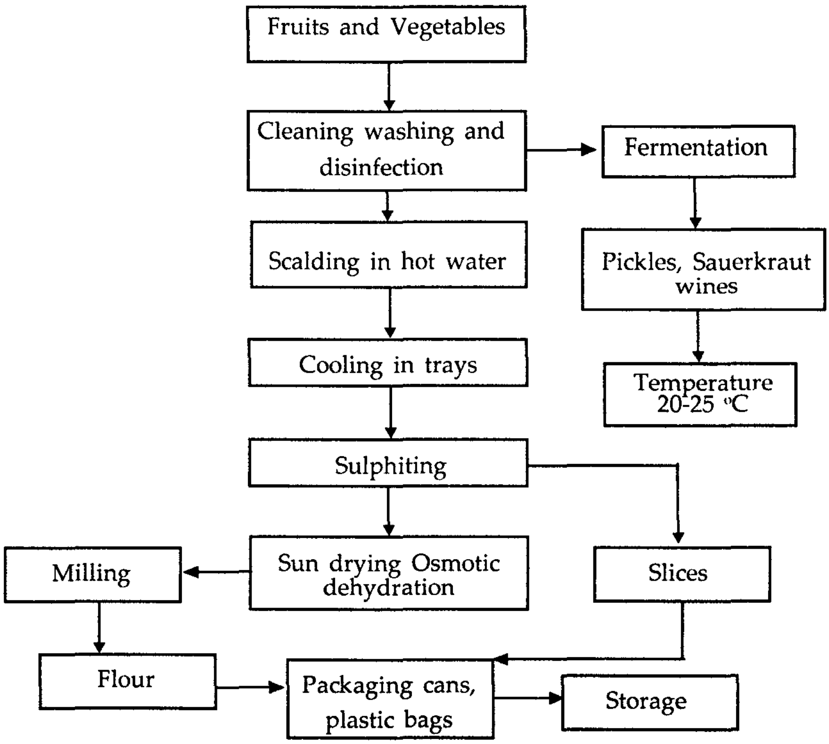

Figure 1. Processing of Fruits and Vegetables in Rural Areas.

Cleaning and washing are often the only preservation treatments applied to minimally processed raw fruits and vegetables (MPRFV). As the first step in processing, cleaning is a form of separation concerned with removal of foreign materials like twigs, stalks, dirt, sand, soil, insects, pesticides, and fertiliser residues from fruits and vegetables, as well as from containers and equipment. The cleaning process also involves separation of light from heavy materials via gravity, flotation, picking, screening, dewatering, and others. Washing is usually done with chlorinated water. The MPRFV product is immersed in a bath in which bubbling is maintained by a jet of air. This turbulence permits one to eliminate practically all traces of air and foreign matter without bruising the product.

Water must be of optimal quality for washing MPRFV products, otherwise cross contamination may occur. According to Wiley R.C., three parameters are controlled in washing MPRFV fruits and vegetables:

1. Quantity of water used: 5-10 L/kg of product
2. Temperature of water: 4°C to cool the product
3. Concentration of active chlorine: 100 mg/L

Two examples of specially designed equipment used to wash fruits and vegetables include: 1) rotary drums used for cleaning apples, pears, peaches, potatoes, turnips, beets; high pressure water is sprayed over the product, which never comes in contact with dirty water, and 2) wire cylinder leafy vegetable washers, in which medium pressure sprays of fresh water are used for washing spinach, lettuce, parsley, and leeks.

In rural areas, fresh produce could be poured into plastic containers filled with tap water to remove the dirt from fruits and vegetables. The dirty water could be drained from the containers and refilled with chlorinated water for rewashing and disinfection of the fruit or vegetable. If electricity is available, fresh produce could be refrigerated until processed or distributed to retailers and markets.

Scalding or blanching in hot water

Fruits, fresh vegetables and root vegetable pieces are immersed in a bath containing hot water (or boiling water) for 1-10 minutes at 91-99°C, to reduce microbial levels, and partially reduce peroxidase and polyphenoloxydase (PPO) activity. The heating time will depend on the type of vegetable product processed Boiling water has been used to provide thermal inactivation of *L. monocytogenes* on celery leaves.

Cooling in trays

This operation is carried out in perforated metal trays through which cool air is passed in order to cool the product prior to packaging in sterile plastic bags, unless another process is to follow.

Sulphiting

During this operation, the fruit or vegetable pieces (or slices) are immersed in a solution of sodium bisulphite (200 ppm) to prevent undesirable changes in colour and any additional microbial and enzyme activity, and to retain a residual concentration of 100 ppm in the final product.

Sun drying and osmotic dehydration

In rural areas, dehydration is probably the most effective method to preserve fruits and vegetables. Fruit slices or vegetable pieces are spread over stainless metal trays or screens spaced 2-3 cm apart and sun dried. The dried fruit and vegetable products are then packaged in plastic bags, glass bottles, or cans, as with fruit slices or milled flour.

In osmotic dehydration and crystallisation, the fruit is preserved by heating the product in sugar syrup, followed by washing and drying to reduce the sugar concentration at the fruit surface. Fruits are dried by direct or indirect sun drying, depending on the quality of the product obtained. The advantage of this method is the prevention of discoloration and browning of fruit produced by enzymatic reactions. Thus, the high concentration of sugar in the fruit produces a dehydrated product with good colouring, without the need of chemical preservatives such as sulphur dioxide.

Fermentation

This is another useful preservation process for fruit and vegetable products. For vegetables, the product is immersed into a sodium chloride solution, as in the case of cucumbers, green tomatoes, cauliflower, onions, and cabbage. Composition of the salt is maintained at about 12% by weight so that active organisms during fermentation, such as Lactic acid bacteria, and the *Aerobacter* group, produce sufficient acid to prevent any food poisoning organisms from germinating. Fruits, on the other hand, can be preserved by fermenting the fruit pulp into wine, by preparing a solution of sugar and water and then inoculating it with a strain of *Saccharomyces cerevisiae.*

Pickles, sauerkraut and wine making

Slightly underripe cucumbers are selected and cleaned thoroughly with water, then size-graded prior to brining. For a large production of pickles, the fermentation process is carried out in circular wooden vats 2.5-4.5 m in diameter and 1.8-2.5 m deep. A small batch of pickles can be produced using appropriate plastic containers capable of holding 4-5 kg of cucumbers. After the cucumbers are put into the vats, a salt solution is added. This concentration is maintained by adding further salt as needed by recirculating the solution to eliminate concentration gradients. Sugar is added if the cucumbers are low in sugar content to sustain the fermentation process. The fermentation process will end after 4-6 weeks, and the salt concentration will rise to 15%. Under these conditions, pickles will keep almost indefinitely. Care must be taken to ensure that the yeast scum on top of the vat does not destroy the lactic acid. This can be done by adding a layer of liquid paraffin on the surface of the pickling solution. After the fermentation process has ended, the pickles are soaked in hot water to remove excess salt, then size-graded and packed into glass jars with acetic acid in the form of vinegar.

Sauerkraut

Selected heads of cabbage are core-shredded and soaked in tap water with 2.5% (by weight) salt concentration and allowed to ferment. During the initial stages of fermentation, there is a rapid evolution of gas caused by *Leuconostoc mesenteroides*; this process imparts much of the pleasant flavour to the product. The next stage involves *Lactobacillus cucumeris* fermentation, resulting in an increase of lactic acid; and finally after approximately 5 days at 20-24°C, the third stage, involving a further group of lactic acid bacteria such as *Leuconostoc pentoaceticus*, which yields more lactic acid combined with acetic acid, ethyl alcohol, carbon dioxide, and mannitol. The fermentation process ends when the lactic acid production is approximately 1-2%. This can be tested by titration of the acid with a 0.1 N sodium hydroxide (NaOH) solution, using phenolphthalein (0.1% w/v) as colour indicator. After the fermentation process, either the tank is sealed to exclude air or the product is then packed into glass jars or canned. It is then ready for consumption.

Wine making

Selected ripened fruits are transported to the farm where they are sorted, washed and macerated or chopped prior to pressing. In rural areas, juice is extracted from the fruit by squeezing (oranges, grapes, etc.) or pulped (mangoes, maracuyá, guava, etc.). The soluble solid content of the pulp is measured with a refractometer in Brix. Soluble solids should be 25%, but if lower, it can be adjusted with sugar.

Clarification

Clarification of wines prior to bottling involves treatment with gelatine, albumin, isinglass, bentonite, potassium ferrocyanide or salts the last two treatments are intended to reduce the level of soluble iron complexes, which would otherwise cause a darkening of the wine, but with fruit wine these are frequently inadequate. Alternative clarification procedures include chilling the wine prior to, or after, refining, and using microfiltration systems. A simple way to clarify wine is to add white gelatine (1 g per L of wine) to the fermented fruit solution, which is then allowed to stand in the refrigerator for 1 week, after which all of the suspended solids are precipitated and a clear transparent wine can be decanted from the top of the container. Following clarification, the wine will normally be flash pasteurised, hot-filled into bottles, or treated to give a residual SO_2 content (100 ppm).

The next stage is to add sodium bisulphite to the fruit juice (200 ppm), allowing it to stand for 2-3 hours. During this process, the unwanted yeast flora present in the fruit pulp is eliminated and the added inoculum can act freely in the fruit juice to produce the desired flavour or bouquet characteristic of fruit wine. Next, the yeast is added to the juice. The fermentation process should be carried out anaerobically, that is in the absence of oxygen, to prevent development of other non-wine making bacteria, such as *Acetobacter spp*, which produces undesirable taste and flavour. The fermentation ends after 3 to 4 weeks at 22-25°C.

The final stage of processing involves the blending, sweetening and flavouring, and stabilisation of the wines. The blending process is done both to ensure consistency of product character and to reduce the strong aroma and flavour of certain wines. Although there is some preference for single wines, many are blended, especially with apple wine, which is relatively low in flavour. Wines can be sweetened using sugar or fruit juice, the latter also serving to increase the natural fruit content. In some cases, it is necessary to adjust the acidity of wine by adding an approved food-grade acid, such as citric or tartaric acid. In many rural areas, where these chemicals are not available, lemon juice can be used instead.

For wine making in rural areas, the fermentation process is usually carried out in a large bottle (18-20 L), in which the ingredients are mixed with water. In order to keep the fermentation process under anaerobic conditions, a water-filled air-lock is fitted into a hollow cork or rubber stopper inside the mouth of the bottle. This can be made simply from a piece of plastic tubing and a bottle.

Storage

Because sun dried and fermented fruit and vegetable products are stable, they can be stored at ambient temperatures or at low refrigeration temperatures, extending the shelf life for several months (6-12 months and beyond). Wine is stored in glass bottles and maintained at room temperature or it can be stored under refrigeration. Other fermented products such as sauerkraut and pickles are usually stored at room temperature.

REFERENCES

Ahvenainen, R. 1996. "New approaches in improving the shelf life of minimally processed fruit and vegetables". *Trends in Food Science and Technology*. 179-197.

Cook, R.L. 1998. "Post-harvest of horticultural crops. Proceedings of the World Conference on Horticulture Research". *Acta Horticulture* No. 494.

FAO. 1995a. *Small-scale Post-harvest Handling Practices -A Manual for Horticulture Crops*. 3rd edition. Series No. 8.

Proceedings on the World Conferences on Horticulture Research.1996. Global horticultural impact: fruits and vegetables in developed countries. Acta Horticulture 495, 39-66.

Thompson, A.K. 1998. *Controlled Atmosphere Storage of Fruits and Vegetables*. Blackwell Science, Berlin, 14-17.

2

Harvest Systems

The harvest is the process of gathering mature crops from the fields. Reaping is the cutting of grain or pulse for harvest, typically using a scythe, sickle, or reaper. The harvest marks the end of the growing season, or the growing cycle for a particular crop, and this is the focus of seasonal celebrations of many religions. On smaller farms with minimal mechanization, harvesting is the most labor-intensive activity of the growing season. On large, mechanized farms, harvesting utilizes the most expensive and sophisticated farm machinery, like the combine harvester. Harvesting in general usage includes an immediate post-harvest handling, all of the actions taken immediately after removing the crop—cooling, sorting, cleaning, packing—up to the point of further on-farm processing, or shipping to the wholesale or consumer market.

Harvest timing is a critical decision, that balances the likely weather conditions with the degree of crop maturity. Weather conditions such as frost, rain (resulting in a "wet harvest"), and unseasonably warm or cold periods can affect yield and quality. An earlier harvest date may avoid damaging conditions, but result in poorer yield and quality. Delaying harvest may result in a better harvest, but increases the risk of weather problems. Timing of the harvest often amounts to a significant gamble.

Harvesting is the gathering of plant parts that are of commercial interest. These include:

- *Fruits*—e.g. tomatoes, peppers, apples, kiwifruits, etc.;
- *Root crops*—e.g. beets, carrots etc;
- *Leafy vegetables*—spinach and Swiss chard;
- *Bulbs*—onions or garlic;
- *Tubers*—potatoes;
- *Stems*—asparagus;

- *Petioles*—celery and
- *Inflorescences*—broccoli, cauliflower etc.

Harvest marks the end of the growing period and the commencement of market preparation or conditioning for fresh products.

Harvesting can be performed by hand or mechanically. However, for some crops—e.g. onions, potatoes, carrots and others—it is possible to use a combination of both systems. In such cases, the mechanical loosening of soil facilitates hand harvesting. The choice of one or other harvest system depends on the type of crop, destination and acreage to be harvested. Fruits and vegetables for the fresh market are hand harvested while vegetables for processing or other crops grown on a large scale are mainly harvested mechanically.

The main advantages of mechanised harvesting are speed and the reduced costs per ton harvested. However, because of the risk of mechanical damage, it can only be used on crops that require a single harvest. A decision to purchase equipment requires careful evaluation of: the initial investment required, maintenance costs and the long period in which equipment may have to stand idle. In addition to this, the entire operation needs to be designed specifically for mechanised harvesting—distances between rows, field leveling, pesticide spraying, cultural practices to varieties which can be adapted to rough handling. Market preparation (grading, cleaning, packing, etc.) and the trade should also be able to handle large volumes of produce.

Hand harvesting is particularly suitable for crops with an extended harvest period. The rate of harvesting can be increased by hiring more workers if, for example, due to climate, there is accelerated ripening and a need to harvest the crop quickly. The main benefit of hand harvesting over mechanised harvesting is that humans are able to select the produce at its correct stage of ripening and handle it carefully. The result is a higher quality product with minimum damage. This is important for tender crops. However, adequate training, including supervision of the harvest crew, is required.

Contractual arrangements with harvest labour also influences the final quality of product harvested. When wages are paid per week, fortnight or month, harvesting is undertaken carefully. However, when payment is per box, meters of row or number of harvested plants, harvesting can be careless. Establishing teams and division of labour also influences quality. Long working days and/or few breaks as well as extremely adverse conditions (excessive heat or cold) can result in unnecessary rough handling of produce. Harvest labour needs to be adequately trained to give them the necessary skills to select produce at the correct stage of ripeness or degree of maturity as well as sorting techniques to minimise damage.

HARVEST RIPENESS AND READINESS FOR HARVEST

In many cases harvest ripeness and readiness for harvest are used synonymously. However, it is more technically accurate to use "ripeness" for fruits such as tomato, peach, pepper, etc. Here, the consumption stage continues after certain changes in colour, texture and flavor. On the other hand, in species where these changes do not occur such as asparagus, lettuce, and beets, the term "readiness for harvest" is preferable.

Maturity is the harvest index most widely used in fruits. However, *physiological maturity* needs to be distinguished from *commercial maturity*. The former is reached when development is over. It may or may not be followed by the ripening process to achieve the commercial maturity required by the market. Every fruit shows one or more apparent signs when it reaches physiological maturity. For example, in tomato, the gelatinous mass fills the internal locules and seeds cannot be cut when fruits are sectioned with a sharp knife. In peppers, seeds become hard and the internal surface of the fruit starts colouring.

Over maturity or over ripening is the stage that follows commercial maturity and is when the fruit softens and loses part of its characteristic taste and flavor. However, it is the ideal condition for preparing jams or sauces. Commercial maturity may or may not coincide with physiological maturity. For cucumbers, zucchinis, snapbeans, peas, baby vegetables, and many others, commercial maturity is reached well before the end of development.

At this point, it is necessary to differentiate between two types of fruits: climacteric and non-climacteric. Climacteric include for example tomatoes, peaches etc. They are capable of generating ethylene, the hormone required for ripening even when detached from the mother plant. Non-climacteric include for example peppers, citrus etc. Commercial maturity is only obtained on the plant (Table 1).

Table 1: Climacteric and non-climacteric fruits.

Non-climacteric		*Climacteric*	
Bell pepper	Olives	Apple	Melons
Blackberries	Orange	Apricot	Nectarine
Blueberries	Pineapple	Avocado	Papaya
Cacao	Pomegranate	Banana	Passionfruit
Cashew apple	Pumpkin	Breadfruit	Peach
Cherry	Raspberries	Cherimoya	Pear
Cucumber	Strawberries	Feijoa	Persimmon
Eggplant	Summer squash	Fig	Plantain
Grape	Tart cherries	Guanábana	Plum
Grapefruit	Tree tomato	Guava	Quince
Lemon		Jackfruit	Sapodilla
Lime		Kiwifruit	Sapote

Loquat	Mamey	Tomato
Lychee	Mango	Watermelon

Climacteric fruits are autonomous from the ripening point of view and changes in taste, aroma, colour and texture are associated with a transitory respiratory peak and closely related to autocatalytic ethylene production. Climacteric fruits such as tomato reach full red colour even when harvested green. On the other hand, in non- climacteric fruits such as bell peppers, slight changes in colour take place after harvest. Full red colour is only obtained while fruit is attached to the plant. As a general rule, the more mature the product, the shorter its post-harvest life. For distant markets, this means climacteric fruits need to be harvested as early as possible, but always after reaching their physiological maturity.

Changes in colour are the most apparent external symptoms of ripening. They are the result of chlorophyll degradation (disappearance of green colour) and the synthesis of specific pigments. In some fruits such as lemons, chlorophyll degradation allows yellow pigments that are already present to show. However, these are masked by the green colour. Other fruits such as peaches, nectarines and some varieties of apples have more of one type of colour—the ground one is associated with ripeness and the cover in many cases is specific to the variety. Maturity can be estimated by colour charts based on the percentage of desired colour or by objective measurements with colourimeters.

Degree of development is the harvest index most widely used in vegetables and some fruits, in particular those harvested immature. In soybean, alfalfa and other legume sprouts, harvest is undertaken before expansion of the cotyledon; in asparagus, when the stems emerging from soil reach a certain length; in haricot beans and other snap-beans when they reach a certain diameter; in snow peas and other legumes before seed development becomes evident. In lettuce, cabbage and other "head" forming vegetables, harvest is based on compactness while "shoulder" width is used in beets, carrots and other roots. Plant size as a harvest index is used in many vegetables such as spinach. However, in the case of potato, sweet potato and other root vegetables, the percentage of tubers of a specific size is utilised.

Many crops show apparent external symptoms when ready for harvest. These include for example tops falling over in onions, development of abscission layers in the pedicel of some melons, hardness of the epidermis of certain pumpkins, or shell fragility in some nuts. Degree of filling is an index used in bananas and mangoes while sweet corn is harvested when kernels are plump and no longer "milky".

Colour, degree of development or both are the main criteria used for harvest in most fruits and vegetables. It is, however, common to combine these with other objective indices. These include for example, firmness (apple, pear, stone fruits), tenderness (peas), starch content (apple, pear), soluble solid content (melons, kiwifruit), oil content (avocado), juiciness (citrus), sugar content/acidity ratio (citrus), aroma (some melons), etc. For processing crops, it is important to keep a constant flow of raw material in the harvesting schedule. It is therefore normal practice to calculate the number of days from flowering and/or the accumulation of heat units.

HANDLING DURING HARVEST

Harvesting involves a number of other activities undertaken in the field. This includes those of commercial interest. Examples of operations to facilitate preparation for the market include pre-sorting, removal of foliage and other non-edible parts. In some cases, the product is completely prepared for the market in the field. However, the normal practice is to empty the harvest containers into larger ones for transportation to the packinghouse. Here, they are dry or water dumped onto grading lines. While these activities are being undertaken, bruising which has a cumulative effect can affect the final quality of product.

Different types of lesions exist. Wounds (cuts and punctures) occur as a result of loss of tissue integrity. This type of damage is frequent during harvest and mainly produced by the harvesting tools used for the removal of plants. Other causes include the nails of pickers or peduncles from other fruits. Rotting fungi and bacteria penetrate produce in this way. This type of damage can be easily detected and is usually removed during grading and packing. Bruises are more common than wounds. They are less noticeable and symptoms show up several days later when the product is in the hands of the consumer. There are three main causes of bruises:

1. *Impact:* Injury caused either by dropping the fruit (or packed fruits) onto a hard surface or the impact of fruit rubbing against other fruit.These types of bruises are common during harvest and packing.
2. *Compression:* Deformation under pressure. This often occurs during storage and bulk transportation and is caused by the weight of the mass of fruits on bottom layers. It also happens when the packed mass exceeds the volume of the container or by the collapse of weak boxes or packages unable to withstand the weight of those piled up high.
3. *Abrasion:* Superficial damage produced by any type of friction (other fruits, packaging materials, packing belts, etc.) against thin-skinned fruit such as pears. In onions and garlic abrasion results in the loss of protective scales.

Bruise symptoms depend on the affected tissue, maturity, type and severity of the bruise. They are cumulative and in addition to their traumatic effect, trigger a series of responses to stress, including the onset of healing mechanisms. This physiological reaction is as follows: a temporary increase in respiration which is associated with degradation; a transient production of ethylene, which accelerates maturation and contributes to softening. In some cases, mechanical disruption of membranes puts enzymes in contact with substrates which leads to the synthesis of secondary compounds that may affect texture, taste, appearance, aroma or nutritive value. Firmness on the site of impact decreases rapidly because of damage and cell death as well as the loss of tissue integrity. The more mature the product, the more severe the damage. Its effect is exacerbated by higher temperatures and longer storage periods. Ethylene removal or neutralisation under controlled or modified atmosphere conditions reduces the speed of healing. However, atmospheric composition also reduces the rate of stress response mechanisms.

HARVEST RECOMMENDATIONS

- If the time of day can be selected, it is recommended to harvest during the cool morning hours. This is because products are more turgid. Furthermore, less energy is required for refrigeration.
- Harvesting maturity is a function of the distance to the destination market: those within close proximity, allow ripening on the plant.
- Harvested product needs to be kept in the shade until the time of transportation
- Avoid product bruising. Harvesting scissors or knives should have rounded ends to prevent punctures and be sharp enough to prevent tearing off. Harvest containers should be cushioned, smooth and free of sharp edges. Do not overfill field containers and move them carefully. Minimise drop heights when transferring produce to other containers.
- Train harvest labour to handle produce gently and identify correct maturity for harvest. Wear gloves during harvest and handling to avoid damage to fruits.

CURING

Curing complements harvesting in certain crops and is needed to achieve a quality product. It is a process involving rapid loss of superficial humidity. In addition to developing some tissue changes, it prevents further dehydration. It also acts as a barrier for penetration of pathogens. In onions and garlic, curing is the drying of external scales together with colour development and neck closure. For root crops such as sweet potato, yams and tubers—e.g. potato—skin hardening prevents skinning during harvest and handling and the development of the healing periderma on wounds (suberisation). In pumpkins and other cucurbits, curing is the hardening of the skin while in citrus it is the natural formation of a layer of lignified cells. This prevents the formation and development of pathogens.

Curing is normally undertaken in the field. In garlic and onions it is performed by undercutting and windrowing plants to protect them from direct sun or in heaps or burlap bags for a week or more. In potato, tubers must remain in the soil for 10-15 days after foliage is destroyed with herbicides. In sweet potato and other roots it is similar although it is normally carried out under shelters. If required, curing may be performed artificially in storage facilities by forced circulation of hot and humid air (Table 2). After curing, temperature and relative humidity conditions are set for long-term storage.

Table 2. Recommended temperature and relative humidity conditions for curing.

	Temperature (°C)	*Relative humidity (%)*
Potato	15-20	85-90
Sweet potato	30-32	85-90
Yam	32-40	90-100
Cassava	30-40	90-95
Onion & garlic	33-45	60-75

HARVEST FESTIVALS

A harvest festival is an annual celebration which occurs around the time of the main harvest of a given region. Given the differences in climate and crops around the world, harvest festivals can be found at various times throughout the world. Harvests festivals typically feature feasting, both family and public, with foods that are drawn from crops that come to maturity around the time of the festival. Ample food and freedom from the necessity to work in the fields are two central features of harvest festivals: eating, merriment, contests, music and romance are common features of harvest festivals around the world. In Asia, the Chinese Moon Festival is one of the most widely-spread harvest festivals in the world. In India, Pongal in January, Holi in February-March and Onam in August-September are a few famous harvest festivals. In North America, Canada and the US each have their own Thanksgiving celebrations in October-November. Numerous religious holidays, such as Sukkot, have their roots in harvest festivals.

In Britain, thanks have been given for successful harvests since pagan times. The celebrations on this day usually include singing hymns, praying, and decorating churches with baskets of fruit and food in the festival known as Harvest Festival, Harvest Home or Harvest Thanksgiving.

In British churches, chapels and schools and in Canadian churches, people bring in food from the garden, the allotment or farm. The food is often distributed among the poor and senior citizens of the local community, or used to raise funds for the church, or charity.

Nowadays the festival is held at the end of harvest, which varies in different parts of Britain. Sometimes neighbouring churches will set the Harvest Festival on different Sundays so that people can attend each other's thanksgivings.

Farmers celebrated the end of the harvest with a big meal called a harvest supper. Some churches and villages still have a Harvest Supper.

The modern British tradition of celebrating Harvest Festival in churches began in 1843, when the Reverend Robert Hawker invited parishioners to a special thanksgiving service at his church at Morwenstow in Cornwall. Victorian hymns such as "We plough the fields and scatter", "Come ye thankful people, come" and "All things bright and beautiful" but also Dutch and German harvest hymns in translation helped popularise his idea of harvest festival and spread the annual custom of decorating churches with home-grown produce for the Harvest Festival service.

As British people have come to rely less heavily on home-grown produce, there has been a shift in emphasis in many Harvest Festival celebrations. Increasingly, churches have linked Harvest with an awareness of and concern for people in the developing world for whom growing crops of sufficient quality and quantity remains a struggle. Development and Relief organisations often produce resources for use in churches at harvest time which promote their own concerns for those in need across the globe.

REFERENCES

FAO. 1989. *Prevention of Post-Harvest Food Losses Fruits, Vegetables and Root Crops, a Training Manual.* Rome.

Olaeta-Coscorroza, J.A., and Undurraga-Martínez, P. 1995. Estimación del índice de madurez en paltas. In: *Harvest and Post-harvest Technologies for Fresh Fruits and Vegetables.* Proceedings of the International Conference, Guanajuato, Mexico. February 20-24, 521-425.

Peleg, K. 1985. *Produce Handling, Packaging and Distribution.* The AVI Publishing Co., Westport, Conn, 20-53.

Segre, A. 1998. *Global horticultural impact: Fruits and vegetables in developing countries.* World Conference on Horticultural Research, Rome, Italy, June 17-20.

3

Post-harvest Handling

Postharvest handling is the stage of crop production immediately following harvest, including cooling, cleaning, sorting and packing. The instant a crop is removed from the ground, or separated from its parent plant, it begins to deteriorate. Post-harvest treatment largely determines final quality, whether a crop is sold for fresh consumption, or used as an ingredient in a processed food product.

The most important goals of post-harvest handling are keeping the product cool, to avoid moisture loss and slow down undesirable chemical changes, and avoiding physical damage such as bruising, to delay spoilage. Sanitation is also an important factor, to reduce the possibility of pathogens that could be carried by fresh produce, for example, as residue from contaminated washing water. After the field, post-harvest processing is usually continued in a packing house. This can be a simple shed, providing shade and running water, or a large-scale, sophisticated, mechanized facility, with conveyor belts, automated sorting and packing stations, walk-in coolers and the like. In mechanized harvesting, processing may also begin as part of the actual harvest process, with initial cleaning and sorting performed by the harvesting machinery.

Initial post-harvest storage conditions are critical to maintaining quality. Each crop has an optimum range for storage temperature and humidity. Also, certain crops cannot be effectively stored together, as unwanted chemical interactions can result. Various methods of high-speed cooling, and sophisticated refrigerated and atmosphere-controlled environments, are employed to prolong freshness, particularly in large-scale operations. Regardless of the scale of harvest, from domestic garden to industrialized farm, the basic principles of post-harvest handling for most crops are the same: handle with care to avoid damage (cutting, crushing, bruising), cool immediately and maintain in cool conditions, and cull (remove damaged items).

Once harvested, vegetable and fruit are subject to an active process of decay. Numerous biochemical processes (postharvest physiology) are continuously changing the original composition of the crop until it becomes no longer marketable. The period before drastic change has occurred is defined as the time of "post harvest freshness".Since freshness is an important factor in product quality, its evaluation should rest upon objective methods, but until recently only sensory tests or mechanical and colorimetric, (optical) criteria have been used. A recent study attempted to discover a biochemical marker and fingerprint methods to serve as a freshness index.

MATURITY INDEX FOR FRUITS AND VEGETABLES

The principles dictating at which stage of maturity a fruit or vegetable should be harvested are crucial to its subsequent storage and marketable life and quality. Post-harvest physiologists distinguish three stages in the life span of fruits and vegetables: maturation, ripening, and senescence. Maturation is indicative of the fruit being ready for harvest. At this point, the edible part of the fruit or vegetable is fully developed in size, although it may not be ready for immediate consumption. Ripening follows or overlaps maturation, rendering the produce edible, as indicated by taste. Senescence is the last stage, characterised by natural degradation of the fruit or vegetable, as in loss of texture, flavour, etc. Some typical maturity indexes are described in following sections.

Skin Colour

This factor is commonly applied to fruits, since skin colour changes as fruit ripens or matures. Some fruits exhibit no perceptible colour change during maturation, depending on the type of fruit or vegetable. Assessment of harvest maturity by skin colour depends on the judgment of the harvester, but colour charts are available for cultivars, such as apples, tomatoes, peaches, chilli peppers, etc.

Optical Methods

Light transmission properties can be used to measure the degree of maturity of fruits. These methods are based on the chlorophyll content of the fruit, which is reduced during maturation. The fruit is exposed to a bright light, which is then switched off so that the fruit is in total darkness. Next, a sensor measures the amount of light emitted from the fruit, which is proportional to its chlorophyll content and thus its maturity.

Shape

The shape of fruit can change during maturation and can be used as a characteristic to determine harvest maturity. For instance, a banana becomes more rounded in cross-sections and less angular as it develops on the plant. Mangoes also change shape during maturation. As the mango matures on the tree the relationship between the shoulders of the fruit and the point at which the stalk is attached may change. The shoulders of immature mangoes slope away from the fruit stalk; however, on more mature mangoes the shoulders become level with the point of attachment, and with even more maturity the shoulders may be raised above this point.

Size

Changes in the size of a crop while growing are frequently used to determine the time of harvest. For example, partially mature cobs of *Zea mays saccharata* are marketed às sweet corn, while even less mature and thus smaller cobs are marketed as baby corn. For bananas, the width of individual fingers can be used to determine harvest maturity. Usually a finger is placed midway along the bunch and its maximum width is measured with callipers; this is referred to as the calliper grade.

Aroma

Most fruits synthesize volatile chemicals as they ripen. Such chemicals give fruit its characteristic odour and can be used to determine whether it is ripe or not. These doors may only be detectable by humans when a fruit is completely ripe, and therefore has limited use in commercial situations.

Fruit Opening

Some fruits may develop toxic compounds during ripening, such as ackee tree fruit, which contains toxic levels of hypoglycine. The fruit splits when it is fully mature, revealing black seeds on yellow arils. At this stage, it has been shown to contain minimal amounts of hypoglycine or none at all. This creates a problem in marketing; because the fruit is so mature, it will have a very short post-harvest life. Analysis of hypoglycine 'A' (hyp.) in ackee tree fruit revealed that the seed contained appreciable hyp. at all stages of maturity, at approximately 1000 ppm, while levels in the membrane mirrored those in the arils. This analysis supports earlier observations that unopened or partially opened ackee fruit should not be consumed, whereas fruit that opens naturally to over 15 mm of lobe separation poses little health hazard, provided the seed and membrane portions are removed. These observations agree with those of Brown et al. who stated that bright red, full sized ackee should never be forced open for human consumption.

Leaf Changes

Leaf quality often determines when fruits and vegetables should be harvested. In root crops, the condition of the leaves can likewise indicate the condition of the crop below ground. For example, if potatoes are to be stored, then the optimum harvest time is soon after the leaves and stems have died. If harvested earlier, the skins will be less resistant to harvesting and handling damage and more prone to storage diseases.

Abscission

As part of the natural development of a fruit an abscission layer is formed in the pedicel. For example, in cantaloupe melons, harvesting before the abscission layer is fully developed results in inferior flavoured fruit, compared to those left on the vine for the full period.

Firmness

A fruit may change in texture during maturation, especially during ripening when it may become rapidly softer. Excessive loss of moisture may also affect the texture of crops. These textural changes are detected by touch, and the harvester may simply be able to gently squeeze the fruit and judge whether the crop can be harvested. Today sophisticated devices have been developed to measure texture in fruits and vegetables, for example, texture analysers and pressure testers; they are currently available for fruits and vegetables in various forms. A force is applied to the surface of the fruit, allowing the probe of the penetrometer or texturometer to penetrate the fruit flesh, which then gives a reading on firmness. Hand held pressure testers could give variable results because the basis on which they are used to measure firmness is affected by the angle at which the force is applied. Two commonly used pressure testers to measure the firmness of fruits and vegetables are the Magness-Taylor and UC Fruit Firmness testers. A more elaborate test, but not necessarily more effective, uses instruments like the Instron Universal Testing Machine. It is necessary to specify the instrument and all settings used when reporting test pressure values or attempting to set standards.

The Agricultural Code of California states that "Bartlett pears shall be considered mature if they comply with one of the following: (a) the average pressure test of not less than 10 representative pears for each commercial size in any lot does not exceed 23 lb (10.4 kg); (b) the soluble solids in a sample of juice from not less than 10 representative pears for each commercial size in any lot is not less than 13%". This Code defines minimum maturity for Bartlett pears and is presented in Table 1.

Table 1. Minimum maturity standard of fresh Bartlett pears for selected pear size ranges.

Pear Size	*6.0 cm to 6.35 cm*	*£ 6.35 cm*
Minimum Soluble Solids (%)	*Maximum Test Pressure (kg)*	
Below 10%	8.6	9.1
10%	9.1	9.5
11%	9.3	9.8
12%	9.5	10.0

Table 1 can be simplified by establishing a minimum tolerance level of 13% soluble solids as indicator of a pear's maturity and in this way avoid the pressure test standard control.

Juice Content

The juice content of many fruits increases as the fruit matures on the tree. To measure the juice content of a fruit, a representative sample of fruit is taken and then the juice extracted in a standard and specified manner. The juice volume is related to the original mass of juice, which is proportional to its maturity. The minimum values for citrus juices are presented in Table 2.

Table 2. Minimum juice values for mature citrus.

Citrus fruit	*Minimum juice content (%)*
Naval oranges	30
Other oranges	35
Grapefruit	35
Lemons	25
Mandarins	33
Clementines	40

Oil content and Dry Matter Percentage

Oil content can be used to determine the maturity of fruits, such as avocados. According to the Agricultural Code in California, avocados at the time of harvest and at any time thereafter, shall not contain in weight less than 8% oil per avocado, excluding skin and seed. Thus, the oil content of an avocado is related to moisture content. The oil content is determined by weighing 5-10 g of avocado pulp and then extracting the oil with a solvent in a destillation column (figure 1). This method has been successful for cultivars naturally high in oil content. A round flask is used for the solvent. Heat is supplied with an electric plate and water recirculated to maintain a constant temperature during the extraction process. Extraction is performed using solvents such as petroleum ether, benzene, diethyl ether, etc., a process that takes between 4-6 h. After the extraction, the oil is recovered from the flask through evaporation of the water at 105°C in an oven until constant weight is achieved.

Moisture Content

During the development of avocado fruit the oil content increases and moisture content rapidly decreases. The moisture levels required to obtain good acceptability of a variety of avocados cultivated in Chile are listed in Table 3.

Sugars

In climacteric fruits, carbohydrates accumulate during maturation in the form of starch. As the fruit ripens, starch is broken down into sugar. In non-climacteric fruits, sugar tends to accumulate during maturation. A quick method to measure the amount of sugar present in fruits is with a brix hydrometer or a refractometer. A drop of fruit juice is placed in the sample holder of the refractometer and a reading taken; this is equivalent to the total amount of soluble solids or sugar content. This factor is used in many parts of the world to specify maturity. The soluble solids content of fruit is also determined by shining light on the fruit or vegetable and measuring the amount transmitted. This is a laboratory technique however and might not be suitable for village level production.

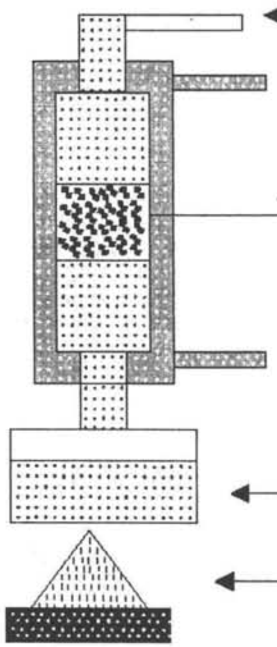

Figure 1. Distillation column used for oil determination

Table 3. Moisture content of avocado fruit cultivated in Chile.

Cultivar	*Moisture content* (%)
Negra de la Cruz	80.1
Bacon	77.5
Zutano	80.5
Fuerte	77.9
Edranol	78.1
Hass	73.8
Gwen	78.4
Whitesell	79.1

Starch Content

Measurement of starch content is a reliable technique used to determine maturity in pear cultivars. The method involves cutting the fruit in two and dipping the cut pieces into a solution containing 4% potassium iodide and 1% iodine. The cut surfaces stain to a blue-black colour in places where starch is present. Starch converts into sugar as harvest time approaches. Harvest begins when the samples show that 65-70% of the cut surfaces have turned blue-black.

Acidity

In many fruits, the acidity changes during maturation and ripening, and in the case of citrus and other fruits, acidity reduces progressively as the fruit matures on the tree. Taking samples of such fruits, and extracting the juice and titrating it against a standard alkaline solution, gives a measure that can be related to optimum times of harvest. Normally, acidity is not taken as a measurement of fruit maturity by itself but in relation to soluble solids, giving what is termed the brix: acid ratio. Sanchez et al. studied the effect of inducing maturity in banana (*Musa sp (L.), AAB*) "Silk" fruits with 2-chloroethyl phosphoric acid ("ethephon"), in some trials in Venezuela. Four treatments (0, 1000, 3000, and 5000 ppm) were applied. The results obtained revealed that the "ethephon" treatments increased the acidity and total soluble solids. The sucrose formation accelerated while the pH was not affected significantly. On the other hand, the relationship of the Brix/acidity ratio was increased according to the "ethephon" dose, as presented in Table 4.

Table 4. Effect of "ethephon" on the maturity index (Brix/acidity ratio) of banana (manzano) "Silk" fruits.

Stage of maturity	*Days*	*Ethephon doses (ppm)*			
		0	*1000*	*3000*	*5000*
Green	1	29.35	23.99	20.59	19.31
Slightly ripen	3	33.27	33.53	58.29	46.27
Slightly ripen	5	51.15	66.44	63.01	57.00
Slightly ripen	7	60.69	69.35	64.31	68.35
Ripen	9	53.27	57.36	54.67	55.42
Variation (%)		81.50	139.10	165.52	187.00

Means with different letters in a row are significantly different at $p<0.05$.

Specific Gravity

Specific gravity is the relative gravity, or weight of solids or liquids, compared to pure distilled water at 62°F (16.7°C), which is considered unity. Specific gravity is obtained by comparing the weights of equal bulks of other bodies with the weight of water. In practice, the fruit or vegetable is weighed in air, then in pure water. The weight in air divided by the weight in water gives the specific gravity. This will ensure a reliable measure of fruit maturity. As a fruit matures its specific gravity increases. This parameter is rarely used in practice to determine time of harvest, but could be used in cases where development of a suitable sampling technique is possible. It is used however to grade crops according to different maturities at post-harvest. This is done by placing the fruit in a tank of water, wherein those that float are less mature than those that sink.

HARVESTING CONTAINERS

Harvesting containers must be easy to handle for workers picking fruits and vegetables in the field. Many crops are harvested into bags. Harvesting bags with shoulder or waist slings can be used for fruits with firm skins, like citrus fruits and avocados. These containers are made from a variety of materials such as paper, polyethylene film, sisal, hessian or woven polyethylene and are relatively cheap but give little protection to the crop against handling and transport damage. Sacks are commonly used for crops such as potatoes, onions, cassava, and pumpkins. Other types of field harvest containers include baskets, buckets, carts, and plastic crates. For high risk products, woven baskets and sacks are not recommended because of the risk of contamination.

TOOLS FOR HARVESTING

Depending on the type of fruit or vegetable, several devices are employed to harvest produce. Commonly used tools for fruit and vegetable harvesting are secateurs or knives, and hand held or pole mounted picking shears. When fruits or vegetables are difficult to catch, such as mangoes or avocados, a cushioning material is placed around the tree to prevent damage to the fruit when dropping from high trees. Harvesting bags with shoulder or waist slings can be used for fruits with firm skins, like citrus and avocados. They are easy to carry and leave both hands free. The contents of the bag are emptied through the bottom into a field container without tipping the bag. Plastic buckets are suitable containers for harvesting fruits that are easily crushed, such as tomatoes. These containers should be smooth without any sharp edges that could damage the produce. Commercial growers use bulk bins with a capacity of 250-500 kg, in which crops such as apples and cabbages are placed, and sent to large-scale packinghouses for selection, grading, and packing.

Packing in the Field and Transport to Packinghouse

Berries picked for the fresh market are often mechanically harvested and usually packed into shipping containers. Careful harvesting, handling, and transporting of fruits and vegetables to packinghouses are necessary to preserve product quality.

Polyethylene bags

Clear polyethylene bags are used to pack banana bunches in the field, which are then transported to the packinghouse by means of mechanical cableways running through the banana plantation. This technique of packaging and transporting bananas reduces damage to the fruit caused by improper handling.

Plastic field boxes

These types of boxes are usually made of polyvinyl chloride, polypropylene, or polyethylene. They are durable and can last many years. Many are designed in such a way that they can nest inside each other when empty to facilitate transport, and can stack one on top of the other without crushing the fruit when full.

Wooden field boxes

These boxes are made of thin pieces of wood bound together with wire. They come in two sizes: the bushel box with a volume of 2200 in^3 (36052 cm^3) and the half-bushel box. They are advantageous because they can be packed flat and are inexpensive, and thus could be non-returnable.

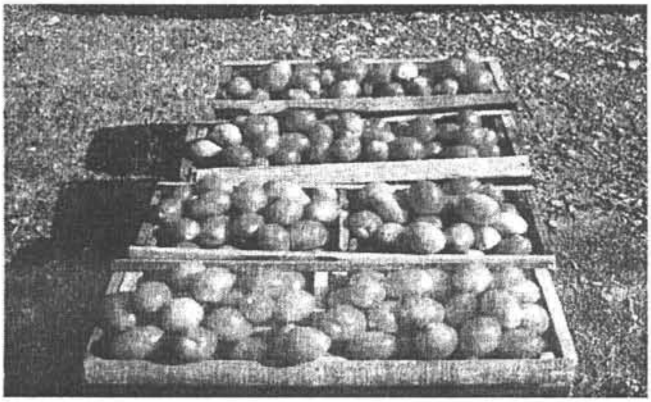

Figure 2. Typical wooden crate holding fresh tomatoes

Bulk bins

Bulk bins of 200-500 kg capacity are used for harvesting fresh fruits and vegetables. These bins are much more economical than the field boxes, both in terms of fruit carried per unit volume and durability, as well as in providing better protection to the product during transport to the packinghouse. They are made of wood and plastic materials. Dimensions for these bins in the United States are 48 × 40 in, and 120 × 100 cm in metric system countries. Approximate depth of bulk bins depends on the type of fruit or vegetable being transported (Table 5)

Table 5. Approximate depth of bulk bins.

Commodity	*Depth (cm)*
Citrus	70
Pears, apples	50
Stone fruits	50
Tomatoes	40

POST-HARVEST HANDLING STRATEGIES

Curing of Roots, Tubers, and Bulb Crops

When roots and tubers are to be stored for long periods, curing is necessary to extend the shelf life. The curing process involves the application of high temperatures and high relative humidity to the roots and tubers for long periods, in order to heal the skins wounded during harvesting. With this process a new protected layer of cells is formed. Initially the curing process is expensive, but in the long run, it is worthwhile. The conditions for curing roots and tubers are presented in Table 6.

Table 6. Conditions for curing roots and tubers.

Commodity	*Temperature (°C)*	*Relative Humidity (%)*	*Storage time (days)*
Potato	15-20	90-95	5-10
Sweet potato	30-32	85-90	4-7
Yams	32-40	90-100	1-4
Cassava	30-40	90-95	2-5

Curing can be accomplished in the field or in curing structures conditioned for that purpose. Commodities such as yams can be cured in the field by piling them in a partially shaded area. Cut grass or straw can serve as insulating material while covering the pile with canvas, burlap, or woven grass matting. This covering will provide sufficient heat to reach high temperatures and high relative humidity. The stack can be left in this state for up to four days.

Onions and garlic can be cured in the field in windrows or after being packed into large fibre or net sacks. Modern curing systems have been implemented in housing conditioned with fans and heaters to produce the heat necessary for high temperatures and high relative humidity, as illustrated below:

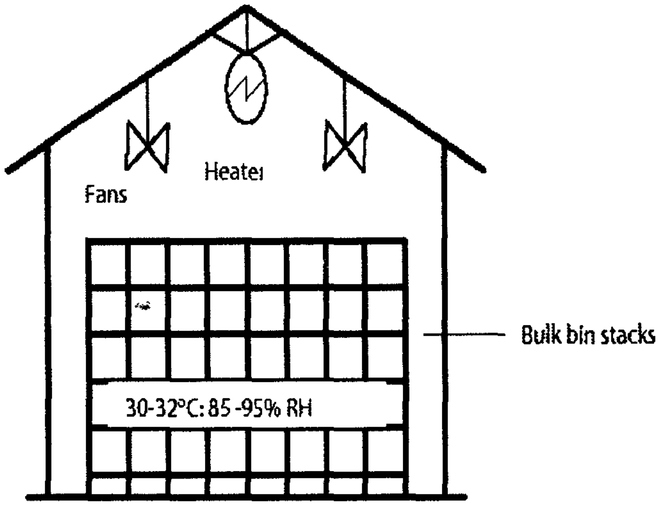

Figure 2. Typical Curing Houses for Roots and Tubers

The fans are used to redistribute the heat to the lower part of the room where the produce is stored. Bulk bins are stacked with a gap of 10 to 15 cm between rows to allow adequate air passage. The system shown in Figure 2 can be used for curing onions; an exhaust opening near the ceiling must be provided for air recirculation. Care should be taken to prevent over-dryness of the onion bulbs. When extreme conditions in the field exist, such as heavy rain or flooded terrain, and curing facilities are not available, a temporary tent must be constructed from large tarpaulins or plastic sheets to cure the onions and avoid heavy loss. Heated air is forced into a hollow area at the centre of the produce-filled bins. Several fans are used to recirculate the warm air through the onions while curing.

Operations Prior to Packaging

Fruits and vegetables are subjected to preliminary treatments designed to improve appearance and maintain quality. These preparatory treatments include cleaning, disinfection, waxing, and adding of colour.

Cleaning

Most produce receives various chemical treatments such as spraying of insecticides and pesticides in the field. Most of these chemicals are poisonous to humans, even in small concentrations. Therefore, all traces of chemicals must be removed from produce before packing. The fruit or vegetable passes over rotary brushes where it is rotated and transported to the washing machine and exposed to the cleaning process from all sides.

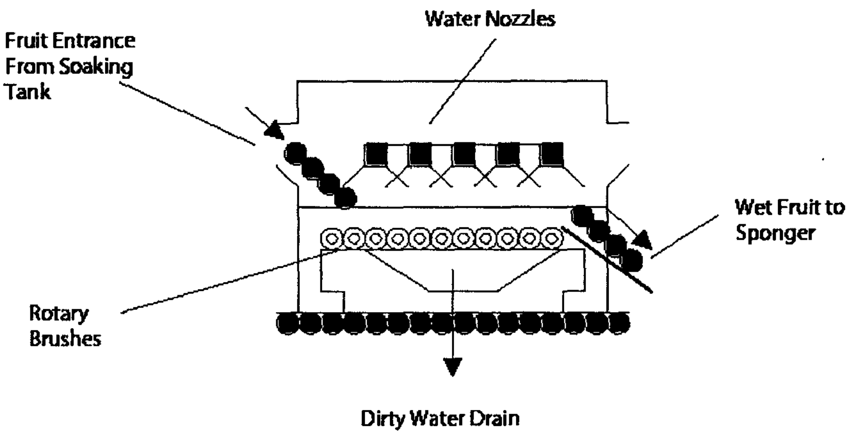

Figure 3. Typical produce washing machine

From the washing machine, the fruit passes onto a set of rotary sponge rollers (similar to the rotary brushes). The rotary sponges remove most of the water on the fruit as it is rotated and transported through the sponger.

Disinfection

After washing fruits and vegetables, disinfectant agents are added to the soaking tank to avoid propagation of diseases among consecutive batches of produce. In a soaking tank, a typical solution for citrus fruit includes a mixture of various chemicals at specific concentration, pH, and temperature, as well as detergents and water softeners. Sodium-ortho-phenyl-phenate (SOPP) is an effective citrus disinfectant, but requires precise control of conditions in the tank. Concentrations must be kept between 0.05 and 0.15%, with pH at 11.8 and temperature in the range of 43-48°C. Recommended soaking time is 3-5 minutes. Deviation from these recommendations may have disastrous effects on the produce, since the solution will be ineffective if the temperature or concentration is too low. Low concentrations of chlorine solution are also used as disinfectant for many vegetables. The advantage of this solution is that it does not leave a chemical residue on the product.

Artificial waxing

Artificial wax is applied to produce to replace the natural wax lost during washing of fruits or vegetables. This adds a bright sheen to the product. The function of artificial waxing of produce is summarised below:

- Provides a protective coating over entire surface.
- Seals small cracks and dents in the rind or skin.
- Seals off stem scars or base of petiole.
- Reduces moisture loss.
- Permits natural respiration.
- Extends shelf life.
- Enhances sales appeal.

Brand name application

Some distributors use ink or stickers to stamp a brand name or logo on each individual fruit. Ink is not permissible in some countries (e.g., Japan), but stickers are acceptable. Automatic machines for dispensing and applying pressure sensitive paper stickers are readily available. The advantage of stickers is that they can be easily peeled off.

Packaging

According to Wills et al., modern packaging must comply with the following requirements:

a) The package must have sufficient mechanical strength to protect the contents during handling, transport, and stacking.

b) The packaging material must be free of chemical substances that could transfer to the produce and become toxic to man.

c) The package must meet handling and marketing requirements in terms of weight, size, and shape.

d) The package should allow rapid cooling of the contents. Furthermore, the permeability of plastic films to respiratory gases could also be important.

e) Mechanical strength of the package should be largely unaffected by moisture content (when wet) or high humidity conditions.

f) The security of the package or ease of opening and closing might be important in some marketing situations.

g) The package must either exclude light or be transparent.

h) The package should be appropriate for retail presentations.

i) The package should be designed for ease of disposal, re-use, or recycling.

j) Cost of the package in relation to value and the extent of contents protection required should be as low as possible.

Classification of packaging

Packages can be classified as follows:

- Flexible sacks; made of plastic jute, such as bags (small sacks) and nets (made of open mesh)
- Wooden crates
- Cartons (fibreboard boxes)
- Plastic crates
- Pallet boxes and shipping containers
- Baskets made of woven strips of leaves, bamboo, plastic, etc.

Uses for above packages

Nets are only suitable for hard produce such as coconuts and root crops (potatoes, onions, yams).

Wooden crates are typically wire bound crates used for citrus fruits and potatoes, or wooden field crates used for softer produce like tomatoes. Wooden crates are resistant to weather and more efficient for large fruits, such as watermelons and other melons, and generally have good ventilation. Disadvantages are that rough surfaces and splinters can cause damage to the produce, they can retain undesirable odours when painted, and raw wood can easily become contaminated with moulds.

Fibreboard boxes are used for tomato, cucumber, and ginger transport. They are easy to handle, light weight, come in different sizes, and come in a variety of colours that can make produce more attractive to consumers. They have some disadvantages, such as the effect of high humidity, which can weaken the box; neither are they waterproof, so wet products would need to be dried before packaging. These boxes are often of lower strength compared to wooden or plastic crates, although multiple thickness trays are very widely used. They can come flat packed with ventilation holes and grab handles, making a cheap attractive alternative that is very popular. Care should be taken that holes on the surface (top and sides) of the box allow adequate ventilation for the produce and prevent heat generation, which can cause rapid product deterioration.

Plastic crates are expensive but last longer than wooden or carton crates.

They are easy to clean due to their smooth surface and are hard in strength, giving protection to products. Plastic crates can be used many times, reducing the cost of transport. They are available in different sizes and colours and are resistant to adverse weather conditions. However, plastic crates can damage some soft produce due to their hard surfaces, thus liners are recommended when using such crates.

Pallet boxes are very efficient for transporting produce from the field to the packinghouse or for handling produce in the packinghouse. Pallet boxes have a standard floor size (1200 × 1000 mm) and depending on the commodity have standard heights. Advantages of the pallet box are that it reduces the labour and cost of loading, filling, and unloading; reduces space for storage; and increases speed of mechanical harvest. The major disadvantage is that the return volume of most pallet boxes is the same as the full load. Higher investment is also required for the forklift truck, trailer, and handling systems to empty the boxes. They are not affordable to small producers because of high, initial capital investment.

Cooling Methods and Temperatures

Several methods of cooling are applied to produce after harvesting to extend shelf life and maintain a fresh-like quality. Some of the low temperature treatments are unsuitable for simple rural or village treatment but are included for consideration as follows:

Precooling

Fruit is precooled when its temperature is reduced from 3 to 6°C (5 to 10°F) and is cool enough for safe transport. Precooling may be done with cold air, cold water (hydrocooling), direct contact with ice, or by evaporation of water from the product under a partial vacuum (vacuum cooling). A combination of cooled air and water in the form of a mist called hyraircooling is an innovation in cooling of vegetables.

Air precooling

Precooling of fruits with cold air is the most common practice. It can be done in refrigerator cars, storage rooms, tunnels, or forced air-coolers (air is forced to pass through the container via baffles and pressure differences).

Icing

Ice is commonly added to boxes of produce by placing a layer of crushed ice directly on the top of the crop. An ice slurry can be applied in the following proportion: 60%

finely crushed ice, 40% water, and 0.1% sodium chloride to lower the melting point. The water to ice ratio may vary from 1:1 to 1:4.

Room cooling

This method involves placing the crop in cold storage. The type of room used may vary, but generally consists of a refrigeration unit in which cold air is passed through a fan. The circulation may be such that air is blown across the top of the room and falls through the crop by convection. The main advantage is cost because no specific facility is required.

Forced air-cooling

The principle behind this type of precooling is to place the crop into a room where cold air is directed through the crop after flowing over various refrigerated metal coils or pipes. Forced air-cooling systems blow air at a high velocity leading to desiccation of the crop. To minimise this effect, various methods of humidifying the cooling air have been designed such as blowing the air through cold water sprays.

Hydrocooling

The transmission of heat from a solid to a liquid is faster than the transmission of heat from a solid to a gas. Therefore, cooling of crops with cooled water can occur quickly and results in zero loss of weight. To achieve high performance, the crop is submerged in cold water, which is constantly circulated through a heat exchanger. When crops are transported around the packhouse in water, the transport can incorporate a hydrocooler. This system has the advantage wherein the speed of the conveyer can be adjusted to the time required to cool the produce. Hydrocooling has a further advantage over other precooling methods in that it can help clean the produce. Chlorinated water can be used to avoid spoilage of the crop. Hydrocooling is commonly used for vegetables, such as asparagus, celery, sweet corn, radishes, and carrots, but it is seldom used for fruits.

Vacuum cooling

Cooling in this case is achieved with the latent heat of vaporisation rather than conduction. At normal air pressure (760 mmHg) water will boil at 100°C. As air pressure is reduced so is the boiling point of water, and at 4.6 mmHg water boils at 0°C. For every 5 or 6°C reduction in temperature, under these conditions, the crop loses about 1% of its weight. This weight loss may be minimised by spraying the produce with water either before enclosing it in the vacuum chamber or towards the end of the vacuum cooling operation (hydrovacuum cooling). The speed and effectiveness of cooling is related to the ratio between the mass of the crop and its surface area. This method is particularly suitable for leaf crops such as lettuce. Crops like tomatoes having a relatively thick wax cuticle are not suitable for vacuum cooling.

Recommended minimum temperature to increase storage time

There is no ideal storage for all fruits and vegetables, because their response to reduced temperatures varies widely. The importance of factors such as mould growth and chilling injuries must be taken into account, as well as the required length of storage. Storage temperature for fruits and vegetables can range from -1 to 13°C, depending on their perishability. Extremely perishable fruits such as apricots, berries, cherries, figs, watermelons can be stored at -1 to 4°C for 1-5 weeks; less perishable fruits such as mandarin, nectarine, ripe or green pineapple can be stored at 5-9°C for 2-5 weeks; bananas at 10°C for 1-2 weeks and green bananas at 13°C for 1-2 weeks. Highly perishable vegetables can be stored up to 4 weeks such as asparagus, beans, broccoli, and Brussels sprouts at -1-4°C for 1-4 weeks; cauliflower at 5-9°C for 2-4 weeks. Green tomato is less perishable and can be stored at 10°C for 3-6 weeks and non-perishable vegetables such as carrots, onions, potatoes and parsnips can be stored at 5-9°C for 12-28 weeks. Similarly, sweet potatoes can be stored at 10°C for 16-24 weeks. The storage life of produce is highly variable and related to the respiration rate; there is an inverse relation between respiration rate and storage life in that produce with low respiration generally keeps longer.

For example, the respiration rate of a very perishable fruit like ripe banana is 200 mL $CO_2.kg^{-1}h^{-1}$ at 15°C, compared to a non-perishable fruit such as apple, which has a respiration rate of 25 mL $CO_2.kg^{-1}$ h^{-1} at 15°C.

High temperatures

Exposure of fruits and vegetables to high temperatures during post-harvest reduces their storage or marketable life. This is because as living material, their metabolic rate is normally higher with higher temperatures. High temperature treatments are beneficial in curing root crops, drying bulb crops, and controlling diseases and pests in some fruits. Many fruits are exposed to high temperatures in combination with ethylene (or another suitable gas) to initiate or improve ripening or skin colour.

Storage

The marketable life of most fresh vegetables can be extended by prompt storage in an environment that maintains product quality. The desired environment can be obtained in facilities where temperature, air circulation, relative humidity, and sometimes atmosphere composition can be controlled. Storage rooms can be grouped accordingly as those requiring refrigeration and those that do not. Storage rooms and methods not requiring refrigeration include: *in situ*, sand, coir, pits, clamps, windbreaks, cellars, barns, evaporative cooling, and night ventilation:

In situ. This method of storing fruits and vegetables involves delaying the harvest until the crop is required. It can be used in some cases with root crops, such as cassava, but means that the land on which the crop was grown will remain occupied and a new crop cannot be planted. In colder climates, the crop may be exposed to freezing and chilling injury.

Sand or coir: This storage technique is used in countries like India to store potatoes for longer periods of time, which involves covering the commodity under ground with sand.

Pits or trenches are dug at the edges of the field where the crop has been grown. Usually pits are placed at the highest point in the field, especially in regions of high rainfall. The pit or trench is lined with straw or other organic material and filled with the crop being stored, then covered with a layer of organic material followed by a layer of soil. Holes are created with straw at the top to allow for air ventilation, as lack of ventilation may cause problems with rotting of the crop.

Clamps. This has been a traditional method for storing potatoes in some parts of the world, such as Great Britain. A common design uses an area of land at the side of the field. The width of the clamp is about 1 to 2.5 m. The dimensions are marked out and the potatoes piled on the ground in an elongated conical heap. Sometimes straw is laid on the soil before the potatoes. The central height of the heap depends on its angle of repose, which is about one third the width of the clump. At the top, straw is bent over the ridge so that rain will tend to run off the structure. Straw thickness should be from 15-25 cm when compressed. After two weeks, the clamp is covered with soil to a depth of 15-20 cm, but this may vary depending on the climate.

Windbreaks are constructed by driving wooden stakes into the ground in two parallel rows about 1 m apart. A wooden platform is built between the stakes about 30 cm from the ground, often made from wooden boxes. Chicken wire is affixed between the stakes and across both ends of the windbreak. This method is used in Britain to store onions.

Cellars. These underground or partly underground rooms are often beneath a house. This location has good insulation, providing cooling in warm ambient conditions and protection from excessively low temperatures in cold climates. Cellars have traditionally been used at domestic scale in Britain to store apples, cabbages, onions, and potatoes during winter.

Barns. A barn is a farm building for sheltering, processing, and storing agricultural products, animals, and implements. Although there is no precise scale or measure for the type or size of the building, the term barn is usually reserved for the largest or most important structure on any particular farm. Smaller or minor agricultural buildings are often labelled sheds or outbuildings and are normally used to house smaller implements or activities.

Evaporative cooling. When water evaporates from the liquid phase into the vapour phase energy is required. This principle can be used to cool stores by first passing the air introduced into the storage room through a pad of water. The degree of cooling depends on the original humidity of the air and the efficiency of the evaporating surface. If the ambient air has low humidity and is humidified to around 100% RH, then a large reduction in temperature will be achieved. This can provide cool moist conditions during storage.

Night ventilation. In hot climates, the variation between day and night temperatures can be used to keep stores cool. The storage room should be well insulated when the crop is placed inside. A fan is built into the store room, which is switched on when the outside temperature at night becomes lower than the temperature within. The fan switches off when the temperatures equalise. The fan is controlled by a differential thermostat, which constantly compares the outside air temperature with the internal storage temperature. This method is used to store bulk onions.

Controlled atmospheres are made of gastight chambers with insulated walls, ceiling, and floor. They are increasingly common for fruit storage at larger scale. Depending on the species and variety, various blends of O_2, CO_2, and N_2 are required. Low content O_2 atmospheres (0.8 to 1.5%), called ULO (Ultra -Low Oxygen) atmospheres, are used for fruits with long storage lives (e.g., apples).

Pest Control and Decay

Crops may be immersed in hot water before storage or marketing to control disease. A common disease of fruits known as anthracnose, caused by the infection of fungus *Colletotrychum spp.* can be successfully controlled in this way. Combining appropriate doses of fungicides with hot water is often effective in controlling disease in fruits after harvesting. Fruit and vegetable decay is also caused by storage conditions. Too low temperatures can cause injury during refrigeration of fruits and vegetables. High temperatures can cause softening of tissues and promote bacterial diseases. The damage that microorganisms inflict on fresh fruits and vegetables is mainly in the physical loss of edible matter, which may be partial or total.

REFERENCES

FAO. 1997. "Guidelines for Small-Scale Fruit and Vegetable Processors". FAO. *Agricultural Service Bulletin* 127. Rome.

Ryall, A.L. and Pentzer, W.T. 1982. *Handling, Transportation and Storage of Fruits and Vegetables.* The AVI Publishing Company, INC. Westport, CT. 2: 98-143.

Thompson, A.K. 1996. *Post-harvest Technology of Fruit and Vegetables.* Blackwell Science, Berlin.

Thayer, D.W. and Rajkowski, K.J. 1999. "Development in irradiation of fresh fruits and vegetables". *Journal Food Technology.* 53(11), 62-65.

Wills, R.B.H., W.B. McGlasson, D. Graham, T.H. Lee, and E.G. Hall. 1989. *Post-harvest: An Introduction to the Physiology and Handling of Fruits and Vegetables.* Van Nostrand Reinhold, New York.

4

Packaging of Horticultural Products

Part of the post-harvest losses of fresh produce in less developed regions are a result of mechanical injuries due to poor handling and inadequate packaging. In more developed marketing systems packages serves also other objectives, such as market penetration, competitiveness. Proper packaging of a product can reduce not only bruising and crushing, but can also improve marketing of produce, reduce moisture loss, prevent (re-)contamination of the product with spoilage organisms, reduce pilferage, maintain a sanitary environment during marketing.

All aspects of packaging must be taken into account when considering the introduction of new packaging. These aspects involve, among others, cost of packaging material, labour, acceptance by trader and consumers and changes in product condition. The ultimate goal of packaging must lead to easier handling of the produce, a better quality and better marketable product.

The characteristics of packaging are to contain, to protect, to communicate and to market the product.

A. *To contain produce*

- As an efficient handling unit, easy to be handled by one person.
- As a marketable unit. e.g. units with the same content and weight.

B. *To protect produce against*

- Rough handling during loading, unloading and transport - rigid crate.
- Pressure during stacking.
- Moisture or water loss with consequent weight and appearance loss.
- Heat: air flow through crate or box via ventilation holes.
- Fumigation possible through ventilation holes.

C. *To communicate:*

- Identification: a label with country of origin, volume, type or variety of product, etc. printed on it.
- Marketing, advertising: recognisable trade name and trademark.

D. *To market the product:*

- Proper packaging will lead to reduced injuries of fruits and vegetables and subsequently to improvement of appearance.
- Standard units (weight, count) of a certain produce will increase speed and efficiency of marketing.
- With reduced costs of transport and handling, stacking and combining of packages into layer units like pallets is possible. A more efficient use of space and reduced losses will lower the marketing costs.
- Labels and slots facilitate inspection.

PACKAGING MATERIALS

Requirements and Functions of Food Containers

The following are among the more important general requirements and functions of food packaging materials/ containers:

a) they must be non-toxic and compatible with the specific foods;

b) sanitary protection;

c) moisture and fat protection;

d) gas and odour protection;

e) light protection;

f) resistance to impact;

g) transparency;

h) tamperproofness;

i) ease of opening;

j) pouring features;

k) reseal features;

l) ease of disposal;

m) size, shape, weight limitations;

n) appearance, printability;

o) low cost;

p) special features.

Primary and Secondary Containers

The terms primary and secondary containers have been used. Some foods are provided with efficient primary containers by nature, such as nuts, oranges, eggs and the like. In packaging these, we generally need only a secondary outer box, wrap, or drum to hold units together and give gross protection.

Other foods such as milk, dried eggs and fruit concentrates often will be filled into primary containers such as plastic liners which are then packaged within protective cartons or drums. In this case the secondary container provided by the carton or drum greatly minimises the requirements that must be met by the primary container.

Except in special instances, secondary containers are not designed to be highly impervious to water vapour and other gases, especially at zones of sealing, dependence for this being placed upon the primary container.

Since primary containers by definition are those which come in direct contact with the food, we will be far more concerned with them than with secondary containers.

Hermetic Closure

Two conditions of the greatest significance in packaging are hermetic and non-hermetic closure.

The term hermetic means a container which is absolutely impermeable to gases and vapours throughout its entirety, including its seams.

Such a container, as long as it remains intact, will automatically be impervious to bacteria, yeasts, moulds, and dirt from dust and other sources since all of these agents are considerably larger than gas or water vapour molecules.

On the other hand, a container which prevents entry of micro-organisms, in many instances will be non-hermetic. A container that is hermetic not only will protect the product from moisture gain or loss, and from oxygen pickup from the atmosphere, but is essential for strict vacuum and pressure packaging.

The most common hermetic containers are rigid metal cans and glass bottles, although faulty closures can make them non-hermetic. With very rare exceptions flexible packages are not truly hermetic for one or more of the following reasons.

First, the thin flexible films, even when they do not contain minute pinholes, generally are not completely gas and water-vapour impermeable although the rates of gas and water vapour transfer may be exceptionally slow; second, the seals are generally good but imperfect; and third, even where film materials may be gas- and water-vapour-tight, such as certain gages of aluminium foil, flexing of packages and pouches leads to minute pinholes and crease holes.

Hermetic rigid aluminium containers can be readily formed without side seams or bottom end seams. The only seam then to make hermetic is the top end double seam, which may be closed on regular tin can sealing equipment.

Glass containers are hermetic provided the lids are tight. Lids will have inside rings of plastic or cork. Many glass containers are vacuum packed and the tightness of the cover will be augmented by the differential of atmospheric pressure pushing down the cover.

Crimping of the covers, as in the case of pop bottle caps which operate against positive internal pressure, also can make a gas-tight hermetic seal. But bottles fail more often than cans in becoming non-hermetic.

PROTECTION OF FOOD BY PACKAGING MATERIALS

Films and Foils; Plastics

Films and foils have different values for moisture and gas permeability, strength, elasticity, inflammability and resistance to insect penetration and many of these characteristics depend upon the film's thickness. Important characteristics of the types of films and foils commonly used in food packaging are given in Table 1.

Table 1. Properties of packaging films

Material	*Properties*
Paper	Strength; rigidity; opacity; printability.
Aluminium foil	Negligible permeability to water-vapour, gases and odours; grease proof, opacity and brilliant appearance; dimensional stability; dead folding characteristics.
Cellulose film (coated)	Strength; attractive appearance; low permeability to water vapour (depending on the type of coating used), gases, odours and greases; printability.
Polythene	Durability; heat-sealability; low permeability to water-vapour; good chemical resistance; good low-temperature performance.
Rubber hydrochloride	Heat-sealability; low permeability to water vapour, gases, odours and greases; chemical resistance.

Cellulose acetate	Strength; rigidity; glossy appearance; printability; dimensional stability.
Vinylidene chloride	Low permeability to water vapour, gases, copolymer odours and greases; chemical resistance; heat-sealability.
Polyvinyl chloride	Resistance to chemicals, oils and greases; heat-sealability.
Polyethylene terephtalate	Strength; durability; dimensional stability; low permeability to gases, odours and greases.

For the most part such films are used in the construction of inner containers. Since they are non-rigid, their main functions are to contain the product and protect it from contact with air or water vapour. Their capacity to protect against mechanical damage is limited, particularly when thin films are considered. These materials can exist in many forms, depending upon such variables as identity and mixture of polymers, degree of polymerisation and molecular weight, spatial polymer orientation, use of plasticisers (softeners) and other chemicals, methods of forming such as casting, extrusion or calendering, etc.

One of the newer classes of plastic materials referred to as copolymers illustrate what can be done with mixtures of the basic units from which plastics are built. The term copolymer refers to a mixture of chemical species in the resin from which films and other forms can be made. The many variations possible make copolymers an important class of plastics to extend the range of useful food packaging applications.

Plastic Sheets

- Cellophane paper can be used for packing of dried products, mainly for dried fruit leathers.
- Polyethylene sheets have a variety of uses. They are flexible, transparent and have a perfect resistance to low temperatures and impermeability to water vapour. An important advantage is that these sheets can be easily heat-sealed. Utilisation is in forms of sheets and bags. It is a good packing material for primary protection of dehydrated products. If a good protection is needed to prevent flavour and gas losses, it will be necessary to combine polyethylene with other materials.

Receptacles and Packagings in Plastic Materials

In this class there are three categories:

a) receptacles that can be heat treated: boxes, bottles and bags. Sterilisable bags used up to 120° C can be manufactured from same raw materials as described under plastic sheets and up to 100° C from cellophane. Polyethylene bags could be used to some extent for packing and pasteurisation of sauerkraut.

b) receptacles that are not heat treated during processing of fruit and vegetables, also divided in bags and boxes. Bags are the most used type of packing from plastic materials and they are manufactured from polyethylene or cellophane; an important utilisation is for dried/dehydrated fruits and vegetables.

c) special packagings - which can be contacted by action of heat once the finished product is already inside the pack and the air is evacuated.

Laminates

Various flexible materials such as papers, plastic films, and thin metal foils have different properties with respect to water vapour transmission, oxygen permeability, light transmission, burst strength, pin holes and crease hole sensitivity, etc. and so multi-layers or laminates of these materials which combine the best features of each are used.

Commercial laminates containing up to as many as eight different layers are commonly custom designed for a particular product.

Laminations of different materials may be formed by various processes including bonding with a wet adhesive, dry bonding of layers with a thermoplastic adhesive, hot melt laminating where one or both layers exhibit thermoplastic properties, and special extrusion techniques. Such structured plastic films may be complete in themselves or be further bonded to papers or metal foils to produce more complex laminates.

GLASS CONTAINERS

As far as food packaging is concerned, glass is chemically inert, although the usual problems of corrosion and reactivity of metal closures will of course apply. The principal limitation of glass is its susceptibility to breakage, which may be from internal pressure, impact, or thermal shock, all of which can be greatly minimised by proper matching of the container to its intended use and intelligent handling practices. Here consultation with the manufacturer cannot be over-stressed.

The heavier a jar or bottle for a given volume capacity the less likely it is to break from internal pressure. The heavier jar, however, is more susceptible to both thermal shock and impact breakage. Greater thermal shock breakage of the heavier jar is due to wider temperature differences which cause uneven stress between the outer and inner surfaces of the thicker glass. Greater impact breakage susceptibility of the heavier jar is due to the lower resilience of its thicker wall.

Coatings of various types can markedly reduce each of these types of breakage. These coatings, commonly of special waxes and silicones, lubricate the outside of the glass. As a result, impact breakage is lessened by bottles and jars glancing off one another rather than sustaining direct hits when they are in contact in high speed filling lines.

Surface coating after annealing protects glass surfaces from many of the minute scratches appearing in normal handling after annealing ovens; surface coating also improves the high gloss appearance of glass containers and is said to decrease the noise from glass to glass contact at filling lines.

With regard to thermal shock, it is good practice to minimise temperature differences between the inside and outside of glass containers whenever possible. Some manufacturers will recommend that a temperature difference of 44° C (80° F) between the inside and the outside not be exceeded. This requires slow warming of bottles before use for a hot fill and partial cooling before such containers are placed under refrigeration.

Classification

Glass used for receptacles in fruit and vegetable processing is a carefully controlled mixture of sand, soda ash, limestone and other materials made molten by heating to about 1500° C (2800° F). Main classes of glass receptacles are:

a) jars which are resistant to heat treatments,

b) jars, glasses, etc. for products not submitted to heat treatment (marmalades, acidified vegetables, etc.);

c) glass bottles for pasteurised products (tomato juice, fruit juices, etc.) or not pasteurised (syrups) and

d) receptacles with higher capacity (flasks, etc.)

Jars for sterilised/pasteurised canned products

These receptacles may replace metal cans, taking into considering both the advantages and disadvantages they present. Advantages are: they do not react to food content; they are transparent and can be manufactured in various shapes; they use cheap raw materials and are reusable. Disadvantages: heavier than metal can of same capacity; fragile; lower thermal conductance and a limited resistance to thermal shocks. Receptacles in this category must assure a perfect hermeticity after their pasteurisation/sterilisation and cooling and this has to be achieved by the use of metallic (or glass) caps and specific materials for tightness. Taking into account the receptacles' closure method, there are two categories of receptacles:

a) glass jars with mechanical closure.

b) glass jars with pneumatic closure.

Jars for products without heat treatment

For marmalades, jellies and jams glass jars with non hermetic closures using metal, glass or rigid plastic caps are used; however for these products the receptacles mentioned above may also be used.

The use of jars with pneumatic closure presents the advantage that some products (e.g. marmalades, jams) can be filled hot and therefore sterile in receptacles. Pneumatic closing generally protects against negative air action which is in this case eliminated from receptacles.

Glass bottles

These receptacles are widely used both for

a) finished products which need pasteurisation (ea. tomato juice, Knit juices, etc.) and for

b) those which are preserved as such (ea. fruit syrups).

Glass bottles in category: a) are closed hermetically with metallic caps, provided with special materials for tightness. For glass bottles in category b) various corks, and aluminium caps with tightness materials may be used.

Glass receptacles with high capacity

In this category there are glass flasks with 3 and 10 litre capacity which can be hermetically closed by a SKO caps system and are resistant to product pasteurisation (ea. tomato juice).

As bigger receptacles it is possible to use glass demijohns with usual capacity of 25 and 50 litre; these receptacles are used for preservation of fruit juices by warm process. Closing is performed with flexible rubber hoods.

PAPER PACKAGING

As primary containers few paper products are not treated, coated or laminated to improve their protective properties. Paper from wood pulp and reprocessed waste paper will be bleached and coated or impregnated with such materials as waxes, resins, lacquers, plastics, and laminations of aluminium to improve water vapour and gas impermeability, flexibility, tear resistance, burst strength, wet strength, grease resistance, sealability, appearance, printability, etc.

Paper sheets

— Kraft paper is the brown unbleached heavy duty paper commonly used for bags and for wrapping; it is seldom used as a primary container;

- parchment paper: acid treatment of paper pulp modifies the cellulose and gives water and oil resistance and considerable wet strength to this type of packaging material;
- glassine-type papers are characterised by long wood pulp fibres which impart increased physical strength;
- paper with plastic material sheets.

"Tin can"/tinplate

The "tin can" is a container made of tinplate. Tinplate, a rigid and impervious material, consists of a thin sheet of low carbon steel coated on both sides with a very thin layer of tin. It can be produced by dipping sheets of mild steel in molten tin (hot-dipped tinplate) or by the electro-deposition of tin on the steel sheet (electrolytic tinplate). With the latter process it is possible to produce tinplate with a heavier coating of tin on one surface than the other (differentially coated).

Tin is not completely resistant to corrosion but its rate of reaction with many food materials is considerably slower than that of steel. The effectiveness of a tin coating depends on:

a) its thickness which may vary from about 0.5 to 2.0 μm (20 to 80 x 10(-6) in.);
b) the uniformity of this thickness;
c) the method of applying the tin which today primarily involves electrolytic plating;
d) the composition of the underlying steel base plate;
e) the type of food, and
f) other factors.

Some canned vegetables including tomato products actually owe their characteristics flavours to a small amount of dissolved tin, without which these products would have an unfamiliar taste. On the other hand, where tin reacts unfavourably with a particular food the tin itself may be lacquer coated.

The thickness of tinplate sheets may vary from 0.14 mm to 0.49 mm and is determined by weighing a sheet of known area and calculating the average thickness.

Tinplate sheets may be lacquered after fabrication to provide an internal or external coating to protect the metal surface from corrosion by the atmosphere or through reaction with the can contents. They may also be printed by lithography to provide suitable instructions or information on containers fabricated from tinplate sheets.

Under normal conditions the presence of the tin coating provides a considerable degree of electrochemical protection against corrosion, despite the fact that in both types of tinplate the tin coating is discontinuous and minute areas of steel base plate are exposed. With prolonged exposure to humid conditions, however, corrosion may become a serious problem.

Common organic coatings of FDA approved materials and their uses are indicated in Table 2.

The coatings not only protect the metal from corrosion by food constituents but also protect the foods from metal contamination, which can produce a host colour and flavour reactions depending upon the specific food. Particularly common are dark coloured sulphides of iron and tin produced in low acid foods that liberate sulphur compounds when heat processed, and bleaching of red plant pigments in contact with unprotected steel, tin, and aluminium.

Table 2. General types of can coatings

Coating	*Typical uses*	*Type*
Fruit enamel	Dark coloured berries, cherries and other fruits requiring protection from metallic salts	Oleoresinous
C-enamel	Corn, peas and other sulphur-bearing products	Oleoresinous w. suspended zinc oxide
Citrus enamel	Citrus products and concentrates	Modified oleoresinous
Beverage can enamel	Vegetable juices; red fruit juices; highly corrosive fruits; non-carbonated beverages	Two-coated w. resinous base coat and vinyl top coat.

PACKAGING AND POST-HARVEST LOSSES

Post-harvest losses are losses occurring in the period between harvesting and consumption. The term 'losses' in the context of this manual is used in a wider sense, including all types of losses for the farmer, trader and consumer (e.g. weight loss, quality loss, financial loss, loss of goodwill, loss of marketing opportunities, loss of nutritional value, etc.).

The distribution system for fresh produce in the Eastern Caribbean is complex. The movement of the produce from the farm to the consumer consists of many handling steps, uses low technology and is in the hands of many small traders. These factors, amongst others and combined with the high perishability of fresh produce, are contributing to high spoilage and unnecessary loss of produce.

Post-harvest losses are generally classified according to their primary causal agent. Frequently a post-harvest loss is a result of multiple causes and a succession of malpractices along the marketing chain.

Mechanical Injuries

Losses caused by mechanical injuries include cuts, bruises, abrasions and punctures and can be categorised into four major types of injuries.

a) Impact injuries, resulting from:

- dropping the product onto a hard surface;
- dropping the product into the back of a car;
- excessive drops during loading and unloading;
- suddenly stopping or accelerating a vehicle.

Loading and unloading is mostly done by hand, whereby crates are thrown into the pick-up, on board and into the hold.

Proper, rigid packages possibly with cushioning of each item within the package can reduce these impact losses

b) Vibration or abrasion injuries result when produce is able to move within a container because of:

- vehicles with small wheels and bad shock-absorbers;
- weak crates;
- bad roads;
- transmission vibration.

Fields in isolated hilly areas cannot always be reached by vehicles, so that produce has to be carried from the field to the road or track, which are often in a bad condition. Trucks and pick-ups used on these roads are also often in a bad condition. Tight filling of the crates can decrease the vibration of produce within the boxes and consequently reduce the injury. If the box is not completely filled with produce, it is suggested to use for instance shredded paper to tight-fill the box. Over-tight filling can lead to compression injury.

c) Compression injuries are caused by improper packing and inadequate package performance resulting from:

- over-packing of crates and boxes;

- too high stacking of crates;
- weak packaging.

A high stack of (weak) crates or baskets leads to bulging and consequently to compression of the produce inside.

Rain or sea water can weaken the strength of carton boxes resulting in more compression injuries on the produce.

d) Puncturing injuries resulting from:
- nails or splinters from the crate or box;
- fingers or nails of a person;
- other crates, fork-lifts, etc.
- hard and sharp stalks of fruit.

Baskets and old wooden crates and some of the plastic crates often have sharp edges which can easily damage the produce. Rigid crates with proper grips can reduce the incidence of puncturing.

Physical and Environmental Factors

Physical and environmental losses include the various responses of produce to excessive or insufficient heat, cold, gases or humidity.

Proper packaging is required to allow ventilation and heat exchange to maintain proper temperature level, to reduce the air and gas exchange (oxygen, carbon dioxide, ethylene) and to minimise water loss.

Holes in cartons should be at least five percent of the total box surface to allow for ventilation. Consumer packages slow the respiration rate by maintaining low oxygen and high carbondioxyde levels, protect the produce from ethylene and odour absorption and reduce the waterlogs.

Biological and Microbiological Losses

Biological and microbiological losses refer to the consumption of or damage to produce by insects, birds, rodents, bacteria, etc. Correct packaging, stacking and storing can reduce the incidence of this type of losses.

(Bio-)Chemical and Physiological Losses

Chemical and biochemical losses include undesirable reactions between chemical compounds and contamination with harmful substances such as certain pesticides.

Treating the timber for the wooden crates incorrectly may influence the quality of the produce. An example of losses due to physiological reactions is the sprouting of tubers.

Indirect Causes of ost-harvest Losses

Indirect or secondary causes of post-harvest losses are losses due to external factors. Packaging can improve marketability and handling, thus decreasing losses. Some indirect causes of post-harvest losses are:

a. *Consumers' demand.* Promotional campaigns for local produce could include nice looking packaging material.

b. *Inadequate marketing systems.* The large number of people involved in marketing of produce regionally contributes to greater losses since every person is responsible for a step in the marketing chain, often resulting in delayed marketing of produce. Suitable, uniform packaging with control of the content could speed up the flow of produce through the marketing channels.

d. *Facilities.* Limited access exists to facilities such as stores, coldrooms, drying and curing rooms. Improved packaging will contribute to more efficient handling in and use of these facilities. More efficient use of these facilities will reduce the cost and thus decrease the price of the produce.

   Transport of fresh produce in the Eastern Caribbean is not adequate and rather costly. In general, small pickups are used to transport produce from the farm to the port and wooden schooners are used for the transport between the islands. Produce is stowed up to three meters high in the hold without any physical protection. Deck cargo is either not protected against sun, rain or sea water, or is completely sealed in canvas preventing an airflow and suffocating the produce.

   As long as small pickups and wooden schooners are used for transport standardised packaging cannot be introduced successfully.

e. *Policy changes (e.g. agricultural diversification, quality standards, price policy).* Change of supply can be caused by for example seasonality, large imports or by Government policies like the ban Barbados placed on imports of mangoes from Dominica and St. Lucia due to mango seedweevil pest.

   Government rules can force a trader to use special type of packaging such as carton boxes required for the French speaking islands.

f. Lack of training and awareness among people involved in the marketing system.

g. Underdeveloped infrastructure (roads, harbour facilities).

h. *Cost of transport.* The inter-island freight cost is paid per unit, whether it is a box, crate or basket. These units are made as large as possible and packed as full as possible in order to save on transport costs. As a result product losses are high and crates are too heavy and too large to be carried by one person.

i. Unreliable supplies of packaging or high cost of packaging.

CLASSIFICATION AND DESIGNS FOR PACKAGING

There are many different types of package in use throughout the world, many of which have been carefully evaluated with respect to produce and market system, while other types have often been adopted for general use without thorough evaluation. Changes to improve such packages are still required. Some different types of package include:

1. *Sacks:* flexible, made of plastic or jute.
   i) bags: small size sack
   ii) nets: sacks made of open mesh
2. Wooden crates.
3. Carton or fibreboard boxes.
4. Plastic crates.
5. Pallet boxes and shipping containers.
6. Baskets: made of woven strips of leaves, bamboo, plastic, etc.

Sacks and Nets

Materials

The materials used for sacks and nets may be woven natural fibre (jute, kenaf, sisal, cotton), woven synthetic (polypropylene, polyethylene), knitted natural fabric (cotton), knitted synthetic (polyethylene) or non-woven synthetic (propylene).

Advantages and disadvantages of sacks and nets

The advantages of using sacks and nets are merely financial. The sacks and nets are cheap, have a low weight/volume ratio and, if made of a synthetic material, will not rot.

The disadvantages include a low protection against puncturing, compression, vibration and impact injuries such as dropping, difficult stacking, a low rate of vapour transmission and the need of special stitching equipment.

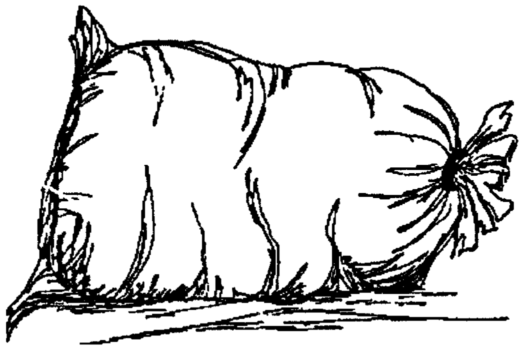

Figure 1. Packaging in a sack

In general, nets are only suitable for hard produce such as coconuts and root crops (potatoes, onions).

Wooden Crates

Advantages and disadvantages

Commonly used are wirebound crates for citrus/potatoes, wooden trays for tomatoes and wooden field crates.

The advantages of wooden crates are:

- The crates can be manufactured and repaired locally.
- Wood is relatively resistant to different weather conditions and (sea)water.
- Wooden crates are often used on more than one journey and have a higher efficiency for larger fruits, e.g. watermelons.
- Most crates have good ventilation and fast pre-cooling is possible.

Disadvantages of wooden crates are:

- Untreated wood can easily become contaminated with fungi and bacteria.
- Treatment of wooden crates with paint or other chemicals may cause produce deterioration.
- The material may be too hard or rough for produce like soft fruits, and therefore liners of a soft material may be needed.

– Disposal of the crates after use.

– Manufacturing of wooden crates puts an extra claim on the natural forest resources.

Design

A wooden crate consists of rigid corners with planks nailed or stretched against those corners. Plank thickness varies normally between 3 and 8 mm. Cutting the wood will result in loss due to the saw thickness (2-3 mm). A slicing machine can be used for thin planks up to 6 mm but these machines are expensive. There are several different constructions possible for wooden crates:

a) *Nailed crates: (e.g. apple or pear crate, field crate):* Nailed crates are rigid and strong boxes which serve as multi-trip containers with a long life time.

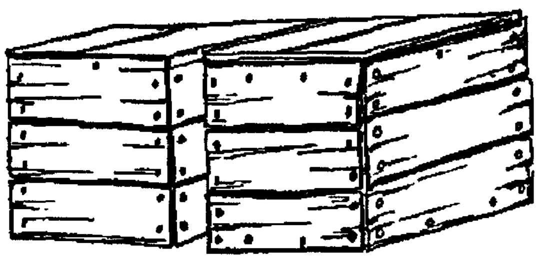

Figure 2. Nailed crates

The planks have a thickness of at least 6 mm. Because of the rigidity the crate is quite heavy and the initial cost is high compared to, for instance, wirebound crates. Spacing between the planks, (bottom, sides) and/or between top side plank and the bottom of the next crate creates is recommended for good ventilation.

Nailed crates are frequently used for domestic transport e.g. as a field crate or as a crate to transport produce from the producer to the wholesaler or trader.

Water has no direct influence on the strength of the crate, but rot will. An advantage of nailed crates is the possibility to repair the crate.

Disadvantages of the rigid nailed crate include the high return freight volume. A partial solution to this problem is to put one crate in two other crates which are placed opposite each other; so three empty crates will take up the space of two stacked crates.

b) *Stitched crates: (tomato)* Stitched crates are made of thin (3-4 mm) pieces of wood stitched together. Corner pieces, mostly triangular, provide the necessary strength to stack crates. This type of crate is mainly used for single journeys.

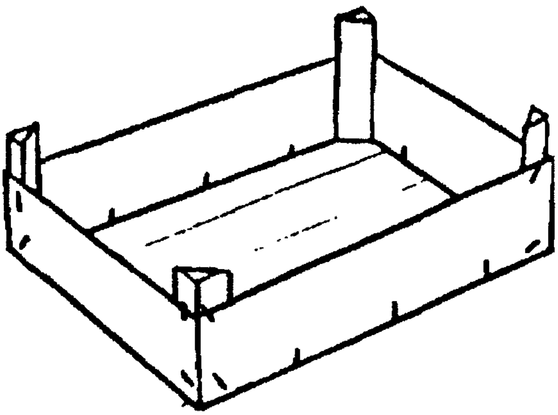

Figure 3. Stitched crate

c) *Wirebound crates: (orange crate, grapefruit crate, potato crate):* As a rigid, cheap crate with a good stacking strength it is mainly used for single journeys. Wirebound crates are stitched crates with a wire under the stitches which gives extra strength to the container. The wire also serves as a hinge and as a lock for the lid. These crates provide good ventilation and fast pre-cooling is possible. The price of these crates is low.

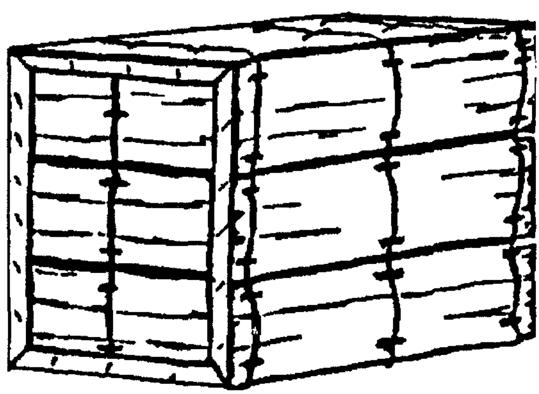

Figure 4. Wirebound crate

Using them carefully, wirebound crates are capable of sustaining several journeys, which is proven by the (re-)use of Dutch wirebound potato crates in the inter-island trade.

d) *Wooden collapsible crate (TDRI):* A wooden crate was designed by the Tropical Development and Research Institute (TDRI) for the huckster trade from Dominica. It consists of a removable top and bottom part and the crate can be folded using the hinges on the corners. The crate performed well in trials and it was possible to make up to twelve trips to other islands using the same crate. The price in 1987 was around US$ 8.00.

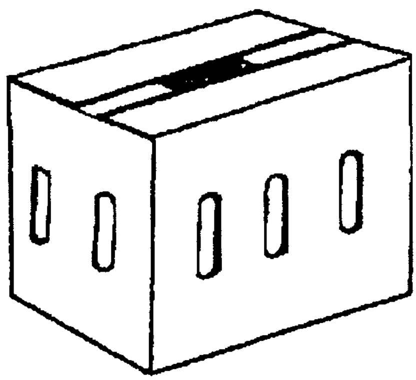

Figure 5. Wooden collapsible crate

Fibreboard Boxes

Fibreboard boxes are frequently used because of their low weight, their range of sizes and shapes and their availability.

Materials

a) *Solid fibreboard boxes (cartons):* have a thickness between 0.85 and 3 mm. If treated with wax these boxes are reasonably moisture resistant. The boxes are used for tomato, cucumber and ginger transport. Most of them are printed with attractive colours, a brand name and a label. The information can be stamped on this label after filling the box.

b) *Corrugated fibreboard boxes:* have a thickness varying from 1.2 up to 8 mm. The strength of corrugated fibreboard is determined by the type of fluting material, the type of facing material and its thickness and a single or double wall. Fluting and facings are kept in place by water resistant glue.

New box designs are usually tested for bursting strength, puncture strength, flat crush strength and edge crush (stacking) strength and it is advisable to use only such tested designs.

Advantages and disadvantages

Advantages of fibreboard boxes:

- Low weight and easy to handle.
- The relatively soft walls have a cushioning effect.
- The box can have any design, although it is recommended to use sizes fitting on the standard design of pallets.
- The boxes are delivered flat and assembling boxes can be done locally.
- The box has a low purchase cost.
- The material can be printed to give the box a pleasant and recognisable appearance. Also the label can be included in this print.

Disadvantages of fibreboard boxes:

- Moisture and high humidity can seriously weaken the box. Washed produce should be dried before putting it into the box. Empty boxes should be stored in a dry place preferably flat on top of pallets and not for long periods of time. For certain commodities waxed carton boxes are preferred.
- The low rigidity causes the stacking strength to be lower than for wooden or plastic crates. The fibreboard boxes are easily damaged by rough handling and ropes and too much weight on top of the box can crush the perishable produce inside.
- Ventilation holes are usually small, because large holes would seriously influence the strength of the box. It is advised that the hole surfaces are at least 5 percent of the total box surface. Decreasing the size of the holes by not properly closing telescope boxes or not properly stacking the boxes will decrease heat exchange, resulting in higher temperatures of the produce and increased spoilage. Vertical oblong slots, instead of round holes, have the advantage that the hole stays partly open even when the telescope box lid is not completely closed.
- The boxes are not re-usable.

Plastic Crates

In general, plastic crates are more expensive than wooden crates or carton boxes, but as a result of their longer life span the running costs are relatively low. Of course the possibility of pilferage of the crates should be taken into account when considering purchase of this type of packaging.

The hard surfaces have no cushioning effect, but, on the other hand, a hard, smooth surface is easy to clean and gives good protection to the produce.

Materials

Plastic crates are usually made of high density polyethylene (HDPE) or polypropylene (PP). Polyethylene has a higher impact strength and a low degradation by ultra-violet radiation while polypropylene has a better scratch resistance. The performance of both materials can be improved by adding anti-oxidants and UV protectants (for sunlight protection).

Advantages and disadvantages

Advantages of plastic crates:

- As a strong, rigid crate these plastic crates can be used for many journeys, making the cost per journey relatively low.
- Different sizes and shapes are available to suit different customers needs. Colours can be used for marketing purposes.
- The containers are easy to clean and to disinfect.
- Plastic crates are strong and weather resistant and, because of their water resistance, the containers can be used in humid areas and during hydro-cooling.

Disadvantages of plastic crates:

- The hard surfaces can damage the produce and it is advised to use liners.
- The high purchase cost combined with the risk of pilferage could make this type of crate a financial risk.
- These crates generally have to be imported.
- Because this crate can be used several times, the extra cost for the return trip should be included in the total running cost.
- The loss of space (40-80 mm on the sides and around 10 mm from the height).

Design

Plastic crates can have a stacking, a stack-nest or a collapsible design, the differences being particularly important when the crate is transported empty, since the volume determines the price to be paid for transport.

Collapsible plastic crates are the most expensive crates to purchase followed by stack-nest plastic crates and then the stacking crates. Prices F.O.B. in 1987 for a plastic crate with a size of 600 x 400 x 300 mm were respectively around US$ 25.-, US$ 13.- and US$ 11.-. It should be mentioned here that a similar size stacking crate can be purchased in Venezuela for approximately F.O.B. US$ 5.20 (1988 price).

a) *Stacking crates:* Because of the squared design with only the corner slightly rounded, an efficient use of available space is possible. Depending on the size of the crate, the loss of loading space compared with loose break bulk is between 20 and 30 percent.

   Although stacking crates have a rigid design, some space during the return trip can be gained by putting one crate inside two others and in order to overlap crates during stacking some space gaps in the rim of the crate are needed.

b) Stack-nest crates:

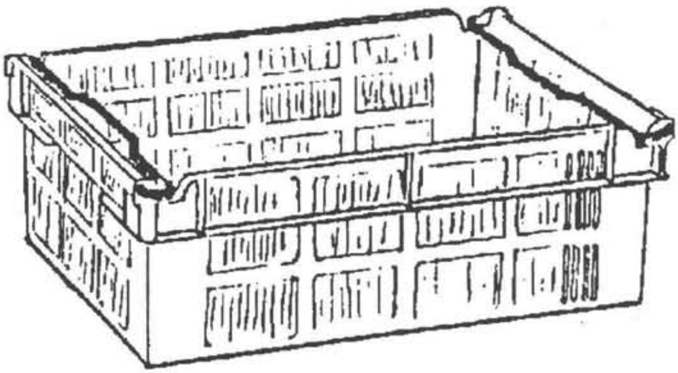

Figure 6. Stack-nest crate

   i) *Stack-nest crate with swing bars.* Because of its vertically tapered shape the inside volume of a stack-nest crate is less than that of a crate with a squared design. Effective loading space is 5080 percent depending on the size of the crate. With the swing bar design five nested crates will use up the space of two stacked crates of the same size. If the bars are swung out the crates can be nested. A swing bar (9 mm) is swung from the outside or from the side over the top of the crate and forming a support for the following crate. The stack-nest crate is slightly weaker than the stack crate, because the bar is not resting on the corners (the strongest part of the crate) but on the long side of the crate. The swing bar is placed 1 to

2 cm under the rim of the crate and stacking is therefore easy. The crate on top should be placed within this rim. Sometimes a provision is made on the bottom side of the crate for the swine bar to fit in.

ii) *Stack-nest crate with cover.* Instead of the swing bar, the crate is closed by two cover parts on top of which the next crate can be stacked. An advantage is that this cover can be sealed, preventing pilferage of produce. The crates with cover are up to 50 percent more expensive than the ones without a cover.

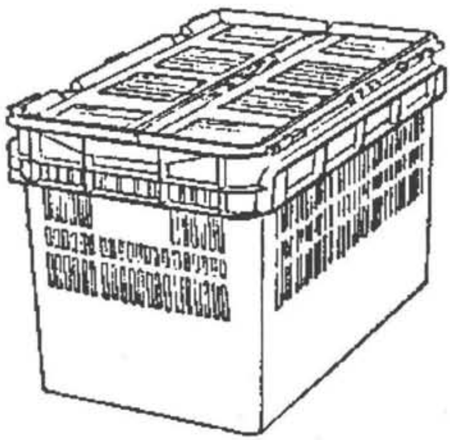

Figure 7. Stack-nest crate with cover

iii) *180° stack-nest crate.* By making supports at several places inside the box, the box can be stacked and in a 180 degrees turned position be nested. These supports require extra space and dirt will assemble in the corners created by the supports.

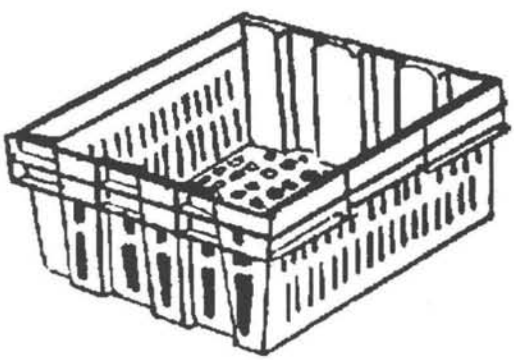

Figure 8. 180° stack-nest crate

c) *Collapsible crates:* A collapsible crate consists of a base with sides attached to it by plastic or metal hinges. Despite the saving of space when folded and their attractive design, this crate is generally not accepted in trade, most likely because of the high purchase cost.

Pallet Boxes

Where conditions like the size of the field, the method of harvesting, the level of processing and packaging and the commodity allow better transport and storage, a higher efficiency can be reached by using pallet boxes.

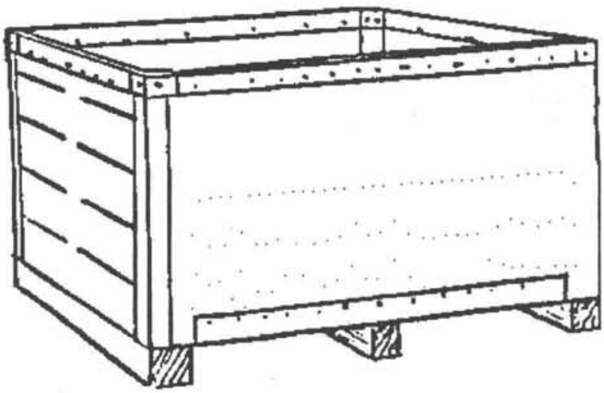

Figure 9. Pallet box

Pallet boxes have the standard floor size of a pallet (1200 x 1000 mm)and, depending on the commodity, have standard heights.

Advantages of a pallet box system:

- Less manual handling and thus reduced cost in loading, filling and unloading (e.g. citrus harvest).
- More efficient use of available storage as compared to smaller crates.
- Increased speed of mechanical harvest.

Disadvantages of a pallet box system:

- The return volume of most of the pallet boxes is the same as the full load.
- The system requires higher investments in fork-lift trucks, trailers and handling systems to empty the pallet box.

- Because of the larger volumes, the produce is more easily injured during filling and unloading and the top layers will have made more movements during transport than when packed in smaller boxes.

UNITISATION AND STANDARDISATION

A unit is a certain quantity or volume chosen as a standard. Several units can be combined to one larger unit (e.g. pallet) or divided into smaller sub-units (e.g. consumer packages). The advantages of a system where all involved use the same standard sizes and preferably the same type of packaging are:

- A uniform handling method and the use of combined, larger, quantities at one time, resulting in reduction of handling time, labour cost and damage to the produce.
- If the produce in the combined unit (e.g. a pallet full of boxes with oranges) has the same quality grade, this combined unit can be marketed as a whole.
- Standard units will have standard shipping tariffs.
- Higher production volumes of crates of only a few sizes will decrease the cost per crate, decrease the storeroom size for the different crates and guarantee a more stable supply of crates.

Combined units are of course most efficiently used if larger quantities of one commodity are transported. Nonetheless, even a small trader with uniform size crates or boxes can benefit from standardisation.

In Europe there is a move towards the ISO/OECD1 standards and the United States Department of Agriculture is supporting the MUM standards in the United States. Both standards are more or less similar using the standard size pallet of 1200 x 1000 mm.

Pallets and Containers

The most common pallet sizes are 1200 mm x 1000 mm and 1200 mm x 800 mm. A standard pallet with sizes 48 x 40 inches (1219 mm x 1016 mm), as used in the United States, is comparable to the 1200 mm x 1000 mm pallet and integrates very well into the metric system. The use of pallets and standard boxes will reduce handling of the boxes and therefore save handling time and reduce post-harvest losses.

The boxes on the pallet should be aligned in such a way that the ventilation holes of the different boxes are aligned and thus air can flow through the stack. Boxes stacked on the pallet should be secured with posts on the four corners tied together with a rope or with a net over the stack or with glue between the boxes or with tape around and over the stack. Pallets loaded with rigid wooden or plastic crates can be stacked on top of each other. A higher utilisation grade of the store may be reached since the height of the storeroom is fully utilised.

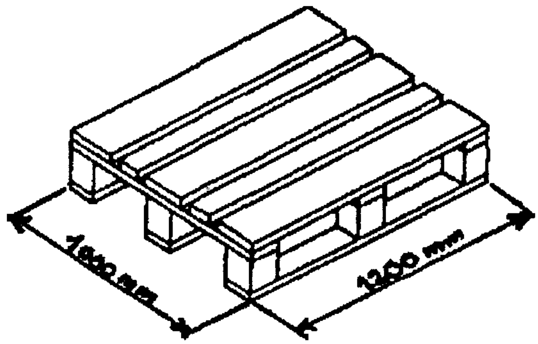

Figure 10. Pallets and containers

Sometimes pallets do not fit properly in containers or on trailers, resulting in a loss of available transport space. Shipping containers usually have the following dimensions:

Type of container	*Size*	*Dimensions*	
Twenty foot	External	20 x 8 x 8 feet	(6.10 x 2.44 x 2.44 m)
Internal			(5.29 x 2.18 x 2.02 m)
Forty foot	External	40 x 8 x 8 feet	(12.19 x 2.44 x 2.44m)
Internal			(11.33 x 2.28 x 2.19 m)

Trailers have according to traffic regulations a maximum outside width of 2.60 meter. With thin, high quality insulation it is just possible to position the pallets in the refrigerated trailer with one pallet using the width (1.20 meter) and one pallet the length (1.00 meter), using a total width of 2.20 meter.

Where containers or smaller trailers are used, pallets should be positioned in the length, thus using only 2.00 meter of the width. In any case, it is advisable to keep some space between the (hot) wall and the crates. The cold air in the refrigerated container or trailer will form a barrier between the hot wall and the produce. The use of pallets requires investment in handling and transport devices such as fork-lifts, trucks, hand carts and loading forklift devices on a ship. Also the vessels should have a preferably squared hold to reach the highest efficiency possible, when loading the pallets. Thus practically none of the vessels currently used in the inter-island trade are suitable for loading with palletised loads.

Standards for Packages

The International Standard Organisation (ISO) gives a series of dimensions for rigid rectangular packages based on a standard plan dimension or module of 600 x 400 mm.

This is the external size of a package unit when fully loaded (including 'bulge'). No plus tolerance is allowed, although a minus tolerance of up to 10 mm is accepted. ISO standard 3394 gives a most complete picture of multiples and submultiples divided from the module size.

Both the OECD and MUM standards have pallet size 1200 mm x 1000 mm as a standard unit and derive the sub-multiples from these sizes. The OECD and MUM standards are less comprehensive than the ISO standard.

Recommended sizes in mm for OECD and MUM standards are:

	OECD	*MUM*
Pallet size (mm)	1200 x 1000	1200 x 1000
	1200 x800	-
Box size (mm)	-	600 x 500
	600 x400	600 x 400
	500 x 400	
	500 x300	500 x 300
	400 x300	400 x300

All standards leave the height of the crate to the discretion of the user. The height is greatly influenced by the commodity, type of crate, required weight/count, stacking method, etc. Using standard heights would simplify the transport of crates.

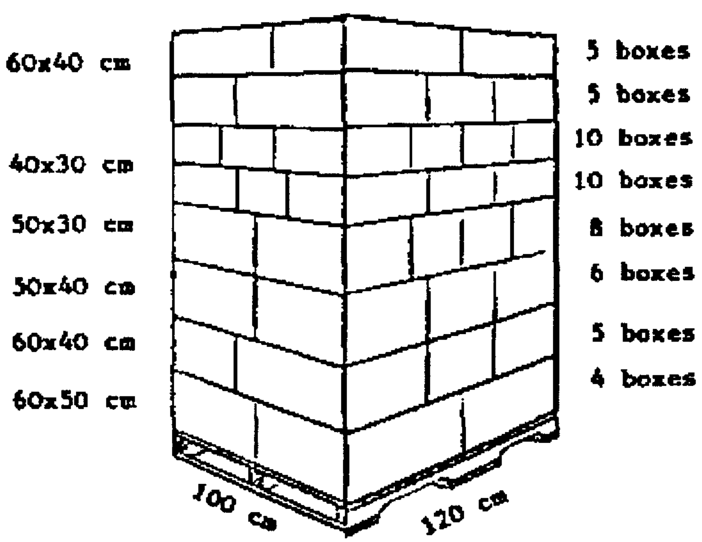

Figure 11. Mixed load layer concept

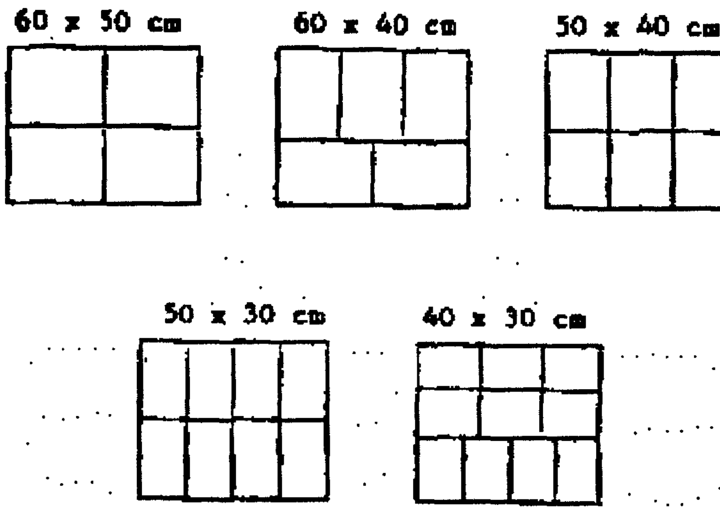

Figure 12. Stacking pattern per layer

The United Fresh Fruit and Vegetable Association (UFFVA) together with the United States Development Agency (USDA) tested several package sizes and showed that most of the packages now in use can be replaced by one of the five MUM-sizes with little or no change in volume, weight and/or count.

COST CALCULATION

Before making a decision on which package type to introduce it is wise to analyse costs and benefits. The packing costs will depend on:

- The type of the crate.
- The size of the crate.
- The design of the crate.
- The quantity of crates purchased.
- Transport and import costs and duties.
- The container assembling costs (carton boxes).
- The need for internal packaging materials (liners, pads, dividers).

Also factors such as acceptance by the customer, pilferage, possibility to repair, local manufacturing and availability should be taken into account when calculating the cost of a crate.

The importance of the characteristics of packaging will depend on the situation in which the packages are used. However, it may be difficult to estimate cost benefits from reduced losses, increased goodwill of consumers, increased marketing efficiency, better quality of the produce and reduced handling time.

An example is given below of a cost analysis of four different types of packaging: a wooden collapsible crate, a plastic stack-nest crate, a plastic stack crate and a carton (fibreboard) box.

Instruction sheet 2 clearly outlines the different direct costs which determine the total cost of a certain type of package.

a) Wooden collapsible crate (600 x 400 x 330 mm)

	US$
Crate locally made in Dominica (approximately EC$ 20.-)	7.50
Estimated number of trips: 12 trips per crate	0.63
Freight and return costs per trip (1 + 2/5 times US$ 2.50) 3.50	
Total cost wooden crate per return trip	US$ 4.13

b) Plastic stack-nest crate (600 x 400 x 310 mm) (July 1988, US$ 1.00 - DF1 2.05)

	US$
Container: 780 crates x DF1 21.95	8,351.71
Cost, Freight and Insurance	3,365.85
	+
Total price 780 crates C.I.F. Barbados	11,717.56
Per crate C.I.F.	15.02

Taking into consideration customs duty, consumption tax, stamp duty and local transport one crate would cost approximately US$ 24.00. With an estimated number of forty journeys the cost per trip is around US$ 0.60 per trip. If we estimate the cost of transport between two islands at US$ 2.50 plus 2/5 of this cost for the return freight (nested) the total transport cost is US$ 3.50 per trip.

Total cost stack-nest crate per return trip US$ 4.10

c) Plastic stack crate (600 x 400 x 310 mm) (September 1988)

	US$
One container: approximately 600 crates x US$ 5.17	3102.00
Cost, Freight and Insurance (Venezuela - Barbados)	1000 00
	+
Total C.I.F. Barbados, 600 crates	4102.00

Per crate C.I.F.	6.84
60% duty, tax	4 10
	+
Total price per crate	10.94

During the return trip when crates are empty, one crate can be stored inside two others. This type of crate will be able to withstand an estimated forty trips and this means US$ 10.94/40 - US$ 0.27 per trip. The transport costs (US$ 2.50 and 2/3 * US$ 2.50 for the return freight) are around US$ 4.17.

Total cost plastic stack crate per return trip - US$ 4.44

d) Carton (banana) box (508 x 330 x 184 mm)

	US$
Price St. Lucia (EC$ 2.35)	0.87
Price Dominica (EC$ 3.00)	1.11
Freight costs per single trip	1.50
Total cost per box (Dominica) per single trip	2.61

Because the volume of the carton box is only 39% of the volume of the plastic and wooden crates, the total cost has to be multiplied by 2.57 to enable a comparison with the other crates.

Total cost for 2.57 carton boxes per single trip - US$ 6.70

From an economical point of view, the above comparison is in favour of the plastic stack and stack-nest and the wooden collapsible crate, but the risk of pilferage of plastic crates is high and therefore the actual running cost for the plastic crates may be much higher. The carton boxes have no return freight and the traders do not have to worry about returning of boxes. Also government policies or consumers demands could force the farmer or trader to use the more expensive carton boxes in order to get the produce sold.

Plastic crates are very suitable as field crates for transporting produce from the field to the packing shed. In that case the farmer can keep control over his crates, or where there is an abundance of plastic crates, a refund system can be established. If the crates are to be used as field crates the economical comparison, without the transport cost, is as follows:

Wooden collapsible crate	US$ 0.63
Plastic stack-nest crate	US$ 0.60
Plastic stack crate	US$ 0.27
Carton box (US$ 0.87 * 2.57)	US$ 2.24

Using these figures only, the plastic stack crate is clearly the cheapest crate and, as was to be expected, it is not advisable to use carton boxes as field crates.

LABELLING OF PACKAGES

Each container should be marked with a label with the following information:

- Country of origin.
- Name and address of exporter or grower.
- Brand name.
- Description of content (product, variety, size, class, quality grade).
- Gross weight.
- Net weight or count.
- Overall dimensions in metric units.
- Full name and address of receiver.

The following rules should be maintained with regards to labels:

1. Each container should have at least two labels on both short sides of the container.
2. The label should be placed in such a way that it is least liable to be damaged or dirtied.
3. Each long side of the container should contain general information such as brand name, type of commodity and a logo.
4. Extra information such as FRAGILE, TOP or special storage or handling requirements should be placed on top and at least on one of the sides of the crate.
5. Only water-proof ink should be used.
6. Differences in colour for the different commodities and grades should be used, where these additional cost can be accounted for.
7. Obsolete labels should be removed or taped off.
8. Hand written information on the label should be in blockwriting.

9. Other remarks such as date of packaging, legal remarks and marking for electronic scanning could be included.

Large exporters will use their own labels with their name, address and the product already printed on them.

A whole pallet load will receive a packing list with the name and address of the receiver, the variety, class, weight and other information of the load.Smaller exporters can design their own blank label and stencil it.

Stamps can be used for the name of the exporter and for other information required. The name of the receiver can be filled in with a water-proof marker pen.

If the labels are not self-adhesive, special label gluers (4 or 6 inches width) can be used to glue the label. The most simple solution of course is to use a brush to add the glue to the box and onto the label. Special care must be taken to prevent the glue from touching the produce, since this may affect quality.

RETAIL PACKAGING

Prepackaging or retail packaging of certain commodities in specially designed consumer packages has the following advantages:

a) Deterioration or decay is slowed down.

b) The reduction of spoilage caused by consumers selecting out of a bulk of produce.

c) Time needed for weighing and checking after selecting by the consumer will be reduced.

d) Advertisement by abundant supply.

e) More protection to the produce.

Deterioration or decay is decreased because the prepackages create a micro-climate with a lower oxygen and a higher carbon dioxide level and a higher relative humidity is reached. Too high a relative humidity, however, can lead to sprouting of roots and tubers and low oxygen levels will decrease respiration to such a level that produce will suffocate and rot.

In general, leafy vegetables require a high relative humidity level to prevent wilting and only a few holes in the package are recommended. Root crops require more holes, or even the use of nets as packaging material because too high relative humidities or too low oxygen levels cause sprouting.

Moulded trays, wrapped with film liners, combine four to six units (citrus, apple, etc.) to one larger unit. The tray will give the produce protection from the bottom side and some protection on the sides. The top will only be properly protected when the larger units are properly stacked.

Most commonly used materials are low-density polypropylene for bagging, regenerated cellulose or cellophane for overwrapping the trays and polyvinyl chloride film for overwrapping trays.

Polyethylene and polypropylene have a low permeability for gases and vapour and it is necessary to make holes in the bags. Other materials have higher permeabilities or permeabilities for only one of the gases or vapour and even between different brands of the same material are differences in permeability. It is recommended to purchase film material suitable for a certain commodity and to test this film material first on a small scale.

REFERENCES

FAO. 1988. *Packaging for Fruits, Vegetables and Root Crops*. FAO. Rome.

Holdsworth, S.D. 1983. *The Preservation of Fruit and Vegetable Food Products. Science in Horticulture Products.* Macmillan Press, London, 109-110.

Leistner, L. 1992. "Food preservation by combined methods". Food Research International. 25, 151-158.

Nagy, S. and Shaw, P.E. 1980. *Tropical and Subtropical Fruits. Composition, Properties and uses.* AVI Publishing, Westport, Connecticut, 127.

Ryall, A.L. and Pentzer, W.T. 1979. *Handling, Transportation and Storage of Fruits and Vegetables*, 320-332.

Sloan, A.E., Labuza, T.P. 1975. "Investigating alternative humectants for use in foods". Food Product Development 9(7), 75-88.

Sofos, J.N. 1989. *Sorbate Food Preservatives.* CRC Press, Boca Raton, 16-17.

5

Hygiene and Sanitation in Post-harvest Handling

Concerns about food safety when handling fresh fruits and vegetables have increased over the past decade. Recent outbreaks of food-bourne disease have been associated with berries, tomatoes, leafy greens and cut fruits. Wholesale buyers and consumers are increasingly interested in the use of handling practices that will ensure food safety. It is the responsibility of growers and postharvest handlers to document their practices to protect fresh produce from contamination. Retailers such as large supermarket chains are demanding compliance with food safety practices from their suppliers.

The typical causes and sources of food safety problems during production and postharvest handling fall into the following three major categories.

- *Physical Hazards*: Examples of physical hazards which may become imbedded in produce during production handling or storage are such things as:
  - fasteners (staples, nails, screws, bolts)
  - pieces of glass
  - wood splinters
- *Chemical Hazards*: Examples of chemical hazards which may contaminate produce during production handling or storage are such things as:
  - pesticides, fungicides, herbicides, rodentacides
  - machine lubricants from forklifts or packing line equipment
  - heavy metals (Lead, Mercury, Arsenic)
  - industrial toxins
  - compounds used to clean and sanitize equipment
- *Human Pathogens*: There are four main types of human pathogens associated with fresh produce:

- soil associated pathogenic bacteria (*Clostridium botulinum, Listeria monocytogenes*)
- *feces associated pathogenic bacteria (*Salmonella spp., Shigella spp., E. coli *and others)*
- *pathogenic parasites (*Cryptosporidium, Cyclospora*)*
- pathogenic viruses (Hepatitis, Enterovirus).

Many of these pathogens are spread via a human (or domestic animal) to food to human transmission route. Handling of fruits and vegetables by infected field-workers or consumers, cross contamination, use of contaminated irrigation water, use of inadequately composted manure or contact with contaminated soil are just a few of the ways that transmission of human pathogens to food can occur.

While produce quality can be judged by outward appearance on such criteria as color, turgidity and aroma; food safety can not. Casual inspection of produce cannot determine if it is in fact safe and wholesome to consume. Management of growing and postharvest handling conditions are paramount in preventing the contamination of fresh produce by physical hazards, harmful chemicals and human pathogens.

MICROBIOLOGICAL RISKS

Products go through different stages of operations after harvest. This provides many opportunities for contamination besides those which naturally occur in the field. Consumers strongly reject foreign materials on products or inside packages. These include for, example, dirt, animal feces, grease or lubricating oils, human hairs, insects, plant debris, etc. However, because this is usually due to insufficient care in handling, they are relatively easy to detect and to eliminate. Amore serious problem is the presence of human pathogens on produce. These may not be visible or detected because of changes in appearance, flavor, colour or other external characteristics. It has been shown that specific pathogens are able to survive on produce sufficiently long to constitute a threat. In fact, many cases of illness related to consumption of produce have been reported (Table 1).

Three types of organisms can be transported on fruits and vegetables, which may constitute a risk to human health: virus (hepatitis A, for example), bacteria (*Salmonella* spp., *Escherichia coli, Shigella* spp., and others) and parasites (*Giardia* spp., for example). Mycotoxins and fungi do not usually constitute a problem. This is because fungi development is usually detected and eliminated well before the formation of mycotoxins. In most cases, bacteria is responsible for illnesses related to the consumption of fruits and vegetables.

Produce can become contaminated through mechanisms that are complex. The best strategy to obtain a safe product is to prevent contamination at various points throughout treatments and maintaining produce under conditions (mainly temperature) which do not favour the development of micro-organisms. This approach is known as the "systems approach".

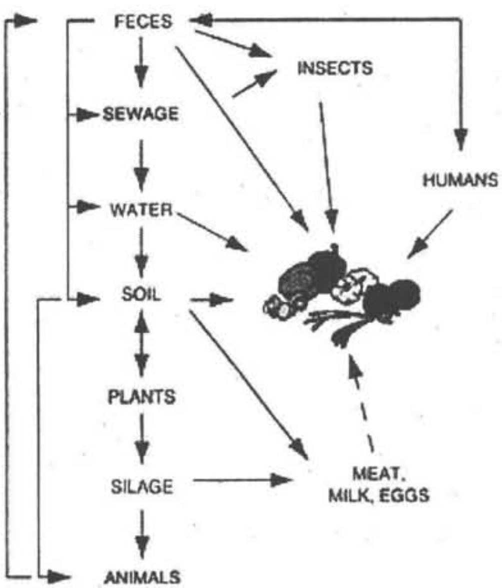

Figure 1. Mechanisms by which fruit and vegetable can become contaminated with pathogenic microorganisms.

Every step of the process is a part of an integrated system. Records and/or documentation of all activities and treatments are required so that a tracing scheme is established. In this way, it is possible to identify areas of weaknesses within the system and to take corrective measures. Following strict written procedures for good agricultural practices (GAP) and/or good manufacturing practices (GMP) are critical factors for the implementation of such a system. This should be combined with such systems as Hazard Analysis Critical Control Point (HACCP) analysis in order to identify the critical points at which known safety food hazards must be controlled.

This section briefly describes critical factors where risk of microbiological contamination in the production and distribution of fruits and vegetables can affect health and safety.

Before Harvest

Some human pathogens are naturally present in the environment. However, fecal

Some human pathogens are naturally present in the environment. However, fecal deposits(human, animal, or wild animals) are the main source of contamination of produce. Entry is mainly through irrigation or washing water. Microorganisms in surface water (rivers, lakes, etc.) may come from upstream dumping of untreated municipal wastes. Underground water may also be contaminated from septic tanks leaching through soil into aquifers. If only contaminated water is available, underground drip irrigation is the only irrigation system recommended to avoid contamination of above-ground edible plants.

Table 1. Isolated pathogens in fruits and vegetables and reported illnesses.

Aeromonas spp.	Alfalfa sprouts, asparagus, broccoli, cauliflower, lettuce, pepper
Bacillus cereus	Sprouts
Escherichia coli O157:H7	Cabbage, celery, cilantro, lettuce(*), pineapple, apple cider(*), alfalfa sprouts(*)
Listeria monocytogenes	Bean sprouts, cabbage, cucumber, shredded cabbage(*), potato, radish, mushrooms(*), salads(*), tomatoes and other vegetables
Salmonella spp.	Artichoke, bean sprouts(*), tomato(*), alfalfa sprouts(*), apple cider(*), cauliflower, celery, eggplant, Belgian endives, pepper, cantaloupe(*), watermelon(*), lettuce, radish and several vegetables
Clostridium botulinum	Shredded cabbage(*)
Shigella spp.	Parsley, leafy vegetables, shredded lettuce(*)
Cryptosporidium spp.	Apple cider(*)
Cyclospora spp.	Raspberry(*), basil(*), lettuce(*)
Hepatitis A	Lettuce(*), strawberry(*), frozen strawberry(*)

(*) Reported illnesses.

The production and harvest of fruits and vegetables tend to rely heavily on human labour. Other sources of contamination include the hygiene conditions of field workers. First, production fields are usually a long distance from bathrooms, together with other sanitary facilities for the hygiene of personnel, Second, hired teams of migrant labour temporarily live in the fields. Here, conditions and sanitary practices are considered unacceptable. In addition to providing portable toilets, staff need to understand the importance of proper hygiene practices for food safety.

The type of product also has an influence: in vegetables which are characterised by low acidity in tissues, bacteria tends to dominate, while fruits are mainly colonised by fungi. Crops growing close to the ground like strawberry and leafy vegetables in general, are more susceptible to contamination by water, soil, or animals when compared to tree crops. Finally, some chemical constituents of tissues such as organic acids, essential oils, pigments, phytoalexins etc, have antagonistic effects and provide some form of protection against the development of micro-organisms. As with other handling operations, numerous opportunities exist for contamination during harvest. Wounds and bruises may exude latex and other plant liquids from tissues and provide the substrate for the growth of microorganisms transmitted by hands, tools, clothes, water, or containers. Contamination at any point throughout the distribution chain can be exacerbated by the conditions to which the produce is exposed. Temperature is the most important factor to be considered.

Market Preparation

The issues highlighted in previous paragraphs on product handling and personal hygiene are equally valid for preparation of the product for market. However, some additional factors need to be taken into account. In packinghouses or processing plants, people who are ill or have open wounds should be forbidden from making contact with the product. Workers should use hairnets and clean outfits when handling the product.

Table 2. Potential risks of microbial contamination and recommended preventive measures.

Production step	*Risks*	*Prevention*
Production field	Animal fecal contamination	Avoid animal access, either wild, production or even pets.
Fertilising	Pathogens in organic fertilisers	Use inorganic fertilisers. Proper composting
Irrigation	Pathogens in water	Underground drip irrigation Check microorganisms in water
Harvest	Fecal contamination	Personal hygiene. Portable bathrooms. Risk awareness
	Pathogens in containers and tools	Use plastic bins. Cleaning and disinfecting tools and containes.
Packhouse	Fecal contamination	Personal hygiene. Sanitary facilities. Avoid animal entrance. Eliminate places may harbor rodents.
	Contaminated water	Alternative methods for precooling. Use potable water. Filtration and chlorination of recirculated water. Multiple washing
Storage and transportation	Development of microorganisms on produce	Adequate temperature and relative humidity. Watch conditions inside packaging. Cleaning and disinfection of facilities. Avoid repackaging. Personal hygiene. Do not store or transport with other fresh products. Use new packing materials
Sale	Product contamination	Personal hygiene. Avoid animal access. Sell whole units. Cleaning and disinfection of facilities. Discard garbage daily.

Street clothes must be left outside the working area and eating or drinking in the packhouse should be forbidden. Workers should wash their hands daily at the beginning of operations and every time they return to work, particularly after having used restrooms.However, the main source of contamination in terms of product preparation for market, is probably water. Water is essential for packinghouse operations either for washing the product, containers, and facilities or for dumping, hydrocooling. Other uses include personal hygiene or as a medium for waxes, chemicals, etc.

Water disinfection

Water impurities are frequently concerned with: the suspension of materials, microorganisms, organic matter, off-colour, off-odor as well as minerals and dissolved gases. Municipal water is filtered and treated (normally with low chlorine concentrations) to ensure that it meets the chemical and microbiological requirements for food safety and contact with food. Alternative sources of water must be filtered and sanitised.

Sanitation is necessary to avoid the spread and contamination to other units, even with the use of municipal water. Different methods exist for water disinfection. These include chemical, thermal, ultrasonic waves or irradiation. In postharvest operations, chlorine and its derivatives are the cheapest and most widely used substances to destroy bacteria and fungi in water as well as on the surface of fruits.

Chlorine is a gas with a strong and penetrating odor and is extremely reactive chemically. At post harvest level, it is used mainly in three different forms: as pressurised gas from metal cylinders, as calcium hypochlorite (solid) or liquid as sodium hypochlorite, commonly known as "bleach" for household whitening and sanitising. Chlorine gas is difficult and dangerous to handle and is normally limited to large operations such as municipal water treatment. Calcium hypochlorite is widely used in concentrations of 65% but is difficult to dissolve in cold water. Sodium hypochlorite is more expensive than the other two formulations in terms of chlorine concentration (5 to 15%). However, its easy dosage makes it convenient for small size operations.

In aqueous solution, chlorine exists as hypochlorous acid, hypochlorite ion, or as a variation of both, depending on the pH solution: the former predominates in acidic solutions while the latter in alkaline solutions. Germicidal action of hypochlorous acid is about 50-80 times higher than hypochlorite. In order to maximise the effect on microorganisms, the pH solution should have a range of between 6.5 and 7.5. Below this range, the hypochlorous form is extremely unstable and tends to escape as a gas resulting in irritation and discomfort to workers. It also becomes extremely corrosive for the equipment. On the other hand, its effectiveness as a sanitiser is significantly reduced above 7.5. To keep pH values within permitted ranges, vinegar could be used to acidify while sodium hydroxide could be used to alkalinise. Maintenance kits for swimming as hypochlorite, either of calcium or sodium, this will be increased.Concentration of active chlorine is expressed in parts per million (ppm). Concentrations of active chlorine in the range of 0,2 to 5 ppm are able to kill most bacteria and fungi present in water. However, in commercial operations higher concentrations are used (100-200 ppm) for washing and hydrocooling. Aliter of household bleach (80 g active chlorine/dm^3) in 400 liters of water represents about 200 ppm, and in 800 and 1600 liters, about 100 and 50 ppm, respectively. It is convenient to start daily operations with: low concentrations (100-150 ppm); to increase the amount of chlorine in solution as water becomes contaminated with dirt and plant debris and an increase in microorganisms.

Quick exposure (around 3-5 minutes) is adequate for the purposes of disinfection. However, in addition to pH level and impurities, the temperature of the solution is also important. This is because low temperatures can reduce activity. Another important factor is the extent to which microorganisms can be developed. This is because their spores are from 10 to 1000 times more difficult to kill compared to their vegetative state.

The use of chlorine in fruits and vegetables is banned in some countries. This is because it is possible for it to react with organic matter leading to the formation of chlorate compounds and trihàlomethans. These are suspected of being carcinogenic. As a result of this, the industry is investigating alternative sources of sanitisers.

Ozone is a gas with a strong oxidising action in concentrations of 0,5-2 ppm. It has been approved for water sanitation. However, it is difficult to apply. This is because reliable methods for monitoring the level of concentrations do not currently exist. In addition to this, it is only effective within a reduced pH range of (6-8) and must be generated in the same place of application. It is dangerous to humans in concentrations higher than 4 ppm and may cause damage to some plant tissues. In spite of these limitations, it is probably the most promising compound to replace chlorine. Ultraviolet light in wavelengths of 250-275 nm can also be used. It is unaffected by water temperature or pH. However, water must be filtered as turbidity reduces its efficacy.

Water management is also important. This is because several washes are required. This is more effective than a single wash. The following is an outline of a procedure for good cleaning practices: First, undertake an initial wash to eliminate dirt and plant debris. Second, wash with chlorinated water and finally rinse with plain water. Brushing or water agitation increase washing efficiency. Water recirculation should be undertaken in reverse to the flow of the product, i.e. rinsing waters can be reused for the initial washing. Hydro cooling is one of the most efficient systems for precooling. It is, however, also one of the most risky in terms of microbial contamination. This can be caused by water infiltration inside the fruits. As a result of this, it is important to consider alternative precooling methods such as forced air.

alternative precooling methods such as forced air.

Plant hygiene

Industrial facilities follow a system of strict hygiene measures. However, when produce is prepared for the fresh market, limited attention is normally paid to hygiene facilities. This is particularly the case when low cost materials have been used in the construction of the packing shed.

Although other factors need to be taken into account prior to layout and organisation, it is important that the packing shed be designed to allow for thorough cleaning procedures. The reception area should be kept separate from the delivery area. Similarly, "clean areas" or areas where product is prepared, should be kept separate from other areas or where product is handled as receivables from the field. There should be a clean area where workers can take breaks, change clothes, and take care of personal hygiene. For example, the availability of hot water, showers, and clean restrooms within a clean and comfortable environment.

While it is a requirement that dust and other impurities are eliminated, liquid sanitisers should be used to disinfect the facility and equipment, particularly those in contact with produce. Chlorine based sanitisers are the most widely used disinfectants. However, the choice depends on type of water, pH, cost and the type of equipment. Iodine based disinfectants (iodophors) are less corrosive to metals than chlorine. They are unaffected by organic matter but their effectiveness within the pH range is quite narrow (2,5-3,5). In addition to this, they may stain surfaces. Quaternary ammonium compounds are widely used for disinfecting floors, walls, and aluminum equipment. While effective over a wide pH range, they are not affected by organic matter and are non-corrosive. However, they are expensive and leave residues on surfaces. There are other sanitisers available on the market that can be used in food plants.

Animals of all types, including mammals, birds, reptiles, and insects can spread microorganisms with their droppings. Their entry into packing areas should be forbidden, including pets. It is necessary to seal crevices and keep doors, windows, and air inlets closed or fitted with insect-proof screens. It is also important to have insect and rodent control programs, together with approved pesticides, traps, and baits. Facilities and the surrounding environment must be kept clean and tidy to prevent the nurturing and harboring of insects, rodents, reptiles and other animals. Garbage and waste materials should be removed daily.

Storage and Transport

In terms of sanitation, there are two potential sources of risk: contamination by human hygiene of personnel and facilities are also applicable here. Two additional recommendations include: the use of new containers and not undertaking repackaging. Other considerations to prevent cross contamination include not storing or transporting fruits and vegetables with other fresh food items.

The best strategy to prevent growth and development of human pathogens is to keep product at recommended storage conditions, particularly temperature. Microorganisms can be divided into three main categories acording to their level of adaptation to temperature. These are: psychrotrophic - the ability to grow under refrigerated conditions, although the optimum ambient temperature is (20-30 °C); b) mesophilic - those that develop best at ambient temperature (20-40 °C) but not under refrigeration and c) ther-mophillic - requiring temperatures above 40 °C. The last two (i.e. b and c) do not concern fruits and vegetables for the fresh market, but may be present in inadequatelt processed items. Generally, refrigeration inhibits growth of microorganisms, but psy-chrotrophics may develop on produce if storage time is too long.

The atmosphere at which a product is stored also influences microbial development. *Clostridium botulinum*, for example, is not a concern when a product is prepared for the fresh market. However, it may develop and produce toxins on tissues with a pH higher than 4,6 and under conditions of low oxygen. It may be present in inadequately pasteurised canned products but it may also develop under modified atmosphere conditions. It has been reported that this bacterium can cause human poisoning.

Sale

Fruits and vegetables may become contaminated at the point of sale, storage, and home preparation. The previous discussions on personal hygiene and prevention of contact with animals are also valid here. The common practice at retail of cutting large fruits into portions (pumpkins, watermelons, melons, etc.) should be avoided and refrigeration is recommended for the most perishable items.

FOOD SAFETY ON THE FARM

Practices related to these four simple principles can reduce the risk that produce may become contaminated on the farm.

Clean Soil

- Avoid the improper use of manure.
- Compost manure completely to kill pathogens, and incorporate it into soil at least two weeks prior to planting.

- Compost manure completely to kill pathogens, and incorporate it into soil at least two weeks prior to planting.
- Keep domestic and wild animals out of fields to reduce the risk of fecal contamination.
- Provide portable toilet facilities near the field.
- Prevent run-off or drift from animal operations from entering produce fields.
- Do not harvest produce within 120 days of a manure application.

Clean Water

- Test surface water that is used for irrigation for fecal pathogens on a regular basis, especially if water passes close to a sewage treatment or livestock area.
- Keep livestock away from the active recharge area for well-water that will be used for irrigation.
- Keep chemicals away from the active recharge area for well-water that will be used for irrigation.
- Filter or use settling ponds to improve water quality.
- Where feasible, use drip irrigation to reduce crop wetting and minimize risk.
- Use potable water for making up chemical pest management sprays.

Clean Surfaces

- Tools and field containers must be kept clean. Wash and sanitize these items before each use.

Clean Hands

- Workers who harvest produce must wash their hands after using the toilet.
- Provide soap, clean water and single-use towels in the field and insist that all workers wash their hands before handling produce.

Proper hand-washing is an effective strategy for reducing risk of contamination, but food safety experts have observed that few people wash their hands properly. Cornell's Good Agricultural Practices Program provides the following steps:

- Wet hands with clean, warm water, apply soap and work up a lather.
- Rub hands together for 20 seconds.

– Rinse under clean, running water.
– Dry hands with a single use towel.

Minimizing Pathogen Contamination during Harvest

During harvesting operations field personnel may contaminate fresh fruits and vegetables by simply touching them with an unclean hand or knife blade. Portable field latrines as well as hand wash stations must be available and used by all harvest crew members. Monitoring and enforcement of field worker personnel hygiene practices such as washing hands after using the latrine are a must, to reduce the risk of human pathogen contamination. Workers who are ill with hepatitis A or who have symptoms of nausea, vomiting or diarrhea should not be assigned to harvest fresh produce.

Produce once harvested should not be placed upon bare soils before being placed in clean and sanitary field containers. Field harvesting tools and gloves should be clean, sanitary and not be placed directly in contact with soil. Field containers should be cleaned and sanitized on a regular basis as well as being free of contaminants such as mud, industrial lubricants, metal fasteners or splinters. Do not allow workers to stand in field bins during harvest to reduce pathogen spread by shoes.

Plastic field bins and totes are preferred to wooden containers since plastic surfaces are easier to clean and sanitize, which should be done after every use. If containers are not cleaned and sanitized after every use, they may become contaminated and then contaminate the next products which are placed in the container. Wooden containers or field totes are almost impossible to sanitize since they have a porous surface and wooden or metals fasteners such as nails from wooden containers may accidentally be introduced into produce. Cardboard field bins if reused should be visually inspected for cleanliness and lined with a polymeric plastic bag before reuse to prevent the risk of cross contamination.

Depending upon the commodity, produce may be field packaged in containers that will go all the way to the destination market or be temporarily placed in bulk bins, baskets or bags which will be transported to a packing shed. Employees, equipment, cold storage facilities, packaging materials and any water which will be contacting the harvested produce must be kept clean and sanitary to prevent contamination.

Minimizing Pathogen Contamination during Postharvest Handling

Employee Hygiene

Gloves, hairnets and clean smocks are commonly worn by packinghouse employees in export oriented packing sheds. The cleanliness and personnel hygiene of employees

Gloves, hairnets and clean smocks are commonly worn by packinghouse employees in export oriented packing sheds. The cleanliness and personnel hygiene of employees handling produce at all stages of production and handling must be managed to minimize the risk of contamination. Adequate bathroom facilities and handwash stations must be provided and used properly to prevent contamination of produce by packinghouse employees. Shoe or boot cleaning stations may also be in place to reduce the amount of field dirt and contamination which enters the packing shed from field operations. Employee training regarding sanitary food handling practices should be done when an employee is hired and reviewed before they begin work each season.

Equipment

Food contact surfaces on conveyor belts, dump tanks etc. should be cleaned and sanitized on a regular scheduled basis with food contact surface approved cleaning compounds. A 200 parts per million sodium hypochlorite (bleach) solution is an excellent example of a food contact surface sanitizer. Sanitizers should be used only after thorough cleaning with abrasion to remove organic materials such as dirt or plant materials. Use of steam to clean equipment should be avoided since steam may actually cake organic materials and form a biofilm, which renders equipment almost impossible to sanitize. Steam may also aerosolize bacteria into the air and actually spread contamination throughout the packing house facility.

Packaging materials

All packaging materials should be made of food contact grade materials to assure that toxic compounds in the packaging materials do not leach out of the package and into the produce. Toxic chemical residues may be present in some packaging materials due to use of recycled base materials. Empty packages such as boxes and plastic bags should be stored in an enclosed storage area to protect them from insects, rodents, dust, dirt and other potential sources of contamination. These actions protect not only against the potential loss of valuable materials but protects the integrity and safety of these materials.

Wash and Hydrocooling Water

All water which comes in contact with produce for washing or hydrocooling must be safe to drink. Water should contain between 100 and 150 parts per million total chlorine and have a pH of between 6 and 7.5. Chlorine use prevents the potential for cross contamination of all produce in the washing or hydrocooling system, it will not sterilize the produce. Change the water in dump tanks and hydro-coolers regularly.

Ice for cooling

Refrigerated Transport

Produce is best shipped in temperature controlled refrigerated trucks. Pre-cool the vehicles prior to loading. Maintaining perishables below 5ºC (41º F) even while being transported to destination markets will extend shelf-life and significantly reduce the growth rate of microbes including human pathogens. Temperatures used for tranporting chilling sensitive produce will not protect against the growth of most pathogens. Trucks used during transportation should be cleaned and sanitized on a regular basis. Trucks which have been used to transport live animals, animal products or toxic materials should never be used to transport produce.

Sanitizing field containers, tools and packhouse surfaces

High pressure wash, rinse and sanitize all crop containers, tools and packhouse surfaces prior to each day's harvest. Sanitizers should be used only after thorough cleaning with abrasion to remove organic materials such as dirt or plant materials. Most commercial sanitizers contain chlorine or quaternary ammonium compounds (QUATS, QAC, benalkonium chloride, N-alkyl dimethybenzyl ammonium chloride). Chlorine solutions prepared from chlorine gas, hypochlorites and cloramines are not compatible with quaternary ammonium compound sanitizers. Selection of the sanitizer to use depends upon the surface to be cleaned, hardness of the water, application equipment available, effectiveness under ambient conditions and cost. All require extreme care when handled as either compressed gas, powders or concentrated liquids.

Fruits and vegetables are microbiologically safer compared to meat, milk, poultry, and other foods. However, during the process of fighting organisms they do not usually undergo a kill step so many organisms are not destroyed (by cooking) and are therefore potentially dangerous if contamination exists. It is difficult to estimate how real this potential threat is. This is because it is usually reported when it becomes serious. In addition as fruits and vegetables are regarded as "healthy food", they are not considered to be the cause of food-related illnesses. Instead, other food eaten during the course of the same day is usually to blame. However, available evidence seems to indicate that this is increasingly becoming a problem. The reasons for this may be twofold: First, there is a trend towards environmentally friendly practices in agriculture. The use of manure based organic fertilisers or soil amendments increases the risk of contamination. Second, the concentration of supply particularly through supermarket distribution centers supplying a large number of stores, means that a single case of contamination can have an enormous impact throughout the system.

To obtain high quality produce with minimum risk levels, the first step is to understand the complexity of microbial contamination and recognise its importance. The examples of good agricultural and manufacturing practices described in these understand the complexity of microbial contamination and recognise its importance. The examples of good agricultural and manufacturing practices described in these paragraphs may not apply to all fruits and vegetables. However, they may be useful to devise specific preventative measures. With the current level of technology, it is not possible to eliminate this risk. However, it is important to know how to minimise it as much as possible. It is cheaper and more effective to prevent microbial contamination of fruits and vegetables than to have to confront the problem when it occurs. A successful food safety program requires serious commitment from everyone throughout the food chain from production to consumption. Key factors to be considered are: the availability of trained personnel, and a system that ensures that there are no missing links in the quality chain as regards contamination prevention.

Many different testing procedures exist for the detection of microorganisms, such as total plate counts or aerobic plate count. They give an idea of the extent of microbial contamination, but have limited value in terms of assessing food safety. A wide range of microorganisms exist naturally on the surfaces of fruits and vegetables and they will colonise a growing medium. However, this does not mean that they are a health hazard. These types of tests are useful for monitoring the hygiene system or evaluating the impact of certain sanitary measures. Detection of *Salmonella* spp., fecal coliforms, *E. coli,* and other pathogens require specific tests and their lack of detection does not mean that the produce is free from other harmful microorganisms. As a result, the best strategy is to minimise the risk and to prevent as much contamination as possible. An important aspect in any program of good agricultural or manufacturing practices is to have a tracing system. This is because it is possible to identify and pinpoint quickly problems of contamination. The necessary corrective measures can be undertaken as soon as possible. The short lead time between harvest and consumption of fruits and vegetables makes it difficult to react in time if an outbreak is detected. In spite of these limitations, keeping records may help to reduce the population at risk and should complement all preventive measures described in this section.

REFERENCES

Alzamora, S.E., Tapia, M.S., and López-Malo, A. 2000. *Minimally Processed Fruits and Vegetables: Fundamental Aspect and Applications.* Aspen Pub. Co., Inc., Maryland, US, 277-286.

Brown, M.; Bates, R.P.; McGowan, C.; Cornell, J.A. 1992, 1994. Influence of Fruit Maturity on the Hypoglycin A Level in Ackee (Blighia Sapida). Journal of Food Safety. 12 (2), 167-177.

Cantwell, M. 2001. *Post-harvest Handling Systems: Minimally Processed Fruit and Vegetables.* Vegetable Information. University of California, Vegetable Research and Information Center.

FAO. 1995. *Fruit and Vegetable Processing.* FAO Agricultural Services Bulletin 119. Rome.

Shafiur Rahman. *Handbook of Food Preservation.* Marcel Dekker, Inc., New York, 339-382.

6

Storage of Fruits and Vegetables

Most fruit and vegetable production in temperate areas is seasonal. In contrast, cultivation and harvest periods are much longer in tropical and subtropical areas. Demand is year round and it is normal practice to use storage in order to ensure continuity of supply. Moreover, storage is a strategy for achieving higher returns. Produce can be held temporarily to overcome gluts thus limiting price falls or to address shortage periods when prices are high.

Storage time depends on the intrinsic characteristics and perishability of the product. Shelf life ranges from short - e.g. raspberries and other berries - to those which naturally adapt to longer storage periods - e.g. onions, potato, garlic, pumpkins, etc. Storage conditions also depend on specific product characteristics. For example, some commodities tolerate temperatures close to 0 °C such as leafy vegetables. Others, such as most tropical fruits (Table 1), cannot tolerate exposure to temperatures below 10 °C.

To optimise storage conditions, not more than one crop should be stored in the same room, unless this is for a short period of time. Sharing the same storage area can result in: differences in temperature and relative humidity conditions; chilling and ethylene sensitivity; odor contamination and other problems affecting shelf life and quality.

REQUIREMENTS FOR A STORAGE FACILITY

Generally, storage facilities are linked or integrated to packinghouses or other areas where there is a concentration of product. However, often storage can also be undertaken on-farm, either naturally or in specifically designed facilities. Even under conditions of mechanical refrigeration, location and design have an impact on system operations and efficiency. First, climate is an important factor for the location of the storage facility. For example, altitude reduces temperature by 10 °C for every 1 000 meters of elevation. It also increases overall efficiency of the refrigeration equipment by facilitating heat exchange with ambient temperature, thereby reducing energy costs. Shading particularly of loading and unloading areas reduces thermal differences between field and storage temperatures.

Table 1. Recommended temperature and relative humidity for fruits and vegetables and the approximate storage life under these conditions.

Crop	*Temperature (°C)*	*Relative humidity (%)*	*Storage life (days)*
A-B			
Amaranth	0-2	95-100	10-14
Apple	-1-4	90-95	30-180
Apricot	-0.5-0	90-95	7-21
Artichoke	0	95-100	14-21
Asian pear	1	90-95	150-180
Asparagus	0-2	95-100	14-21
Atemoya	13	85-90	28-42
Avocado	3-13	85-90	14-56
Babaco	7	85-90	7-21
Banana - Plantain	13-15	90-95	7-28
Barbados cherry	0	85-90	49-56
Basil	7-10	85-95	7
Bean (dry)	4-10	40-50	180-300
Beet (bunched)	0	98-100	10-14
Beet (topped)	0	98-100	120-180
Belgian endive	0-3	95-98	14-28
Blackberry	-0.5-0	90-95	2-3
Black sapote	13-15	85-90	14-21
Blueberries	-0.5-0	90-95	14
Bok Choy	0	95-100	21
Breadfruit	13-15	85-90	14-42
Broadbeans	0-2	90-98	7-14
Broccoli	0	95-100	14-21
Brussels sprouts	0	95-100	21-35
C-D-E			
Cabbage	0	98-100	150-180
Cactus leaves	2-4	90-95	14-21
Caimito	3	90	21
Calamondin	9-10	90	14
Cantaloupe (half slip)	2-5	95	15
Cantalupo (full slip)	0-2	95	5-14
Carambola	9-10	85-90	21-28
Carrot (bunched)	0	95-100	14
Carrot (topped)	0	98-100	210-270
Cassava	0-5	85-96	30-60
Cashew apple	0-2	85-90	35

Cauliflower	0	95-98	21-28
Celery	0	98-100	30-90
Celeriac	0	97-99	180-240
Chayote	7	85-90	28-42
Cherimoya	13	90-95	14-28
Cherries	-1-0.5	90-95	14-21
Chicory	0	95-100	14-21
Chinese cabbage	0	95-100	60-90
Chives	0	95-100	14-21
Coconut	0-1.5	80-85	30-60
Cranberries	2-4	90-95	60-120
Cucumber	10-13	95	10-14
Currants	-0,5-0	90-95	7-28
Custard apple	5-7	85-90	28-42
Daikon	0-1	95-100	120
Dates -18-0	75	180-360	
Durian	4-6	85-90	42-56
Eggplant	8-12	90-95	7
Escarole	0	95-100	14-21
F-G-H-I-J-K-L			
Fennel	0-2	90-95	14-21
Feijoa5-10	90	14-21	
Fig	-0.5-0	85-90	7-10
Garlic	0	65-70	180-210
Ginger	13	65	180
Grape	-0.5-0	90-95	14-56
Grapefruit	10-15	85-90	42-56
Green onions	0	95-100	21-28
Guanabana	13	85-90	7-14
Guava	5-10	90	14-21
Horseradish	-1-0	98-100	300-360
Husk tomato	13-15	85-90	21
Jaboticaba	13-15	90-95	2-3
Jackfruit	13	85-90	14-42
Jerusalem artichoke	-0.5-0	90-95	120-150
Jicama	13-18	65-70	30-60
Kale	0	95-100	10-14
Kiwano	10-15	90	180
Kiwifruit	-0.5-0	90-95	90-150
Kohlrabi	0	98-100	60-90
Kumquat	4	90-95	14-28
Leek	0	95-100	60-90
Lemon	10-13	85-90	30-180

Lettuce	0-2	98-100	14-21
Lima bean	3-5	95	5-7
Lime	9-10	85-90	42-56
Longan	1-2	90-95	21-35
Loquat	0	90	21
Lychee	1-2	90-95	21-35
M-N-O-P-Q-R			
Malanga	7	70-80	90
Mamey	13-18	85-95	14-42
Mandarin	4-7	90-95	14-28
Mango	13	90-95	14-21
Mangosteen	13	85-90	14-28
Melon (Others)	7-10	90-95	12-21
Mushrooms	0-1.5	95	5-7
Nectarine	-0.5-0	90-95	14-28
Okra	7-10	90-95	7-10
Onions (dry)	0	65-70	30-240
Olives, fresh	5-10	85-90	28-42
Orange	0-9	85-90	56-84
Papaya	7-13	85-90	7-21
Parsley	0	95-100	30-60
Parsnip	0	95-100	120-180
Passionfruit	7-10	85-90	21-35
Peach-0.5-0	90-95	14-28	
Pear	-1.5-0.5	90-95	60-210
Peas	0	95-98	7-14
Cucumber	5-10	95	28
Pepper (bell)	7-13	90-95	14-21
Persimmon	-1	90	90-120
Pineapple	7-13	85-90	14-28
Pitaya	6-8	85-95	14-21
Plum	-0.5-0	90-95	14-35
Pomegranate	5	90-95	60-90
Potato (early)	7-16	90-95	10-14
Potato (late)	4.5-13	90-95	150-300
Prickly pear	2-4	90-95	21
Pumpkins	10-15	50-70	60-160
Quince	-0.5-0	90	60-90
Radichio	0-1	95-100	14-21
Radish	0	95-100	21-28
Rambutan	10-12	90-95	7-21
Raspberries	-0.5-0	90-95	2-3
Rhubarb	0	95-100	14-28
Rutabaga	0	98-100	120-180

S-T-U-V-W-X-Y-Z			
Salsify	0	95-100	60-120
Sapodillla	15-20	85-90	14-21
Scorzonera	0	95-98	180
Snapbeans	4-7	95	7-10
Snowpeas	0-1	90-95	7-14
Spinach	0	95-100	10-14
Sprouts	0	95-100	7
Strawberry	0-0.5	90-95	5-7
Sweet corn	0-1.5	95-98	5-8
Sweet potato	13-15	85-90	120-210
Swiss chard	0	95-100	10-14
Summer squash	5-10	95	7-14
Tamarind	7	90-95	21-28
Taro	7-10	85-90	120-150
Tart cherries	0	90-95	3-7
Tomato (MG)	12.5-15	90-95	14-21
Tomato (red)	8-10	90-95	8-10
Tree tomato	3-4	85-90	21-28
Turnip	0	90-95	120
Watercress	0	95-100	14-21
Watermelon	10-15	90	14-21
White sapote	19-21	85-90	14-21
Yam	16	70-80	60-210
Yellow sapote	13-15	85-90	21

Building design is an important factor to be taken into consideration. For example, a square shaped floor perimeter is thermally more efficient than a rectangular one. The roof is the most important part of the structure. This is because it has to protect produce from rain and radiant heat. Its slope should allow easy fall off of rainwater; its dimensions should exceed the perimeter of the building to protect walls from the sun and provide a dry area around the building in rainy weather. Floors should be of concrete, isolated from soil humidity, and elevated to avoid penetration of water. Doors need to be wide enough for mechanised handling.

Storage facilities should be thoroughly cleaned before filling. This includes brushing and washing of walls and floors to eliminate dirt and organic debris that could harbor insects and diseases. Before product is placed in the storage room, inspection and presorting should be undertaken. This is in order to remove all potential sources of contamination for the remaining load. Product should be stacked in such a way that there is free circulation of air. During storage, it should also be possible to carry out quality control inspections. If the storage facility becomes full during a long harvest period, it needs to be organised around the principles of the system "first in first out".

STORAGE SYSTEMS

As a rule, there are many ways of storing a product. The length of storage time can be longer in specifically designed structures. With refrigeration and controlled atmospheres, storage periods can be even longer. The technology utilised depends on whether the benefits (higher prices) outweigh the costs.

Natural or Field Storage

This is the most rudimentary system and is still in use for many crops. For example, roots (carrots, sweet potato, and cassava) and tubers (potato). Crops should be left in the soil until preparation for the market. This is similar to how citrus and some other fruits are left on the tree. Although storing products under natural conditions is widely practiced, it leaves them exposed to pests and diseases as well as to adverse weather conditions. This can have a detrimental effect on quality.

Another method widely used is field storage in heaps. This method ensures that produce is free from soil humidity and is protected from the weather with a tarpaulin, straw, or plastic materials. It is a low cost alternative for bulky crops that require large buildings. For example, potato, onions, pumpkins, sweet potato etc. Field storage in bins is a more recent variation where a pair of them (one on top of the other, the one above protected from the weather) is left in the field. It has the additional advantage of making it possible to undertake mechanical handling later.

Natural Ventilation

Amongst the wide range of storage systems, this is the most simple. It takes advantage of the natural airflow around the product to remove heat and humidity generated by respiration. Buildings providing some form of protection from the external environment and with gaps for ventilation can be used. Produce can be placed in bulk, bags, boxes, bins, pallets etc. Although simple, some key concepts need to be taken into account for the efficient operation of this system.

1. Differences in internal temperature and relative humidity conditions compared to conditions externally, need to be minimal. What this means is that this system can only be used with crops that store well under natural conditions such as potato, onions, sweet potato, garlic, pumpkins, etc.
2. For adequate ventilation, openings need to be wide. This means they need to be fitted with screens to keep animals, rodents, and pests out.
3. As with any other type of fluid, air follows the path of least resistance. This means that if product is stored in a compact mass, air will circulate to remove heat and gases

which have accumulated as a result of respiration. Efficient ventilation requires adequate space. However, this reduces storage capacity.

4. Hot and humid air rises within the storage facility. If no ventilation gaps exist, this leads to the build up of hot and humid areas which in turn affects the quality of stored goods. This presents the ideal conditions for the development of disease.

Within certain limits, it is possible to take advantage of natural changes in temperature and relative humidity. This can be achieved by selectively opening and closing the storage ventilation. At noon, ambient temperature and relative humidity are higher and lower, respectively. However, at night the opposite happens. To reduce temperature of stored products, buildings should be left open when external air temperatures are lower. Internal relative humidity can also be managed in a similar way.

External conditions constantly change, even during the same day. However, in comparison to air, stored mass is slower to gain and release heat. In order to handle this efficiently, internal and external electronic sensors for temperature and relative humidity are required. In addition to this, although crops suitable for this type of storage have low respiratory rates, some ventilation may be required. This is in addition to the automated opening and closing schedules.

Forced Air Ventilation

Heat and gas exchange can be improved provided air is forced to pass through the stored product. This system allows for more efficient utilisation of space for bulk storage. Air conducts run under a perforated floor and air is forced through the product. Again, as air follows the least resistance path, loading patterns as well as fan capacity and conduct dimensions should be carefully calculated. This is to ensure that there is uniform distribution of air throughout the product.

Removable perforated ducts can be used for storage space when there are no products in storage.

Fan selection is the most critical factor and specialised personnel should design the system based on volume and number of air changes per unit of time required. The latter is a function of respiratory rates of products to be stored. Static pressure or resistance to the airflow by conducts and stored mass should be considered. Ideally, sensors reacting to the internal/external ambient relationship should control the system. If closed, internal air circulation only occurs. On the other hand, if opened internal atmosphere is replaced by ventilation. A partial opening produces a mix of internal and external air to reach the desired combination of temperature and relative humidity.

Refrigeration

Controlling temperature is one of the main tools for extending postharvest life: low temperatures slow product metabolism and the activity of microorganisms responsible for quality deterioration. As a result, reserves are maintained with a lower respiration rate, ripening is retarded and vapor pressure between product and ambient is minimised, reducing water loss. These factors contribute towards maintaining freshness by reducing the rate at which quality deteriorates and the nutritional value of the product is preserved.

A refrigerated room is a relatively airtight and thermally insulated building. The refrigeration equipment should should have an external escape outlet to release externally the heat generated by the product. Refrigeration capacity of the equipment should be adequate to extract the heat generated by crops with a high respiration rate. It is also important to precisely control temperature and relative humidity conditions inside the refrigerated storage environment.

Refrigerated space depends on the maximum storage volume. Other factors to be considered include walkways and aisles to handle the product mechanically and the additional space to ensure uniform distribution of cold air. It is not uncommon to find that produce occupies only 75-80% of total surface area. Chamber height depends on product and stacking pattern: three meters for hand stacking but more than six may be required if forklifts are utilised.

Refrigerated rooms can be made with concrete, metal, wood, or other materials. All external surfaces should be thermally insulated, including the floor and ceilings. Type and thickness of insulation material depends on building characteristics, produce to be stored and the difference in temperature required between external and internal conditions. Polyurethane, expanded polystyrene, cork and other such materials can be used as insulation materials. Avapor barrier should be placed on the warm side of the insulation material.

Mechanical refrigeration has two main components: the evaporator, inside the storage area and the condenser which is outside connected by tubing filled with refrigerant. Normally, both elements are finned coils made of high thermal conductivity materials and integrated to a fan. This facilitates heat exchange. An evaporator is placed in the upper part of one of the walls forcing cold air to flow parallel to the ceiling. Returning air is forced past the evaporator transferring to the coil the heat extracted from the product. A refrigerant absorbs this heat as it changes to gas, cooling the air, which is forced again into the room as cold air. The refrigerant is transported as gas to the condenser where under the pressure provided by a compressor, it is transformed again into the liquid form. The internal heat is then released outside. With this repeated cycle, the system behaves like a pump - heat is extracted from the stored product and then released outside. Another key aspect of the mechanical refrigeration system is the expansion valve, which regulates the evaporation and flow of refrigerant. Ammonia and Freon gas are the most widely used refrigerants. However, they are now being replaced by more environmentally friendly products.

In addition to design and consideration of building materials, to gain maximum benefit from refrigeration the following conditions need to be met: refrigeration capacity needs to be adequate - this is in order to extract respiration heat from the product as well as conductive heat (through floors, walls, and ceiling); convective heat gains (door openings), and the heat produced by equipment (forklifts, lights, pumps, etc.).

Every crop has an optimal combination of temperature and relative humidity for storage. In many cases, there are differences even within varieties. As previously mentioned, it is recommended not to store more than one crop in the same room, unless this is for a very short period (less than a week) or during transportation. Very incompatible crops should not be in the same room for more than 1 or 2 days.

Precooling

Refrigeration equipment is designed to keep product chilled. However, they are not capable of reducing field heat rapidly. Field temperature is close to the ambient one and is much higher if produce is not protected from the sun. When produce is exposed to colder ambient conditions, it loses field temperature only slowly. It may take up to 24 or 48 hours in order to reach the new ambient temperature. The rate at which temperature falls depends on a number of factors. These include: differences in temperature, individual volume of product, total mass required for precooling and capacity of the refrigeration equipment. Metabolic activity (respiration, ethylene production, biochemical, and enzymatic reactions) also decreases with temperature - when storage temperature is reached rapidly, this results in reduced losses in energy, stored reserves, and quality.

Precooling is the rapid reduction of field temperature prior to processing, storage, or refrigerated transport. Generally it is a separate operation requiring special facilities, but complementary to cold storage. As deterioration is proportional to the time produce is exposed to high temperatures, precooling is beneficial even when produce returns later to ambient conditions. It is critical in maintaining quality in fruits and vegetables and forms part of the "cold chain" to maximise postharvest life.

Product temperature loss is not linear. This is because it is rapid at the beginning but slows down as it approaches the medium refrigerating temperature. Operation costs increase for each degree reduced. In commercial operations, produce is precooled to reach 7/8th of the difference between field and the final temperature required. The remaining 1/8th is lost during refrigerated storage or transport. For example, a product precooled with a field temperature of 30 ºC followed by exposure to a refrigerating medium of 10 ºC, should be terminated when 7/8th of the temperature difference is removed (final temperature = 12.5 ºC).

$$T_{final} = T_{initial\ product} - [\ 7 \times (T_{initial\ product} - T_{refrigerant})/8\ ]$$

$$T_{final} = 30 - [\ 7 \times (30 - 10)/8\ ] = 12.5\ ^{\circ}C$$

The rate of cooling depends on individual volume and the exposed surface of product. The difference in temperature between product and the refrigerating medium also needs to be taken into account. For example, due to large exposed surfaces, leafy vegetables cool almost 5 times faster than large fruit such as melons or watermelons. Other factors which have an influence include the type of cooling medium and the amount of circulation surrounding the product. Water has more capacity to absorb heat than air and rapid circulation increases their cooling capacity.

Each system listed below has its advantages and disadvantages.

a) Cold air: Room cooling
Forced air cooling

b) Cold water: Hydrocooling

c) Contact with ice: Crushed ice
Liquid ice
Dry ice

d) Evaporation of surface water:
Evaporative
Vacuum cooling

Room cooling

This is probably the most widely used system and is based on the product's exposure to cold air inside a refrigerated room. It is simple to operate as the product is cooled and stored in the same room. However, the removal of heat slowly makes this system unsuitable for highly perishable commodities. This is because the product needs at least 24 hours to reach the required storage temperature. Almost all crops are suitable for this type of cooling but it is mainly used in potato, onions, garlic, citrus, etc. (Table 2).

Table 2. Crops usually room cooled

Artichoke	Coconut	Melons	Salsify
Asian pear	Custard apple	Onion	Sapote
Atemoya	Garlic	Orange	Scorzonera
Banana	Ginger	Parsnip	Summer squash
Beans (dry)	Grapefruit	Cucumber	Sweet potato
Beet	Horseradish	Pineapple	Tangerine
Breadfruit	Husk tomato	Plantain	Tomato
Cabbage	J. artichoke	Potato	Tree tomato
Cactus leaves	Jicama	Prickly pear	Turnip
Carambola	Kiwano	Pumpkin	Watermelon
Cassava	Kohlrabi	Quince	Yam
Celeriac	Kumquat	Radish	
Chayote	Lime	Rhubarb	
Cherimoya	Lemon	Rutabaga	

Forced air cooling

This system includes cold air being forced to pass through produce by means of a pressure gradient across packages. Cooling is 4 to 10 times more rapid than room cooling and its rate depends on airflow and the individual volume of produce.Amongst the wide range of systems available, this is probably the most versatile. This is because it can be applied to all crops (Table 3), particularly berries, ripe tomatoes, bell peppers and many other fruits.

Table 3. Crops usually precooled by forced air.

Anona	Coconut	Mango	Prickly pear
Atemoya	Cucumber	Mangosteen	Pumpkin
Avocado	Eggplant	Melons	Quince
Banana	Feijoa	Mushrooms	Rhubarb
Barbados cherry	Fig	Okra	Sapote
Berries	Ginger	Orange	Snapbeans
Breadfruit	Grape	Papaya	Snowpeas
Brussels sprouts	Grapefruit	Passionfruit	Strawberry
Cactus leaves	Guava	Pepino	Summer squash
Caimito	Husk tomato	Pepper (Bell)	Tangerine
Carambola	Kiwifruit	Persimmon	Tomato
Cassava	Kumquat	Pineapple	Tree tomato
Chayote	Lima bean	Plantain	Yam
Cherimoya	Lychee	Pomegranate	

It is slow compared to hydrocooling but is a good alternative for crops requiring rapid heat removal which cannot tolerate wetting or chlorine of cooling water. However, inadequate airflow may produce dehydration. Package ventilation openings should be large enough to allow adequate air flow, particularly if products are stacked or palletised. Adequate airflow is necessary. This is because fruits in the center of packages tend to lose heat at a slower rate, compared to those on the exterior.

Hydrocooling

The refrigerating medium is cold water. Because of its higher capacity to absorb heat, it is faster than forced air cooling. Hydrocooling can be achieved by immersion or through means of a chilled water shower. In this final system, produce must be arranged in thin layers for uniform cooling. Not all crops can be hydrocooled. This is because they need to be able to tolerate wetting, chlorine, and water infiltration. Tomato, asparagus and many other vegetables are hydrocooled commercially (Table 4).

Table 4. Crops normally hydrocooled.

Artichoke	Cassava	Kiwifruit	Radish
Asparagus	Celeriac	Kohlrabi	Rhubarb
Beet	Celery	Leek	Salsify
Belgian endive	Chinese cabbage	Lima bean	Snapbeans
Broccoli	Cucumber	Orange	Snowpeas
Brussels sprouts	Eggplant	Parsley	Spinach
Caimito	Escarole	Parsnip	Summer squash
Cantaloupe	Green onions	Peas	Sweet corn
Cauliflower	Horseradish	Pomegranate	Swiss chard
Carrot	J. artichoke	Potato (early)	Watercress

Chlorination of water (150-200 ppm) is important to prevent accumulation of pathogens.

Ice cooling

This is probably one of the oldest ways to reduce field temperature. The most common method of ice cooling is at the individual pack level - crushed ice is added to the top of the product before the package is closed. Ice layers may also be interspersed with produce. As it melts, cold water cools the lower layers of product. Liquid icing is another system where a mix of water and crushed ice (40% water + 60% ice + 0,1% salt) is injected into open containers so that a big ice block is formed. The main disadvantage of ice cooling is that it is limited to ice tolerant crops (Table 5). It also increases costs because of the heavier weight for transportation and the need for oversised packages. In addition to this, as water melts, storage areas, containers, and shelves become wet.

Table 5. Crops that can be ice cooled.

Belgian endive	Chinese cabbage	Kohlrabi	Spinach
Broccoli	Carrot	Leek	Sweet corn
Brussels sprouts	Escarole	Parsley	Swiss chard
Cantaloupe Green onions	Pea/snowpeas	Watercress	

Evaporative

This is one of the most simple cooling systems. It involves forcing dry air through wet product. Heat is absorbed from product as water evaporates. This method has a low energy cost but cooling efficiency is limited by the capacity of air to absorb humidity. As a result, it is only useful in areas of very low relative humidity.

Vacuum cooling

Is one of the more rapid cooling systems. However, this is accomplished at very low pressures. At a normal pressure of 760 mmHg, water evaporates at 100 ºC, but it does at 1 ºC if pressure is reduced to 5 mmHg. Product is placed in sealed containers where vacuum is performed. Vacuum cooling produces about 1% product weight loss for each 5 ºC of temperature reduction. Modern vacuum coolers add water as a fine spray in the form of pressure drops. Similar to the evaporation method, this system is in general appropriate for leafy vegetables. This is because of their high surface-to-mass ratio (Table 6).

Table 6. Crops that can be vacuum cooled.

Belgian endive	Celery	Mushrooms	Sweet corn
Brussels sprouts	Escarole	Radiccio	Swiss chard
Carrot	Leek	Snapbeans	Watercress
Cauliflower	Lettuce	Snowpeas	
Chinese cabbage	Lima bean	Spinach	

Chilling injury

Refrigeration is the most widely used method for extending the postharvest life of fruits and vegetables. However, low temperatures may produce injuries to plant tissues. Freezing (prolonged exposure to temperatures lower than 0 °C); forms ice crystals inside tissues. This causes damage. Symptoms are readily apparent when thawing occurs - there is loss of turgidity and a general breakdown of plant tissues. One of the main causes for this injury is unattended or malfunctioning refrigeration equipment.

Chilling injury on crops that do not tolerate long exposure to temperatures in the range of 0 - 15 °C are less noticeable. Most chilling sensitive crops are of tropical or subtropical origin. For example, tomatoes, peppers, eggplants, pumpkins, summer squash, sweet potato, banana etc. Some temperate crops may also be sensitive. For example, asparagus, potato, some apple varieties, peaches etc. Critical temperatures for these crops range from 0-5 °C, while those of tropical origin are from 7-15 °C.

Symptoms of chilling injury depend on the type of crop and become noticeable when product is returned to ambient temperature. In banana, for example, a blackening of the skin and softening takes place while in tomato, pepper, eggplants and other fruits, sunken areas are apparent. This is usually associated with decay organisms and followed by rapid and uneven ripening. In many cases internal darkening or other discolourations are present. Severity of chilling injury depends on crop, temperature and length of exposure. As a general rule, immature fruits are more susceptible to damage than mature ones.

From a physiological point of view, chilling injury is the result of a cumulative breakdown of cellular metabolism. This is reversible during the first phase. A small rise in temperature restores the product to its former condition provided injuries are of a temporary nature. Different studies show that periodic (from 6-7 to 15 days) and short interruptions (5 to 48 hours) of cold storage through increases in temperature (from 12 to 25 °C) contribute towards extending post harvest life. Chilling injury is cumulative. In many cases it is the result of field, storage, and/or low transport temperatures.

Ethylene and other gaseous contamination

Under relatively airtight storage conditions, metabolic gases accumulate and ethylene and other volatiles are some of the most frequent contaminants.

Ethylene is a fitohormone, which regulates many growing, development and senescence processes in plant tissues. It is produced in large quantities by climacteric fruits during ripening. It is also induced by certain types of stress such as physical injuries and is also part of the healing process. Ethylene is released as a gas and accumulates to physiologically active levels when not eliminated by ventilation or chemical means.

When ethylene releasing and sensitive (Table 7) crops are placed in the same room, undesirable reactions take place. For example, these include an increase in respiratory rate, ripening and senescence, loss of green colour, yellowing, necrotic areas on plant tissues, formation of abscission layers, sprouting in potatoes, development of bitter flavour in roots, asparagus toughening, etc. Indirect effects include an increase in sensitivity to chilling, or susceptibility to pathogens and the stimulation of some decay organisms. The level of ethylene in storage areas should be less than 1 ppm to avoid problems.

Table 7. Ethylene and odor producers and sensitives.

	Ethylene producer	*Ethylene sensitive*	*Odor producer*	*Odor sensitive*
Anona	X	X		
Apple	X	X	X	X
Apricot	X	X		
Asian pear	X	X		
Asparagus		X		
Atemoya	X	X		
Avocado	X	X	X	X
Banana	X	X		
Basil		X		
Belgian endive		X		
Broccoli		X		
Brussels sprouts		X		
Cabbage		X		X
Cactus leaves		X		
Carrot		X	X	X
Cauliflower		X		
Celery		X		X
Cherimoya	X	X		
Cherry				X
Chinese cabbage		X		
Chives		X		
Cucumber		X		
Dates				X
Eggplant		X		X
Escarole		X		
Feijoa	X			
Fig	X			X
Grape			X	X
Green onions		X	X	
Guava	X	X		
Husk tomato		X		
Jackfruit	X	X		
Kale		X		
Kiwano		X		

Kiwifruit	X	X		
Leek		X	X	
Lemon			X	
Lettuce		X		
Lima bean		X		
Lime			X	
Lychee	X	X		
Mandarin		X		
Mango	X	X		
Melons	X	X		
Mushrooms	X	X		X
Nectarines	X	X		
Okra		X		
Olives, fresh		X		
Onion			X	X
Oranges		X	X	
Papaya	X			
Parsley		X		
Parsnip		X		
Passionfruit	X	X		
Pea		X		
Peach	X	X		
Pear	X	X	X	X
Pepino		X		
Pepper (Bell)		X	X	
Persimmon	X	X		
Prickly pear		X		
Pineapple				X
Plum	X	X		
Potato		X	X	X
Quince	X	X		
Rambutan	X	X		
Sapodilla	X	X		
Sapote	X	X		
Snapbeans		X		X
Snowpeas		X		
Spinach		X		

Summer squash		X	
Sweet corn			X
Sweet potato		X	
Swiss chard		X	
Tomato	X	X	
Watercress		X	
Watermelon		X	
Yam		X	

Aroma, odors, and other volatiles form an integral part of the metabolism of the plant. As with ethylene, there is contamination when producing species and sensitive crops share the same storage area (Table 7).

Relative humidity

Fruits and vegetables are largely composed of water. An important factor in maintaining post harvest quality is to ensure that there is adequate relative humidity inside the storage area. Water loss or dehydration means a loss in fresh weight. This in turn affects the appearance, texture, and in some cases the flavor. Water loss also affects crispiness and firmness. Consumers tend to demand and associate these qualities with freshness, perceiving them as just harvested.

The percentage of relative humidity is the most widely used parameter to express the amount of water in the air. It is defined as the relationship between the pressure of water in the air and the temperature at saturation point. As with other gases, water vapour moves from higher to lower pressure areas. In plant tissues, water is mainly present as cellular liquids, but in equilibrium with the intercellular spaces where it exists as a vapor saturated atmosphere (100% relative humidity). Exposure to identical air conditions of relative humidity and temperature will prevent water loss from tissues.

Capacity of air to hold water increases with temperature. The reverse is also true. This means that refrigeration increases the relative humidity of air. However, in some cases humidifiers are needed to increase the moisture content so as to reach the ideal conditions for storage. Onion, garlic, pumpkin etc provide some exceptions. They are best stored at relative humidity in the range of 60-70%. Most fruits and vegetables are required to be kept at a relative humidity of 90-95%, while some others at values close to saturation.

Short term storage - Refrigerated transport

Refrigeration in cold stores is not always used to maximise the postharvest life. On the contrary, it is probably used more often during the short time required for the sequence of activites in the cold chain ending at the consumption point. Refrigerated transport is probably the best example of this. However, there are many other opportunities for the use of temporary cold storage e.g. during preparation and sale of product for the market. For example, holding product until processing, packaging, or transport is carried out. Other examples include the use of refrigerated facilities at wholesale or retail. Cold storage is also used in the home to prolong the shelf-life of products.

It is hard to define what constitutes "short term and long-term storage". This is because 7 days is a long time for raspberries while for potato, onion, garlic and other products that require longer periods of storage this is considered to be relatively short.

It is preferable not to store different crops together. However, this is common practice and is unavoidable in many cases, particularly at distribution or retail. This does not pose a problem provided products are not exposed to suboptimal conditions for too long and build up of ethylene is avoided. A strategy widely practiced is to set cold chambers at an average of around 5 °C and 90-95% level of relative humidity.

If possible, mixed loads should have different regimes depending on the specific combination of fruits and vegetables in store. This is assuming that ambient ethylene concentration does not exceed 1 ppm. The University of California recommends three combinations of temperature and relative humidity: 1) 0-2 °C and 90-98% RH for leafy vegetables, crucifers, temperate fruits and berries; 2) 7-10 °C and 85-95% RH for citrus, subtropical fruits and fruit vegetables; 3) 13-18 °C and 85-95% RH for tropical fruits, melons, pumpkins and root vegetables. On the other hand, Tan recommends 5 different storage conditions: 1) 0 °C and 90-100% RH; 2) 7-10 °C and 90-100% RH 3) 13 °C and 85-90% RH; 4) 20 °C and 5) ambient conditions. Other species are divided into five groups. Group 1 - apple, apricot, figs, ripe kiwifruit, peaches, pears, leafy vegetables, grape, beet, crucifers, celery, etc. Group 2 - avocado, cantaloupes, and honey dew melons, guava, cucumber, snap beans, peppers, summer squash, eggplants and in general citrus etc. Group 3 - banana, cherimoya, papaya, potatoes, pumpkin, etc. Group 4 - pineapple and Group 5 - garlic, nuts, onions, potato and shallots.

Transport is an examples of temporary refrigerated storage. Mixed loads cause incompatibility problems highlighted previously. Because packaging dimensions are different, they are usually not fully stackable and the ventilation openings of packages of different dimensions do not match to each other. This prevents ventilation and creates microambient conditions which are undesirable.

Combination of Storage Systems

Facilities for long-term storage of potato, onion, sweet potato etc, often include using a combination of forced air systems as well as heating and/or refrigeration equipment.

Because these are crops that initially require a curing period, hot and humid air is introduced at the beginning. Later, the temperature is reduced with either through forced air cooling or natural ventilation. Adequate temperatures are obtained by mixing external and internal atmospheres and if required, the air is heated or refrigerated. In this way, the same building is used for both curing and storage - an important consideration in mechanised harvesting systems.

Controlled Atmospheres

With atmosphere modification, the low metabolic rate achieved with refrigeration is extended even further. As a result, the storage period is prolonged without further losses in quality.

Composition of normal atmosphere at sea level is around 78,1% nitrogen, 21% oxygen y 0,03% carbon dioxide. A "controlled" or "modified" atmosphere is obtained when its composition varies from the norm. In controlled atmosphere, gas composition is exactly maintained. It is often used for extremely long periods of storage in purpose built facilities. Modified atmospheres, on the other hand, are obtained when produce is packed in semi permeable films and are used for short periods. The atmospheric composition inside the package changes until it is in equilibrium with the ambient one. Equilibrium atmosphere depends on product, film characteristics, and storage temperature.

The modification of storage atmosphere delays the biochemical and physiological changes associated with senescence. This mainly involves the respiratory rate, ethylene production, softening and compositional changes. Other effects include the reduction in sensitivity to ethylene, and in some cases chilling and the severity of pathogen attack. The atmospheric composition can also be used to control insects. The risk of using abnormal atmospheres is that they may cause fermentation, tissue asphyxia, and the development of off-odors or off-flavors.

From the construction point of view, controlled atmosphere facilities are similar to refrigeration facilities. However, they should be airtight to allow creation of an atmosphere different from normal. The Oxygen consumption and its replacement by carbon dioxide by respiration, create the atmosphere. When the appropriate combination has been reached, a limited intake of oxygen is required to satisfy the reduced rate of respiration. Accumulation of carbon dioxide is removed by means of different methods. Because internal atmosphere behaves differently, a pressure compensating system is required to attain equilibrium with the external or ambient atmosphere. As controlled atmosphere rooms are kept locked until the end of the storage period, inspection windows are required to control refrigeration equipment. Product should also be placed at the top of one of the walls. Atmospheric composition is crop specific. However, as a general rule the most common combinations are 2-5% oxygen and 3-10% carbon dioxide.

Many crops benefit from atmosphere modification. However, usage is limited. It is difficult to define products ideal for storing under controlled atmosphere. However, one of the most important factors is that investment and operating costs should be recovered. Other factors include: First, products should be seasonal and have a stable demand during a long marketing period. Second, product should have some unique qualities and not be easily substituted by similar products. In other words, it is beneficial to use controlled atmosphere technology when there are no competitor products on the market. This may go some way towards explaining why its usage is limited to specific crops, particularly apples and pears.

REFERENCES

Bachmann, J. and R. Earles. 2000. "Postharvest Handling of Fruits and Vegetables". *ATTRA Horticulture Technical Note*. 19 pp.

Hardenburg, R.E.. et al. 1986. *The Commercial Storage of Fruits. Vegetables. and Florist and Nursery Stocks.* USDA Agriculture Handbook 66. 130 pp.

Walker, D. J. 1992. *World Food Programme Food Storage Manual.* Chatham, UK: Natural Resources Institute.

Wills, R., B. McGlasson, D. Graham, and D. Joyce. 1998. *Postharvest: An Introduction to the Physiology and Handling of Fruit, Vegetables, and Ornamentals.* CAB International, Wallingford, UK, 262 pp.

Zagory, D. 1999. "Effects of post-processing handling and packaging on microbial populations". *Postharv. Biol. Technol.* 15:313-321.

7

Post-harvest Quality and Safety Management

Fruits, nuts, and vegetables play a significant role in human nutrition, especially as sources of vitamins, minerals, dietary fibre, and antioxidants. Increased consumption of a variety of fruits and vegetables on a daily basis is highly recommended because of associated health benefits, which include reduced risk of some forms of cancer, heart disease, stroke, and other chronic diseases.

Both quantitative and qualitative losses occur in horticultural commodities between harvest and consumption. Qualitative losses, such as loss in edibility, nutritional quality, caloric value, and consumer acceptability of fresh produce, are much more difficult to assess than are quantitative losses. Quality standards, consumer preferences and purchasing power vary greatly across countries and cultures and these differences influence marketability and the magnitude of post-harvest losses.

Post-harvest losses vary greatly across commodity types, with production areas and the season of production. Losses of fresh fruits and vegetables in developed countries are estimated to range from 2 percent for potatoes to 23 percent for strawberries, with an overall average of 12 percent losses between production and consumption sites. In contrast, the range of produce losses in developing countries varies widely. Losses at the retail, food-service, and consumer levels are estimated at approximately 20 percent in developed countries and about 10 percent in developing countries. Overall, about one third of horticultural crops produced are never consumed by humans.

Reduction of post-harvest losses can increase food availability to the growing world population, decrease the area needed for production, and conserve natural resources. Strategies for loss prevention include:

1. use of genotypes that have longer post-harvest-life;

2. use of integrated crop management systems and Good Agricultural Practices that result in good keeping quality of the commodity; and
3 use of proper post-harvest handling practices in order to maintain the quality and safety of fresh produce.

Although minimising post-harvest losses of already produced food is more sustainable than increasing production to compensate for these losses, less than 5 percent of the funding of agricultural research and extension programs worldwide is devoted to activities related to maintenance of produce quality and safety during post-harvest handling. This situation must be changed if success is to be achieved in reducing post-harvest losses of horticultural perishables.

QUALITY FACTORS

Quality, the degree of excellence or superiority, is a combination of attributes, properties, or characteristics that give each commodity value, in terms of its intended use. The relative importance given to a specific quality attribute varies in accordance with the commodity concerned and with the individual (producer, consumer, and handler) or market concerned with quality assessment. To producers, high yields, good appearance, ease of harvest, and the ability to withstand long-distance shipping to markets are important quality attributes. Appearance, firmness, and shelf-life are important from the point of view of wholesale and retail marketers. Consumers, on the other hand, judge the quality of fresh fruits, ornamentals, and vegetables on the basis of appearance (including 'freshness') at the time of initial purchase. Subsequent purchases depend upon the consumer's satisfaction in terms of flavor (eating) quality of the edible part of produce. Following is a description of the factors that contribute to the various quality attributes of fresh produce:

Appearance (Visual) Quality Factors

These may include size, shape, color, gloss, and freedom from defects and decay. Defects can originate before harvest as a result of damage by insects, diseases, birds, and hail; chemical injuries; and various blemishes (such as scars, scabs, russeting, rind staining). Post-harvest defects may be morphological, physical, physiological, or pathological.

Textural (Feel) Quality Factors

These include firmness, crispness, juiciness, mealiness, and toughness, depending on the commodity. Textural quality of horticultural crops is not only important for their eating and cooking quality but also for their shipping ability. Soft fruits cannot be shipped over long distances without substantial losses due to physical injuries. In many cases, the shipment of soft fruits necessitates that they be harvested at less than ideal maturity, from the flavor quality standpoint.

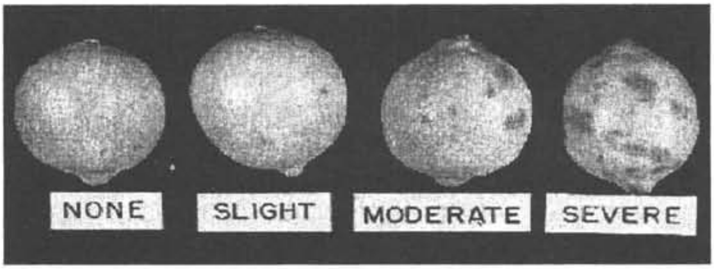

Figure 1: Oil spotting on lemons (the result of mechanical damage during the harvesting and handling of turgid lemons)

Flavor (Eating) Quality Factors

These include sweetness, sourness (acidity), astringency, bitterness, aroma, and off-flavors. Flavor quality involves perception of the tastes and aromas of many compounds. An objective analytical determination of critical components must be coupled with subjective evaluations by a taste panel to yield useful and meaningful information about the flavor quality of fresh fruits and vegetables. This approach can be used to define a minimum level of acceptability. In order to assess consumer preference for the flavor of a given commodity, large-scale testing by a representative sample of consumers is required.

Nutritional Quality Factors

Fresh fruits and vegetables play a significant role in human nutrition, especially as sources of vitamins (Vitamin C, Vitamin A, Vitamin B, thiamine, niacin), minerals, and dietary fibre. Other constituents of fresh fruits and vegetables that may lower the risk of cancer and other diseases include carotenoids, flavonoids, isoflavones, phytosterols, and other phytochemicals (phytonutrients).

Grade standards identify quality attributes in a commodity that are the basis of its use and value. Such standards, if enforced properly, are essential tools of quality assurance during marketing and provide a common language for trade among growers, handlers, processors, and receivers at terminal markets.

SAFETY FACTORS

A number of factors threaten the safety of fruits and vegetables. These include naturally-occurring toxicants, such as glycoalkaloids in potatoes; natural contaminants, such as fungal toxins (mycotoxins) and bacterial toxins, and heavy metals (cadmium, lead, mercury); environmental pollutants; pesticide residues; and microbial contamination. While health authorities and scientists regard microbial contamination as the number one safety concern, many consumers rank pesticide residues as their most important safety concern.

Unless fertilised with animal and/or human waste or irrigated with water containing such waste, raw fruits and vegetables should normally be free of most human and animal enteric pathogens. Organic fertilisers, such as chicken manure, should be sterilised prior to their application in fruit and vegetable production, so as to avoid the risk of contaminating fresh produce with *Salmonella, Listeria,* and other pathogens. Commodities that touch the soil are more likely to be contaminated than those that do not come in contact with the soil. The best approach to achieving and maintaining the safety of fresh fruits and vegetables is to focus on limiting potential contamination during their growth, harvesting, handling, treatment, packaging and storage. Strict adherence to Good Agricultural Practices, i.e. basic food safety principles associated with minimising biological, chemical and physical hazards from the field throughout the distribution chain of fresh fruits and vegetables; Good Hygienic Practices, i.e. conformance to sanitation and hygienic practices to the extent necessary to protect against contamination of food from direct or indirect sources, is strongly recommended to minimise microbial contamination. Careful handling and washing of all produce to be consumed raw and the strict observance of proper sanitary measures are strongly recommended to reduce microbial contamination at the food-service, retail, and consumer levels.

FACTORS INFLUENCING QUALITY AND SAFETY OF HORTICULTURAL CROPS

Genetic Factors

Within each commodity grouping there is a range of genotypic variation in composition, quality, and post-harvest-life potential. Plant breeders have been successful in selecting carrot, sweet potato, and tomato cultivars with comparably high carotenoid levels and vitamin A content; onion and tomato cultivars with longer shelf-lives, sweet corn cultivars that maintain their sweetness longer after harvest; cantaloupe and watermelon cultivars with higher sugar content and firmer flesh, and pineapple cultivars with higher contents of ascorbic acid, carotenoids, and sugars. These are just a few examples of how genetic manipulation has contributed to improving the quality of fruits and vegetables. However, in many cases, commercial cultivars selected for their ability to withstand the rigors of marketing and distribution, tend to lack sufficient sensory quality, in particular flavor.

Horticultural plant breeders have an unprecedented opportunity to address human nutritional needs by developing fruit and vegetable cultivars that are rich in nutrients.

In so doing, a multidisciplinary approach should be taken with emphasis the enhancement of nutritional quality for maximum impact on human nutrition and wellness.

Many opportunities exist for applying biotechnology to improving the post-harvest quality and safety of fresh produce. Priority goals in this regard, should, be focused on:

1. Attaining and maintaining good flavor and nutritional quality, so as to satisfy consumer demands and
2. Introducing resistance to physiological disorders and/or decay-causing pathogens, so as to reduce the use of chemicals on fruits and vegetables.

Climatic Conditions

Climatic factors, in particular temperature and light intensity, greatly impact on the nutritional quality of fruits and vegetables. Consequently, the location of production and the season in which plants are grown can determine their ascorbic acid, carotene, riboflavin, thiamine, and flavonoid contents. In general, the lower the light intensity the lower the ascorbic acid content of plant tissues. Temperature influences the uptake and metabolism of mineral nutrients by plants, since transpiration rates increase with increasing temperature. Rainfall affects water supply to the plant, which may influence the composition of the harvested plant part and its susceptibility to mechanical damage and decay during subsequent harvesting and handling operations.

Cultural Practices

Soil type, the rootstock used for fruit tree cultivation, mulching, irrigation, and fertilisation influence the water and nutrient supply to the plant, which can in turn affect the nutritional quality of the harvested plant part. The effect of fertilisers on the vitamin content of plants is less important than are the effects of genotype and climatic conditions. The effects of mineral and elemental uptake from fertilisers by plants are, however, significant and variable.

Selenium and sulfur uptake for example influence the concentrations of organosulfur compounds in *Allium* and *Brassica* species. High calcium uptake in fruits has been shown to reduce respiration rates, and ethylene production, to delay ripening, increase firmness, and reduce the incidence of physiological disorders and decay, all of which result in increased post-harvest shelf-life. High nitrogen content on the other hand, is often associated with reduced post-harvest-life due to increased susceptibility to mechanical damage, physiological disorders, and decay. Increasing the nitrogen and/or phosphorus supply to citrus trees results in somewhat reduced acidity and ascorbic acid content in citrus fruits, while increased potassium fertilisation results in increased acidity and ascorbic acid content.

Numerous physiological disorders are associated with mineral deficiencies. Bitter pit of apples; blossom-end rot of tomatoes, peppers, and watermelons; cork spot in apples and pears; and red blotch of lemons are all associated with calcium deficiency in these fruits. Boron deficiency results in corking of apples, apricots, and pears; lumpy rind of citrus fruits, and cracking of apricots. Poor color of stone fruits may be related to iron and/or zinc deficiencies. Excess sodium and/or chloride results in reduced fruit size and higher soluble solids content.

Severe water stress results in increased sunburn of fruits, irregular ripening of pears, tough and leathery texture in peaches, and incomplete kernel development in nuts. Moderate water stress reduces fruit size and increases soluble solids content, acidity, and ascorbic acid content. On the other hand, excess water supply to plants results in cracking of fruits, excessive turgidity leading to increased susceptibility to physical damage, reduced firmness, delayed maturity, and reduced soluble solids content.

Cultural practices such as pruning and thinning determine the crop load and fruit size, which can in turn influence the nutritional composition of fruit. The use of pesticides and growth regulators does not directly influence fruit composition but may indirectly affect it due to delayed or accelerated fruit maturity. Effective pre-harvest disease control greatly influences disease incidence and severity during post-harvest handling of fruits and vegetables

MATURITY AT HARVEST IN RELATION TO QUALITY

Maturity at harvest is the most important determinant of storage-life and final fruit quality. Immature fruit are highly susceptible to shriveling and mechanical damage, and are of inferior flavor quality when ripe. Overripe fruit are likely to become soft and mealy with insipid flavor soon after harvest. Fruit picked either prematurely or too late, are more susceptible to post-harvest physiological disorders than are fruit picked at the proper stage of maturity.

With a few exceptions all fruits attain optimal eating quality when allowed to ripen on the plant. Some fruits are, however, picked at a mature but unripe stage of development so as to allow them to withstand post-harvest handling conditions when shipped over long-distances. Maturity indices for such fruit are based on a compromise between those indices that would ensure the best eating quality to the consumer and those that provide flexibility in marketing.

Fruit can be divided into two groups:

1. Those that are incapable of continuing their ripening process once removed from the plant, and
2. Those that can be harvested at the mature stage and allowed to ripen off the plant.

Group 1 includes cane berries, cherry, citrus fruits, grape, lychee, pineapple, pomegranate, strawberry, and tamarillo. Group 2 on the other hand, includes apple, apricot, avocado, banana, cherimoya, guava, kiwifruit, mango, nectarine, papaya, passion fruit, pear, peach, persimmon, plum, quince, sapodilla, and sapote.

Fruit of the Group 1 category, produce very small quantities of ethylene and do not respond to ethylene treatment except in terms of degreening (removal of chlorophyll); these should be picked when fully-ripe, if good flavor quality is to be ensured. Fruit of the Group 2 category on the other hand, produce comparably larger quantities of ethylene which is associated with their ripening, and undergo more rapid and uniform ripening upon exposure to ethylene.

Many vegetables, in particular leafy vegetables, and immature fruit-vegetables (such as cucumbers, sweet corn, green beans, peas, and okras), attain optimum eating-quality prior to reaching full maturity. This often results in delayed harvest, and consequently in produce of low quality.

Method of Harvesting in Relation to Physical Damage and Uniformity of Maturity

The method of harvesting can significantly impact upon the composition and post-harvest quality of fruits and vegetables. Mechanical injuries can accelerate loss of water and vitamin C resulting in increased susceptibility to decay-causing pathogens. Most fresh fruits and vegetables and all flowers are harvested by hand. Root crops and some commodities destined for processing are mechanically harvested.

Management of harvesting operations, whether manual or mechanical, can have a major impact on the quality of harvested fruits and vegetables. Proper management procedures include selection of optimum time to harvest in relation to product maturity and climatic conditions, training and supervision of workers, and proper implementation of effective quality control. Expedited and careful handling, immediate cooling after harvest, maintenance of optimum temperatures during transit and storage, and effective decay-control procedures are important factors in the successful post-harvest handling of fruits and vegetables.

Attention must be paid to all of these factors, regardless of the method of harvesting used. These factors are nevertheless more critical in the case of mechanically harvested commodities.

It should be noted that any practice that reduces the number of produce handling steps will help minimise losses. Field packing of produce at the time of harvest can greatly reduce the number of handling steps in preparation for marketing. Mobile field packing stations with adequate shading are used for those fruits and vegetables that do not require washing as part of their preparation for marketing.

POST-HARVEST MANAGEMENT PROCEDURES

Packing and Packaging of Fruits and Vegetables

Preparation of produce for market may be done either in the field or at the packing house. This involves cleaning, sanitising, and sorting according to quality and size, waxing and, where appropriate, treatment with an approved fungicide prior to packing into shipping containers. Packaging protects the produce from mechanical injury, and contamination during marketing. Corrugated fiberboard containers are commonly used for the packaging of produce, although reusable plastic containers can be used for that purpose. Packaging accessories such as trays, cups, wraps, liners, and pads may be used to help immobilise the produce within the packaging container while serving the purpose of facilitating moisture retention, chemical treatment and ethylene absorption. Either hand-packing or mechanical packing systems may be used. Packing and packaging methods can greatly influence air flow rates around the commodity, thereby affecting temperature and relative humidity management of produce while in storage or in transit.

Temperature and Relative Humidity Management

Temperature is the most important environmental factor that influences the deterioration of harvested commodities. Most perishable horticultural commodities have an optimal shelf-life at temperatures of approximately 0 °C. The rate of deterioration of perishables however increases two to three-fold with every 10 °C increase in temperature (Table 1). Temperature has a significant effect on how other internal and external factors influence the commodity, and dramatically affects spore germination and the growth of pathogens.

Table 1: Effect of temperature on the deterioration rate of a non-chilling sensitive commodity

Temperature (°C)	*Assumed* Q_{10}	*Relative velocity of deterioration*	*Relative postharvest-life*	*Loss per day (%)*
0	-	1.0	100	1
10	3.0	3.0	33	3
20	2.5	7.5	13	8
30	2.0	15.0	7	14
40	1.5	22.5	4	25

Temperatures either above or below the optimal range for fresh produce can cause rapid deterioration due to the following disorders:

Freezing : Perishable commodities are generally high in water content, and possess large, highly vacuolate cells. The freezing point of their tissues is relatively high (ranging from -3 °C to -0.5 °C), and disruption caused by freezing generally results in immediate collapse of their tissues and a total loss of cellular integrity. Freezing occurs in cold storage systems either due to inadequate refrigerator design, or to thermostat failure. Freezing can also occur upon exposure to inclement weather conditions as occurs when produce is allowed to remain for even short periods of time on unprotected transportation docks during winter.

Chilling injury: Some commodities respond unfavorably to storage at low temperatures which are well above their freezing points, but below a critical temperature termed their chilling threshold temperature or lowest safe temperature (Table 2). Chilling injury is manifested in a variety of symptoms including surface and internal discoloration, pitting, water soaking, failure to ripen, uneven ripening, development of off flavors and heightened susceptibility to pathogen attack.

Table 2: Classification of chilling-sensitive fruits and vegetables according to their lowest safe temperature for transport and storage

Lowest safe temperature (°C)	*Commodity*
3	Asparagus, cranberry, jujube
4	Cantaloupe, certain apple cultivars (such as McIntosh and Yellow Newton), certain avocado cultivars (such as Booth and Lula), lychee, potato, tamarillo
5	Cactus pear, cowpeas, durian, feijoa, guava, kumquat, lima bean, longan, mandarin, orange, pepino
7	Certain avocado cultivars (such as Fuerte and Hass), chayote, okra, olive, pepper, pineapple, pomegranate, snap bean
10	Carambola, cucumber, eggplant, grapefruit, lime, mango (ripe), melons (casaba, crenshaw, honeydew, persian), papaya, passion fruit, plantain, rambutan, squash (soft rind), taro, tomato (ripe), watermelon
13	Banana, breadfruit, cherimoya, ginger, jackfruits, jicama, lemon, mango (mature-green), mangosteen, pumpkin and hard-rind squash, sapotes, sweet potato, tomato (mature-green), yam

Heat injury: High temperature conditions are also injurious to perishable crops. Transpiration is vital to maintaining optimal growth temperatures in growing plants. Organs removed from the plant, however, lack the protective effects of transpiration, and direct sources of heat, such as sunlight, can rapidly elevate the temperature of tissues to above the thermal death point of their cells, leading to localised bleaching, necrosis (sunburn or sunscald) or general collapse.

Relative humidity (RH): is defined as the moisture content of the atmosphere, expressed as a percentage of the amount of moisture that can be retained by the atmosphere at a given temperature and pressure without condensation. The moisture holding capacity of air increases with temperature. Water loss is directly proportional to the vapor pressure difference (VPD) between the commodity and its environment. VPD is inversely related to the RH of the air surrounding the commodity.

RH can influence water loss, decay development, the incidence of some physiological disorders, and uniformity of fruit ripening. Condensation of moisture on the commodity (sweating) over long periods of time is probably more important in enhancing decay than is the RH of ambient air. An appropriate RH range for storage of fruits is 85 to 95 percent while that for most vegetables varies between 90 and 98 percent. The optimal RH range for dry onions and pumpkins is 70 to 75 percent. Some root vegetables, such as carrot, parsnip, and radish, can best be held at 95 to 100 percent RH.

RH can be controlled by one or more of the following procedures:

1) adding moisture (water mist or spray, steam) to air with the use of humidifiers;
2) regulating air movement and ventilation in relation to the produce load in the cold storage room;
3) maintaining the temperature of the refrigeration coils in the storage room or transit vehicle to within about 1 °C of the air temperature;
4) providing moisture barriers that insulate walls of storage rooms and transit vehicles;
5) adding polyethylene liners in packing containers and using perforated polymeric films for packaging;
6) wetting floors in storage rooms;
7) adding crushed ice in shipping containers or in retail displays for commodities that are not injured by the practice;
8) sprinkling produce with sanitised, clean water during retail marketing of commodities that benefit from misting, such as leafy vegetables, cool-season root vegetables, and immature fruit vegetables.

Cooling Methods

Temperature management is the most effective tool for extending the shelf life of fresh horticultural commodities. It begins with the rapid removal of field heat by using one of the cooling methods listed in Table 3.

Packing fresh produce with crushed or flaked ice provides rapid cooling, and can provide a source of cooling and high RH during subsequent handling. The use of crushed ice is, however, limited to produce that is tolerant to direct contact with ice and packaged in moisture-resistant containers. Clean, sanitised water is used as the cooling medium for the hydrocooling (shower or immersion systems) of commodities that tolerate water contact and are packaged in moisture-resistant containers. Vacuum cooling is generally applied to leafy vegetables that release water vapor quickly, thereby allowing them to be rapidly cooled. During forced-air cooling on the other hand, refrigerated air is forced through produce packed in boxes or pallet bins. Forced-air cooling is applicable to most horticultural perishables.

Table 3.Comparison of methods used for cooling

Variable	*Cooling method*				
	Ice	*Hydro*	*Vacuum*	*Forced-air*	*Room*
Cooling times (h)	0.1-0.3	0.1-1.0	0.3-2.0	1.0-10.0	20-100
Water contact with the product	yes	yes	no	no	no
Product moisture loss (%)	0-0.5	0-0.5	2.0-4.0	0.1-2.0	0.1-2.0
Capital cost	high	low	medium	low	low
Energy efficiency	low	high	high	low	low

Precise temperature and RH management are required to provide the optimum environment for fresh fruits and vegetables during cooling and storage. Precision temperature management (PTM) tools, including time-temperature monitors, are increasingly being employed in cooling and storage facilities.

Refrigerated Transport and Storage

Cold storage facilities should be appropriately designed, of good construction, and be adequately equipped. Their insulation should include a complete vapor barrier on the warm side of the insulation; sturdy floors; adequate and well-positioned doors for loading and unloading; effective distribution of refrigerated air; sensitive and properly located controls; refrigerated coil surfaces designed to adequately minimise differences between the coil and air temperatures; and adequate capacity for expected needs. Commodities should be stacked in the cold room or the refrigerated vehicle with air spaces between pallets and room walls so as to ensure proper air circulation. Storage rooms should not be loaded beyond their capacity limit if proper cooling is to be achieved. Commodity temperature rather than air temperature should be measured in these facilities.

Temperature management during transportation of fresh fruits and vegetables over long distances is critical. Loads must be stacked so as to enable proper air circulation, in order to facilitate removal of heat from the produce as well as to dissipate incoming heat from the atmosphere and off the road. Stacking of loads must also incorporate consideration for minimising mechanical damage. Transit vehicles must be cooled prior to loading the fresh produce. Delays between cooling after harvest and loading into transit vehicles should also be avoided. Proper temperature maintenance should be ensured throughout the handling system.

As far as possible, environmental conditions should be optimised in transport vehicles. Treatment with ethylene to initiate ripening during transportation is feasible, and is commercially used to a limited extent on mature green bananas and tomatoes. Produce should be cooled prior to loading and should be loaded with an air space between the palletised product and the walls of the transport vehicles in order to facilitate temperature control. Vibration during transportation should be minimised, so as to avoid damage due to bruising. Controlled-atmosphere and precision temperature management should, where possible, be observed so as to allow non-chemical insect control for markets which possess quarantine restrictions against pests endemic to exporting countries and for markets that do not want their produce exposed to chemical fumigants.

Mixing several produce items in one load is common and often compromises have to be made in selecting an optimal temperature and atmospheric composition when transporting chilling-sensitive with non-chilling sensitive commodities or ethylene-producing with ethylene-sensitive commodities. In the latter case, ethylene scrubbers can be used to remove ethylene from the circulating air within the vehicle. Several types of insulating pallet covers are available for protecting chilling-sensitive commodities when transported with non-chilling-sensitive commodities at temperatures below their threshold chilling temperatures.

Cold Chain

The cold chain encompasses all the critical steps and processes that foods and other perishable products must undergo in order to maintain their quality. Like any chain, the cold chain is only as strong as its weakest link. Major limitations experienced by the cold-chain include poor temperature management due to either the lack of, or limitations in, refrigeration, handling, storage, and humidity control. Investment in cold chain infrastructure ultimately leads to a reduction in the level of losses and quality degradation in fresh produce, with overall net positive economic returns.

Relative Humidity Management

Deficiencies in cold chain management whether due to limitations in refrigeration, improper handling and storage, or inadequate humidity control, can lead to losses in profits as well as in horticultural crops. Overcoming such deficiencies necessitates improvements in methodologies, operations and handling along the chain. Often the level of investment required in overcoming such deficiencies is minimal in comparison to the level of losses sustained over time.

A University of California study determined that a one-hour delay in cooling strawberries after harvest resulted in a 10 percent loss due to decay during marketing. The resulting economic loss exceeded the increased cost of expedited handling of the strawberries by more frequent deliveries of harvested fruit to the cooling facility and initiation of forced-air cooling. Similarly, a University of Georgia study showed that poor temperature management of lettuce resulted in a net income loss of US$172.50 per truck-load of 900 cartons.

MINIMISING PRODUCE CONTAMINATION

Treatments to Reduce Microbial Contamination

Over the past few years, food safety has become and continues to be the number one concern of the fresh produce industry. A "Guide to Minimise Microbial Food Safety Hazards for Fresh Fruits and Vegetables," was published by the U.S. Food and Drug Administration in October 1998. This guide is based on the following principles:

1) Prevention of microbial contamination of fresh produce is favored over reliance on corrective actions once contamination has occurred;
2) In order to minimise microbial food safety hazards in fresh produce, growers, packers, or shippers should use good agricultural and management practices in those areas over which they have control;
3) Fresh produce can become microbiologically contaminated at any point along the farm-to-table food chain. Human and/or animal faeces are the source of microbial contamination of fresh produce;
4) Whenever water comes in contact with produce, its quality dictates the potential for contamination. The potential of microbial contamination from water used with fresh fruits and vegetables must be minimised;
5) The use of animal manure or municipal biosolid wastes as fertilisers should be closely managed in order to minimise the potential for microbial contamination of fresh produce; and
6) Worker hygiene and sanitation practices during production, harvest, sorting, packing, and transport play a critical role in minimising the potential for microbial contamination of fresh produce."

A training manual for trainers, entitled "Improving the Safety and Quality of Fresh Fruits and Vegetables," was published by the United States Food and Drug Administration (USFDA) in November 2002, with the objective of providing uniform, broad-based scientific and practical information on the safe production, handling, storage, and transport of fresh produce.

Clean water containing an appropriate concentration of sanitisers is required in order to minimise the potential transmission of pathogens from water to produce, from healthy to infected produce within a single lot, and from one lot of produce to another, over time. Waterborne microorganisms, including post-harvest plant pathogens and agents of human illness, can be rapidly acquired and taken up on plant surfaces. Natural plant surface contours, natural openings, harvest and trimming wounds and scuffing can provide points of entry as well as safe harbor for microbes. When located in these protected sites, microbes are largely unaffected by common or permitted doses of post-harvest water sanitising treatments. It is therefore essential that the sanitiser concentration is sufficient to kill microbes before they attach or become internalised in produce. The concentration of sanitiser is important in some pre-harvest water uses and in all post-harvest procedures involving water, including washing, cooling, water-mediated transport (flumes), and post-harvest drenching with calcium chloride or other chemicals.

Treatments to Minimise Water Loss

Transpiration, or evaporation of water from the plant tissues, is one of the major causes of deterioration in fresh horticultural crops after harvest. Water loss through transpiration not only results in direct quantitative losses, but also causes losses in appearance, textural quality, and nutritional quality. Transpiration can be controlled either through the direct application of post-harvest treatments to the produce or through manipulation of the environment.

Treatments that can be applied to minimise water loss in fruits and vegetables include:

a) Curing of certain root vegetables, such as garlic, onion, potato, and sweet potato.
b) Waxing and the use of other surface coatings on commodities, such as apple, citrus fruits, nectarine, peach, plum, pomegranate, and tomato.
c) Packaging in polymeric films that act as moisture barriers.
d) Careful handling to avoid physical injuries, which increase water loss from produce.
e) Addition of water to those commodities that tolerate misting with water, such as leafy vegetables.

Treatments to Reduce Ethylene Damage

The promotion of senescence in harvested horticultural crops by ethylene (1 ppm or higher) results in acceleration of deterioration and reduced post-harvest life. Ethylene accelerates chlorophyll degradation and induces yellowing of green tissues, thus reducing the quality of leafy, floral, and immature fruit-vegetables and foliage ornamentals. Ethylene induces abscission of leaves and flowers, softening of fruits, and several physiological disorders. Ethylene may increase decay development of some fruits by accelerating their senescence and softening and by inhibiting the formation of antifungal compounds in the host tissue. In some cases, ethylene may stimulate the growth of fungi, such as *Botrytis cineria* on strawberries and *Penicillium italicum* on oranges.

The incidence and severity of ethylene-induced deterioration symptoms is dependent upon temperature, time of exposure, and ethylene concentration. The yellowing of cucumbers can, for example, result from exposure to either 1 ppm ethylene over 2 days or to 5 ppm ethylene over 1/2 day at 10 °C. Ethylene effects are cumulative throughout the post-harvest life of the commodity.

Treatment of ornamental crops with 1-methylcylopropene (1-MCP), which is an ethylene action inhibitor, provides protection against ethylene damage. The commercial use of this product at concentrations of up to 1 ppm on apples, apricots, avocados, kiwifruit, mangoes, nectarines, papayas, peaches, pears, persimmons, plums, and tomatoes was approved by the United States Environmental Protection Agency. The use of 1-MCP will no doubt be extended to several other fruits and vegetables, and to use in other regions.

Treatments for Decay Control

A major cause of losses in perishable crops is the action of a number of microorganisms on the commodity. Fungi and bacteria may infect the plant organ at any time. "Latent" infections, in which fungi invade fruit tissues shortly after flowering, become apparent only at the onset of ripening.

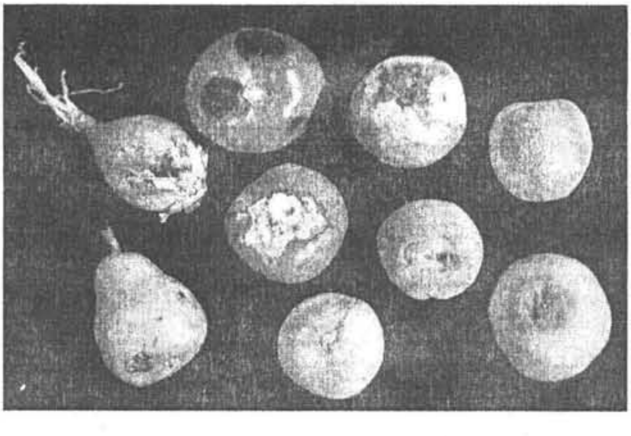

Figure 2. Symptoms of fruit decay

Post-harvest rots frequently occur as a result of rough handling during the marketing process and are caused by a wide array of microorganisms. The grey mold *Botrytis cineria* is a very important cause of loss in many commodities (such as grapes, kiwifruit, pomegranates, raspberries, and strawberries), and is an aggressive pathogen, even at low temperatures. Virus infection frequently lowers the quality of perishable commodities, usually as a result of visual deterioration, although viruses may also affect flavor and composition.

Curing is a post-harvest treatment (Table 5) that facilitates certain anatomical and physiological changes that can prolong the storage life of some root crops. It is one of the most effective and simple means of reducing water loss and decay during subsequent storage of root, tuber, and bulb crops, such as those listed in Table 5.

Sanitation practices include treatment to reduce populations of microorganisms on equipment, on the commodity, and in the wash water used to clean it. Water washes alone are effective in removing nutrients that allow microorganisms to grow on the surfaces of produce as well as in removing inoculum of post-harvest pathogens. The addition of sanitisers to water dumps and spray or dip washes, reduces inoculum levels of decay-causing organisms from fruit surfaces, inactivates spores brought into solution from fruit or soil and prevents the secondary spread of inoculum in water. Treatments for decay control include: (1) heat treatments, such as dipping mangoes in water at a temperature of 50 °C, for 5 minutes in order to reduce subsequent development of anthracnose; (2) use of post-harvest fungicides, such as imazalil and/or thiabendazole on citrus fruits; (3) use of biological control agents, such as "Bio-Save" (*Pseudomonas syringae*) and "Aspire" (*Candida oleophila*) alone or in combination with fungicides at lower concentrations on citrus fruits; (4) use of growth regulators such as gibberellic acid or 2, 4-D to delay senescence of citrus fruits; (5) use of 15-20 percent CO_2 in air or 5 percent O_2 on strawberries, cane berries, figs, and pomegranates; and (6) use of SO_2 fumigation (100 ppm for one hour) on grapes.

Table 5: Conditions for curing root, tuber, and bulb crops

Crops	*Temperature* (°C)	*Relative humidity%*	*Duration* (days)
Cassava root	30-40	90-95	2-5
Onion and garlic bulbs	30-45	60-75	1-4
Potato tubers	15-20	85-90	5-10
Sweet Potato roots	30-32	85-90	4-7
Yam tubers	32-40	90-100	1-4

Treatments for insect control

Fresh fruits, vegetables and flowers may harbor a large number of insects during post-harvest handling. Many of these insect species, in particular fruit flies of the family

Tephritidae (e.g. Mediterranean fruit fly, Oriental fruit fly, Mexican fruit fly, Caribbean fruit fly), can seriously disrupt trade among countries. The identification and application of acceptable disinfestation treatments including irradiation will greatly facilitate globalisation of trade in fresh produce. Criteria for the selection of the most appropriate disinfestation treatment for a specific commodity include cost, the efficacy of that treatment against insects of concern, safety of the treatment as well as the ability of that treatment to preserve and maintain produce quality. Currently approved quarantine treatments, other than irradiation, include certification of insect-free areas, use of chemicals (e.g. methyl bromide, phosphine, hydrogen cyanide), cold treatments, heat treatments, and combinations of these treatments, such as methyl bromide fumigation in conjunction with cold treatment. The use of alternative treatments, such as fumigants (carbonyl sulphide, methyl iodide, sulphuryl fluoride) and insecticidal atmospheres (oxygen concentrations of less than 0.5 percent and/or carbon dioxide concentrations ranging between 40 and 60 percent) alone or in combination with heat treatments, and ultraviolet radiation, are currently under investigation. These treatments are not, however, broad-spectrum treatments and are potentially phytotoxic when applied to some commodities.

Most insects become sterile when subjected to irradiation doses ranging between 50 and 750 Gy. The actual dosage required to produce sterility in insects varies in accordance with the species concerned and its stage of development. An irradiation dose of 250 Gy was approved by the United States quarantine authorities for application to fresh commodities, such as lychees, mangoes, and papayas in light of the efficacy of that dose in preventing the reproduction of tropical fruit flies. Irradiation doses of 250 Gy can be tolerated by most fresh fruits and vegetables with minimal detrimental effects on quality. Doses ranging between 250 and 1000 Gy, can, however, be damaging to some commodities. Fruits, in general, are more tolerant to the expected dose range than non-fruit vegetables and cut flowers. Detrimental effects of irradiation on fresh produce may include loss of green color (yellowing), abscission of leaves and petals, tissue discoloration, and uneven ripening. These detrimental effects may not become visible until after the commodity reaches the market. The effects of irradiation must therefore be tested on individual commodities, prior to large-scale commercialisation of the irradiation treatment.

ENHANCING QUALITY

Modified Atmosphere Storage

When used as supplements to keeping fresh horticultural perishables within their optimum ranges of temperature and relative humidity, controlled atmospheres (CA) or modified atmospheres (MA) can serve to extend their post-harvest-life (Table 6).

Optimum oxygen and carbon dioxide concentrations lower respiration and ethylene production rates, reduce ethylene action, delay ripening and senescence, retard the growth of decay-causing pathogens, and control insects. CA conditions which are not suited to a given commodity can, however, induce physiological disorders and enhance susceptibility to decay.

Several refinements in CA storage technology have been made in recent years. These include: the creation of nitrogen-on-demand by separation of nitrogen from compressed air through the use of either molecular sieve beds or membrane systems; use of low (0.7 to 1.5 percent) oxygen concentrations that can be accurately monitored and controlled; rapid establishment of CA, ethylene-free CA, programmed (or sequential) CA (such as storage in 1 percent O_2 for 2 to 6 weeks followed by storage in 2-3 percent O_2 for remainder of the storage period), and dynamic CA where levels of O_2 and CO_2 are modified as needed based on monitoring specific attributes of produce quality, such as ethanol concentration and chlorophyll fluorescence.

The use of CA in refrigerated marine containers continues to benefit from technological and scientific developments. CA transport is used to continue the CA chain for commodities (such as apples, pears, and kiwifruits) that had been stored in CA immediately after harvest. CA transport of bananas permits their harvest at a more advanced stage of maturity, resulting in the attainment of higher yields at the field level. In the case of avocados, CA transport facilitates use of a lower shipping temperature (5 °C) than if shipped in air, since CA ameliorates chilling injury symptoms. CA in combination with precision temperature management allows insect control without the use of chemicals, in commodities destined for markets that have restrictions against pests endemic to exporting countries and for markets with a preference for organic produce.

Table 6: Classification of horticultural crops according to their controlled atmosphere storage potential at optimum temperatures and relative humidities.

Range of storage duration (months)	*Commodity*
More than 12	Almond, Brazil nut, cashew, filbert, macadamia, pecan, pistachio, walnut, dried fruits and vegetables
6-12	Some cultivars of apples and European pears
3-6	Cabbage, Chinese cabbage, kiwifruit, persimmon, pomegranate, some cultivars of Asian pears
1-3	Avocado, banana, cherry, grape (no SO_2), mango, olive, onion (sweet cultivars), some cultivars of nectarine, peach and plum, tomato (mature-green)
<1	Asparagus, broccoli, cane berries, fig, lettuce, muskmelons, papaya, pineapple, strawberry, sweet corn; fresh-cut fruits and vegetables; some cut flowers.

The use of polymeric films for packaging produce and their application in modified atmosphere packaging (MAP) systems at the pallet, shipping container (plastic liner), and consumer package levels continues to increase. MAP(usually designed to maintain 2 to 5 percent O_2 levels and 8 to 12 percent CO_2 levels) is widely applied in extending the shelf-life of fresh-cut fruits and vegetables. Use of absorbers of ethylene, carbon dioxide, oxygen, and/or water vapor as part of MAP is increasing. Although much research has been done on the use of surface coatings to modify the internal atmosphere within the commodity, commercial applications are still very limited due to inherent biological variability of commodities.

At the commercial level, CA is most widely applied during the storage and transport of apples and pears. It is also applied to a lesser extent on kiwifruits, avocados, persimmons, pomegranates, nuts and dried fruits. Atmospheric modification during long-distance transport is used for apples, avocados, bananas, blueberries, cherries, figs, kiwi-fruits, mangoes, nectarines, peaches, pears, plums, raspberries and strawberries. Technological developments geared toward providing CA during transport and storage at reasonable cost (positive benefit/cost ratio) are essential if the application of this technology to fresh fruits and vegetables is to be expanded.

Although MA and CA have both been shown to be effective in extending the post-harvest life of many commodities (Table 6), their commercial application has been limited by the relatively high cost of these technologies. There are however a few cases in which a positive return on investment (cost/benefit ratio) can be demonstrated. In a comparison of losses due to decay during retail marketing of strawberries shipped in air and those shipped in an environment consisting of 15 percent CO_2-enriched air (modified atmosphere within pallet cover), the use of modified atmosphere was observed to reduce losses by 50 percent (an average of 20 percent losses was sustained in strawberries shipped in air vs 10 percent losses in those shipped by MA). The economic loss of 10 percent value (US$50-75 per pallet) was much greater than the cost of using MA (US$15-25 per pallet).

Use of controlled atmosphere (CA) during marine transportation can extend the post-harvest-life of those fruits and vegetables that would normally have a short post-harvest-life potential, thereby allowing the use of marine transportation instead of air transport for the shipment of such produce. In terms of cost and benefit, savings realised with the use of marine transportation are much greater than is the added cost of CA service.

Ethylene Exclusion and Removal

Many green vegetables and most horticultural produce are quite sensitive to ethylene damage. Their exposure to ethylene must therefore be minimised. Ethylene contamination in ripening rooms can be minimised by 1) using ethylene levels of 100 ppm instead of the higher levels often used in commercial ripening operations, 2) venting ripening rooms to the outside on completion of exposure to ethylene, 3) at least once per day ventilating the area around the ripening rooms or installing an ethylene scrubber, 4) use of battery-powered forklifts instead of engine-driven units in ripening areas.

Ethylene-producing commodities should not be mixed with ethylene-sensitive commodities during storage and transport. Potassium permanganate, an effective oxidiser of ethylene, is commercially used as an ethylene scrubber. Scrubbing units based on the catalytic oxidation of ethylene are used to a limited extent in some commercial storage facilities.

Return on Investment in Reducing Ethylene Damage

A University of California study showed that the use of an ethylene scrubber in storage facilities used for lettuce significantly reduced russet spotting. The difference in value of lettuce that was protected from ethylene vs that which was exposed to ethylene was estimated to be 20 to 25 percent, which was greater than the cost of the ethylene scrubber. Similar results were found with kiwi fruits, which soften very rapidly when exposed to ethylene levels as low as 50 ppb.

Treatments to enhance uniformity in fruit ripening

Ethylene treatment is commercially used to enhance the rate and uniformity of ripening of fruits such as bananas, avocados, mangoes, tomatoes, and kiwifruits. Optimal ripening conditions are as follows:

Temperature:	18 °C to 25 °C (65 °C to 77 °F)
Relative humidity:	90 to 95 percent
Ethylene concentration:	10 to 100 ppm
Duration of treatment:	24 to 74 hours depending on fruit type and stage of maturity
Air circulation:	Sufficient to ensure distribution of ethylene within the ripening room
Ventilation:	Require adequate air exchange in order to prevent accumulation of O_2 which reduces the effectiveness of C_2H_4.

Criteria for the Selection of Appropriate Post-harvest Technologies

The basic recommendations for maintaining post-harvest quality and safety of produce are the same regardless of the distribution system (direct marketing, local marketing, export marketing). However, the level of technology needed to provide the recommended conditions varies in accordance with the distance and time between production and consumption sites, the intended use of the produce (fresh vs. processing) and the target market. In situations where the point of sale is only a matter of hours away from the site of harvest, careful harvesting and handling and the observance of proper sanitation practices are adequate measures for assuring the quality and safety of fruits and vegetables targeted for the fresh market. Pre-cooling, refrigeration and packaging however become essential when fresh produce must be moved over long distances. The following should be considered when selecting appropriate post-harvest technologies:

A) The technology used elsewhere is not necessarily the best for use under conditions of a given developing country. Many of the recent developments in post-harvest technology in developed countries have come about in response to the need to economise on labor, materials, and energy use, and to protect the environment. Currently used practices in other countries should be studied, but only those which are appropriate for local conditions should be adopted and used.

B) Expensive equipment and facilities are useless without proper management. Furthermore, over-investment in handling facilities can result in economic losses, if consumers in the target market are unable to absorb these added costs. Proper education of all stakeholders along the post-harvest chain is more critical than the level of sophistication of the equipment used in post-harvest handling. Effective training and supervision of personnel must, therefore, be an integral part of quality and safety-assurance programs.

C) Commodity requirements can be met through the use of simple and inexpensive methods in many cases. Proper temperature management procedures, for example, include: (1) Protection from exposure to the sun; (2) Harvesting during cooler periods of the day or even at night; (3) Adequate ventilation in containers and non-refrigerated transport vehicles; (4) Use of simple and inexpensive cooling procedures, such as evaporative cooling or night ambient air; and (5) Expedited handling of fresh produce.

D) Mechanical injuries are major causes of losses in the quality and quantity of fresh horticultural commodities in all handling systems. The incidence and severity of mechanical injury can be greatly minimised by reducing the number of steps involved in harvesting and handling and by educating all personnel involved, about the need for careful handling.

E) Assuring food safety throughout the post-harvest handling system is very critical to successful marketing of produce and should be given the highest priority.

F) Solving the post-harvest technology problems in a given country necessitates cooperation and effective communication among research and extension personnel. Post-harvest horticulturists therefore need to coordinate their efforts and to cooperate with production horticulturists, agricultural marketing economists, engineers, food technologists, microbiologists, and others who may be involved in various aspects of the marketing systems. In most cases, solutions to existing problems in the post-harvest handling system require the use of existing information rather than new research. The following is a proposed program for improving the post-harvest handling system in a developing country:

1) Survey the magnitude and causes of losses in quality and quantity during harvesting and post-harvest handling of major commodities.
2) Survey available tools and facilities for harvesting, packing and packaging, transport, storage, and marketing of each commodity in the region of production and during the season of production.
3) Evaluate the impact of simple modifications in the handling system (such as stage of harvesting, method of harvest, type of container, and quality sorting) on quality and safety maintenance.
4) Extend information on recommended harvesting and handling procedures to all those who can use it. All appropriate extension methods for the intended audiences should be used.
5) Identify problems which require further research, conduct the needed research and extend.

REFERENCES

Kitinoja, L. and Gorny, J.R "Postharvest Technology for Small-Scale Produce Marketers: Economic Opportunities, Quality and Food Safety". 1999. *UC PTRIC Horticultural Series* No. 21

Liu, F.W.. 1988. "Developing practical methods and facilities for handling fruits in order to maintain quality and reduce losses". *Postharvest Handling of Tropical and Subtropical Fruit Crops*, Food and Fertilizer Technical Center for the Asian and Pacific Region, Taipei 10616, Taiwan.

Natural Resources Institute. 1994. *Manual for Horticultural Export Quality Assurance.* Chatham, UK: Natural Resources Institute.

Shewfelt, R.L. 1990. Quality of Fruits and Vegetables. A Scientific Status Summary by the Institute of Food Technologists' Expert Panel on Food Safety and Nutrition. Institute of Food Technologists, 221 North LaSalle Street, Chicago, Illinois 60601.

8

Preservation of Fruits and Vegetables

Our country is blessed with an abundance of fruit and vegetable crop. In order to avoid post harvest losses, it becomes imperative to preserve the product. As a result food preservation industries have emerged everywhere. Alongside, the demand for trained personnel in the field has also increased substantially. Successful processing and preservation of foods can lead to number of economic activities like newer techniques of fruit and vegetable preservation, starting up a small- scale industry or production unit or developing new products, etc. But one must posses the required expertise and skills to run food preservation as a profitable business.

PRESERVATION TECHNOLOGIES

Water Activity (a_w) Concept

The concept of a_w has been very useful in food preservation and on that basis many processes could be successfully adapted and new products designed. Water has been called the universal solvent as it is a requirement for growth, metabolism, and support of many chemical reactions occurring in food products. Free water in fruit or vegetables is the water available for chemical reactions, to support microbial growth, and to act as a transporting medium for compounds.

In the bound state, water is not available to participate in these reactions as it is bound by water soluble compounds such as sugar, salt, gums, etc., and by the surface effect of the substrate (matrix binding). These water-binding effects reduce the vapour pressure of the food substrate according to Raoult's Law. Comparing this vapour pressure with that of pure water (at the same temperature) results in a ratio called water activity (a_w). Pure water has an a_w of 1, one molal solution of sugar - 0.98, and one molal solution of sodium chloride - 0.9669. A saturated solution of sodium chloride has a water activity of 0.755. This same NaCl solution in a closed container will develop an equilibrium relative humidity (ERH) in a head space of 75.5%. A relationship therefore exists between ERH and a_w since both are based on vapour pressure.

$$a_w = \frac{ERH}{100}$$

The ERH of a food product is defined as the relative humidity of the air surrounding the food at which the product neither gains nor loses its natural moisture and is in equilibrium with the environment.

Microorganisms vs. a_w value

The definition of moisture conditions in which pathogenic or spoilage microorganisms cannot grow is of paramount importance to food preservation. It is well known that each microorganism has a critical a_w below which growth cannot occur. For instance, pathogenic microorganisms cannot grow at a_w <0.86; yeasts and moulds are more tolerant and usually no growth occurs at a_w <0.62. The so-called intermediate moisture foods (IMF) have a_w values in the range of 0.65-0.90.

Enzymatic and chemical changes related to a_w values

According to Rahman and Labuza, enzyme-catalysed reactions can occur in foods with relatively low water contents. The authors summarised two features of these results as follows:

1. The rate of hydrolysis increases with increased water activity but is extremely slow with very low activity.
2. For each instance of water activity there appears to be a maximum amount of hydrolysis, which also increases with water content.

The apparent cessation of the reaction at low moisture cannot be due to the irreversible inactivation of the enzyme, because upon humidification to a higher water activity, hydrolysis resumes at a rate characteristic of the newly attained water activity. Rahman and Labuza reported the investigation of a model system consisting of avicel, sucrose, and invertase and found that the reaction velocity increased with water activity. Complete conversion of the substrate was observed for water activities greater than or equal to 0.75. For water activities below 0.75, the reaction continued with 100% hydrolysis. In solid media, water activity can affect reactions in two ways: lack of reactant mobility and alternation of active conformation of the substrate and enzymatic protein. The effects of varying the enzyme-to-substrate ratios on reaction velocity and the effect of water activity on the activation energy for the reaction could not be explained by a simple diffusional model, but required postulates that were more complex:

1. The diffusional resistance is localised in a shell adjacent to the enzyme.
2. At low water activity, the reduced hydration produces conformational changes in the enzyme, affecting its catalytic activity.

The relationship between water content and water activity is complex. An increase in aw is usually accompanied by an increase in water content, but in a non-linear fashion. This relationship between water activity and moisture content at a given temperature is called the moisture sorption isotherm. These curves are determined experimentally and constitute the fingerprint of a food system.

Recommended equipment for measuring a_w

Many methods and instruments are available for laboratory measurement of water activity in foods. Methods are based on the colligative properties of solutions. Water activity can be estimated by measuring the following:

- Vapour pressure
- Osmotic pressure
- Freezing point depression of a liquid
- Equilibrium relative humidity of a liquid or solid
- Boiling point elevation
- Dew point and wet bulb depression
- Suction potential, or by using the isopiestic method
- Bithermal equilibrium
- Electric hygrometers
- Hair hygrometers

Vapour pressure

Water activity is expressed as the ratio of the partial pressure of water in a food to the vapour pressure of pure water with the same temperature as the food. Thus, measuring the vapour pressure of water in a food system is the most direct measure of a_w. The food sample measured is allowed to equilibrate, and measurement is taken by using a manometer or transducer device as depicted in Figure 1. This method can be affected by sample size, equilibration time, temperature, and volume. This method is not suitable for biological materials with active respiration or materials containing large amounts of volatiles.

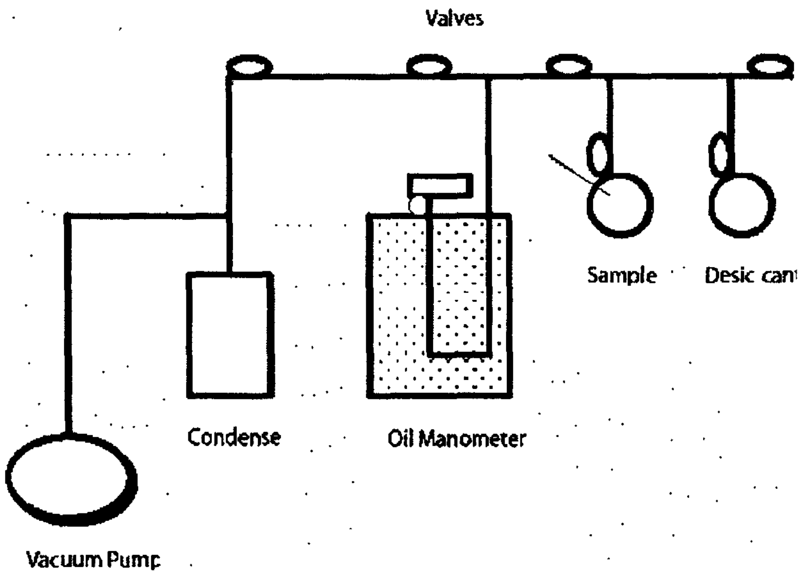

Figure 1. Vapour pressure manometer

Freezing point depression and freezing point elevation

This method is accurate for liquids in the high water activity range but is not suitable for solid foods. The water activity can be estimated using the following two expressions:

Freezing point depression:

$$-\log a_w = 0.004207\ DT_f + 2.1\ E\text{-}6\ DT^2_f \qquad (1)$$

where DT_f is the depression in the freezing temperature of water

Boiling point elevation:

$$-\log a_w = 0.01526\ DT_b - 4.862\ E\text{-}5\ DT^2_b \qquad (2)$$

where DT_b is the elevation in the boiling temperature of water.

Osmotic pressure

Water activity can be related to the osmotic pressure (p) of a solution with the following equation:

$$p = RT/V_w \ln(a_w) \qquad (3)$$

where V_w is the molar volume of water in solution, R the universal gas constant, and

T the absolute temperature. Osmotic pressure is defined as the mechanical pressure needed to prevent a net flow of solvent across a semi-permeable membrane. For an ideal solution, Equation (3) can be redefined as:

$$p = RT/V_w \ln(X_w) \quad (4)$$

where X_w is the molar fraction of water in the solution. For non-ideal solutions, the osmotic pressure expression can be rewritten as:

$$p = RTfnm_b(m_w V_w) \quad (5)$$

where n is the number of moles of ions formed from one mole of electrolyte, mw and mb are the molar concentrations of water and the solute, respectively, and f the osmotic coefficient, defined as:

$$f = -m_w \ln(a_w)/nmb \quad (6)$$

Dew point hygrometer

Vapour pressure can be determined from the dew point of an air-water mixture. The temperature at which the dew point occurs is determined by observing condensation on a smooth, cool surface such as a mirror. This temperature can be related to vapour pressure using a psychrometric chart. The formation of dew is detected photoelectrically, as illustrated in the diagram below:

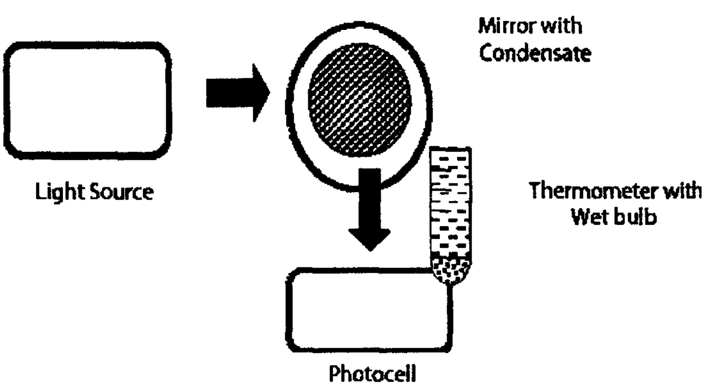

Figure 2. Dew point determination of water activity

Thermocouple Psychrometer

Water activity measurement is based on wet bulb temperature depression. A thermocouple is placed in the chamber where the sample is equilibrated. Water is then sprayed over the thermocouple before it is allowed to evaporate, causing a decrease in temperature. The drop in temperature is related to the rate of water evaporation from the surface of the thermocouple, which is a function of the relative humidity in equilibrium with the sample.

Isopiestic method

The isopiestic method consists of equilibrating both a sample and a reference material in an evacuated desiccator until equilibrium is reached at 25°C. The moisture content of the reference material is then determined and the a_w obtained from the sorption isotherm. Since the sample was in equilibrium with the reference material, the a_w of both is the same.

Electric hygrometers

Most hygrometers are electrical wires coated with hygroscopic salts or sulfonated polystyrene gel in which conductance or capacitance changes as the coating absorbs moisture from the sample. The major disadvantage of this type of hygrometer is the tendency of the hygroscopic salt to become contaminated with polar compounds, resulting in erroneous a_w determinations.

Hair hygrometers

Hair hygrometers are based on the stretching of a fibre when exposed to high water activity. They are less sensitive than other instruments at lower levels of activity (<0.03 a_w) and the principal disadvantage of these types of meters is the time delay in reaching equilibrium and the tendency to hysteresis.

Today we find many brands of water activity meters in the market. Most of these meters are based on the relationship between ERH and the food system, but differ in their internal components and configuration of software used. One of the water activity meters most used today is the AcquaLab Series 3 Model TE, developed by Decagon Devices, which is based on the chilled-mirror dew point method. This instrument is a temperature controlled water activity meter that allows placement of the sample in a temperature stable environment without the use of an external water bath. The temperature can be selected on the screen and is monitored and controlled with thermoelectric components. Most of the older generations of water activity instruments are based on a temperature-controlled environment. Therefore, a margin of error greater than 5% can be expected due to temperature variations. This equipment is highly recommended for measuring water activity in fruits and vegetables since it measures a wide range of water activity.

The major advantages of the chilled-mirror dew point method are accuracy, speed, ease of use and precision. The AquaLab's range is from 0.030 to 1.000a_w, with a resolution of ±0.001a_w and accuracy of ±0.003a_w. Measurement time is typically less than five minutes. Capacitance sensors have the advantage of being inexpensive, but are not usually as accurate or as fast as the chilled-mirror dew point method. Capacitive instruments measure over the entire water activity range 0 to 1.00 a_w, with a resolution of ±0.005a_w and accuracy of ±0.015a_w. Some commercial instruments can complete measurements in five minutes while other electronic capacitive sensors usually require 30 to 90 minutes to reach equilibrium relative humidity conditions.

Intermediate Moisture Foods (IMF) Concept

Traditional intermediate moisture foods (IMF) can be regarded as one of the oldest foods preserved by man. The mixing of ingredients to achieve a given aw, that allowed safe storage while maintaining enough water for palatability, was only done, however, on an empirical basis. The work done by food scientists approximately three decades ago, in the search for convenient stable products through removal of water, resulted in the so-called modern intermediate moisture foods. These foods rely heavily on the addition of humectants and preservatives to prevent or reduce the growth of microorganisms. Since then, this category of products has been subjected to continuous revision and discussion.

Definitions of IMF in terms of a_w values and moisture content vary within wide limits (0.6-0.90 a_w, 10-50% moisture), and the addition of preservatives provides the margin of safety against spoilage organisms tolerant to low a_w. Of the food poisoning bacteria, *Staphylococcus aureus* is one of the organisms of high concern since it has been reported to tolerate a_w as low as 0.83-0.86 under aerobic conditions. Many of the considerations on the significance of microorganisms in IMF are made in terms of a_w limits for growth. However, microbial control in IMF does not only depend on a_w but on pH, *Eh*, *F* and *T* values preservatives, competitive microflora, etc., which also exert an important effect on colonising flora.

Fruits preserved under IMF concept

The application of IMF technology has been very successful in preserving fruits and vegetables without refrigeration in most Latin American countries. For instance, the addition of high amounts of sugar to fruits during processing will create a protective layer against microbial contamination after the heat process. The sugar acts as a water activity depressor limiting the capability of bacteria to grow in food. IMF foods are those with a_w in the range of 0.65 to 0.90 and moisture content between 15% and 40%. Food products formulated under this concept are stable at room temperature without thermal processing and can be generally eaten without rehydration. Some processed fruits and vegetables are considered IMF foods. These include cabbage, carrots, horseradish, potatoes, strawberries, etc.; their water activities at 30°C follow:

Foods	a_w
Cabbage	0.64
	0.75
Carrots	0.64
	0.75
Horseradish	0.75
Potatoes	0.75
	0.64
Strawberries	0.65
	0.75

Under these conditions, bacterial growth is inhibited but some moulds and yeast may grow at a_w greater than 0.70. In addition, chemical preservatives are generally used to inhibit the growth of moulds and yeasts in fruits and vegetables.

Advantages and disadvantages of IMF preservation

Advantages

Intermediate moisture foods have an a_w range of 0.65-0.90, and thus water activity is their primary hurdle to achieving microbial stability and safety. IMF foods are easy to prepare and store without refrigeration. They are energy efficient and relatively cheap. They are not readily subject to spoilage, even if packages have been damaged prior to opening, as with thermostabilised foods, because of low a_w. This is a plus for many developing countries, especially those in tropical climates with inadequate infrastructure for processing and storage, and offers marketing advantages for consumers all over the world.

Disadvantages

Some IMF foods contain high levels of additives (i.e., nitrites sulphites, humectants, etc.) that may cause health concerns and possible legal problems. High sugar content is also a concern because of the high calorific intake. Therefore, efforts are been made to improve the quality of such foods by decreasing sugar and salt addition, as well as by increasing the moisture content and a_w, but without sacrificing the microbial stability and safety of products if stored without refrigeration. This may be achieved by an intelligent application of hurdles.

Fruit products from intermediate moisture foods (IMF) appear to have potential markets. However, application of this technology to produce stable products at ambient temperature is limited by the high concentration of solutes required to reduce water activities to safe levels. This usually affects the sensory properties of the food.

COMBINED METHODS FOR PRESERVATION

Food preserved by combined methods remains stable and safe even without refrigeration, and is high in sensory and nutritive value due to the gentle process applied. Hurdle technology is the term often applied when foods are preserved by a combination of processes. The hurdle includes temperature, water activity, redox potential, modified atmosphere, preservatives, etc. The concept is that for a given food the bacteria should not be able to "jump over" all of the hurdles present, and so should be inhibited. If several hurdles are used simultaneously, a gentle preservation could be applied, which nevertheless secures stable and safe foods of high sensory and nutritional properties. This is because different hurdles in a food often have a synergistic or additive effect.

For instance, modified foods may be designed to require no refrigeration and thus save energy. On the other hand, preservatives could be partially replaced by certain hurdles in a food. Moreover, a hurdle could be used without affecting the integrity of food pieces or in the application of high pressure for the preservation of other foods. Hurdle technology is applicable both in large and small food industries. In general, hurdle technology is now widely used for food design in making new products according to the needs of processors and consumers. For instance, if energy preservation is the goal, then energy consumption hurdles such as refrigeration can be replaced by hurdles that do not require energy and still ensure a stable and safe product.

The hurdle effect is an illustration of the fact that in most foods several factors contribute to stability and safety. This hurdle effect is of fundamental importance for the preservation of food, since the hurdles in a stable product control microbial spoilage and food poisoning as well as undesirable fermentation.

Increasing consumer demand for fresh quality products is turning processors to the so-called minimally processed products (MP), an attempt to combine freshness with convenience to the point that even the traditional whole, fresh fruit or vegetable is being packaged and marketed in ways formerly reserved for processed products. According to these authors, the widely accepted concept of MP refrigerated fruits involves the idea of living respiring tissues. Because MP refrigerated products can be raw, the cells of the vegetative tissue may be alive and respiring, and biochemical reactions can take place that lead to rapid senescence and/or quality changes. In these products, the primary spoilage mechanisms are microbial growth and physiological and biochemical changes, and in most cases, minimally processed foods are more perishable than the unprocessed raw materials from which they are made.

The technology for shelf-stable high moisture fruit products (HMFP) is based on a combination of inhibiting factors to combat the deleterious effects of microorganisms in fruits, including additional factors to reduce major quality losses from reactions. In order to select a combination of factors and levels, the type of microorganism and quality loss from reactions that might occur must be anticipated.

Minimal processing may encompass pre-cut refrigerated fruits, peeled refrigerated whole fruits, sous vide dishes, which may include pre-heated vegetables and fruits, cloudy and clarified refrigerated juices, freshly squeezed juices, etc. All of these products have special packaging requirements coupled with refrigeration. These products, apart from special handling, preparation, and size reduction operations, might also require special distribution and utilisation operations such as Controlled atmosphere/Modified atmosphere/air flow rate/vacuum storage (O_2, CO_2, N_2, CO, C_2H_2, H_2O controls), computer controlled warehousing, retailing and food service, communications network, etc. HMFP fruits are less sophisticated than MPR fruits and should be priced lower when introduced commercially. Careful selection of these processes should of course be made to find the appropriate methods suited to a particular rural or village situation.

An example of the hurdle technology concept is presented in Figure 3. in which a comparison of HMFP, IMF and MPR fruits in terms of hurdle(s) involved is made. Example A represents an intermediate moisture fruit product containing two hurdles (pH, and a_w). The microorganisms cannot overcome (jump over) these hurdles, thus the food is microbiological stable.

In this case, a_w is the most relevant hurdle exerting the strongest pressure against microbial proliferation of IMF. In the preservation system of HMFP, it is obvious that a_w does not represent the hurdle of highest relevance against microbial proliferation; pH is the hurdle exerting the strongest selective pressure on microflora. As in example A, HMFP does not require refrigerated storage. In example C, the mild heat treatment T(t) is applied and the chemical preservative, P, added affects the growth and survival of the flora. With these considerations in mind, it is possible to understand and anticipate the types of microorganisms that could survive, as well as their behaviour and control in such fruits.

Recommended Substances to Reduce a_w in Fruits

Glucose

Glucose is not a very good humectant due to the lower water holding capacity (WHC), which makes it difficult to obtain the isotherm curve at low a_w.

Fructose

Fructose has a higher water activity reduction capacity and therefore is more desirable as a humectant in stabilising food products.

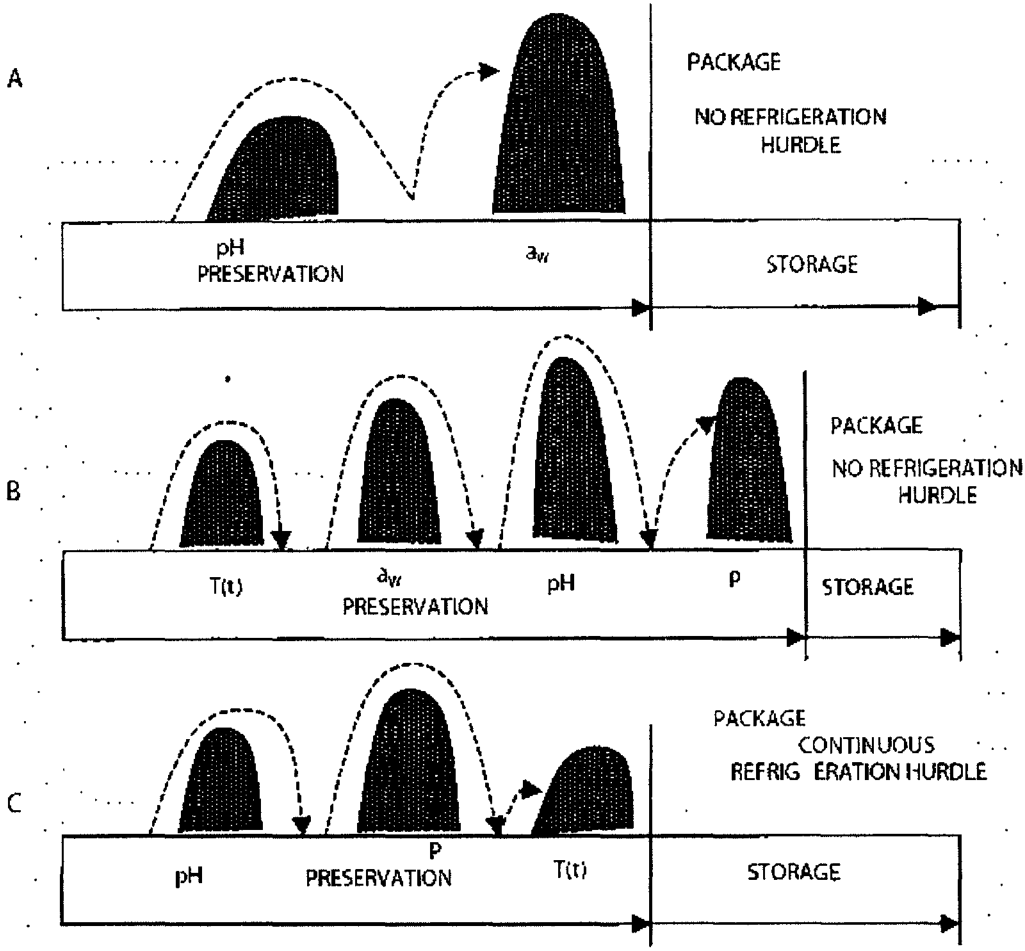

Figure 3. Schematic representation of hurdles: water activity (aW), pH, preservatives (P), and slight heat treatment, T(t), involved in three fruit preservation systems. (A) an intermediate moisture fruit product; (B) a high-moisture fruit product; (C) a minimally processed refrigerated fruit product.

Sucrose

Sucrose is one of the most studied sugars and is widely used in food systems, in the confectionary industry, both in the U.S. and Europe, but has a lower water activity reduction capacity compared to fructose.

Other humectants

Based solely on the water activity reduction capacity, sorbitol and fructose are the most desirable humectants. Sucrose has the third best reduction capacity and lactose the poorest. The amorphous form absorbs more water at specific a_w than the corresponding crystalline form. As seen in Table 3.1, NaCl and KCl salts appear to be superior humectants at a high range of a_w. The increased a_w lowering ability exhibited by the salts may be explained by the smaller molecular weight, increasing the ability to bind or structure more water.

Other sugars used as humectants in food stability include lactose and sorbitol. The amorphous form absorbs more water at specific a_w than the crystalline form. Polyols are better humectants than sugars because of their greater water activity reduction capacity and are less hygroscopic than sugars. The most widely used polyols as humectants in foods are 1,3- butyleneglycol, propylene glycol, glycerol, and polyethylene glycol 400.

Recommended Substances to Reduce pH

Organic acids

Organic acids, whether naturally present in foods due to fermentation or intentionally added during processing, have been used for many years in food preservation. Some organic acids behave primarily as fungicides or fungistats, while others tend to be more effective at inhibiting bacterial growth. The mode of action of organic acids is related to the pH reduction of the substrate, acidification of internal components of cell membranes by ionisation of the undissociated acid molecule, or disruption of substrate transport by alteration of cell membrane permeability. The undissociated portion of the acid molecule is primarily responsible for antimicrobial activity; therefore, effectiveness depends upon the dissociation constants (pKa) of the acid. Organic acids are generally more effective at low pH and high dissociation constants. The most commonly used organic acids in food preservation include: citric, succinic, malic, tartaric, benzoic, lactic, and propionic acids.

Citric acid is present in citrus fruits. It has been demonstrated that citric acid is more effective than acetic and lactic acids for inhibiting growth of thermophilic bacteria. Also, combinations of citric and ascorbic acids inhibit growth and toxin production of C. botulinum type B in vacuum-packed cooked potatoes.

Malic acid is widely found in fruits and vegetables. It inhibits the growth of yeasts and some bacteria due to a decrease in pH.

Tartaric acid is present in fruits such as grapes and pineapples. The antimicrobial activity of this acid is attributed to pH reduction.

Benzoic acid is the oldest and most commonly used preservative. It occurs naturally in cranberries, raspberries, plums, prunes, cinnamon, and cloves. As an additive, sodium salt in benzoic acid is suitable for foods and beverages with pH below 4.5. Benzoic acid is primarily used as an antifungal agent in fruit-based and fruit beverages, fruit products, bakery products, and margarine.

Lactic acid is not naturally present in foods; it is formed during fermentation of foods such as sauerkraut, pickles, olives, and some meats and cheeses by lactic acid bacteria. It has been reported that lactic acid inhibits the growth of spore forming bacteria at pH 5.0 but does not affect the growth of yeast and moulds.

Propionic acid occurs in foods by natural processing. It is found in Swiss cheese at concentrations up to 1%, produced by Propionicbacterium shermanii. The antimicrobial activity of propionic acid is primarily against moulds and bacteria.

Inorganic acids

Inorganic acids include hydrochloric, sulphuric, and phosphoric, the latter being the principal acid used in fruit and vegetable processing). They are mainly used as buffering agents, neutralisers, and cleaners.

Fermentation by-products

Fermentation by-products are formed during fermentation of fruits and vegetables, as in sauerkraut processing, pickling, and wine making. One by-product, lactic acid, is formed during fermentation of cabbage or cucumbers. This acid decreases the pH of fruits and vegetables, producing the characteristic flavour of sauerkraut, and acts as a controller of pathogens that may develop in the final fermented product.

Recommended Chemicals to Prevent Browning

Sulphites, bisulphites, and metabisulphites

Sodium bisulphite is a potential browning inhibitor in fruit and vegetable products. This preservative when used in food production can delay or prevent undesirable changes in the colour, flavour, and texture of fresh fruits and vegetables, potatoes, drinks, wine, etc. Potassium bisulphite is used in a similar way to sodium bisulphite, and is used in the food industry to prevent browning reactions in fruit and vegetable products.

Sulphites, bisulphites, and metabisulphites of both sodium and potassium together with gaseous sulphur dioxides are all chemically equivalent. Sulphite levels in processed foods are expressed as SO_2 equivalents, and range from zero to about 3000 ppm in dry weight. Dehydrated, light coloured fruits contain the greatest amounts in this range. Dehydrated vegetables and prepared soup mixes range from a few hundred to about 2000 ppm; instant potatoes contain approximately 400 ppm. The dose for wine is about 100-400 ppm and for beer about 2-8 ppm. The maximum legal sulphite level in wines permitted by the Food and Drug Administration (FDA) is 300 ppm. In the U.S. most wines have a sulphite level of 100 ppm.

Sulphites are highly effective in controlling browning in fruits and vegetables, but are subject to regulatory restrictions because of adverse effects on health. Sulphites inhibit non-enzymatic browning by reacting with carbonyl intermediates, thereby preventing further reaction. Sulphite levels in foods vary widely depending on the application. Residual levels never exceed several hundred per million but could reach 100 ppm in some fruits and vegetables.

The maximum sulphur dioxide levels in fruit juices, dehydrated potatoes, and dried fruits permitted by the FDA are 300, 500, and 2000 ppm, respectively.

Recommended Additives to Inhibit Microorganisms

Potassium sorbate

Potassium sorbate is a white crystalline powder that has greater solubility in water than sorbic acid, which may be used accordingly in making concentrates for dipping, spraying, or metering fruit and vegetable products. It has antimycotic actions similar to sorbic acid, but usually 25% more potassium sorbate must be used than sorbic acid to secure the same protection.

The common salt of potassium sorbate was developed because of its high solubility in water, which is 58.2% at 20°C. In water, the salt hydrolysis yielded is the active form. Stock solutions of potassium sorbate in water can be concentrated up to 50%, which can be mixed with liquid food products or diluted dips and sprays. Sorbates are effective in retarding the growth of many food spoilage organisms. Sorbates have many uses because of their milder taste, greater effectiveness, and broader pH range (up to 6.5), when compared to either benzoate or propianate. Thus, in foods with very low pH, sorbate levels as low as 200 ppm may give more than adequate protection. The solubility of potassium sorbate is 139 g/100 mL at 20°C; it can be applied in beverages, syrups, fruit juices, wines, jellies, jams, salads, pickles, etc.

Sodium benzoate

The use of sodium benzoate as a food preservative has been limited to products that are acid in nature. Therefore, it is mainly used as an antimycotic agent. The benzoates and parabenzoates have been used primarily in fruit juices, chocolate syrup, candied fruit peel, pie fillings, pickled vegetables, relishes, horseradish, and cheeses. Sodium benzoate is more effective in food systems where the pH is as low as 4.0 or below.

Other additives

Other naturally antimicrobial compounds found in fruits and vegetables include:

Vanillin (4-hydroxi-3-methoxybenzaldehyde) is found primarily in vanilla beans and in the fruit of orchids (Vanilla planifola, Vanilla pompona, or Vañilla tahitensis). Vanillin is most active against moulds and non-lactic acid gram-positive bacteria. The effectiveness of vanillin against certain moulds such as A. flavus, A. niger, A. ochraceus, or A. parasiticus has been demonstrated in laboratory media, as well as its effectiveness against yeasts such as Saccharomyces cerevisiae, Pichia membranaefaciens, Zygosaccharomyces bailii, Z. rouxii and Debaryomyces hansenii.

Allicin is an antimicrobial present in the juice vapour of garlic. This compound is effective in inhibiting the growth of certain pathogenic bacteria such as B. cereus, C. botulinum, E. coli, Salmonellae, Shigellae, S. aureus, A. flavus, Rhodotorula, and Saccharomyces.

Cinnamon and eugenol are reported to have an inhibitory effect on the spores of Bacillus anthracis. Also, cinnamon was found to inhibit the growth of the aflatoxin of *A. parasiticus.* Aqueous clove infusions of 0.1 to 1.0% and 0.06% eugenol were reported to inhibit the growth of germinated spores of *B. subtilis* in nutrient agar.

Oregano, thyme, and rosemary have been found to have inhibitory activity against certain bacteria and moulds due to the presence of antimicrobial compounds in their essential oils (e.g., terpenes, carvacol, and thymol).

Recommended Thermal Treatment for Food Preservation

The role of heat

The main function of heat in food processing is to inactivate pathogenic and spoilage organisms, as well as enzyme inactivation to preserve foods and extend shelf life. Other advantages of heat processing include the destruction of anti-nutritional components of foods (e.g., trypsin inhibitors in legumes), improving the digestibility of proteins, gelatinisation of starches, and the release of niacin. Higher temperatures for shorter periods achieved the same shelf life extension as food treated at lower temperatures and longer periods, and allowed retention of sensory and nutritional properties.

Hot water

Hot water plays an important role in the sanitation of food products before processing. Some food products are treated with hot water to eliminate insects, and to inactivate microorganisms and enzymes. Foods are retained in a water blancher at 70-100°C for a specific time and then removed to a dewatering and cooling system.

Steam

Steam is a more effective means than hot water for blanching foods such as fruits and vegetables. This method is especially suitable for foods with large areas of cut surfaces. It retains more soluble compounds and requires smaller volumes of waste for disposal than those from water blanchers. This is particularly so if air-, rather than water-cooling is used. Furthermore, steam blanchers are easier to clean and sterilise.

Effects of heat on aerobic and anaerobic mesophylic bacteria, yeasts, and moulds

Temperatures ranging from 10 to 15°C above the optimum temperature for growth will destroy vegetative cells of bacteria, yeasts, and moulds. Most vegetative cells, as well as viruses, are destroyed when subjected to temperatures of 60 to 80°C for an appropriate time. Somewhat higher temperatures may be needed for thermophilic or thermoduric microorganisms. All vegetative cells are killed in 10 min at 100°C and many spores are destroyed in 30 min at 100°C. Some spores, however, will resist heating at 100°C for several hours.

Procedure for Vegetables Preserved by Combined Methods

Vegetables are subjected to several preliminary operations before processing and after harvesting. As a result of peeling, grating and shredding, produce will change from a relatively stable product with a shelf life of several weeks or months to a perishable one with a shelf life as short as 1-3 days at chill temperatures. The major preliminary operations include:

Washing: Root vegetables are washed first to remove all field dirt and to allow inspection.

Inspection: Vegetables are inspected for quality to comply with consumer demands.

Selection: Vegetables are selected and graded on a basis of firmness, cleanness, size, weight, colour, shape, maturity, mechanical damage, foreign matter, disease, and insects. This operation can be done manually, or by employing a variety of separation machines to separate and discard unfit produce.

Subsequent operations

Peeling, cutting and shredding: Some vegetables such as potatoes and carrots require peeling. Ideal peeling is done very gently, by hand with a sharp knife. It has been reported that hand peeling of carrots increases the respiration rate over that of unpeeled carrots, by approximately 15%, whereas abrasion peeling almost doubles the respiration rate compared to hand peeled carrots. Carborundum abrasion peeled potatoes must be treated with a browning inhibitor, whereas washing is enough for hand peeled potatoes. These authors proposed the following guidelines for prepeeled and sliced potatoes:

Processing temperature	*4-5°C*
Raw material	A suitable variety or raw material lot should be selected using a rapid storage test of a prepared sample at room temperature. Attention must be focused on browning.
Pretreatment	Careful washing with good quality water before peeling is required. Damaged and contaminated parts, as well as spoiled potatoes, must be removed.
Peeling	1) One-stage peeling: knife machine. 2) Two-stage peeling: slight carborundum peeling first, followed by knife peeling.
Washing	Washing is done immediately after peeling. The temperature and amount of washing water should be 4-5°C and 3 L/kg potato, respectively. Washing time: 1 min. Observation: microbiological quality of washing water must be excellent. In washing water, for sliced potatoes in particular, it is preferable to use citric acid with ascorbic acid (maximum concentration of both, 0.5%), combined with calcium chloride, sodium benzoate, or 4-hexyl resorcinol to prevent browning.
Slicing	Slicing should be done immediately after washing using a sharp knife.
Straining off	Loose water should be strained off through a colander.
Packaging	Packaging is done immediately after washing in vacuum or in gas mixture of 20% CO_2 + 80% N_2. The head space volume of a package is 2 L/kg of potatoes. Suitable oxygen permeability of packaging materials: 70 cm^3/cm^2, 24 hr, 101.3 kPa, 23°C, 0% RH (80 mm nylon-polyethylene).
Storage	Preferably in dark at 4-5°C.
Other remarks	Good manufacturing practices (GMP) must be followed (hygiene, low temperatures, and disinfection).
Shelf life	Shelf life of prepeeled potatoes is 7-8 days at 5°C. Due to browning, sliced potato has very poor stability; the shelf life is only 3-4 days at 5°C.

Second washing and drying: Commonly, a second washing is needed after peeling and/or cutting. For instance, Chinese cabbage and white cabbage should be washed after shredding, whereas carrots should be washed before grating. Washing after peeling and cutting removes microbes and tissue fluid, thus reducing microbial growth and enzymatic oxidation during subsequent storage. Washing fruits and vegetables in flowing or carbonated water is more preferable than dipping the product into a tank of water. The microbiological and sensory quality of the washing water must be good and its temperature low, preferably < 5°C. The recommended quantity of water used is 5-10 L/kg for produce before peeling/cutting and 3 L/kg after peeling/cutting.

Preservatives can be used in the washing water to reduce microbial load and to retard enzymatic activity, thus improving the shelf life and sensory quality of produce. The recommended dosage for chemical preservatives in washing water is 100-200 mg/L of chlorine or citric acid. These levels are effective in the washing water before, after, or during cutting to extend the shelf life. However, when chlorine is used, vegetable materials require a subsequent rinse to reduce the chlorine concentration to the level of drinking water and to improve the sensory shelf life. The effectiveness of chlorine should be improved by using low pH, high temperature, pure water, and correct contact time. The optimum contact time for chlorine is 12-13 s, if the chlorine concentration is 70 mg/L. According to Ahvenainen, chlorine compounds are effective in inactivating microorganisms in solutions and on equipment, and in reducing the aerobic microorganism count. Chlorine compounds are not very effective at inhibiting the growth of *Listeria monocytogenes* in shredded lettuce or Chinese cabbage.

Another disadvantage of chlorine is that some food constituents may react with chlorine to form potentially toxic reactive products. Thus, the safety of chlorine use for food or water treatment has been questioned, and future regulatory restrictions may require the development of alternatives. Some proposed alternatives are chlorine dioxide, ozone (O_3), trisodium phosphate, and hydrogen peroxide. The use of hydrogen peroxide (H_2O_2) as an alternative to chlorine for disinfecting freshly cut fruits and vegetables shows some promise. H_2O_2 vapour treatment appears to reduce the microbial population on freshly cut vegetables such as cucumbers, green bell peppers, and zucchini. Moreover, H_2O_2 vapour treatment extends the shelf life of vegetable products without leaving significant residues or causing loss of quality. However, more research is needed to optimise H_2O_2 treatments with regard to efficacy in delaying the growth of spoilage bacteria in a wide variety of vegetable products.

According to Alzamora et al., the following processing guidelines for shredded Chinese cabbage and white cabbage should be followed:

Processing temperature	*0-5°C*
Raw material	A suitable variety or raw material lot should be selected using a rapid storage test on a prepared sample at room temperature.
Pretreatment	Outer contaminated leaves and damaged parts, as well as stem and spoiled cabbage, must be removed.
Shredding	Shelf life of shredded cabbage: the finer the shredding grade, the shorter the shelf life. The optimum shredding thickness is about 5 mm.
Washing	Done immediately after shredding in two stages. Temperature and amount of washing water: 0-5°C and 3 L of water/kg of cabbage. Washing time: 1 min. N.B: microbiological quality of washing water must be excellent.

	Stage 1: Washing with water containing 0.01% active chlorine or 0.5% citric acid. *Stage 2:* Washing with plain water (rinsing).
Centrifugation	Done immediately after washing. The centrifugation rate and time must be selected so that centrifugation removes only loose water and does not break vegetable cells.
Packaging	Done immediately after centrifugation. Typical packaging gas is air with a headspace volume of 2 L/kg for cabbage. Suitable permeability of oxygen for the packaging material is between 1,200 (e.g., oriented polypropylene) and 5,800, preferably 5,200-5,800 (i.e., oriented polypropylene-ethylene vinyl acetate) cm^3/cm^2, 24 hr, 101.3 kPa, 23°C, 0% RH. For white cabbage, perforation (one microhole 150/cm3) can be used. The diameter of a microhole is 0.4 mm.
Storage	Preferably in dark at 5°C.
Other remarks	Good manufacturing practices (GMP) must be followed (hygiene, low temperature, and disinfection).
Shelf life	Seven (7) days for Chinese cabbage and 3-4 days for white cabbage at 5°C.

Waxing: During washing, fresh vegetables (also fruits) lose part of their outer layer of wax, which protects against humidity loss. As a result, waxing is re-established after washing with an artificial layer of wax that has adequate thickness and consistency to improve appearance and to reduce the loss of water.

Classification: The main objective of this operation is to attain a uniform product for the market. Fresh vegetables are classified by size, weight, or degree of maturity. Classification by size can be done manually in small packing houses with trained personnel. In mechanised packing houses, operations are carried out with perforated belts, divergent belts or cylinders, and sieving. Sorting by mass is usually done electronically but some manually operated machines can classify different weights by a tipping mechanism. Classification by degree of maturity can be done using colour charts or by optical methods.

Labelling: Commercial fresh vegetables (as well as fruits) can be labelled individually with automatic adhesive stickers to identify the product brand, farmer, or retailer. This is extremely important when exporting produce to other countries.

Premarketing operations

Packaging: This operation is one of the most critical in the marketing of vegetables, and involves putting a number of required units in the appropriate package according to weight. Generally, for exporting fresh fruits, corrugated fibreboard boxes of variable capacity are employed.

The most common packaging technique for prepared raw vegetables and fruits is modified atmosphere packaging (MAP). The basic principle of MAP is that a modified atmosphere can be created passively by using specified permeable packaging materials or by actively using a specified gas mixture in combination with such materials.

Storage: The packaged fresh product can be stored at ambient or refrigeration temperature until it is shipped to the overseas market.

Combined Optional Treatments

Irradiation

Most studies conducted on irradiation of vegetables have been targeted to alter ripening and to control post-harvest pathogens and disinfectants. Several countries are exploring alternative methods suitable for the control of human pathogens in fruits and vegetables, and ionisation radiation could be one such alternative. It has been demonstrated in literature that application of ionising radiation is an effective technology for controlling spoilage microorganisms and for increasing the shelf life of strawberries, lettuce, sweet onions, and carrots. Although extensive studies exist on the control of pathogens in meat and poultry products with irradiation, very few studies exist on the value of ionising radiation in eliminating food borne pathogens in fruit juice, fruits and vegetables, such as lettuce and sprouts. Pathogens in these foods when eaten raw have not generally been controlled in most parts of the world, although this could often be accomplished by combined methods, such as controlled atmosphere packaging (MAP) and ionising radiation. Thayer and Rajkowski presented a review on the different dosages of ionising radiation applied to vegetables to control spoilage and pathogens. In general, most vegetables can withstand irradiation dosages up to a maximum of 2.25 kGy; higher doses can, however, interfere with the organoleptic properties of food products. Combining irradiation with temperature control and gaseous environment, along with adequate processing conditions, is one of the most effective approaches to vegetable preservation.

The moisture content in foods and the surrounding environment during treatment influence the sensitivity of microorganisms to irradiation. For example, high environmental relative humidity and high water content in foods reduce the effectiveness of irradiation; therefore, control of these parameters during irradiation treatments could extend the shelf life and quality of irradiated vegetables. Recently, disinfections of vegetables with chlorinated water have been replaced with irradiation treatments. Treatment of shredded carrots with irradiation at 2 kGy inhibited the growth of aerobic and lactic acid bacteria, in which case sensory analysis panellists preferred the irradiated vegetables.

Refrigeration

Refrigeration of vegetables can halt the growth of certain pathogen and spoilage microorganisms but will not eliminate them. It is generally recognised that maintaining foods at 5°C is sufficient to prevent the growth of most common food-borne pathogens. However, some emerging psychrotrophic pathogens such as *Listeria monocytogenes, Yersinia enterocolitica, Clostridum botulinum* types A and E, *Aeromonas hydrophyla, (enterotoxigenic), and E. coli* are able to multiply slowly in refrigerated foods. Therefore, refrigeration cannot be solely relied upon to maintain the safety of high moisture foods (HM). Considering the increased popularity of MPR foods, this issue has great significance, because refrigeration may be the only hurdle in the preservation of such products. And since psychrotrophic pathogens might eventually prevail, additional factors in the preservation system are needed for safety assurance.

In the conventional refrigeration storage environment, three important factors must be controlled: temperature, relative humidity, and air movement.

Temperature: The system should always be able to meet the demands placed upon it and controlled automatically by the use of thermocouples, pressure valves, etc.

Relative humidity (RH) should be kept high in a refrigerated storage room by controlling the refrigerant temperature. High RH prevents water loss affects texture, freshness, colour appearance and overall quality of food products.

Air movement in the refrigeration environment must be sufficient to remove respiration heat, gases, and the heat penetrating through the door, junctions, and structure of the refrigeration room. However, excessive air movement can cause food dehydration. Air circulation must be uniform throughout the room. Packages must be correctly stacked to achieve good air circulation.

Modified atmospheres

A modified atmosphere (MA) implies removal of, or the addition of gases, resulting in an atmospheric composition different from the one normally existing in air. For example, the N_2 and CO_2 levels may be higher, and the O_2 levels lower than those found in a normal gaseous atmosphere (78% N_2, 21% O_2, and 0.03% CO_2). In this type of storage, the CO_2 and O_2 levels are not controlled under specified conditions.

Appropriate use of MA can supplement refrigerated storage for some products, which could translate into considerable reduction in post-harvest loss. Major benefits can be obtained from its use:

- Reduction in senescence associated with biochemical changes, such as reduction in respiration rate and ethylene production, softening, and compositional changes in fresh produce.

- Decreased sensitivity of fruit to ethylene action at levels of O_2 and CO_2 below 8% and 1%, respectively.
- Can relieve some physiological disorders such as cooling damage in a variety of products.
- Can have a direct or indirect effect on post-harvest pathogens and insect control.

Some disadvantages of MA include:

- Initiation of physiological damage, such as black spots in potatoes.
- Irregular maturation of certain fruits, such as bananas and tomatoes ($O_2 < 2\%$ and $CO_2 > 5\%$).
- Abnormal development of flavours and odours at low O_2 concentrations (anaerobic conditions).
- Increase susceptibility to diseases.
- Stimulation of sprouting and delay of epidermis development in roots and tubers (e.g., potatoes).

Pickling

Vegetables can be macerated in a brine solution for pickling, which preserves the product for a long time. The high concentration of salts in the brine inhibits the growth of microorganisms that decompose and change the flavour, colour, and texture of vegetables. Vegetables can be maintained under maceration with a salt concentration of 6 to 10% during the first ten days of the pickling process. Then, the salt concentration is gradually increased to 16% for six weeks.

Under these conditions, vegetables can be kept in barrels for long periods until final processing. This involves washing the vegetables with water to release large amounts of salt (as much as possible), and packaging the product into glass jars with 5% vinegar and 3% salt. An alternative method is to precook vegetables at 80 to 90°C for 2 to 10 min. Then, packaging is performed using a blend of 3% salt, 6% vinegar, and 5% sucrose.

Fermentation

Vegetables can also be preserved by a fermentation process. During fermentation of raw vegetables, lactic acid bacteria develop, transforming the natural sugars present and the added sugar into acid. In general, a low salt concentration of 3-5% is used to prevent the growth of spoilage bacteria, while lactic acid bacteria are under development. The characteristic flavour and texture of fermented vegetables is produced by the action of lactic acid bacteria. Vegetables must be kept submersed in the liquid to prevent contact with air, which can cause decomposition, due to action of yeasts and moulds. During the fermentation process, the salt becomes diluted due to water drained from the vegetables, therefore salt must be frequently added to maintain the concentration at 3 to 5%. The pickled vegetables are washed with water and packaged into glass jars containing a solution of 3% salt and 5% vinegar. Vegetables can be pasteurised and packages hot filled.

A typical formulation and application

Lactic acid fermentation occurs when small amounts of salt are used. This allows bacteria to convert the sugar in vegetables to lactic acid; the acid mixed with salt inhibits the growth of other microorganisms that would cause major damage. This type of fermentation is used to prepare sauerkraut or sour cabbage, and in pickling cucumbers (pickles). Because salting is very softening, -both vegetables and salt are edible, thus preserving nearly all of the nutrients.

A typical application is in the preparation of sauerkraut:

1. Select good, mature cabbages; remove external leaves; wash remaining heads well.
2. With a sharp knife cut the heads into four sections, removing the hearts. Slice two and a half kilos of cabbage into fine strips approximately 2 to 3 cm long.
3. Put above cabbage in pot or plastic container and mix well, adding two tablespoons of salt. Let stand for 15 minutes or more, while preparing another batch of cabbage. The quantity of salt added must be in accordance with the amount of cabbage used for proper fermentation. While the cabbage is in repose, the salt works to reduce the lot size, extract the juice, and soften the cabbage. This will prevent breakage of strips during packaging.
4. The cabbage is packed into clean wide-mouth 4 L glass or plastic jars.
5. Eliminate air bubbles from the cabbage by pressing hard with hand. This allows juices to penetrate the tissues and holes formed between strips. Soft pressing is recommended to avoid breaking the finer strips.
6. Place plastic bag full of water on top of the cabbage to prevent air from penetrating the container and the cabbage. Close the jars tightly. After approximately 24 hours of fermentation, the juices should have completely covered the cabbage. Otherwise, add a brine solution composed of 25 g of salt per L of water until all cabbage strips are covered. The presence of bubbles is an indication that fermentation is in progress. This process lasts from 5 to 6 weeks or until the bubbles disappear from the solution, after which the fermented cabbage is heated in a pot until boiling.

7. Pack cabbage into sterile jars and cover with hot juice, leaving a head space of 2.5 cm below the jar's rim.
8. Place lids on each jar and sterilise the jars in a boiling water bath for 15 and 20 minutes for 0.5 L and 1 L jars, respectively.

Packaging Methods

Plastic containers and bags

The plastic containers used to handle fresh and processed vegetables are tough, easy to handle due to light weight, can be reused, and facilitate the stacking of produce into piles without damaging the product. Initially, the cost of plastic containers and bags is high, but if protected from sun and extreme conditions, they can last for years. In developed countries various plastics are used at all stages of post-harvest packaging and processed fruits and vegetables. Polyvinylchloride (PVC) is used primarily for overwrapping, while polypropylene (PP) and polyethylene (PE), for bags, are the films most widely used for packaging minimally processed products. Plastic bags are suitable for handling small amounts of vegetable products, and used at supermarkets and retail stores in developed and developing countries.

Vacuum packaging

Vacuum packaging extends the shelf life of vegetables for long periods. This technique relies on withdrawing air from the package with a suctioning machine. Removal of air retards the development of enzymatic reactions and bacterial spoilage. Vacuum packaging and gas flushing establish the modified atmosphere quickly and increase the shelf life and quality of processed products. For example, browning of cut lettuce occurs before a beneficial atmosphere can be established by the product's respiration. In addition to vacuum packing the specifics of handling must be taken into account, especially the time delays and temperature fluctuations.

Modified atmosphere packaging

For some products, such as fast respiring broccoli florets, impermeable barrier films with permeable membrane "patches" to modify the atmosphere through the product's respiration are used. It is not yet agreed as to which films and atmospheres are preferred for minimally processed products. Modified atmosphere packaging (MAP), can be created passively by using proper permeable packaging materials, or by actively using a specified gas mixture, together with permeable packaging materials. The purpose of this procedure is to create an optimal gas balance inside the package, where the respiration activity of the product is as low as possible; on the other hand, the oxygen concentration is not detrimental to the product. In general, the objective is to have a gas composition of 2-5% CO_2, 2-5% O_2, and the rest nitrogen. One limitation in the design of control atmosphere packaging is in finding good permeable material that will match the respiration rate of the produce; only a few choices are available in the market. Most films do not result in optimal O_2 and CO_2 atmospheres in products with high respiration rates. This problem can be tackled by making micro holes of defined sizes and quantity in the material to prevent anaerobiosis. Another alternative is to combine ethylene vinyl acetate with oriented polypropylene and low-density polyethylene at a specified thickness. These materials have significantly higher permeability than the polyethylene or oriented polypropylene used in the packaging of salads, gas permeability should however be even higher. These materials have good heat-sealing properties and are commercially available. High O_2 MAP treatment has been found to be particularly effective at inhibiting enzymatic browning, preventing anaerobic fermentation reactions, and inhibiting aerobic and anaerobic bacterial growth. The modified atmospheres that best maintain the quality and storage life of minimally processed products have been found to have an oxygen range of 2 to 8 percent and carbon dioxide concentration of 5 to 15 percent.

Preservation in Open vs. Refrigerated Vehicles

After harvest, open vehicles are used to transport the product to the packing houses and retail markets. These vehicles are not equipped with refrigeration units and thus the produce decays faster, compared to that in refrigerated transport. If the produce is treated with chemicals or additives after harvest, it can withstand longer distances in open vehicles, without noticeable damage, especially in cases where produce is consumed or processed upon reaching its final destination. Refrigerated vehicles contain installed refrigeration units with sufficiently low temperatures to maintain vegetables in a fresh-like state. These types of vehicles are hermetically sealed with insulation material inside the walls of the cave or container, which maintains the cooled product at maximum quality. Vegetables must be classified in order to separate those susceptible to cold temperatures and those that are not. This eliminates the possibility of product damage when cooling at low temperatures during transport. Refrigeration temperatures can vary from 0°C (32°F) to 13°C (55.4°F) and RH from 70 to 95%. Maintaining a high RH in the refrigerated container is very important, as it prevents water loss and degradation in product appearance. This can be accomplished through strict control of the temperature. There is usually little or no environmental humidity control available during transport and marketing. Thus, the packaging must be designed to provide a partial barrier against movement of water vapour from the product. Plastic liners designed with small perforations to allow some gas exchange are one option.

Unloading

Unloading vegetables and fruits from vehicles is a very delicate operation and can be done by hand with a box tipper or with the aid of a forklift. Generally, vegetables and fruits are stacked on pallets to ease the unloading process and to prevent damage to the product. Exported crops arrive at the unloading port in bulk containers are unloaded directly into the storage container with the aid of conveyor belts connected from the vehicle to the container. At village level a range of head packages and barrows are used to transfer crops from the field. Cushioned surfaces must still be used, however, to protect the crop when unloading.

Storage temperature vs. shelf life

Recommended storage temperatures for vegetables can range from 0°C (32°F) to 13°C (55.4°F) with relative humidity between 70 and 95%; under these conditions shelf life can range from days to months. Controlled or modified atmosphere packaging techniques assist in maintaining adequate temperature control and relative humidity for refrigerated products. These systems can be used during transportation of fresh produce for short or prolonged storage periods. During pre-cooling of some vegetables, high levels of O_2 are utilised for shelf life extension. Recently, injection of CO_2 (%) gas into controlled or modified atmosphere systems to control pathogens was carried out.

Repackaging considerations

Repackaging of vegetables is common when the product has been packaged in large containers, such as sacks, boxes, plastics containers, etc. The repackaging process is often carried out using small trays covered with transparent plastic film, which gives the product an appearance more appealing to consumers. Supermarkets and retail stores display packaged vegetables either on refrigerated shelves or under ambient conditions. Some retail stores and market places use open packages so that consumers can also handle the goods.

Optimal utilisation of the final product

Optimal utilisation of the final product can vary according to consumer demand. In some cases, the demand is for fresher products. Thus, the optimal utilisation of fresh vegetables should be for direct consumption, with perhaps very small quantities remaining for processing or industrial uses. The latter usually occurs with seasonal crops when an abundance of fresh produce floods the market. The produce must meet official regulations concerning product safety and quality whether it is marketed as fresh or processed. Vegetables must be free of foreign matters, chemicals, and microbes that constitute a risk to human health. Therefore, good manufacturing practices (GMP) should be followed during handling, transport, and processing of vegetables for human consumption.

In developing countries, preservation of commodities represents a big problem for small farm crops because of the lack of adequate infrastructure to store harvested products. A novel alternative is to use combined methods technology for preserving large quantities of vegetables without using sophisticated equipment. To implement this preservation technology for stable vegetable products with high moisture content (HMVP), the following considerations should be addressed:

- Technology must be easy to use and be located near production centres.
- Technology must be cheap: does not require the use of sophisticated equipment or machinery, or the use of refrigeration or freezer storage.
- Resulting product must be of high quality: safe and tasty.

Quality Control

Recommended microbial tests

Control tests for microbial invasion in fresh vegetables must be assayed to analyse the growth of spoilage and pathogenic microorganisms. Total aerobic, psychrophile, and coliform bacteria counts are performed in standard plate count agar (SPC) and red violet bilis agar (VRBA). A series of dilutions are made in sterile 0.1% peptone and then pour plated onto SPC and VRB agars; plates for total aerobic and coliform bacteria are incubated at 35-37°C ± 2°C (95-98.6°F ±2°F) for 24/48 hours, and psychrophile bacteria at 7°C ± 2°C (45± 2°F ± 2°F) for 7 days, respectively. However, major contaminants and spoilage organisms in fresh vegetables and fruits or by-products, are moulds and yeasts. These organisms are counted by using potato dextrose agar (PDA) and poured plates, and are incubated at room temperature for 5 to 7 days.

Nutritional changes

Minimally processed vegetables retain nutritional and fresh-like properties because heat is not a major detrimental factor during processing. When using controlled or modified atmosphere packaging in combination with refrigerated storage, prolonged shelf life of vegetable products and retention of vitamins is favoured compared to thermally treated vegetables, in which high amounts of nutrients are lost due to severe temperature treatment.

Changes in sensory attributes and acceptability

Since minimally processed vegetables resemble fresh produce, changes in sensory attributes and acceptability are minimised during processing. Thus, flavour, texture, and appearance are retained. Traditional food preservation processes involving high temperature treatments, freezing or dehydration produce an adverse effect, however, on the texture, flavour and aroma of processed food products.

The following factors are critical in maintaining the quality and shelf life of minimally processed products: using the highest quality raw product; reducing mechanical damage before processing; reducing piece size by tearing or by slicing with sharp knives; rinsing cut surfaces to remove released cellular nutrients and to kill microorganisms; centrifugation to the point of complete water removal or even slight desiccation; packaging under a slight vacuum with some addition of CO_2 to retard discoloration; and maintaining product temperature from 1° to 2°C (34° to 36°F) during storage and handling. Temperature maintenance is currently recognised as the most deficient factor in the cool chain.Other undesirable sensorial changes are a result of enzymatic activity in raw vegetable products. Two groups of enzymes are responsible for these changes:Oxidative enzymes such as in unprocessed vegetable and fruit products cause browning or other changes in colour. Changes in taste and flavour are caused by lipid oxidation due to the action of the enzyme lipoxygenase.

Hydrolytic enzymes cause softening of vegetable and fruit products; and sweetening of vegetables and fruits by hydrolysis of the starch. Activity of such enzymes can be prevented by application of thermal treatment, but since the products are minimally processed, the use of heat is not a true option. One has to use other barriers to prevent changes in colour such as anti-browning agents and anti-oxidising agents as well as calcium salts to enhance texture firmness of vegetable tissues.

REFERENCES

Aiyer, RS. et al. 1978. "No-cost method for preserving fresh cassava roots". *Cassava Newsletter* 4: 8-9. Cali, Colombia: CIAT.

Alzamora, S.M., Cerruti, P., Guerrero, S., and López-Malo, A., Díaz, R.V. 1995. "Minimally processed fruits by combined methods". In: *Fundamentals and Applications of Food Preservation by Moisture Control.* ISOPOW Practicum II, Barbosa-Cánovas, G. and Welti, J., Eds., Lancaster, PA, Technomic Publishing, 565-602.

Holdsworth, S.D. 1983. The Preservation of Fruit and Vegetable Food Products. Science in Horticulture Products. Macmillan Press, London, 109-110.

Leistner, L. 1992. "Food preservation by combined methods". *Food Research International.* 25, 151-158.

Rahman, M.S., Labuza, T.P. "Water activity and food preservation". 1999. In: *Handbook of Food Preservation,* edited by M. Shafiur Rahman. Marcel Dekker, Inc., New York, 339-382.

9

Processing of Fruits and Vegetables

Food processing as a scientific and technological activity covers a broader area than food preparation and cooking. It involves the application of scientific principles to slow down the natural processes of food decay caused by micro-organisms, enzymes in the food or environmental factors such as heat, moisture and sunlight - and so preserve the food. Much of this knowledge is known traditionally and put into practice by experience and information handed down through the generations. In most developing countries food processing is also a method of generating employment and family incomes. Under these circumstances, producers must compete with others in the same country and with imported products. With some important exceptions, traditional processing methods produce foods that are usually inadequate to compete with the 'newer' products. This is particularly important with respect to packaging and presentation of the processed foods.

The benefits of small scale fruit and vegetable processing for people in developing countries can be broadly stated as follows:

- raw materials are readily available (often in surplus)
- most technologies are available, accessible and affordable at scales that are suitable for small operations
- equipment can often be manufactured locally, creating additional employment
- the products, if chosen correctly, have a widespread demand
- compared to some other technologies, small-scale fruit and vegetable processing is particularly suitable for women
- most processes have few environmental impacts.

However, the selection of suitable products for small scale manufacture and the processes chosen to make them, require very careful consideration. It is not sufficient to assume, as many 'advisers' do, that simply because there is a surplus of a raw material each year, a viable fruit and vegetable processing venture can be created to use up the excess. There must be a demand for the processed food which is clearly identified before a business is set up. Otherwise the most likely result is to produce a processed commodity that no-one wants to buy with substantial financial losses to those involved.

There are numerous examples of misguided development projects that have resulted from a desire to prevent piles of rotting fruit from accumulating each season by processing them. Instead, the result has been shelves of more expensive, rotting processed foods that no-one wants to eat.

In general the types of products that are suitable for small scale production are those for which there is a high demand, and a higher value can be added by processing. Typically fruits and vegetables have a low price when in their raw state, but can be processed into a range of snackfoods, dried foods, juices, pickles, chutneys etc., which have a considerably higher value.

The high added-value means that the amount of food that must be processed to earn a reasonable income is relatively small. Hence the size and type of equipment required to operate at this scale can kept to levels that are affordable to most aspiring entrepreneurs.

A further consideration that applies to both home processing and commercial production is the safety of the fruit and vegetable products that are produced. Although there are many similarities between fruit and vegetables, it is important to note the following difference: most fruits are acidic and this acidity controls the type of micro-organisms that are able to grow in the processed products. Food poisoning bacteria cannot grow in the acidic conditions, but moulds and yeasts are able to grow and produce obvious visible spoilage which stops consumers from eating the food. Even if a contaminated fruit product is eaten, yeasts and moulds rarely cause severe food poisoning.

Vegetables however, are generally less acidic than fruits and a wider range of micro-organisms are able to grow in vegetable products, including food poisoning bacteria. This is particularly dangerous when certain types of bacteria release poisons (or 'toxins') into the food, but do not produce obvious signs of spoilage. Consumers may therefore be unaware of the contaminating bacteria and eat the poisoned food. Careful control of processing conditions and attention to hygiene are therefore essential when processing less acidic vegetable products.

Dried fruits and vegetables do not allow micro-organisms to grow, provided that drying is carried out correctly and the food is kept dry. However, if the food is heavily contaminated before drying, or if it is allowed to get damp during storage, these micro-organisms can grow again before the food is eaten.

In addition to the actions of micro-organisms, naturally occurring enzymes rapidly change the colour, flavour and texture of fruits and vegetables after harvest. In general, these changes, due to both micro-organisms and enzymes, produce a characteristically short shelf life and rapid processing after harvest is therefore necessary.

Details of the points in a process where control is needed to ensure food safety or to maintain food quality are given in the descriptions of each production process in Part 2 and a summary of good food handling practices is given in Appendix I.

In many countries, vegetables and fruits are among the most accessible raw materials for processing. Traditionally, cultivation of vegetables in small garden plots has been common in most tropical regions and the planting of fruit trees around the house or compound has provided shade and wood as well as fruit.

These activities are being expanded and promoted in a large number of both home gardening programmes to improve household nutrition and in orchard planting and regeneration programmes designed to address environmental concerns such as soil erosion and also to improve fruit quality and varieties.

These programmes, together with an increasing awareness of the value of processing for improved food security and income generation, has resulted in fruit and vegetable processing being seen by many development agencies and government institutions as an important method to improve the livelihoods of both rural and urban populations.

However, to be successful these initiatives should from the outset have clearly defined objectives concerning the expected benefits of processing. These may include direct benefits to participating groups or individuals, such as:

- Improved storage of fresh produce without excessive losses
- improved nutritional status through consumption of fruits and vegetables for a larger part of the year
- increased income for sale of processed fruits and vegetables
- preservation of seasonal gluts which would otherwise be wasted.

There may also be improved backward linkages to farmers and suppliers (especially in integrated development programmes) as a result of increased demand for raw materials by processors. This may:

- improve the amount, quality and varieties of fruits and vegetables that are grown
- improve the rural environment as a result of planting fruits and vegetables. Such improvements may include soil regeneration and rainwater retention due to orchard or vegetable planting

- improve incomes to farmers from higher sales of raw materials to processors, or secure supply contracts that reduce farmers' dependency on seasonal price fluctuations
- increase demand for equipment, packaging materials and ingredients which stimulates development of associated supplier industries and creates strategic alliances between different manufacturing sectors.

PROCESSING FOR HOME CONSUMPTION

The majority of fruits and vegetables grow in short seasons and one main reason for processing is therefore to secure a supply of these foods when they are not available in a fresh state. This is both because some (tomatoes, onions, spices etc.) are used in daily cooking in different societies and because regular consumption of fruits and vegetables is necessary to maintain health.

In different societies throughout the world, the consumption of fruits and vegetables has different levels of significance in the diet. In some areas, such as the cold, infertile conditions of Central Asian steppes, mountainous regions of Latin America and arid deserts of Africa and Asia, fruit and vegetable cultivation is difficult and has a short annual growing season. These products do not therefore play an important role in local diets and there is greater reliance on animal products. However, the requirement to eat fruit and vegetable products to maintain health means that in almost all of these societies, small amounts of leafy vegetables and collected fruits are preserved for winter or dry seasons and as a result of their shortage, they have a high value.

By contrast, in almost every country of the humid tropics and sub-tropical regions, the soils and climate are suitable for fruit and vegetable cultivation and there is an historic reliance on these products as an important part of the normal daily diet. Indeed in some areas this may be reinforced by religious beliefs, such as Hinduism, which requires followers to be vegetarians. In many communities throughout the world, vegetables are eaten daily as an accompaniment to a main cereal or root crop meal, with or without meat and fish. Fruits are eaten fresh when in season as appetisers, snacks, juices and desserts.

There are a large number of traditional processed fruit and vegetable products that are traditionally made in the home. Examples from Asia include fruit 'leathers' (dried sheets of fruit paste that have an appearance of thin leather), fruit pastes, pickles and chutneys. In Africa and Latin America, a wide range of dried chips, dried and powdered leaves, fruit beers and other fermented fruit and vegetable products are traditionally produced. Each of these products is stored for future use and is often not intended for sale, although no clear distinction is possible. Some products that are processed for home consumption may also be sold to neighbours or at village markets when additional income is needed.

In general terms because of low incomes, home processing requires simple, cheap equipment and will usually be done without specialised machines, using existing kitchen utensils and simple pieces that can be made from local materials at almost no cost. Processing methods are also inexpensive but in some cases are complex and sophisticated, involving a sequence of process stages that require considerable experience and expertise to perform correctly.

Some of the main reasons for home processing are to maintain a secure supply of food for seasons of shortage (to provide food security) and to maintain health through an adequate supply of nutrients in the diet. These aspects are described in more detail below.

Food Security, Nutrition and Health

Fruits and vegetables provide an abundant, cheap source of fibre and several vitamins and minerals. In general, they have the highest nutritional value when eaten fresh, although an exception may be fermented foods, in which the process of fermentation can increase the content of B-vitamins.

However, fresh fruits and vegetables have a relatively short life before they begin to decay and if they are to be stored for an extended period, it is necessary to process them by one or more of the various methods that are available. The extent to which preservation is required depends in part on the type of plant material that is being considered. For example, fast-growing parts such as shoots have a short life before rotting, whereas bulbs and tubers can be stored without preservation for much longer at room temperature (25°C).

The extent to which nutrients are lost during processing varies according to both the type of fruit or vegetable and the process that is used.

The purposes of processing fruits and vegetables in the home may therefore be summarised as follows:

- preservation of seasonal gluts for survival in times of shortage
- provision of cooking ingredients throughout the year
- increase in convenience by having part-prepared foods available when required.
- availability of different foods throughout the year to provide variety and greater nutritional balance in the diet.

Table 1. Dietary fibre, selected vitamins and minerals in fruits and vegetables compared with some other foods.

Food	*Fibre (g/100g)*	*Carotene (μ g/100g)*	*Thiamine (mg/100g)*	*Ascorbic acid (Vitamin C) (mg/100g)*	*Calcium (mg/100g)*	*Iron (mg/100g)*
Soya flour	11.9	-	0.75	0	210	6.9
Wholemeal bread	8.5	0	0.26	0	23	2.5
Boiled rice	2.4	0	0.01	0	1	0.2
Doughnut	-	0	-	-	70	1.9
Whole goats' milk	0	22	0.04	1.5	130	0.04
Yoghurt	0	5	0.05	0.4	180	0.09
Eggs (raw)	0	tr	0.09	0	52	2.0
Beef (raw)	0	tr	0.05	0	7	1.9
Chicken (raw)	0	tr	0.10	0	10	0.7
Green beans (raw)	2.9	400	0.05	20	27	0.8
Green cabbage (boiled)	2.2	500	0.03	25	30	0.5
Carrot (raw)	2.9	12,000	0.06	6	48	0.6
Okra (raw)	1.3	90	0.10	25	70	1.0
Plantain (raw)	5.8	60	0.05	20	7	0.5
Tomato (raw)	1.5	600	0.06	20	13	0.4
Apricot (raw)	2.1	1,500	0.04	7	17	0.4
Banana (raw)	3.4	200	0.04	10	7	0.4
Mango (raw)	1.5	1,200	0.03	30	10	0.5
Orange (raw)	2.0	38	0.08	38	31	0.3
Pineapple (raw)	1.2	60	0.08	25	12	0.4

When the objective of a programme is to improve health and nutritional status by increasing the effectiveness of food processing, it is usually necessary to combine education and training with practical improvements to facilities and equipment. In order for people to learn from each others' experience and to make such interventions cost effective, it is usually necessary for participants to organise themselves into groups. This in itself can be a long and difficult process in some communities, but where groups such as mothers' clubs or farmers' societies already exist, they can be approached to act as a focus for a new programme. In some instances, successful food processing developments for improved nutrition have also been linked to health centres.

Any improvements to facilities and equipment need to be low cost and easily maintained if they are to be used in a sustained way. Whereas the capital cost of a new building or item of processing equipment can be donated, the facility will cease to operate if both funds and responsibility for maintenance are not established at the outset. Many attempts have been made to share the costs of processing by establishing various forms of producer associations or village co-operatives, with varying degrees of success.

Table 2. Rate of spoilage of different parts of fruit and vegetable plants

Part of plant	*Time before spoilage starts (days)*
Fast growing shoots	1-2
Leaves	2-3
Stems	5-50
Fruits	10-30
Roots and tubers	15-50
Bulbs	30-100

One important factor is the degree of trust and willingness to work together that exists in a community. If there is no history of a communal approach to problem solving or implementing a new development, it can take many years to introduce these ideas. However, there are many examples of successful village associations that have been operating for several years and have supported on-going education and training programmes in health and nutrition, together with the establishment of community systems and facilities for crop processing.

Improvements to Home Processing and Storage

In most cases, simple methods of processing and storage that are based on traditional knowledge have the greatest chance of being successfully introduced. Improvements to existing practices are more likely to succeed than completely new technologies, not only because they are more familiar to people, but also because traditional methods are suited to local environmental conditions, whereas new technologies may not be. A good example of such an approach is improved drying and storage.

Drying

Drying is one of the most accessible and hence the most widespread processing technology. When combined with improved food stores, it can lead to significant improvements in food security in most regions. Important examples of dried fruits and vegetables are okra, cabbage, spinach, mango slices or leathers, garlic and other flavourings, all of which are stored for use in daily cooking.

Sun drying is traditionally practised because there is negligible cost in processing and the work of spreading and turning the crop as it dries can be shared among family members, including young children. Some of the reasons why the introduction of solar dryers into village communities has not been widely successful concern these factors of cost and workload. Even when constructed from locally available materials, the simplest dryer still has a higher cost than sun drying. Additionally, the work involved in loading and carrying trays of fruits and vegetables and removing them regularly to turn and mix the products, is not suitable for children and therefore places an additional workload on the parents, usually the mothers. Furthermore, the possibility of improved quality products and shorter drying times using solar dryers may not be important factors to families who may be satisfied with the existing quality of dried foods and the time and effort required to dry them.

Under such circumstances, a focus on improvements to sun drying is likely to yield greater results. Examples include raising crops off the ground on woven matting or wooden drying frames to reduce contamination by dust, crawling insects or rodents; covering the crop with mosquito netting to reduce damage and contamination from birds and flying insects; cutting the fruits and vegetables into smaller pieces so that they dry faster and blanching vegetables to retain a better colour. Although it is beyond the scope of this book, it may be possible in some programmes to link drying improvements to agricultural developments and the introduction of crop varieties that are better suited to drying than traditional types.

Concentration by boiling

Relatively few fruits and vegetables are preserved in the home by concentration, mainly because of the additional fuel-wood consumption, but important foods in some societies are tomato paste, extracts from wild plants such as baobab fruit, that are used as flavourings, chutneys and syrups made from fruits or saps. The main requirement to improve processing of these products is to control the rate of heating to prevent localised burning of the product, particularly when it has become thickened towards the end of boiling.

Fermentation

Production of fruit wines and beers is possibly the second most common form of home processing after drying, in countries where alcohol consumption is not prohibited by religious beliefs. A wide range of fruits is used, particularly pineapple, melon and pawpaw. In the example below from East Africa, banana is used. It is difficult to produce a clear juice from bananas but the following description by the processor indicates the complexity and degree of skill required to produce a satisfactory product.

'Bananas are harvested when they are not quite ripe and not over-ripe. They are stored in a pit covered with banana leaves for up to 4 days to ripen. If necessary a fire is lit in a small hole leading into the pit to warm the bananas and hasten ripening. The bananas are peeled and placed into a large wooden trough. They are then crushed to a pulp by walking on the fruit. Two grasses, one of which is young elephant grass, are cut to approximately 15 cm long and carefully mixed in the correct proportions. Thin layers are periodically added to the surface as pulping proceeds and the grass becomes mixed into the pulp. This is to finely divide the pulp into small particles and thus release the juice. Only these two grasses are used as they do not add flavour to the juice in the way that other species do'.

'After approximately 30-45 minutes pulping, the mixed grass and pulp is piled on a coarse filter frame, made from wooden poles lashed together over the trough, and juice is pressed out by standing on the pulp. The juice is then collected using a calabash into which a hole is cut in one side and a hollow handle is fitted to the top. Juice is poured through the hollow handle into a second calabash, which is shaped as a runnel and lined with grass to act as a fine filter. The juice, which is cloudy but without particles, is collected in a clean container. It is tasted at this stage and if necessary, adjusted to the correct sugar content by adding water.

The standardised juice is then returned to a clean wooden trough and sorghum is added in the ratio of 2 kg per 20 litres of juice. The trough is covered with banana leaves and also with the residue from pulping to act as insulation and maintain the temperature of fermentation at ambient (22-26°C) for two days. After fermentation, the liquor is strained through the calabash/grass filter into clean containers or bottles and is then ready for drinking. There are no further clarification or pasteurisation stages and the beer is preserved by the alcohol content (3-5%). As a result it has a shelf life of up to four days without refrigeration. The process could be improved and a longer shelf life obtained, if the product was clarified by filtration or sedimentation and pasteurised in the bottles.'

Home preservation of fruits and vegetables by fermentation to produce pickles is especially common in South and Central Asia, but less so in other regions of the world. Examples include pickles from lime, mango, mixed fruit and a range of vegetables, including different types of cabbage. Each local district may have a slightly different set of ingredients or variations in the process and in India for example, there are estimated to be over 700 different types of fermented pickle.

In all cases the prepared fruit or vegetable is mixed with spices and held in a closed container such as glazed pottery, while a natural sequence of bacteria ferment sugars in the raw materials to produce lactic acid. Provided that the raw materials are not heavily infected with moulds and that insects, which can carry yeasts or moulds on their bodies, are kept out of the container, the build up of lactic acid is sufficient to prevent spoilage and the product can be kept for several months while it is being used.

In the following example from Central Asia, pickled cabbage is produced: a 2 cm layer of salt is placed into the bottom of a wide-necked pottery drum or jar. A 5 cm layer of shredded cabbage is placed onto the salt and the jar is then filled using alternating layers of salt and cabbage. It is then sealed with a wooden or cloth bung and allowed to ferment for several weeks. As the water is drawn out of the cabbage, it forms a pickling brine. If the product is not to be used straight away, the cabbage is weighted down with a clean stone to keep it beneath the brine and to prevent it drying out and spoiling. Little improvement can be made to these processes without substantially increasing capital and/or operating costs. They are well suited to local tastes and environmental conditions.

Pickling

There is also a wide range of unfermented pickles produced in Asia. Two examples below describe the production of lime pickle and mixed pickle from South Asia.

· Well ripened, but not over-ripe limes are washed, cut into four (but the pieces are not separated), and dipped in a concentrated solution of salt. They are then dried in the sun for several days. Sometimes salt crystals are sprinkled onto the lime while it is drying. Drying is continued until the skin develops a brown colour and the pieces can be broken using the fingers. The product is then packed along with the expelled juice in pottery vessels. The salt removes water from the pieces due to osmosis and some sugar is also removed. As a result, salt-tolerant micro-organisms begin to grow while the product is being dried. These bacteria produce some acid, but mostly generate the characteristic flavour of the product, which has a sour and salty taste and can be kept for several months.

The main raw materials for mixed pickle are green chillies, onion, papaya, and spices. The papaya and onion are peeled and cut into slices. The spices are also washed and then ground. All ingredients are placed in a clean pot and mixed by hand while adding vinegar. The product can be kept in the sealed pot for several months, during which time there is a degree of fermentation which improves the flavour, but it does not contribute to the preservation. Other formulations of mixed pickles use raw materials such as dates, pineapple or mango.

Storage

In many cases, the most serious problems of food security are connected with inadequate food storage practices. For example, dried foods are susceptible to spoilage by mould or to attack by insects and rodents, particularly if they are inadequately dried. Losses during storage can be considerable and when these are cereal losses, they can be life threatening. Traditional storage practices for fruits and vegetables vary widely in different parts of the world, but all use locally available materials, usually at little or no cost. It is not possible in a book of this size to detail these differences, but the general principles of storage are described below, followed by some examples of good practice that may assist in improving storage practices and facilities in other places.

The main types of processed fruits and vegetables that are stored in the home are dried foods, followed by fermented and pickled foods and concentrated syrups or pastes. The latter groups are each moist foods but they are preserved by raised concentrations of lactic acid, salt or sugar. All that is required for adequate storage is therefore an impervious pot to contain the contents and an airtight and insect or rodent proof seal to prevent contamination or theft. Glazed pottery or glass vessels, with cork or wooden stoppers, sealed with resin or wax are entirely adequate for the expected shelf life of these products. They should be stored off the floor in a cool dark place, away from sunlight and dampness.

Dried fruits and vegetables need protection from insects, animals and from uptake of moisture. Those foods that are required to remain unbroken also need protection from crushing and those that contain high levels of carotene, such as green leafy vegetables or carrots, also require protection against sunlight. Because of their bulkiness, pottery vessels may be too expensive to store an adequate supply and many families resort to hanging dried fruits and vegetables from rafters or over cooking areas, where they are sure to remain dry. This deters most animals but does not provide adequate protection against insects. Improved storage can be achieved by constructing a simple mesh basket from wooden sticks and mosquito netting, which can be hung from the rafters in a cool, dry place, away from sunlight.

Dried foods should not be stored on the floor. If storage on tables or raised platforms in the house is the only option, the supporting legs should rest in small containers of oil or kerosene to deter crawling insects. Storage containers should be protected by insect proof mesh. Ideally, re-used cans, having press-on lids or similar insect- and rodent-proof containers are used, once they have been thoroughly cleaned and dried.

Home Processing to Earn Extra Family Income

There are very large numbers of people throughout the developing world who process foods in their homes and sell them to neighbours or in local markets, in order to generate a little extra money to supplement family incomes. People in this informal sector are characterised by having little capital to invest in equipment and they are forced to buy inputs such as raw materials, ingredients and packaging in small quantities from retailers, because of a lack of working capital or an uncontrolled cashflow. This increases the unit costs of their products and may make them un-competitive on price with those from the formal sector, or even in some cases with subsidised imports. They have poor access to credit because they have little or no collateral and credit providers cannot justify the high administrative costs of servicing a large number of small loans.

It is also frequently the case that informal processors have little experience of quality control and so their products do not compete well on quality, safety or appearance with those from the formal sector. Because they only process fruits or vegetables until they have earned sufficient money for their immediate needs and they then cease production until the next financial need, informal enterprises are unable to build up trusting relationships with suppliers or retailers and as a result, future orders may be more difficult to obtain.

Thus a complex mix of factors need to be addressed when a programme is designed to assist informal, home-based processors. Provision of accessible credit is one component, but by itself is insufficient to generate success. Technical training in production routines, hygiene and quality assurance is also required and most importantly, an improved ability to identify suitable markets and to develop skills in selling the products is needed.

There are a number of development programmes that are achieving some success in improving the incomes to processors in the informal sector. It is not usually possible for an individual farmer or rural family to adequately learn all of the skills needed to process and sell fruit and vegetable products in competition with large scale producers. But the formation of groups of people that are able work well together with mutual trust among the members has in some cases been shown to overcome these problems. People learn from each other, are empowered by the group, are able to access credit because of the larger needs of the group and in some cases, are able to achieve savings by bulk purchases of inputs.

The division of labour within the group also has social benefits not only in providing a more flexible working environment to take account of household responsibilities but also in developing, encouraging and rewarding an individual's competence and skills in their area of work. This can have dramatic effects on the confidence and determination of individuals to succeed. This approach also removes the need for each member of the group to have expertise in all areas of operating a processing enterprise (for example checking quality, negotiations with suppliers or customers, keeping records, producing financial data, marketing and selling etc.), and allows each member to develop their own specific contribution to the success of the group, based on their individual skills and abilities. There can be various structures for such groups, including producer co-operatives, in which each member has an equal share, groups based on religious beliefs, extended families or those formed around a different existing activity, such as a youth club, a mothers' union or a village development society.

A further development of group activity in the informal sector is the division of responsibility for different parts of the food supply chain. A number of groups can reach agreement to collaborate and share the profits of the joint venture. In some successful approaches, a farmers' group is responsible for supplying a local group of processors with an agreed amount of raw materials of specified quality. This removes the need for farmers to develop skills in marketing their crops and they can concentrate on their farming abilities. The processors may buy from a number of farmers in the local area, thus reducing transport costs for the raw materials. The processors concentrate on producing high quality products at the lowest cost and sell them to a marketing group. The marketing group may buy from a number of processors and concentrate only on finding the highest paying and most reliable markets for the products.

A development of this system may involve part-processing of fruits or vegetables on the farm to reduce transport costs and to add value to the farmers' produce. For example, fruits can be peeled and part-dried or crystallised on the farm and then transported to a local processor in returnable containers. There are some environmental advantages in doing this because not only are fuel costs for transportation reduced, but also localised pollution at the central processing unit is removed and fruit and vegetable wastes are available on the farm for green manure. In this system, the processor standardises the quality of each batch by blending or sorting and then packages each farmers' products under a single brand name. This gives both benefits of lower costs through bulk purchases of packaging and the ability to supply larger amounts to meet demands of retailers who would otherwise not consider purchasing.

There is thus a spectrum of processing enterprises from a single person working intermittently from home, through various forms of single and group-based informal enterprises to more formal structures.

PROCESSING FOR SALE

Interest in small scale food processing as a means of enterprise creation in developing countries has increased substantially in recent years, as a result of a number of factors. These include:

- greater promotion of private sector micro- and small-scale enterprises by national and international development agencies, to help increase incomes and employment opportunities in both rural and urban areas
- development of tastes for non-traditional foods, especially in major urban centres
- a desire by national governments to both increase export opportunities and foreign exchange earnings and to develop national manufacturing capacities
- increased food surpluses in some countries that require preservation and processing as a consequence of successful agricultural interventions or development programmes

- an increasing pride in locally produced products that can effectively compete with imported goods.

However, successful fruit and vegetable processing enterprises require more than the skills that are needed for home processing. Whereas in home or village processing, the consumers and processors know each other and can give feedback on the quality or perceived value of a processed food, in formal food processing businesses the producers usually do not know who eats their food or what their customers think of the products. Similarly the customers have no direct link to the individuals who have produced their food and there are thus very limited opportunities for feedback between processors and consumers. As a result, processors have to learn new skills in developing attractive packaging and in marketing and selling if they are to successfully find customers.

Additionally, consumers expect to find the same food in every pack, having a uniform quality, every time that they buy a product. Producers must therefore control their process to produce uniformity and consistency in their products, and to do this they must learn new skills in quality assurance. There are also other problems that are associated with operating any enterprise that need to be addressed by aspiring entrepreneurs: for example legal aspects such as registration of the business, payment of taxes, employment conditions and business planning.

For those who set out to earn their main income from fruit and vegetable processing, there are special problems which make this type of business different from most others:

- many raw materials are highly perishable and will spoil quickly after harvest unless they are processed quickly
- many fruits and vegetables are also highly seasonal which means that the business can only operate for part of the year, unless crops are either part-processed for intermediate storage, or a succession of crops is processed throughout the year
- seasonably also affects the cashflow in an enterprise, as most raw materials have to be bought during a relatively short harvest period
- yields of fruit and vegetables are subject to considerable variation according to the weather, especially the rainfall patterns, and plant diseases. This can result in an unpredictable supply and large variations in prices for raw materials, which makes business planning more difficult
- some processed foods also have a seasonal demand (for festivals, ceremonies etc.) which further complicates planning and cashflow of a business
- even after processing, some fruit and vegetable products have a limited shelf-life and distribution and sales methods must therefore be organised so that customers receive products in the required amounts before they spoil

- processing must be done to high standards of hygiene and production control to avoid the risk of harming or even killing customers by allowing contamination of the products by foreign materials or the growth of food poisoning micro-organisms.

Fruit and vegetable processing as a business is therefore a more complex activity than processing at home. Although it is true that most people can be trained to make high quality products, it is misleading to say that a person who is able to make a good product at home can then become a successful entrepreneur. Many small scale food processors start by working from home, but their ultimate success is dependent on a number of factors, including their planning and business skills, their creative flair to produce products that have a demand and are different from those of competitors and their determination to succeed.

Characteristically, successful entrepreneurs see food processing as their main source of income. They may take out a loan to buy specialised equipment or secure working capital and they develop business and marketing skills to expand and diversify their enterprise.

There are different definitions of micro- and small-scale enterprises and in this book, the following are used:

A micro-enterprise is one in which the owner works each day to manage the business and produce food. The number of workers is less than 10, the total investment does not exceed $20,000 and annual sales are less than $12,000.

A small scale enterprise is one in which the owners may work at the processing unit or employ a manager. The number of workers is less than 20, the total investment does not exceed $50,000 and annual sales are less than $25,000 (average for African countries).

The availability of services (electricity, clean water, gas, servicing and maintenance skills and facilities etc.) obviously vary between different countries and even between regions of the same country. Similarly the amount of money available to invest and opportunities for obtaining credit also vary considerably. It is therefore not possible to describe precise conditions under which any business can be successful, but where appropriate, guidelines are given on the types of activity and investments that have made other small fruit and vegetable processing enterprises successful.

The criteria that need to be taken into account when deciding which technologies to use are complex and inter-related but are likely to include the following:

- technical effectiveness (will the equipment do the job required at the indicated scale of production)

- relative costs for both purchase and maintenance of equipment and any ancillary services required
- operating costs and overall financial profitability
- health and safety measures in the process
- conformity with existing administrative or production conditions
- training and skill levels required for operation and maintenance
- environmental impact, such as pollution of air or local waterways.

However, these factors are not simply a checklist and each will have a different weighting in different circumstances. There can be no simple solution to the difficult task of assessing all factors in a particular situation and making the 'best-fit' from the available solutions.

In every proposed development, the general principle when starting a business, having decided which product to make, is as follows: conduct market research and produce a draft feasibility study. If the business appears to be profitable, produce a business plan, obtain credit where necessary and register the business with taxation and local government authorities. Then establish production facilities, develop contracts or agreements with suppliers and customers and manage the routine production of the products. Continually review and update business plans to take account of the actions of competitors or changing markets.

The Sections below follow this sequence, starting with a description of product characteristics and production methods for a range of fruit and vegetable products, to assist potential entrepreneurs in deciding which products to make.

SELECTING PRODUCTS AND PRODUCTION METHODS

Fried Products

A small number of starchy fruits, including jakfruit, breadfruit and banana are fried and eaten as snackfoods. Heat during frying destroys enzymes and micro-organisms and if sufficient moisture is removed and the product is packaged, it can have a shelf life of several weeks.

Care is needed to control the temperature of the oil used for frying, not only for safety reasons, as very hot oil can splash onto operators when wet fruit is immersed, but also because of financial and quality considerations. When oil is heated too much, it exceeds its *smoke point* and a blue haze appears above the oil. This is a sign that the oil is breaking down chemically and it will then begin to get more viscous and develop an unpleasant flavour. The flavour is transferred to the product, making it unacceptable. When the oil thickens, more is retained on the product and there is a higher cost in buying more oil than is needed. Too much oil on the product also reduces its shelf life.

Bottled and Canned Products

Bottling and canning are essentially similar processes in that food is filled into a container and heated to destroy enzymes and micro-organisms. Fruits can be packed into jars with a hot, sugar syrup and vegetables can be packed into a hot brine. The filled jars are sealed and pasteurised so that an internal vacuum forms when they are cool. The sealed container then preserves the food by preventing re-contamination and excluding air and sometimes light. Preservation depends on an adequate heat treatment and an air-tight (or 'hermetic') seal.

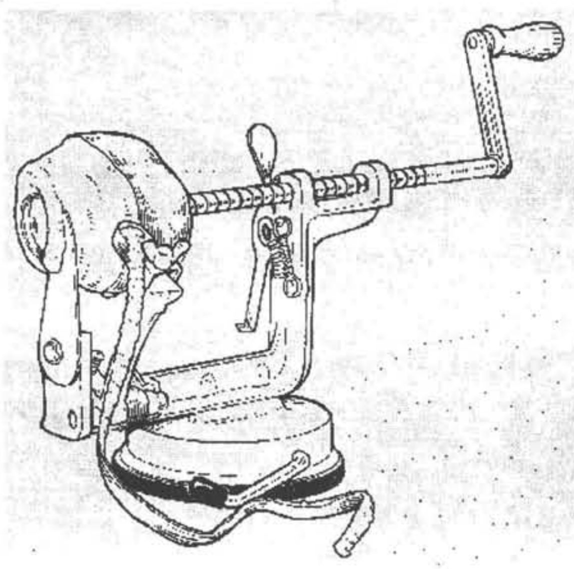

Figure 1. Small scale peeler for fruits

There are three grades of syrup: a light syrup contains 200g sugar per litre, a medium syrup 400-600 g/l and a heavy syrup 800g/l. The concentration of salt in brine is usually 15 g/l. Acidic fruits require relatively mild heating conditions for pasteurisation (e.g. 90-100°C for 10-20 minutes) to destroy yeasts and moulds, whereas less acidic vegetables require more severe heat sterilisation to destroy food poisoning bacteria (e.g. 121°C for 15-40 minutes, depending on the size of the container). Fruits can also be part-processed and stored until required in sugar syrup or sodium metabisulphite solution (equivalent to 1000 ppm.) to allow production to take place for a larger part of the year.

It is not advisable for inexperienced small scale processors to bottle vegetables unless they are acidified, because of the risk of poisoning from inadequately processed foods. Vegetables can however be processed by pasteurisation if the acidity is first adjusted using citric acid or vinegar. Canning is not suitable for small scale processing for the following reasons: the time and temperature of canning are critically important and must be carefully controlled. If the cans are under-processed, there is a risk of serious food poisoning and even death from a type of micro-organism named *Clostridium botulinum*. If cans are over-processed, the vegetables lose much of their texture, colour, vitamins and flavour and are not saleable. The establishment of correct heating conditions depends on the type of food, the size and shape of the can and the initial level of contamination of the vegetables. This requires the skills of a qualified food technologist or microbiologist.

When foods are heated in sealed cans during the canning process, the temperature of sterilisation is above 100°C and the pressure outside the can must equal that inside, to prevent the cans from exploding. This is achieved using high pressure steam and a strong vessel named a 'retort'. Both steam boiler and retort are expensive and likely to be beyond the means of a small scale processor. Additionally, compressed air is needed to maintain the pressure while cans are being cooled, which together with the necessary controllers, adds to the capital cost of equipment.

Even if cans are available in a particular country, they are usually more expensive than other forms of packaging. Different types of product also require a particular internal lacquer to prevent the metal from corroding when it is in contact with the fruits or vegetables and such lacquers may not always be available. In addition a 'seamer' is needed to seal the lid onto the can and regular checks and maintenance are necessary to ensure that the seam is properly formed. Failures in seams are one of the main causes of spoiled or dangerous canned foods.

It is therefore necessary to ensure that seamer operators are fully trained and experienced in adjusting the machines and a 'seam micrometer' is another necessary capital expense to be able to do this. In summary therefore, canning requires a considerable capital investment, trained and experienced staff, regular maintenance of relatively sophisticated equipment, a regular supply of the correct types of cans and a comparatively high operating expenditure. Because of the more acidic nature of fruits, a lower processing temperature is adequate and this process is suitable for small scale operations. In all cases, a food technologist should be consulted to advise on process times and conditions for bottled products.

Dried Fruits and Vegetables

Drying removes most of the water from fruits and vegetables to extend their shelf life and to increase their convenience and value. The reduction in weight and bulk also makes transport cheaper and easier although many dried foods are fragile and require packing in boxes to prevent them from being crushed. Different categories of dried foods can be described as *high-volume, lower-value* crops such as staple cereals and *low-volume, higher-value* foods such as dried fruits, vegetables herbs and spices. This second category offers better opportunities for profitable production by small scale processors.

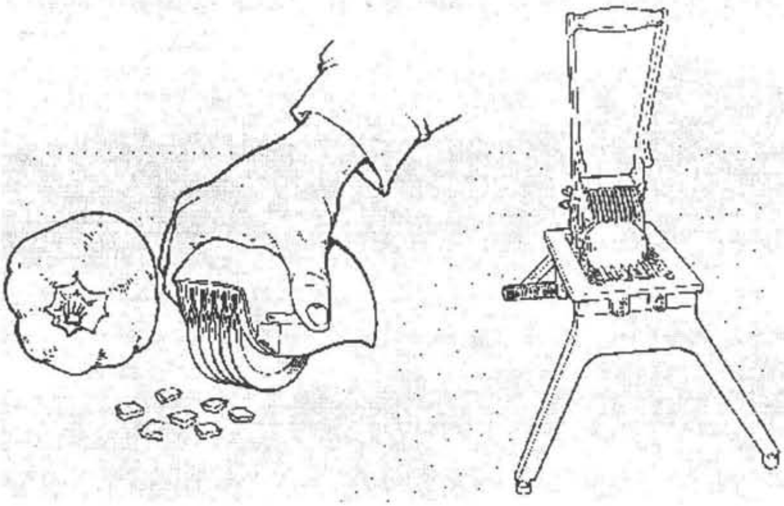

Figure 2. Examples of fruit cutters suitable for small scale production

Air dried products are the most common type of dried fruit and vegetables and other more expensive methods, such as freeze drying, are not considered in this book. Some products may be blanched or sulphured/sulphited to protect their natural colour and help preserve them. Crystallised fruits, peels for marmalade and cake production and osmotically dried fruits (known as 'osmasol' products when dried in a solar dryer) are fruit pieces that are soaked in hot concentrated sugar syrups to extract some of the water before air drying.

Some vegetables and a few fruits such as limes may also be salted before drying. In this case the high salt concentration preserves the food by both drawing out water by osmosis and by the anti-microbial properties of the salt. Salt tolerant micro-organisms begin to grow while the product is sun dried and these produce acids and characteristic flavours, High salt concentrations also prevent the action of some enzymes, which would cause a loss in quality of the dried food during storage. Vegetables must be washed to lower the salt concentration before they are eaten.

Fruits and vegetables must be carefully selected before drying. If fruits in particular are over-ripe they are easily damaged and may be difficult to dry. If they are under-ripe, they have a poorer flavour, colour and appearance. Care and attention to hygiene are essential because any bacteria or moulds that contaminate vegetables before drying are likely to survive on the dried food. The temperature of drying is not high enough to kill them and when the food is re-hydrated, they can grow again and cause food poisoning.

Blanching

Blanching destroys enzymes and prevents changes in colour, flavour and texture during storage. However, by itself, it does not preserve the food and vegetables must therefore be further processed by drying to achieve a long shelf life. Vegetables are blanched by heating in hot water or steam for a short time and then cooled on trays. For production at a small scale, vegetables can be placed in a wire basket and immersed in boiling water.

In steam blanching, vegetables are placed in a strainer and this is then fitted over a pan of boiling water and covered with a lid to prevent the steam escaping. Steaming takes a few minutes longer than water blanching, but has the advantage of retaining more nutrients as they are not lost into the water.

There are optional chemical treatments that help to retain the colour and texture of some dried fruits and vegetables. For example, the bright green colour of leafy vegetables, peas etc. can be retained by adding sodium bicarbonate to blancher water and the texture of some vegetables, such as okra and green beans, can be maintained by blanching in a calcium chloride solution. Both chemicals are usually available from pharmacies in major towns.

Sulphuring and sulphiting

For most fruits, 350-400g sulphur are used per 100 kg fruit, burning for 1-3 hours. Sulphur dioxide prevents browning in foods such as apple, apricot and coconut, although it should not be used with red fruits as it bleaches the colour. Sulphuring (using sulphur dioxide gas) is achieved by exposing pieces of cut or shredded fruits to burning sulphur in a sulphuring cabinet. The amount of sulphur used and the time of exposure depend on the type of fruit, its moisture content and limits placed by law in some countries on the residual amounts of sulphur dioxide in the final product or by commercial limits set by importers. This should be checked with a local Bureau of Standards. There is an increasing consumer resistance to sulphited fruits in some industrialised countries and if the product is considered for export the local Export Development Board or import agents should be consulted.

In sulphiting, the sulphur dioxide is dissolved in water, rather than as the gas used metabisulphite are made into solutions, either by adding one of them to the blanching water or more often, by soaking the food for 5-10 minutes in a sulphite dip. About two thirds of the weight of sodium metabisulphite is formed as sulphur dioxide when it is dissolved in water. For example, to form a 0.001% solution which is equivalent to 1000 ppm, 1.5g is dissolved in a litre of water to form 1g of sulphur dioxide per litre. At this concentration, sulphiting can also be used as a method of intermediate storage of fruits to spread production over several months throughout the year.

Syrup pre-treatment

This method can be used to remove up to half of the water in fruit and is therefore a cheap way of increasing the production rate of a dryer or for part-processing fruits for intermediate storage so that production can be extended throughout the year. In general the method gives good retention of colour in the dried food and produces a sweeter, blander tasting product. However, acids are also removed from fruits during the process and the lower acidity of the product may allow mould growth if the food is not properly dried and packaged.

Table 3. Blanching times for different vegetables

Food	*Blanching time (minutes) using:*	
	Steam	*Water*
Leafy vegetables,	2 - 2.5	1.5
Sliced beans	2 - 2.5	1.5 - 2
Squashes	2.5	1.5 - 2
Cabbage	2.5	5-2
Peas	3	2
Carrots	3 - 3.5	3.5
Cauliflower	4 - 5	3 - 4
Potatoes	6 - 8	5 - 6

In a more complex method, fruit is first boiled in 20% syrup and then soaked overnight. The fruit is then strained from the syrup and transferred each day to 40% and 60% syrups in turn, with optional boiling for 10 minutes at each transfer. After soaking, the syrup is diluted to approximately half of the original concentration. Each day the most dilute syrup (10%) is used for other products and a new 60% syrup is made up. The advantages of this method include reuse of sugar syrups and a softer texture in the final product.

Types of dryers

The higher value of dried fruit and vegetable products, compared for example to cereals crops, may justify the higher capital investment in a fuel-fired dryer or electric dryer and crops, may justify the higher capital investment in a fuel-fired dryer or electric dryer and the extra operating costs for the fuel or electricity. These types of dryer allow higher drying rates and greater control over drying conditions than do solar or sun drying and they can therefore result in a higher product quality. However it is necessary to make a careful assessment of the expected increase in income from better quality products compared to the additional expense, to make sure that this type of dryer is cost-effective.

Sun drying is only possible in areas where, in an average year, the weather allows foods to be fully dried immediately after harvest. The main advantages of sun drying are the low capital and operating costs and the fact that little expertise is required. The main problems with this method are as follows:

- contamination, theft or damage by birds, rats or insects
- slow or intermittent drying and no protection from rain or dew that wets the product, encourages mould growth and may result in a relatively high final moisture content
- low and variable quality of products due to over- or under-drying
- large areas of land needed for the shallow layers of food
- laborious because the crop must be turned, moved if it rains and animals must be kept away
- direct exposure to sunlight reduces the quality (colour and vitamin content) of some fruits and green vegetables.

The quality of sun dried foods can be improved by reducing the size of pieces to get faster drying and by drying on raised platforms, covered with cloth or netting to protect against animals and insects.

Solar drying has been studied in detail by scientists in many countries for many years, but it is not yet widely used commercially. The main applications to date are in Bangladesh for desiccated coconut, in Guatemala for herbal teas and in Uganda for dried fruits for export.

Packaging

If the climate is dry, it may not be necessary to package dried foods as they will not pick up moisture from the air. However a humid climate is likely to result in dried foods gaining moisture and going mouldy. The stability of dried foods depends not only on the humidity of the air at which a food neither gains nor loses weight, but also on the type of food. Different foods can be grouped according to their ability to absorb moisture from the air. The two groups are *hygroscopic,* which absorb moisture easily and *non-*

salt is very hygroscopic and pepper is non-hygroscopic, but similar examples exist for fruit and vegetable products. This difference determines the packaging requirement for different fruit and vegetable products. The moisture content at which a food is stable is known as the *Equilibrium Moisture Content* and examples of this for different fruits and vegetables are shown in Table 4, together with the packaging requirement for different groups of foods.

Table 4. Moisture contents at which selected foods are stable and packaging requirements for each group

Food	*Moisture content (%)*	*Degree of protection required*
Fresh fruit and vegetables	75-85	Package to prevent moisture loss
Marmalade	35	Non-hygroscopic: - Minimum protection or no packaging required
Raisins	7	
Fruit sweets	3	Hygroscopic: - Package to prevent moisture uptake
Potato crisps	1.5	

Dried fruits and vegetables are usually packaged in one of the many different types of plastic film. The selection of the correct type of packaging material depends on a complex mix of considerations which include:

- the temperature and humidity of the air in which the product is stored
- the capacity of the product to pick up moisture from the air
- reactions within the product caused by air or sunlight during storage
- the expected shelf life
- marketing considerations
- cost and availability of different packaging materials.

In general, although thin polythene film is usually the cheapest and most widely available material, it is only suitable for storing dried fruits and vegetables for a short time before they pick up moisture, soften and go mouldy. Polypropylene has better barrier properties and therefore gives a longer shelf life, but it is usually more expensive and it may not be available in many countries. Other more complex films, such as laminated films made from polythene and aluminium foil, offer much better protection to dried foods, but are considerably more expensive and more difficult to find in developing countries.

Most dried foods also need a sturdy box or carton to both prevent crushing and to exclude light which causes loss of colour and development of off-flavours during storage. The properties of different packaging materials for dried foods are shown in Table 5.

The properties of different packaging materials for dried foods are shown in Table 5.

From the table, it can be seen that some types of packages provide good protection against air and moisture pickup for example, whereas other protect against light, crushing, etc. It is therefore common for dried foods to be packed in airtight and moisture-proof bags, which are then placed in an outer container to protect against light, crushing, etc.

Table 5. Properties of packaging materials for dried fruits and vegetables

Type of Packaging	*Protection provided against:*							
	Moisture	*Light*	*Air & odours*	*Heat*	*Micro-organisms*	*Dust*	*Crushing*	*Animals & insects*
Clear glass	3	1	3	2	3	3	3	3
Coloured glass	3	2	3	2	3	3	3	3
Ceramic pot	1	3	3	3	3	3	3	3
Metal tin	3	3	3	1	3	3	3	3
Metal foil	2	3	2	1	2	3	1	1
Plastic pot	3	3	3	2	3	3	2	2
Wooden chest	2	3	1	3	1	3	3	2
Paper board box	1	3	1	3	1	3	2	1
Fibreboard drum	1	3	1	3	2	3	3	2
Paper bag	1	2	1	1	1	2	1	1
Polythene film	2	1	1	1	2	3	1	1
Cellulose film	3	1	3	1	2	3	1	1
Polypropylene film	3	1	3	1	2	3	1	1
Cotton or Jute sack	1	2	1	1	1	2	1	1

CHUTNEYS, PICKLES AND SALTED VEGETABLES

Chutneys

Chutneys are thick, jam-like mixtures made from a variety of fruits and vegetables, sugar, spices and sometimes vinegar. Any edible sour fruit can be used as a base for a chutney, to complement the sweet taste from the sugar. The high sugar content has a preservative effect and vinegar addition is not always necessary, depending on the natural acidity and maturity of the fruits that are used. Most products are boiled, which not only produces a caramelised syrup and alters the taste, colour and thickness, but also pasteurises the product and thus adds to the preservative action of the sugar and acids. Other products are allowed to ferment naturally and the acids produced by a mixture of bacteria preserve the product. Depending on the types of spices that are added, these may also have a preservative effect, in addition to their contribution to flavour. Fruits

Natural acids from the fruit, from vinegar or those produced by fermentation, together with the high sugar content, are used to preserve the chutney after a jar has been opened. A correct balance between the levels of sugar and acid is required to prevent mould growth and a *Preservation Index* can be used to calculate the amounts of ingredients to be added. Alternatively, when sugar is the main ingredient or the product is boiled, a refractometer can be used to check that the final sugar content of the syrup is 68-70%. Sugar is added before heating if a dark product is required or towards the end of boiling to produce a light coloured product.

The Preservation Index is a measure of the preserving power of combinations of acid and sugar (sugar is measured as 'total solids'). This is used to assess whether a chutney or pickle is safe from food spoilage and food poisoning micro-organisms. The value can be calculated as follows:

$$\frac{\text{Total acidity} \times 100}{(100 - \text{total solids})} = \text{not less than } 3.6\%$$

However, if a manufacturer has no access to basic laboratory equipment or is not sure how to carry out the calculation, it is best to take a sample of product to a Bureau of Standards, University Food Science Department or food testing laboratory which can analyse it and recommend adjustments to the recipe if necessary.

Pickles

Vegetables such as cucumber, cabbage, olive and onion are fermented by lactic acid bacteria which can grow in low concentrations of salt. The bacteria ferment sugars in the food to form lactic acid, which then prevents the growth of food poisoning bacteria and moulds or other spoilage micro-organisms. The amount of added salt controls the type and rate of the fermentation. If for example 2-5% salt is used, a natural sequence of different types of bacteria produce the lactic acid. If higher concentrations of salt (up to 16%) are used, a different product called 'salt stock' pickle is produced, which is preserved by the salt and not by fermentation. Fruits and vegetables can be preserved in this way as a method of intermediate storage to spread production over several months throughout the year.

Sometimes, sugar is added to increase the rate of fermentation or to make the product sweeter. Alternatively, vegetables may be packed in vinegar (acetic acid), salt and sometimes sugar to produce a variety of pickled products. Because these vegetables are not fermented they have a different flavour and texture. They are usually pasteurised. Sweet pickles are made from single fruits or mixtures of fruits and vegetables. They are preserved by the combined action of lactic or acetic acid, sugar and in some cases added spices.

Sweet pickles are made from single fruits or mixtures of fruits and vegetables. They are preserved by the combined action of lactic or acetic acid, sugar and in some cases added spices.

Salted vegetables

Salted vegetables are made by building up alternate layers of chopped or shredded vegetable such as cabbage, with layers of salt in a sealed drum. The salt has two preservative actions: it draws out water from the vegetables by osmosis to form a concentrated brine in the base of the drum; and salt also has a direct anti-microbial action. The high levels of salt are reduced by washing the products before they are eaten.

Pickles which have an adequate Preservation Index do not need to be pasteurised. However as an additional measure to prevent spoilage, they can be pasteurised or the sugar/salt/vinegar mixture can be heated, added to the vegetables and the jars filled while product is still hot. In this way the hot product forms a partial vacuum in the jar when it cools and further aids preservation.

Glass jars are the most commonly used packaging material, but if a shorter shelf life is expected, pickles may also be packed in small quantities in polythene pouches and sealed with an electric heat sealer. To avoid seepage of product, which can damage paper labels and make the package unattractive, a double pouch can be used comprising an inner pack that contains the product and an outer pouch with a label between the two.

Pectin and Papain

Pectin is a component of nearly all fruits and vegetables and can be extracted and used in food processing to form the characteristic gel in jams and marmalade. The richest sources of pectin are the peels of citrus fruits such as lime, lemon, orange and passion fruit or the pulp of apple. Commercially, pectin is available as either a light brown powder or as a dark liquid concentrate. It is stable if stored in cool, dry place and it will lose only about 2% of its gelling power per year. There are two main types of pectin:

1) high methoxyl (HM) pectins that form gels in high solds jams (above 55% solids) in a pH range of 2.0-3.5; and

2) low methoxyl (LM) pectins, which do not need sugar or acid to form a gel, but instead use calcium salts.

These form a gel with a wide range of solids (10-80%) within broader pH range of 2.5-6.5. They are used mainly for spreads or for gelling agents in milk products. However, there are a large number of different types of pectin within each group, such as 'rapid set' and 'slow set' pectins, that are made for different applications and it is necessary to specify carefully the type required when ordering from a supplier. It is difficult to of crude pectin in their products by extracting it with water without using solvents. This is useful if the producer is making jam from fruits such as melon that are naturally low in pectin. When using pectin to make set preserves, such as jams, jellies etc., it is important that the pH is within the range of 3.0-3.5 and that they are boiled to at least 68% solids content. Powdered pectin is added to fruit pulp at 3-6g per kg of final product, but it should first be mixed with about five times its weight of sugar to prevent lumps forming when it is added to the pulp or juice.

Papain

Papain is an enzyme that is found in the skin of unripe papaya fruits. It breaks down proteins and finds widespread applications in industrialised countries for meat tenderising and in brewing. Advances in biotechnology during the last twenty years resulted in a synthetic papain that was cheaper than the natural enzyme and as a result there was a decline in the market for natural papain. However, in recent years, there has again been increasing interest in the natural product and it can now achieve a higher value than before.

For profitable production, it is usually necessary to plant papaya trees in orchards, rather than collecting it from widely scattered trees which increases collection costs. Crude (unrefined) papain is normally produced because the refining technology is too expensive for most small-scale entrepreneurs. The process of papain extraction involves making shallow cuts in the skin of unripe fruits while they are still on the tree. The skin then oozes a white, sticky liquid which is collected by scraping the fruit each day for several weeks. This 'latex' is then spread out in shallow trays and sun-dried until it becomes brittle. The crude papain is packaged and exported to refiners. Because papain is an enzyme that attacks proteins, the crude latex should be handled with gloves to avoid damage to the operator's skin.

SAUCES

Sauces are thick viscous liquids, made from pulped fruit and/or vegetables with the addition of salt, sugar, spices and vinegar. They are pasteurised to give the required shelf life, but the basic principle of preservation is the use of vinegar, which inhibits the growth of spoilage and food poisoning micro-organisms. Other ingredients such as salt and sugar contribute to the preservative effect and the correct Preservation Index ensures that the product does not spoil after opening and can be used a little at a time. Some may contain a preservative such as sodium benzoate, but this is not necessary if an adequate Preservation Index is achieved. Sauces can be made from almost any combination of fruit or vegetables, but in practice the market in many countries is dominated by tomato sauce, chilli sauce and to a lesser extent, mixed fruit sauces such as 'Worcester' sauce, which contains apples and dates in addition to tomatoes. Depending on the scale of production, Preservation Index is achieved. Sauces can be made from almost any combination of fruit or vegetables, but in practice the market in many countries is dominated by tomato sauce, chilli sauce and to a lesser extent, mixed fruit sauces such as 'Worcester' sauce, which contains apples and dates in addition to tomatoes. Depending on the scale of production, pulping and sieving out seeds and skins can be done by hand or using special pulper-finisher machines. Similarly, at a small scale, sauces can be made using simple open boiling pans, provided that care is taken to heat slowly with constant stirring to avoid localised burning of the product, especially at the end of heating. At a larger scale, processing is done using steam heated, stainless steel 'double jacketed' pans.

JUICES

The beverage market is divided into products that are intended to quench thirst, such as juices, nectars and carbonated drinks and those that are drunk on special occasions, such as wines and spirits, where religion or custom permit. Competition from large scale manufacturers is among the fiercest in beverage manufacture and considerable amounts of money are spent on advertising, packaging and sophisticated distribution systems in this sub-sector. Thus beverage manufacture is one of the most difficult for small scale producers to become established and successful. However there is a growing trend in urban centres of some developing countries towards increased juice consumption and this market may become larger in future years.

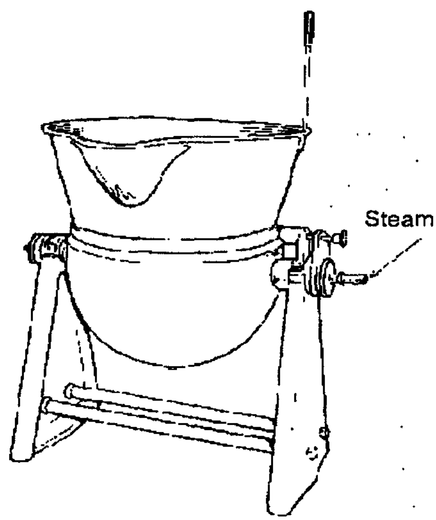

Figure 3. 'Double jacketed' pan for larger scale boiling

Drinks can be divided into those that are drunk immediately after opening and those that are diluted before use. The first group should not contain any preservative but the second group may need a preservative such as sodium benzoate to have a long shelf life after opening. Unopened bottles of both types should have a shelf life of 3-9 months, depending on the storage conditions. Fruit juices should be pure juice, with nothing added, except in products such as some types of melon juice, in which the level of acidity needs to be increased by addition of citric acid to give a pH below approximately 3.5-4.0. Preservation is due to pasteurisation and the natural acidity of the juice. A wide range of drinks can be made from pulped fruit or juice and production can be spread over a larger part of the year by processing a sequence of fruits or by part-processing pulps and storing them in 1000-2000 ppm. sodium metabisulphite solution.

Pulping

Soft fruits such as berries, passion fruit and papaya can be pulped by hand, whereas harder and more fibrous fruits such as pineapple and mango require mechanised pulping. Manually operated pulpers are available for places where there is no electricity and there are also a wide range of powered pulpers and blenders. At higher production rates, pulper-finishers brush fruit through a sieve and separate seeds, skins etc. from the pulp. Juice can also be extracted from fruit using a fruit press or fruit mill or by steaming the fruit. Citrus fruit juices are extracted by reaming the fruit and again comparatively simple equipment is available for this purpose.

Pasteurisation

Drinks need to be pasteurised if they are to have a shelf life of more than a few days. The time and temperature required for pasteurisation depends on the type of product and the bottle size, but is typically 10-20 minutes at 80-90°C. They can either be pasteurised and then hot filled into pre-sterilised bottles, or cold filled and then pasteurised in sealed bottles using a large pan of simmering water with the water level around the shoulder of the bottle. Because the pasteurisation temperature does not exceed 100°C, there is little risk of the bottles bursting. However, as with all glass containers, the temperature difference between the glass and the product or hot water should not exceed 20°C. A water cooler can be constructed to speed up the rate of cooling of filled containers. Hot bottles and cool water pass in a counter-current way through a trough to minimise 'heat shock' to the containers. In order to prevent contamination by dust, insects etc., all bottles must be cleaned properly using hand-held bottle brushes or mechanised brush cleaners. If bottles are re-used, they must be thoroughly washed with detergent to remove any residual material that may have been stored in the bottle and then sterilised by heating to boiling in a water-bath for at least 10 minutes.

Filling

Hand filling from a jug is often too slow for the required throughput and fillers can be constructed by fitting one or more taps to the base of a stainless steel or food grade plastic bucket. More sophisticated fillers measure and control the volume of liquid filled into each bottle. Waxed cartons have become popular because of their lower cost compared to bottles, together with savings in time and money for collection and washing of re-useable bottles. However, the cost of equipment to form and seal the cartons is too high for most small scale producers and cheaper alternatives including plastic pots with sealed foil lids are becoming more popular in some countries.

SQUASHES, CORDIALS AND SYRUPS

Squashes and Cordials

These are drinks that are diluted to taste with water and are thus used a little at a time. The container must therefore be re-closeable and these products may contain a preservative, usually sodium benzoate, to prevent spoilage after opening. Squashes are made from at least 30% fruit juice mixed with sugar syrup. Cordials are simply crystal-clear squashes. Although food dyes are used by some processors, these are not necessary for most products. Regulations on the composition of squashes are in force in some countries.

Syrups

Syrups are filtered juices that are concentrated by boiling until the sugar content reaches 50-70%. The heat and high solids content preserves the syrup and it is used in place of sugar or honey. Syrups can be made from a wide range of fruits, but the most common type is made from grapes.

PRESERVES

Jams, Jellies and Marmalades

Jam is a solid gel made from fruit pulp or juice from a single fruit or from a combination of fruits. The composition is controlled by law in some countries. In mixed fruit jams, the first named fruit should be at least 50% of the total fruit content. The sugar content is normally 68-72%, which will prevent mould growth after opening the jar. Jellies are crystal-clear jams that are produced using filtered juice instead of fruit pulp. Marmalades are produced mainly from clear citrus juices and have fine shreds of peel suspended in the gel. Ginger may also be used alone or in combination with the citrus fruits. The fruit content should not be less than 20% citrus fruit and the sugar content is similar to jam. The correct combination of acid, sugar and pectin is needed to achieve the required gel structure and rapid boiling is necessary to remove water quickly, to concentrate the mixture before it darkens and loses its ability to form a gel.

Pastes and Purees

In principle, pastes and purees can be made from any fruit or vegetable. The most common types are tomato and garlic, which are widely used in cooking. These products can be made at a small scale by carefully evaporating water to concentrate the pulp, with constant stirring to prevent darkening or localised burning. The concentration of solids in the paste is normally around 36%. The high solids content and natural acidity are sufficient to preserve the product for several days but pasteurisation in bottles or cans is needed for a longer shelf life. In some preparations, sugar, salt and vinegar are added to assist in preservation.

Fruit Cheeses

Fruit cheeses are fruit pulps that are boiled until they have a final sugar content of 75-85%. They set as a solid block without the need for added pectin, but they do not have the same gel structure as jams and marmalades. They can be cut into bars or cubes to eat directly or they can be used in small pieces in confectionery or baked goods.

Batch Preparation

A simple way of calculating the amounts of sugar and juice that should be mixed together for squashes and jams is to use the *Pearson Square*. If for example, a squash having 15% sugar is required, made from orange juice having a 10% sugar content, mixed with 60% sugar syrup, the Pearson Square can be used as follows: draw a square, writing the juice and syrup concentrations on the left side and the product concentration in the middle. Subtract the smaller amount from the larger amount diagonally to find the quantities that should be mixed together. Similar Pearson Squares can be drawn to find the amounts that should be used when any two components are mixed together.

Boiling

Boiling is done using a stainless steel pan. If other materials are used there is the risk that fruit acids will react with the pan and cause off flavours to develop. At higher production rates, a steam jacketed pan is preferable as it gives more even and faster heating. If whole fruit is used, there are two heating stages in jam manufacture: initially fruit is heated slowly to soften the flesh and to extract pectin; then the mixture is boiled rapidly until the sugar content reaches 68-72%. This change in heat output requires a sufficiently large and easily controllable heat source. There are three ways to test for the correct point to stop boiling: using a hand-held refractometer reading 68-70% sugar, a sugar thermometer reading 104-105°C or by placing a drop of the product in cold water to see if it sets.

An alternative method to concentration by boiling, when making products such as tomato paste, is to hang the pulp in a sterilised cotton sack for an hour. During this time the thin watery juice leaks out and the pulp loses half its weight. Then 2.5% salt is mixed into the concentrate and it is re-hung for a further hour, during which time the weight falls to one third of the original. The product can then be packaged and pasteurised or further concentrated. This method is reported to produce a product which has a natural flavour using considerably less fuel than concentration by boiling. Preserves should be hot filled into new or re-used glass jars, which are then sealed with a new lid. In some countries, plastic containers have been introduced but they are not easy to hot fill (they melt) and the seals are often inadequate, causing product leakage and insect infestation problems as well as a shorter shelf life. The temperature of filling should be around 85°C. If it is too high, steam condenses on the inside of the lid and water falls onto the surface of the preserve. This dilutes the sugar at the surface and results in mould growth. If the temperature is too low, the preserve thickens and is difficult to fill into containers. Filling can be done using jugs and funnels, but for higher production rates, small hand-operated or semi-automatic piston fillers are available. In all cases the jars should be filled to approximately 9/10ths full, to assist in the formation of a partial vacuum in the space above the product as it cools. This can be checked using a 'headspace gauge'. The jars are kept upright until the gel has formed during cooling.

WINES, VINEGARS AND SPIRITS

Wines are produced by fermentation in which the sugars in the fruit juice/pulp plus added sugar are converted into alcohol and carbon dioxide by varieties of the yeast *Saccharomyces cerevisiae*, named 'wine yeasts'. Producers need to select one variety that works well in their process and then continue to use it to produce a consistent product. Wines are preserved by the raised levels of alcohol and their natural acidity. Almost any fruit can be used to make wine, but the most popular in many developing countries are pineapple, papaya, grape, passionfruit, banana, melon and strawberry. Typically, the alcohol content of wine is 6-12% and in 'fortified' wines, such as sherry, ginger wine etc., it is usually 15-20%. The main problems are concerned with adequately cleaned fermentation vessels, to prevent contamination by other micro-organisms that spoil the wine and adequate sedimentation or filtration to produce a crystal-clear product. A special licence to sell alcohol is needed in most countries.

Vinegar is produced by a second fermentation in which *acetic acid bacteria (Acetobacter species)* convert the alcohol in wine to produce acetic acid. Whereas in wine production, air is excluded from the vessel by an air lock, in this second fermentation it is important for the bacteria to be in contact with air as much as possible. This is done traditionally by allowing the wine to trickle over a stack of wood shavings or twigs that are held in an open framework, named a 'generator' which allows free circulation of air. The wood acid, which preserves the product for many months/years provided that it is sealed in an airtight container to prevent the acetic acid from evaporating. More modem vinegar fermenters pump air into the wine and are sufficiently expensive to be beyond the reach of most small scale producers.

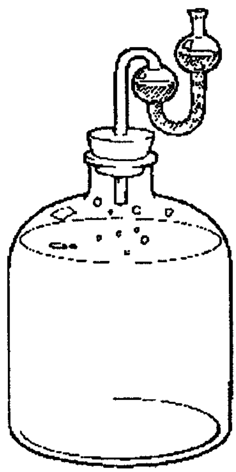

Figure 4. An Air Lock Used in Wine Making

Alcohol has a lower boiling point than water and distillation is used to concentrate the alcohol in spirit drinks. Distillation is carried out in a still which is a clean drum, fitted with a safety valve and a pipe to carry away the vapour. Wine or other alcoholic liquor is placed inside the drum and heated. The alcohol vapour is passed through cooled air or cool water and the distillate condenses and is collected. Note: distillation is illegal in many countries without a government licence.

There are a large number of traditional methods for distillation. One such method in East Africa involves filling fruit wine or beer into an oil drum and placing it at a shallow horizontal angle over a fire. A hollow bamboo pipe, approximately 10 cm in diameter, is fitted to the opening of the drum and sealed with a pulp made from the inner layers of a banana trunk. Five hollow bamboo pipes, approximately 2 cm in diameter, are fitted vertically down from the larger pipe and sealed in a similar way. Each pipe leads to a baked clay pot of approximately 20 litres capacity, submerged in a pit of slow-running water, diverted from a stream. The pots are held below the surface of the water by wood branches that are bent over them and fixed into the soil at each end. Distillation is controlled by sampling each pot at intervals to determine its alcohol strength and adjusting the rate of heating by adding or removing firewood. As the strength declines with continued distillation, the end point is determined by the desired end. Distillation is controlled by sampling each pot at intervals to determine its alcohol strength and adjusting the rate of heating by adding or removing firewood. As the strength declines with continued distillation, the end point is determined by the desired alcohol strength in the product, usually 35-40%. Distillation is continued for 3-4 hours and 40 litres of spirit are filled from the pots into clean bottles and sealed with a stopper made from banana or papyrus leaves. The spirit is preserved by the high alcohol content and has a shelf life of several years.

Modem stills are made entirely of copper or stainless steel and larger ones are fitted with thermostatically controlled heaters. These are too expensive for most small scale producers, but small copper stills for making essential oils have been used for making small amounts of alcohol. Sugar may be added to fruit juice to raise the level to about 20° Brix and after inoculation with about 3% yeast, it is held in a fermentation vessel, made from food grade plastic or glass, for about ten days. It is important to keep the vessel closed to prevent bacteria and mould from infecting the batch. After ten days the fermenting wine is 'racked' (filtered) by passing it through a muslin or nylon straining cloth into narrow necked fermentation vessels, plugged with cotton wool or fitted with a air lock. The fermentation is then continued for between three weeks to three months, depending on the temperature and the strain of yeast being used. The end of the fermentation is seen when there are no more bubbles rising to the surface.

It is then siphoned into clean containers and allowed to clear and mature before it is siphoned into bottles and sealed with sterilised cork stoppers or roll on pilfer-proof (ROPP) screw caps. Some fruit wines, such as pineapple, are difficult to clear because of natural gums in the fruit. These can be removed by heating the juice and allowing the gums to precipitate out before the juice is fermented. This can be a particular problem when waste fruit from other processes (e.g. drying or bottling) is used for wine making. Great care should be taken to ensure that only the fermented liquor is used for distillation. Any suspect liquor or other materials should not be distilled because of the risk that they may contain methanol. This is a type of alcohol which if consumed causes blindness and in sufficient amounts, death.

PROCESSING FACILITIES

All fruit and vegetable processing operations require an hygienically designed and easily cleaned building to prevent products from becoming contaminated during processing. The two main sources of contamination are 1) insects and animals and 2) micro-organisms. Insects and animals are attracted to food buildings if foods or wastes are left lying round after production has finished. Micro-organisms can grow in food residues that are left on equipment, tables or floors which have not been properly cleaned. Micro-organisms require water to grow and wet processing therefore has an inherently greater risk of contamination than dry processing does. However, some types of micro-organism can form inert spores that are able to survive under dry conditions and then grow when they come into contact with water or foods and strict hygiene should also be enforced in drying operations. In dry processing there is an additional risk of contamination by dust, which can spoil foods itself and also harbour micro-organisms. The following aspects of setting up a processing facility should therefore be addressed by entrepreneurs, whether they are constructing a new facility or converting an existing building.

The Site

The location of a food building is very important and the following aspects need to be considered when choosing a site:

- location in relation to raw material supplies and likely markets
- ease of access for staff (public transport, distance down an access road)
- quality of road access (all year, dry season only, potholes that may cause damage to products, especially when glass containers are used)
- nearby swamp land that would be a source of smells and insects
- any potential contamination of water supplies upstream of the processing site
- available land for waste disposal away from the building
- electricity supplies
- cleared land to reduce problems caused by insects and birds (preferably planted with short grass, which acts as a dust trap for airborne dust).

Design and Construction of the Building

In general, a building should have enough space for all production processes to take place without congestion and for storage of raw materials, packaging materials and finished products. However, the investment should be appropriate to the size and expected profitability of the enterprise to reduce start-up capital, the size of any loans taken out and depreciation and maintenance charges.

Roofs and ceilings

In tropical climates, overhanging roofs keep direct sunlight off the walls and out of the building. This is particularly important when processing involves heating, to make working conditions more comfortable. Fibre-cement tiles offer greater insulation against heat from the sun than galvanised iron sheets do. High level vents in roofs both allow heat and steam to escape and encourage a flow of fresh air through the processing room.

The vents must be screened with mesh to prevent insects, rodents and birds from entering the room. If heat is a serious problem, the entrepreneur could consider fitting electric fans or extractors, although this clearly increases capital and operating costs.

Rafters or roof beams within the processing and storage rooms are unacceptable. They allow dust to accumulate, which can fall off in lumps to cause gross contamination of products. Similarly, insects can fall from them into products. They also allow paths for rodents and birds, with consequent risks of contamination from hairs, feathers or excreta. It is therefore essential to have a paneled ceiling fitted to any processing or store-oom, with careful attention when fitting them to ensure that there are no holes in the paneling. Care should also be taken to prevent birds, rodents and flying insects gaining access to the processing room through gaps in the roof structure or where the roof joins the walls.

Walls

As a minimum requirement, all internal walls should be rendered or plastered with a good quality plaster to prevent dust forming in the processing room. An experienced plasterer should be used to ensure that no cracks or ledges remain in the surface finish, which could accumulate dirt and insects. The lower area of walls, to at least 1.08 metres (four feet) above the floor, is most likely to get dirty from washing equipment, from product splashing etc. and special attention should be paid to ensure that this area is easily cleaned. Higher areas of walls should be painted with a good quality emulsion. The lower parts of walls should be either painted with a waterproof gloss paint, preferably white, to allow them to be thoroughly cleaned, or ideally they should be tiled with glazed tiles. If tiling a process room is too expensive, it is possible to select particular areas such as behind sinks or machinery and only tile these parts. In some countries there is a legal requirement for specified internal finishes and this should be checked with the Ministry of Health or other appropriate authority.

Windows and doors

Window sills should be made to slope for two reasons: to prevent dust from accumulating and to prevent operators from leaving cloths or other items lying there, which in turn can attract insects. Windows allow staff to work in natural daylight, which is preferable to and cheaper than electric lighting. However, in tropical climates there is a natural inclination for workers to open windows to allow greater circulation of fresh air. This provides easy access for flying insects, which can readily contaminate the product. Windows should therefore be fitted with mosquito mesh to allow them to be left open.

Normally doors should be kept closed, but if they are used regularly there is again a tendency for them to be left open with similar consequences of animals and insects entering the plant. In this case, thin metal chains or strips of material that are hung vertically from the door lintel may deter insects and some animals, while allowing easy access for staff. Alternatively mesh door screens can be used. Doors should be fitted accurately so that there are no gaps beneath them and all storeroom doors should be kept closed to prevent insects and rodents from destroying stock or ingredients.

Floors

It is essential to ensure that the floors of processing rooms and storerooms are constructed of good quality concrete, smooth finished and without cracks. In some developing countries, it is possible to buy proprietary floor paints or vinyl based coatings, but these are usually very expensive. Generally, it is not adequate to use the red wax floor polishes that are commonly found in households, as these wear away easily and could contaminate either products or packages. Over time, spillages of acidic fruit products react with concrete and cause it to erode. Attention should therefore be paid to cleaning up spillages as they occur and to regularly monitor the condition of the floor.

The comers where the floor and the walls join are places for dirt to collect. During construction of the floor, it should therefore be curved up to meet the wall. It is possible to place fillets of concrete in the comers of an existing floor to fill up the right angle, but care is needed to ensure that new gaps are not created which would harbour dirt and insects. The floor should slope at an angle of approximately 1 in 8 to a central drainage channel. At the end of a day's production, the floor can be thoroughly washed and drained. Proper drainage prevents pools of stagnant water forming, which would in turn risk contamination of equipment and foods. The drainage channel should be fitted with an easily removed steel grating so that the drain can be cleaned. Where the drain exits the building, there is a potential entry point for rodents and crawling insects unless wire mesh is fitted over the drain opening. This too should be easily removed for cleaning.

Lighting and power

General room lighting should be minimised wherever possible. Full use should be made of natural daylight, which is both free and better quality light, especially for intricate work. Where additional lighting is needed, florescent tubes are cheaper to operate than incandescent bulbs. However, if machinery is used that has fast moving exposed parts, these should be lit with incandescent bulbs and not tubes. This is because even though the parts should have guards fitted, a rotating machine can appear to stand still if its speed matches the number of cycles of the mains electricity that powers fluorescent tubes - with obvious dangers to operators.

All electric power points should be placed at a sufficiently high level above the floor that there is no risk of water entering them during washing the floor or equipment. Ideally, waterproof sockets should be used. It is important to use each power point for one application and not use multiple sockets which risk overloading a circuit and causing a fire. If there are insufficient power points for the needs of a process, additional points should be installed, even though this is more expensive. All plugs should be fitted with fuses that are appropriate for the power rating of the equipment and ideally the mains supply should have an earth leakage trip switch. If three-phase power is needed for larger machines or for heavy loads from electric heating, it is important that the wiring is installed by a qualified electrician to balance the supply across the three phases.

Water supply and sanitation

Water is essential in nearly all fruit and vegetable processing, both as a component of products and for cleaning. An adequate supply of potable water should therefore be available from taps around the processing area. In many countries, the mains supply is unreliable or periodically contaminated and it is therefore necessary for the entrepreneur to make arrangements to secure a regular supply of good quality water each day. This can be done by installing two high level, covered storage tanks either in the roof-space or on pillars outside the building. They can be filled alternately when mains water is available and while one tank is being used, any sediment in water in the other tank is settling out. As sedimentation takes several hours, the capacity of each tank should be sufficient for one day's production. The tanks should have a sloping base and be fitted with drain valves above the slope and at the lowest point. In use, water is taken from the upper valve and when the tank is almost empty, the lower valve is opened to flush out any sediment that has accumulated.

Water that is included in a product should be carefully treated to remove all traces of sediment and if necessary, it should be sterilised. This is particularly important if the product is not heated after water has been mixed in as an ingredient.

There are four ways of treating water at a small scale: by filtration; by heating; by ultra-violet light and by chemical sterilants, such as hypochlorite. Other water treatment methods are generally too expensive at a small scale of operation. Filtration through domestic water filters is slow, but having made the capital expenditure, it is relatively cheap. Larger industrial filters are available in some countries. Heating water to boiling and holding it at that temperature for 10-15 minutes is simple and has low capital costs, but it is expensive because of fuel costs and it is time consuming to do routinely. Heating sterilises the water but does not remove sediment and boiled water may therefore require filtering or standing to remove sediment.

Finally, chemical sterilisation using hypochlorite is fast, relatively cheap and effective against a wide range of micro-organisms. Cleaning water should contain about 200 ppm of chorine and water that is used as an ingredient should contain about 0.5 ppm to avoid giving a chlorine flavour to the product. A chlorine concentration of 200 ppm can be made by adding 1 litre of bleach to 250 litres of water and a 0.5 ppm solution is obtained by adding 2.5 ml of bleach to 250 litres of water. Although chlorine kills most micro-organisms, it also has a number of disadvantages: it can corrode aluminium equipment; it can taint foods; bleach must be handled with great care as it damages the necessary, the concentration of chlorine in water can be measured using a chemical dye that produces a colour when it reacts with chlorine. The intensity of the colour is compared to standard colours on glass discs in a 'comparator'.

Good sanitation is essential to reduce the risk of product contamination and to deter insects, rodent and birds. All wastes should be placed in bins and not piled on the floor. Processes should have a management system in place to remove wastes from the building as they are produced, rather than letting them accumulate during the day. Wastes should never be left in a processing room overnight. Good sanitation is essential to reduce the risk of product contamination and to deter insects, rodent and birds. All wastes should be placed in bins and not piled on the floor. Processes should have a management system in place to remove wastes from the building as they are produced, rather than letting them accumulate during the day. Wastes should never be left in a processing room overnight.

Layout of equipment and facilities

Different stages in a process should be physically separated wherever possible. This helps prevent contamination of finished products by incoming, often dirty, raw materials and clearly identifies areas of the room where special attention to hygiene is necessary. This is particularly important to prevent contamination arising from activities such as bottle washing in which inevitable breakages produce glass splinters that could contaminate a product. This separation also reduces the likelihood of accidents or of operators bumping into each other.

Perishable raw materials should be stored separately from non-perishable ingredients and packaging materials. A separate office allows records to be filed and kept clean and provides a quieter working environment for book-keeping. Toilets should either be housed in a separate building or two doors should exist between them and a processing area. All workers should have access to hand-washing facilities with soap and clean towels. Laboratory facilities are generally not needed in fruit and vegetable processing, although a separate table for conducting quality assurance checks or check-weighing packages of finished product could be located in the office or in a separate area of the processing room.

clean towels. Laboratory facilities are generally not needed in fruit and vegetable processing, although a separate table for conducting quality assurance checks or check-weighing packages of finished product could be located in the office or in a separate area of the processing room.

Equipment

When selecting equipment, it should be the correct size for the intended scale of production. Managers should devise regular maintenance and cleaning schedules and ensure that they are followed. All types of fruit and vegetable processing require basic equipment to handle, weigh and prepare raw materials, such as buckets, tables, knives, and scales. Ideally, two sets of scales are used, one with an accuracy of +/- 0.1g to accurately weight small amounts and a second having an accuracy of +/- 50g for larger amounts of raw materials. However, scales are expensive to buy in most countries although the cost of small, electronic domestic scales is falling. A cheaper alternative to buying scales is to calibrate scoops or other measures, so that they contain the correct quantity of material when filled level with the top. In operation, scoops are faster than weighing, but the level of accuracy may be lower and careful training of operators is needed to ensure that the weights are consistent.

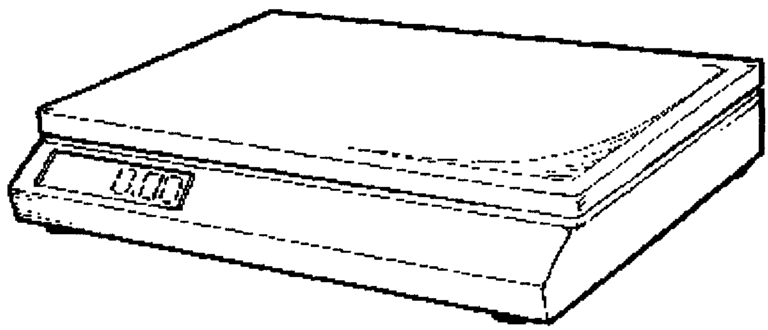

Figure 5. Small electronic weighing scales

Because of the acidic nature of fruits, the parts of equipment that are in contact with foods should be made from either food grade plastic, aluminium or stainless steel. Other metals, such as mild steel, brass and copper should not be used because they react with the fruit and cause off-flavours or colour changes in the product. In general, because of its high cost, stainless steel is only used for cutting blades, boiling pans etc.. Wooden tables are cheaper in most countries than metal ones, but they are more difficult to keep clean. Ideally, wood should be covered in a sheet of thick plastic, aluminium or a 'melamine' type surface for easier cleaning.

Alternatively they can be placed on wire mesh in a steam chamber. Fruits are often sulphured or sulphited to protect their colour. Sulphite dips are contained in a tank made from food grade plastic and sulphuring cabinets, comprising a wooden box, fitted with mesh trays, can easily be made from locally available materials.

At larger scales of operation, there are a range of machines that can be used for preparation of fruits and vegetables. These include cleaners, de-stoners, peelers, cutters and slicing or dicing equipment. Fruits for crystallising are soaked in syrup using food grade plastic tanks and aluminium pans for boiling the syrup. A series of tanks are used to gradually increase the concentration of syrup over 3-4 days, which also allows greater utilisation of sugar compared to single stage soaking. In most countries, sugar contains dust and other contaminants and syrups should therefore be filtered through muslin cloth before use.

The faster drying reduces the risk of spoilage, improves the quality of the product and gives a higher throughput, so reducing the drying area that is needed. However, care is needed when drying fruits to prevent too rapid drying which would result in case hardening and subsequent mould growth. Solar dryers also protect foods from dust, insects, birds and animals. They can be constructed from locally available materials at a relatively low capital cost and there are no fuel costs. They may therefore be useful

1) where fuel or electricity are expensive, erratic or unavailable,
2) where land for sun drying is in short supply or expensive,
3) where sunshine is plentiful but the air humidity is high, and
4) as a means of heating air for artificial dryers to reduce fuel costs.

This last application is likely to gain in importance as fuel prices increase or to reduce dependence on imported fuels. Solar drying is not likely to be useful where the quality of sun dried foods is acceptable to local consumers and where the additional costs of solar drying are not recovered from increased value of the food.

In situations where the control over drying conditions is insufficient using solar dryers, it is necessary to use a fuel-fired dryer. Again, there are a large number of different types and the selection depends on the required throughput, types of fuel and level of investment that are available. The main limitations of fuel-fired dryers, in addition to higher capital and operating costs, are that they are more complex to build and maintain and therefore require skilled labour for operation and maintenance.

One type of dryer that has found application in many developing countries is the cabinet dryer, which is successfully used for drying herbs, herbal teas and spices and is also suitable for fruits and vegetables. In general a drying area of $1m^2$ is needed for 2-6 kg of raw materials, depending on the type of food (6 kg of chopped fruits need $1m^2$ whereas a product like shredded cabbage is less dense and can only be stacked at around

One type of dryer that has found application in many developing countries is the cabinet dryer, which is successfully used for drying herbs, herbal teas and spices and is also suitable for fruits and vegetables. In general a drying area of $1m^2$ is needed for 2-6 kg of raw materials, depending on the type of food (6 kg of chopped fruits need $1m^2$ whereas a product like shredded cabbage is less dense and can only be stacked at around 2 kg/m). These figures allow calculation of the size of the dryer that is needed for a given weight of food to be dried per day.

Boiled, concentrated and pasteurised products

This range of products includes juices, squashes, sauces, pickles and chutneys. For liquid products, juice or pulp can be extracted from fruits or vegetables in a number of ways, depending on the hardness of the raw material. Soft fruits and vegetables, such as berries, tomatoes, grapes etc. can be processed by pressing, using a fruit press or using a juicer attachment to a food processor. Citrus fruits are usually reamed to extract the juice without the bitter pith or skin.

Passion fruit or tomato and harder fruits, such as apple, pineapple etc. are peeled and then pulped using a liquidiser, or at large scales of operation using a pulper-finisher, which separates skins and seeds. Steamers, such as those used for blanching, can also be used to 'dissolve' some types of cut soft fruits such as melon and pawpaw. When a clear juice is required it is necessary to filter it through a fine muslin cloth or stainless steel juice strainers.

The majority of products require heating to either pasteurise or concentrate them. In all cases a stainless steel boiling pan is needed. These are expensive to buy and in many countries local fabrication is difficult because the skills and facilities for welding stainless steel are not readily available. However, there are few alternatives and a producer should regard this expenditure as a necessary investment to be able to produce a high quality product. In some cases, such as squash production, it is possible reduce the capital investment by heating syrup to boiling in a large pan made from cheaper aluminium and then mixing it with juice in a smaller stainless steel pan for a final short heating to achieve the required pasteurisation conditions.

There are two types of boiling pans available, depending on the scale of operation: at smaller scales of operation, a simple stainless steel pan can be placed directly over the heat source. At larger scales of production, an indirectly heated, or 'double jacketed' pan can be used. Steam is produced by a boiler and fed into the space between the outer jacket and inner pan to give more uniform heating and therefore avoid localised burning of the product. This may be particularly important when heating viscous products such as sauces, jams, chutneys etc., which are more likely to stick to a simple pan and burn onto it. This would not only reduce the quality of the product but also significantly slow

Fermented and distilled products

In addition to the equipment required to prepare juices for fermentation, this group of products require more specialised equipment for fermentation and distillation. Wines are fermented in either food grade plastic drums or large glass vessels, which have a narrow opening into which an air lock can be fitted. An alcohol hydrometer is not essential, but it is a useful aid to standardising the alcohol content of the products. It is possible to make vinegar by simply exposing wine to the air, but yields are low and there is a high risk of spoilage. A commercially made vinegar fermenter is too expensive for most producers, but if expertise is available, a locally produced fermenter having a traditional design can be made.

Commercially produced distillation apparatus is also expensive to buy and locally made alternatives are likely to be preferred by small scale producers. With experience and adequate control over heating, these can produce acceptable products. They should be fitted with a pressure safety device, such as a long pipe that is submerged below the level of the liquor and exits the heating vessel to a height of at least 1.5 metres. If the outlet to the still becomes blocked, this will prevent the pressure rising to the point where the still would explode.

Packaging, filling and sealing equipment

All types of plastic film, with the exception of un-coated cellulose, can be sealed using a heat sealer. The differences in the types of sealer are due to the width of the heated bar or wire and the level of control over temperature and time of heating. For dried and liquid foods a relatively wide seal (e.g. 3-5 mm) is required and bar-type sealers are therefore preferable to wire-types. The sealer should also have a thermostat to adjust the sealing temperature, and an adjustable timer to control the time of heating. Care should be taken to ensure that there is no product dust on the inside of the package where the seal is to be made as this will prevent proper sealing.

Solid products, such as pickles and chutneys are usually filled by hand using scoops or ladles into jars, plastic pots or bags. This is a time-consuming operation, which may require a large staff input. However, in most small scale operations, this is the only realistic option because mechanical fillers for these types of product are prohibitively expensive and usually operate at too high a throughput. Although liquid products can also be filled by hand using jugs or ladles, in contrast to solid products there are a number of small liquid fillers available, which are affordable by many small scale producers. Examples of these include gravity fillers, made by fitting gate valves to stainless steel or food grade plastic tanks. Other designs include volumetric fillers and dispensers, in which a measured amount of liquid is filled into each container by the action of a piston. Small machines are available to seal jars, bottles, cans, plastic pots and films.

of small liquid fillers available, which are affordable by many small scale producers. Examples of these include gravity fillers, made by fitting gate valves to stainless steel or food grade plastic tanks. Other designs include volumetric fillers and dispensers, in which a measured amount of liquid is filled into each container by the action of a piston. Small machines are available to seal jars, bottles, cans, plastic pots and films.

Packaging Materials

There is a very wide range of packaging materials that can be used for foods and these cannot be described in detail in a book of this size. Publications in the Bibliography describe some types of packaging in more detail, but entrepreneurs should contact packaging manufacturers or their agents for a complete list of the available types. The following is a brief description of some of the more important points concerning the most widely available types of packaging materials in most developing countries.

Jars and bottles are available in countries that have a glass-works, or have access to an overland supply from a neighbouring country. Because of their heavy weight, high bulk and fragility, glass containers are expensive to transport long distances and are frequently not available to producers in developing countries. Where they are available, they are usually re-used and great care is needed to ensure that they are properly cleaned. New and re-used containers should be sealed with new caps, lids or corks in order to obtain an adequate seal. The most common jar lids are now TOTO type (twist on, twist off), although the 'Omnia' type is still found in many countries. Bottles may be sealed using ROPP (roll on pilfer-proof) caps or corks. Plastic pots and bottles are suitable for some types of foods and they are becoming increasingly common as a result of their lower production and distribution costs. Pots can be either heat sealed with a foil lid or with a snap-on plastic lid. The most common types of plastic film in developing countries are polythene and polypropylene, although increasingly there are agents who can supply more sophisticated (and expensive) imported laminate.

Small laminated plastic/foil/cardboard cartons for UHT juices are appearing in many countries, but these are usually imported under licence to large scale juice manufacturers and are not available to small scale processors. Additionally, the UHT technology is not suitable for small scale production. Other cardboard and paper packaging is more widely available and can usually be printed by local print companies. Other, more traditional types of packaging such as leaves, jute, hessian, wood and pottery are not usually able to convey an image of 'modem' or hygienic products and except for some niche export or tourist markets, these are not widely used.

LEGAL ASPECTS OF HORTICULTURAL PROCESSING

Before starting registration procedures, aspiring entrepreneurs should seek professional and cheaper for these people to register either as personal business with unlimited liability or as a limited company with a single owner/director. However, this may not be appropriate if additional partners are required to contribute capital or specific skills.

Other types of business that can therefore be considered include a limited liability company with several directors or an un-incorporated association that has no limited liability. If the proposed enterprise has a larger number of interested investors, for example a farmers' association, or if the aims also include social benefits, the form of the business could be a co-operative association, a not-for-profit organisation or a registered charity. However, it should be noted that charity law in many countries prohibits trading.

Food Related Laws

In most countries there are general laws that govern the sale of all goods, including foods, which state that any product should be suitable for its intended purpose. There are also food laws relating to the effects of food on health that say: It is an offence for anyone to add anything to food, to process food or to sell food so that it is injurious to health with the intention that it is sold for human consumption. Most countries have laws to protect customers from adulteration of foods or other forms of cheating. Typically these say that it is an offence to sell food that is not of the nature, substance nor quality demanded by the purchaser. It is also an offence to falsely describe a food on the label or in advertising, with the intention of misleading the customer.

Food Composition

Laws relating to the composition of processed foods are complex and specific to particular types of food, particularly those such as pies or prepared foods that present opportunities for adulteration. The intention of the laws is to produce a standard for a particular food and so ensure that all foods sold with that name have that standard composition. This approach is changing in some countries and is being relaxed because of the difficulties of enforcement. Instead the authorities are relying on stricter labelling requirements to inform consumers of the food composition.

In relation to fruit and vegetable products, the following often have compositional standards:

— *Fruit juices and nectars* : Juice should be only pure juice with nothing added except vitamin C, specified acids used to adjust the pH and maximum levels of residual sulphur dioxide if this has been used as a preservative. Typically nectars should contain a minimum % juice, between 25% and 40% juice depending on the type of fruit and a maximum of 20% sugar or honey. There are also minimum limits for the acid content of nectars.

- *Fruit juices and nectars* : Juice should be only pure juice with nothing added except vitamin C, specified acids used to adjust the pH and maximum levels of residual sulphur dioxide if this has been used as a preservative. Typically nectars should contain a minimum % juice, between 25% and 40% juice depending on the type of fruit and a maximum of 20% sugar or honey. There are also minimum limits for the acid content of nectars.
- *Soft drinks* : Squashes, crushes and cordials are each defined in law and have minimum fruit contents specified for different types of fruit. These are typically between 1.5% and 5% minimum fruit content for drinks that are not diluted and 7% to 25% minimum fruit content for those drinks that require dilution. Dilution must be four parts water to one part drink. They each have maximum permitted levels of sugar or artificial sweeteners and can contain specified food acids.
- *Jams and similar products*: Jams should contain a minimum amount of fruit pulp, which varies with the type of fruit being used, but for many is around 200g pulp per kg product. Similarly the amount of fruit juice in jelly and marmalade is specified. Normally jams should have minimum of 60% soluble solids and there are limits on residual sulphur dioxide in all products. There are detailed regulations covering definitions of the names jams, jellies, marmalades, conserves, preserves, extra jam or jelly and reduced sugar jam, jelly or marmalade.
- *Tomato ketchup*: This should have a minimum of 6% tomato solids and not contain seeds. There is a maximum limit on contamination with copper and no other fruits or vegetables can be used except onions, garlic or spices for flavouring.
- *Additives and contaminants*: There are lists of permitted food colours, emulsifies, stabilisers, preservatives and other additives that can be added to foods. Any chemical that is not on these lists cannot be used. There are also maximum levels set for each additive in specific foods and lists of foods that are able to contain specified preservatives. Contaminants, including poisonous metals such as arsenic and lead, have maximum permitted levels in specified foods.

Food Labelling

When prosecutions of food companies are analysed, a large percentage often relate to 'technical' breaches of the law because a label is incorrectly designed. It is therefore in the processors' interest to involve the local Bureau of Standards at an early stage of label design to avoid problems with prosecution and expensive re-design after labels have been printed. There are general labelling requirements that describe the information that must be included on a label, but in many countries there are also very detailed laws concerning some or all of the following aspects:

- specify names that must be given to different types of ingredients

- the visibility of information and the ability of customers to understand it
- claims and misleading descriptions, especially about health-giving or tonic properties, nutritional advantages, diabetic or other medicinal claims
- specifications of the way in which certain words such as flavour, fresh, vitamin etc. can be used.

This is also a complex area, which is not possible to describe in detail in this book and professional advice should be sought from graphic designers who are experienced in label design, or from a Bureau of Standards.

Hygiene and Sanitation

Laws relating to food production premises and the staff who handle foods are among the most widely enforced in most developing countries. There are numerous examples of prosecutions by Food Inspectors from Ministries of Health or other enforcement authorities and in some cases, enforced closure of the business for failure to comply with these laws. Guidelines on the design and construction of premises and hygiene of operators should therefore be consulted before submitting a new processing facility for inspection and certification.

These guidelines should be rigorously enforced in routine production to ensure that safe, high quality products are produced. In summary the laws are concerned with the following aspects of health, hygiene and sanitation:

- processing that is carried out in unsanitary conditions
- or where food is exposed to the risk of contamination
- equipment
- persons handling food and their responsibilities to protect it from contamination
- building design and construction including water supplies,
- drainage, toilet facilities, wash-hand basins, provision of first aid facilities, places to store clothing, facilities for washing food and equipment, lighting, ventilation, protection against infestation by rats and insects and removal of wastes.

Weights and Measures

The aim of this type of legislation is to protect customers from being cheated by unscrupulous manufacturers, for example from being sold underweight packs of food. The laws are to ensure that the amount of food that is declared on the label as the net weight is the same as the weight of food that is actually in the pack. However, it is recognised that not every pack can be filled with exactly the specified weight because

Weights and Measures

The aim of this type of legislation is to protect customers from being cheated by unscrupulous manufacturers, for example from being sold underweight packs of food. The laws are to ensure that the amount of food that is declared on the label as the net weight is the same as the weight of food that is actually in the pack. However, it is recognised that not every pack can be filled with exactly the specified weight because both machine-filling and hand-filling of containers is subject to some variability. The laws are therefore designed to allow for this variability but to prevent fraud.

There are two types of weights and measures legislation in force in different countries: the older method, which is still used in most developing countries, is known as the Minimum Weight System. This is intended to ensure that every pack of food contains at least the net weight that is written on the label. If any pack is found below this weight the producer is liable for prosecution. This system works well to protect customers, but is more expensive for producers because they have to routinely fill packs to just above the declared weight to avoid prosecution and they therefore give a small amount of product away in every pack.

A second type of legislation was introduced in Europe to take account of the automated filling and packaging that is used by most producers there. This is known as the Average Weight System and uses a statistical probability of a defined proportion of packages being above the declared weight as a basis for enforcement. As most small scale producers in developing countries do not use automatic fillers and programmable check-weighers, this system is difficult to operate and un-necessarily complex. If however, a producer is considering export to an industrialised country, advice and information on this legislation should be obtained from a local Export Promotion Board or equivalent institution so that an 'e' mark can be obtained to indicate that the process conforms to this system.

In some countries, there are specified weights that must be used when selling dried fruits and vegetables and jams or marmalades.

Securing Raw Materials

Many small scale processors buy fruits and vegetables daily from their nearest public market. Although this is simple and straightforward, it creates a number of problems for a business: for example, the processors have little control over the price charged by traders each day and because of the large seasonal price fluctuations that characterise these raw materials, this makes financial planning and control over cashflow more difficult. The processor is also unable to schedule the raw materials in the quantities required and it is common for production to fail to meet a target because there are simply at present in most developing countries, possibly because commercial food processing is a relatively recent activity and there is no history of collaboration and formal contracts. However, where this has been done, there are benefits to both processor and suppliers, provided that the arrangements are made honourably and there is mutual trust. The benefits to farmers are a guaranteed price for their crop, based on a sliding scale of quality and a guaranteed market when it is harvested.

However, the traders who tour an area to buy crops provide a number of benefits to farmers that processors should not ignore when arranging contracts: for example the traders frequently buy the whole crop, regardless of quality and either sort it themselves for different markets or sell it on to wholesalers who do the sorting. From the farmers' perspective, they receive payment at the farm, without having to worry about marketing their crop or disposal of substandard items. Although farmers have a 'guaranteed' market by selling to traders, they have virtually no control over the prices offered and can be exploited, particularly at the peak of a growing season when there is an over-supply of a particular crop.

Traders also provide a number of other services that farmers may find difficult to obtain elsewhere: traders may be the only realistic source of farming tools and other inputs such as seeds; they are also a source of immediate informal credit, which farmers may require to buy inputs or for other needs such as funerals and weddings. Although the interest payments on such loans may be much higher than those charged on commercial loans, farmers often have no access to banks or other lenders and in practice have no choice. In many countries, large numbers of farmers are permanently indebted to traders for their lifetimes and are only released from the debt by sale of land.

When processors begin to negotiate contracts with farmers, they should therefore be aware that farmers may be unwilling to break the existing arrangements with traders, either because of genuine fears that they will lose the services provided or because they are indebted to traders and have no ability to make other arrangements. The local power of traders should not be under-estimated and may range from a refusal to offer further loans to farmers, a threat not to buy the crop again if sales are made directly to processors, a demand that farmers repay loans immediately and in extreme cases, physical violence.

Despite the problems described above, there are possibilities for processors to agree contracts to supply fruits and vegetables of a specified variety and quality with individual farmers or with groups of farmers who may be working cooperatively.

Typically a specification would include the variety to be grown, the degree of maturity at harvest, freedom from infection etc. The price paid for the crop is agreed in advance and may be set between the mid-season lowest point and the pre- and post-season high points. Alternatively a sliding scale of prices is agreed, based on one or more easily measurable characteristics such as minimum size or agreed colour range, with an contracts to supply fruits and vegetables of a specified variety and quality with individual farmers or with groups of farmers who may be working cooperatively.

Typically a specification would include the variety to be grown, the degree of maturity at harvest, freedom from infection etc. The price paid for the crop is agreed in advance and may be set between the mid-season lowest point and the pre- and post-season high points. Alternatively a sliding scale of prices is agreed, based on one or more easily measurable characteristics such as minimum size or agreed colour range, with an independent person being present to confirm the agreement in case of later disputes. The agreement may also specify the minimum or maximum amount that will be bought. In a formal contract, these agreement are written down and signed by both parties, although such formal contracts are rare in most developing countries.

Processors should also consider the other forms of assistance that could be offered to farmers. For example, in some other larger scale processing such as tea and coffee production, processors offer training and an extension service to address problems with the crop as they arise throughout the growing season. Although this may be beyond the resources of small scale processors, more limited types of assistance may include purchasing tools, fertiliser or other requirements in bulk with the savings being passed on to farmers. Alternatively, part-payment for the crop can be made in advance so that farmers can buy inputs without the need for credit and the consequent indebtedness.

The advantages to the processor are greater control over the quality of raw materials and the varieties that are planted, some control over the amounts supplied and an advance indication of likely raw material costs which assists in both financial control and production planning. The advantage to the farmer is the security of having a guaranteed market for the crop at a known price, together with any other incentives that may be offered by processors.

However, this type of arrangement can only operate successfully when both processors and farmers honour their side of the agreement. In the author's experience, there have been a number of occasions when these forms of agreement have been tried, but have failed because one party breaks their part of the contract. Typically, this can be farmers who sell part of their crop to traders at each end of the season, when the price is higher than that offered by the processor. The expected volume of crop is not then available to the processor and planned production capacity cannot be achieved, seriously damaging both sales and cashflow. Alternatively, the processor delays payment to farmers, resulting in the need for them to take another loan and greater indebtedness. The processor may also fail to buy the agreed amount of crop and farmers are left to find alternative markets without the option of supplying traders who may refuse to buy it or may offer an insignificant price.

A further development of the approach is for the processor to rent or buy land and set up a separate operation to supply the processing unit. This often happens 'in reverse' when an existing farmer diversifies into processing but retains the farm. In either case the processor hires the labour and supplies all inputs needed to operate the farm. The bulk of the produce supplies the processing unit with any excess being sold in local markets or to traders.

Agreements with Retailers and Other Sellers

Decisions by processors on how to sell their products, and to whom, are part of the marketing strategy for each individual product and these decisions may therefore be different for each product in a range. For example a jam manufacturer may make one range that is sold to wealthy urban consumers and another that is sold to bakers as an ingredient in doughnuts and cakes. Whatever type of sale is envisaged, it is necessary for processors to understand the market in which they operate and know the way in which products move through the market and gain value.

As each seller requires a profit of between 10% and 25% for handling, stocking or transporting the foods, the less direct routes from producer to consumer result in substantial increases in the unit cost of the product. Other points to note on the route map are that a lower producer's profit may be necessary when supplying wholesalers that have control over a large part of the market, distributors add a higher percentage than other groups to account for the high transport charges in most developing countries and street traders and kiosk owners usually have the lowest profit of any group.

The simplest form of selling is directly to customers from the processing unit and this method also results in the lowest cost for consumers. Direct selling is common with bakery products, which have a short shelf life and are generally better preferred when straight from the oven, but is less common with fruit and vegetable products. Exceptions include sale of pickles and chutneys from bulk containers into customers' own pots, a small 'factory shop' selling packs of product at the front of the processing unit and sales of fresh, un-pasteurised juices in cafes or tea rooms that are adjacent to the production unit and may also be owned by the processor.

In these cases, provision has to be made in both the design and layout of the premises to accommodate customers and to have staff available to sell the product. In order to maintain control over hygiene, pilferage and health and safety, it is essential that customers are not allowed into the processing area.

Delivery of goods directly to retailers is feasible if the processing unit is located within a reasonably short radius of a sufficient number. However, the costs of distribution are met by the processor and a higher price should be charged to cover this, although it can still be cheaper for retailers than buying from a wholesaler.

In these cases, provision has to be made in both the design and layout of the premises to accommodate customers and to have staff available to sell the product. In order to maintain control over hygiene, pilferage and health and safety, it is essential that customers are not allowed into the processing area.

Delivery of goods directly to retailers is feasible if the processing unit is located within a reasonably short radius of a sufficient number. However, the costs of distribution are met by the processor and a higher price should be charged to cover this, although it can still be cheaper for retailers than buying from a wholesaler.

Although the above methods are feasible when the production unit is centrally located, in many instances processing is carried out near to a rural area to reduce the cost of transporting raw materials. In this situation, it is more common for either processors to deliver products to one or more wholesalers, or for wholesalers to collect goods from the production unit. The relative advantages and limitations of transporting either raw materials to a production site or alternatively transporting products to a market should be carefully considered when choosing the site of a processing unit during a feasibility study. Particular consideration is needed when glass jars or bottles are to be transported on rural roads, because of the potentially high losses of both empty packaging on the way to the unit and filled product on the way to wholesalers or retailers.

REFERENCES

Campbell-Platt, G. 1987. *Fermented Foods of the World: Dictionary and Guide.* Stonam, Massachussetts: Butterworth Heineman.

Fellows, P. and Hampton, A 1992. *Small-Scale Food Processing A Guide to Appropriate Equipment.* London: Intermediate Technology Publications. 158 pp.

FAO. 1986. *Improvement of Post-Harvest Fresh Fruits and Vegetables Handling.* Regional Office for Asia and the Pacific. Maliwan Mansion, Phra Atit Road, Bangkok, 10200, Thailand.

FAO. 1989. *Prevention of Post-Harvest Food Losses: Fruit. Vegetables and Root Crops. A Training Manual.* Rome: UNFAO. 157 pp.

Shewfelt, R.L. 1986. "Postharvest treatment for extending shelf life of fruits and vegetables". *Food Technology.*

10

Freezing of Fruits and Vegetables

Freezing is one of the oldest and most widely used methods of food preservation, which allows preservation of taste, texture, and nutritional value in foods better than any other method. The freezing process is a combination of the beneficial effects of low temperatures at which microorganisms cannot grow, chemical reactions are reduced, and cellular metabolic reactions are delayed.

Freezing preservation retains the quality of agricultural products over long storage periods. As a method of long-term preservation for fruits and vegetables, freezing is generally regarded as superior to canning and dehydration, with respect to retention in sensory attributes and nutritive properties. The safety and nutrition quality of frozen products are emphasized when high quality raw materials are used, good manufacturing practices are employed in the preservation process, and the products are kept in accordance with specified temperatures.

NEED FOR FREEZING AND FROZEN STORAGE

Freezing has been successfully employed for the long-term preservation of many foods, providing a significantly extended shelf life. The process involves lowering the product temperature generally to -18 °C or below. The physical state of food material is changed when energy is removed by cooling below freezing temperature. The extreme cold simply retards the growth of microorganisms and slows down the chemical changes that affect quality or cause food to spoil.

Competing with new technologies of minimal processing of foods, industrial freezing is the most satisfactory method for preserving quality during long storage periods. When compared in terms of energy use, cost, and product quality, freezing requires the shortest processing time. Any other conventional method of preservation focused on fruits and vegetables, including dehydration and canning, requires less energy when compared with energy consumption in the freezing process and storage. However, when the overall cost is estimated, freezing costs can be kept as low (or lower) as any other method of food preservation.

The frozen food market is one of the largest and most dynamic sectors of the food industry. In spite of considerable competition between the frozen food industry and other sectors, extensive quantities of frozen foods are being consumed all over the world. The industry has recently grown to a value of over US$ 75 billion in the U.S. and Europe combined. This number has reached US$ 27.3 billion in 2001 for total retail sales of frozen foods in the U.S. alone. In Europe, based on U.S. currency, frozen food consumption also reached 11.1 million tons in 13 countries in the year 2000. Developed countries, mostly the U.S., dominate the international trade of fruits and vegetables. The U.S. is ranked number one as both importer and exporter, accounting for the highest percent of fresh produce in world trade. However, many developing countries still lead in the export of fresh exotic fruits and vegetables to developed countries.

Table 1. Frozen food industry in terms of annual sales in 2001

Food items	*Sales US$ (million)*	*% Change vs. 2000*
Total Frozen Food Sales	26 600	6.1
Baked Goods	1 400	9.0
Breakfast Foods	1 050	4.1
Novelties	1 900	10.5
Ice Cream	4 500	5.7
Frozen Dessert/Fruit/Toppings	786	5.4
Juices/Drinks	827	-9.7
Vegetables	2 900	4.3

For developing countries, the application of freezing preservation is favorable with several main considerations. From a technical point of view, the freezing process is one of the most convenient and easiest of food preservation methods, compared with other commercial preservation techniques. The availability of different types of equipment for several different food products results in a flexible process in which degradation of initial food quality is minimal with proper application procedures. As mentioned earlier, the high capital investment of the freezing industry usually plays an important role in terms of economic feasibility of the process in developing countries.

As for cost distribution, the freezing process and storage in terms of energy consumption constitute approximately 10 percent of the total cost. Depending on the government regulations, especially in developing countries, energy cost for producers can be subsidised by means of lowering the unit price or reducing the tax percentage in order to enhance production. Therefore, in determining the economical convenience of the process, the cost related to energy consumption (according to energy tariffs) should be considered. Electricity prices for some countries are given in Table 2.

Table 2. Unit electricity prices for industry

Country	*1999*	*2000*	*2001*	*2002*
Argentina	n.a.	0.075	0.069	n.a.
Belgium	0.056	0.048	n.a.	n.a.
Bolivia	n.a.	0.062	0.069	n.a.
Chile	n.a.	0.052	0.056	n.a.
Chinese Taipei (Taiwan)	0.058	0.061	0.056	n.a.
Colombia	n.a.	0.052	0.042	n.a.
Costa Rica	n.a.	0.068	0.076	n.a.
Cuba	n.a.	0.080	0.078	n.a.
Ecuador	n.a.	0.036	0.061	n.a.
El Salvador	n.a.	0.111	0.110	n.a.
Finland	0.046	0.039	0.038	0.043
Germany	0.057	0.041	0.044	n.a.
Greece	0.050	0.042	0.043	0.046
Guyana	n.a.	0.082	0.080	n.a.
Hungary	0.055	0.049	0.051	0.060
India	0.081	0.080	n.a.	n.a.
Ireland	0.057	0.049	0.060	0.075
Italy	0.086	0.089	n.a.	n.a.
Korea (Korea, South)	0.056	0.062	0.057	n.a.
Mexico	0.042	0.051	0.053	n.a.
Netherlands	0.061	0.057	0.059	n.a.
New Zealand	0.030	0.030	0.028	0.033
Nicaragua	n.a.	0.117	0.115	n.a.
Paraguay	n.a.	0.032	0.036	n.a.
Peru	n.a.	0.056	0.057	n.a.
Poland	0.037	0.037	0.045	0.049
Portugal	0.078	0.067	0.066	0.068
Russia	0.012	0.011	n.a.	n.a.
South Africa	0.017	0.017	0.013	n.a.
Spain	0.049	0.043	0.041	n.a.
Switzerland	0.090	0.069	0.069	0.073
Turkey	0.079	0.080	0.079	0.094
United Kingdom	0.064	0.055	0.048	n.a.
United States	0.044	0.046	0.050	0.048
Uruguay	n.a.	0.064	0.070	n.a.

Consumer Demands

The proportion of fresh food preserved by freezing is highly related to the degree of economic development in a society. As countries become wealthier, their demand for high-valued commodities increases, primarily due to the effect of income on the consumption of high-valued commodities in developing countries. The commodities preserved by freezing are usually the most perishable ones, which also have the highest price. Therefore, the demand for these commodities is less in developing areas. Besides, the need for adequate technology for freezing process is the major drawback of developing countries in competing with industrialised countries. The frozen food industry requires accompanying developments and facilities for transporting, storing, and marketing their products from the processing plant to the consumer. Thus, a large amount of capital investment is needed for these types of facilities. For developing countries, especially in rural or semi-rural areas, the frozen food industry has therefore not been developed significantly compared to other countries.

In recent years, due to the changing consumer profile, the frozen food industry has changed significantly. The major trend in consumer behavior documented over the last half century has been the increase in the number of working women and the decline in the family size. These two factors resulted in a reduction in time spent preparing food. The entry of more women into the workforce also led to improvements in kitchen appliances and increased the variability of ready-to-eat or frozen foods available in the market. Besides, the increased usage of microwave ovens, affecting food habits in general and the frozen food market in particular, as well as allowing rapid preparation of meals and greater flexibility in meal preparation. The frozen food industry is now only limited by imagination, an output of which increases continuously to supply the increasing demand for frozen products and variability.

Market Share of Frozen Fruits and Vegetables

Today in modern society, frozen fruits and vegetables constitute a large and important food group among other frozen food products. The historical development of commercial freezing systems designed for special food commodities helped shape the frozen food market. Technological innovations as early as 1869 led to the commercial development and marketing of some frozen foods. Early products saw limited distribution through retail establishments due to insufficient supply of mechanical refrigeration. Retail distribution of frozen foods gained importance with the development of commercially frozen vegetables in 1929.

The frozen vegetable industry mostly grew after the development of scientific methods for blanching and processing in the 1940s. Only after the achievement of success in stopping enzymatic degradation, did frozen vegetables gain a strong retail and institutional appeal. Today, market studies indicate that considering overall consumption of frozen foods, frozen vegetables constitute a very significant proportion of world frozen-food categories in Austria, Denmark, Finland, France, Germany, Italy, Netherlands, Norway, Sweden, Switzerland, UK, and the USA. The division of frozen vegetables in terms of annual sales in 2001 is shown in Table 3.

Commercialisation history of frozen fruits is older than frozen vegetables. The commercial freezing of small fruits and berries began in the eastern part of the U.S. in about 1905. The main advantage of freezing preservation of fruits is the extended usage of frozen fruits during off-season. Additionally, frozen fruits can be transported to remote markets that could not be accessed with fresh fruit. Also, freezing preservation makes year-round further processing of fruit products possible, such as jams, juice, and syrups from frozen whole fruit, slices, or pulps. In summary, the preservation of fruits by freezing has clearly become one the most important preservation methods.

Trends in Freezing Technology

The frozen food industry is highly based in modern science and technology. Starting with the first historical development in freezing preservation of foods, today, a combination of several factors influences the commercialisation and usage of freezing technology. The future growth of frozen foods will mostly be affected by economical and technological factors. Growth in population, personal incomes, relative cost of other forms of foods, changes in tastes and preferences, and technological advances in freezing methods are some of the factors concerned with the future of freezing technology.

Population growth and increasing demand for food has generated the need for commercial production of food commodities in large-scale operations. Thus, availability of proper equipment suitable for continuous processing would be valuable for freezing preservation methods. In addition depending on personal incomes, relative cost of frozen products is one of the most important of economical factors. Producing the highest quality at the lowest cost possible is highly dependent on the technology used. As a result, developments in freezing technology in recent years have mostly been characterised by the improvements in mechanical handling and process control to increase freezing rate and reduce cost.

Today an increasing demand for frozen foods already exits and further expansion of the industry is primarily dependent on the ability of food processors to develop higher qualities in both process techniques and products. Improvements can only be achieved by focusing on new technologies and investigating poorly understood factors that influence the quality of frozen food products. Improvements in new and convenient forms of foods, as well as more information on relative cost and nutritive values of frozen foods, will contribute toward continued growth of the industry.

Table 3. Frozen vegetables in terms of annual sales in 2001

Vegetables	*Sales US$ (million)*	*% Change vs. 2000*
Broccoli	184	4.4
Com/Corn on the Cob	312	3.5
Green Beans	115	6.0
Mixed Vegetables	450	7.2
Peas	207	3.9
Potatoes	1 070	4.4

Freezing is a widely used method of food preservation based on several advantages in terms of retention of food quality and ease of process. Beginning with the earliest history of freezing, the technology has been highly affected over the years by the developments and improvements in freezing techniques. In order to understand and handle the concepts associated with freezing of foods, it is necessary to examine the fundamental factors governing the freezing process.

FREEZING TECHNOLOGY

Freezing has long been used as a method of preservation, and history reveals it was mostly shaped by the technological developments in the process. A small quantity of ice produced without using a "natural cold" in 1755 was regarded as the first milestone in the freezing process. Firstly, ice-salt systems were used to preserve fish and later on, by the late 1800's, freezing was introduced into large-scale operations as a method of commercial preservation. Meat, fish, and butter, the main products preserved in this early example, were frozen in storage chambers and handled as bulk commodities.

In the following years, scientists and researchers continuously worked to achieve success with commercial freezing trials on several food commodities. Among these commodities, fruits were one of the most important since freezing during the peak growing season had the advantage of preserving fruit for later processing into jams, jellies, ice cream, pies, and other bakery foods. Although commercial freezing of small fruits and berries first began around 1905 in the eastern part of the United States, the commercial freezing of vegetables is much more recent. Starting from 1917, only private firms conducted trials on freezing vegetables, but achieving good quality in frozen vegetables was not possible without pre-treatments due to the enzymatic deterioration. In 1929, the necessity of blanching to inactivate enzymes before freezing was concluded by several researchers to avoid deterioration and off-flavours caused by enzymatic degradation.

The modern freezing industry began in 1928 with the development of double-belt contact freezers by a technologist named Clarence Birdseye. After the revolution in the quick freezing process and equipment, the industry became more flexible, especially with the usage of multi-plate freezers. The earlier methods achieved successful freezing of fish and poultry, however with the new quick freezing system, packaged foods could be frozen between two metal belts as they moved through a freezing tunnel. This improvement was a great advantage in the commercial large-scale freezing of fruits and vegetables. Furthermore, quick-freezing of consumer-size packages helped frozen vegetables to be accepted rapidly in late 1930s.

Today, freezing is the only large-scale method that bridges the seasons, as well as variations in supply and demand of raw materials such as meat, fish, butter, fruits, and vegetables. Besides, it makes possible movement of large quantities of food over geographical distances. It is important to control the freezing process, including the pre-freezing preparation and post-freezing storage of the product, in order to achieve high-quality products. Therefore, the theory of the freezing process and the parameters involved should be understood clearly.

Freezing Process

The freezing process mainly consists of thermodynamic and kinetic factors, which can dominate each other at a particular stage in the freezing process. Major thermal events are accompanied by reduction in heat content of the material during the freezing process. The material to be frozen first cools down to the temperature at which nucleation starts. Before ice can form, a nucleus, or a seed, is required upon which the crystal can grow; the process of producing this seed is defined as nucleation. Once the first crystal appears in the solution, a phase change occurs from liquid to solid with further crystal growth. Therefore, nucleation serves as the initial process of freezing, and can be considered as the critical step that results in a complete phase change.

Freezing point of foods

Freezing point is defined as the temperature at which the first ice crystal appears and the liquid at that temperature is in equilibrium with the solid. If the freezing point of pure water is considered, this temperature will correspond to 0 °C (273°K). However, when food systems are frozen, the process becomes more complex due to the existence of both free and bound water. Bound water does not freeze even at very low temperatures. Unfreezable water contains soluble solids, which cause a decrease in the freezing point of water lower than 0 °C. During the freezing process, the concentration of soluble solids increases in the unfrozen water, resulting in a variation in freezing temperature. Therefore, the temperature at which the first ice crystal appears is commonly regarded as the initial freezing temperature. There are empirical equations in literature that can calculate the initial freezing temperature of certain foods as a function of their moisture content.

There are several methods of food freezing, and depending on the method used, the quality of the frozen food may vary. However, regardless of the method chosen, the main principle behind all freezing processes is the same in terms of process parameters. The International Institute of Refrigeration (IIR) has provided definitions to establish a basis for the freezing process. According to their definition, the freezing process is basically divided into three stages based on major temperature changes in a particular location in the product.

Beginning with the prefreezing stage, the food is subjected to the freezing process until the appearance of the first crystal. If the material frozen is pure water, the freezing temperature will be 0 °C and, up to this temperature, there will be a subcooling until the ice formation begins. In the case of foods during this stage, the temperature decreases to below freezing temperature and, with the formation of the first ice crystal, increases to freezing temperature. The second stage is the freezing period; a phase change occurs, transforming water into ice. For pure water, temperature at this stage is constant; however, it decreases slightly in foods, due to the increasing concentration of solutes in the unfrozen water portion. The last stage starts when the product temperature reaches the point where most freezable water has been converted to ice, and ends when the temperature is reduced to storage temperature.

The freezing time and freezing rate are the most important parameters in designing freezing systems. The quality of the frozen product is mostly affected by the rate of freezing, while time of freezing is calculated according to the rate of freezing. For industrial applications, they are the most essential parameters in the process when comparing different types of freezing systems and equipment.

Freezing time

Again, freezing time is one of the most important parameters in the freezing process, defined as time required to lower product temperature from its initial temperature to a given temperature at its thermal center. Since the temperature distribution within the product varies during freezing process, the thermal center is generally taken as reference. Thus, when the geometrical center of the product reaches the given final temperature, this ensures the average product temperature has been reduced to a storage value. Freezing time depends on several factors, including the initial and final temperatures of the product and the quantity of heat removed, as well as dimensions and shape of product, heat transfer process, and temperature. The International Institute of Refrigeration defines various factors of freezing time in relation to both the product frozen and freezing equipment. The most important are:

- Dimensions and shape of product, particularly thickness
- Initial and final temperatures

- Temperature of refrigerating medium
- Surface heat transfer coefficient of product
- Change in enthalpy
- Thermal conductivity of product

Calculation of freezing time in food systems is difficult in comparison to pure systems since the freezing temperature changes continuously during the process. Using a simplified approach, time elapsed between initial freezing until when the entire product is frozen can be regarded as the freezing time. Plank's equation (Eq.1) is commonly used to estimate freezing time, however due to assumptions involved in the calculation it is only useful for obtaining an approximation of freezing time. The derivation of the equation starts with the assumption the product being frozen is initially at freezing temperature. Therefore, the calculated freezing time represents only the freezing period. The equation can be further modified for different geometries including slab, cylinder, and sphere, where for each geometry, the coefficients are arranged in relation to the dimensions.

Table 4. Coefficients P and R of Equation 1

Geometry	*P*	*R*	*Dimension*
Infinite slab	1/2	1/8	thickness e
Infinite cylinder	1/4	1/16	radius r
Sphere	1/6	1/24	radius r

$$t_F = \frac{\rho\lambda_1}{T_F - T_e}\left[\frac{e^2R}{k} + \frac{eP}{h}\right] \qquad (1)$$

where l_1 is the latent heat of frozen fraction, *k* and *r* are the thermal conductivity and density of the frozen layer, while h is the coefficient of heat transfer by convection to the exterior. T_f denotes the body temperature of the product when introduced into a freezer in wich the external temperature is T_e The coefficients R and P are given in Table 4 and arranged according to the geometry of the product frozen. where the letter e denotes the dimension (i.e. for infinite slab geometry, *e* is thickness of the slab and for infinite cylinder or sphere e is replaced by *k* which denotes the radius of the cly'inder or sphere).

The equation of Plank assumes the food is at a freezing temperature at the beginning of the freezing process. However, the food is usually at a temperature higher than freezing temperature. The real freezing time should therefore be the sum of time calculated from the equation of Plank and the time needed for the product's surface to decrease from initial temperature to freezing temperature.

Several works have attempted to calculate real freezing time, as in one presented by Nagaoka *et al.*. Nagaoka's equation (Eq. 2) calculates the amount of heat elimination required to decrease a product's temperature from initial temperature to freezing temperature, as well as the amount of heat released during the phase change and the amount of heat eliminated to reach freezing temperature.

$$t_F = \frac{\rho \Delta H}{T_F - T_e}\left[\frac{Re^2}{k} + \frac{Pl}{h}\right][1 + 0.008\,(T_i - T_F)] \qquad (2)$$

where Ti is the temperature of the food at the initiation of freezing, DH is the difference between the enthalpy of the food at initial temperature and end of freezing. Re and Pl are the dimensionless numbers, while k and h are the thermal conductivity and the coefficient of heat transfer, respectively.

For calculating freezing time of products with irregular shape, a common property of most food products - especially fruits and vegetables - a dimensionless factor has been employed in equations.

Freezing rate

The freezing rate (°C/h) for a product or package is defined as the ratio of difference between initial and final temperature of product to freezing time. At a particular location within the product, a local freezing rate can be defined as the ratio of the difference between the initial temperature and desired temperature to the time elapsed in reaching the given final temperature. The quality of frozen products is largely dependent on the rate of freezing. Generally, rapid freezing results in better quality frozen products when compared with slow freezing. If freezing is instantaneous, there will be more locations within the food where crystallisation begins. In contrast, if freezing is slow, the crystal growth will be slower with few nucleation sites resulting in larger ice crystals. Large ice crystals are known to cause mechanical damage to cell walls in addition to cell dehydration. Thus, the rate of freezing for plant tissues is extremely important due to the effect of freezing rate on the size of ice crystals, cell hydration, and damage to cell walls. Rapid freezing is advantageous for freezing of many foods, however some products are susceptible to cracking when exposed to extremely low temperature for long periods. Several mechanisms, including volume expansion, contraction and expansion, and building of internal pressure, are proposed in literature explaining the mechanisms of product damage during freezing.

Energy requirements

For fruits and vegetables, the amount of energy required for freezing is calculated based on the enthalpy change and the amount of product to be frozen. The following equation is reported by Riedel for calculation of refrigeration requirements for fruits and vegetables.

$$\Delta H = \left[1 - \frac{X_{SNJ}}{100}\right] \Delta H_j + 1.21 \left[\frac{X_{SNJ}}{100}\right] \Delta T \quad (3)$$

x_{SNJ}: Percentage of the product solids different from juice

DHj: Enthalpy change during freezing of the juice fraction

DT: Temperature difference between initial and final temperature of the product

Refrigeration

Refrigeration is defined as the elimination of heat from a material at a temperature higher than the temperature of its surroundings. The mechanism of refrigeration is a part of the freezing process and freezing storage involved in the thermodynamic aspects of freezing. According to the second law of thermodynamics, heat only flows from higher to lower temperatures. Therefore, in order to raise the heat from a lower to a higher temperature level, expenditure of work is needed. The aim of industrial refrigeration processes is to eliminate heat from low temperature points towards points with higher temperature. For this reason, either closed mechanical refrigeration cycles in which refrigeration fluids circulate, or open cryogenic systems with liquid nitrogen (LIN) or carbon dioxide (CO_2), are commonly used by the food industry.

The main elements in a closed mechanical refrigeration system are the condenser, compressor, evaporator, and the expansion valve. The refrigerants hydrochlorofluorocarbon (HCFC) and ammonia are examples of the refrigerants circulated in these types of mechanical refrigeration systems.

Starting at the suction point of the compressor, fluid in a vapor state is compressed into the compressor where an increase in temperature and pressure takes place. The fluid then flows through the condenser where it decreases in energy by giving off heat and converting to a liquid state. After the phase, a change occurs inside the condenser, the fluid flows through the expansion valve where the pressure decreases to convert liquid into a form of liquid-gas mixture. Finally, the liquid-gas mixture flows through the evaporator where it is converted into a saturated vapor state and removes heat from the environment in the process of cooling. With this last stage the loop restarts again.

The other refrigeration system employed by the food industry is the cryogenic system with carbon dioxide or liquid nitrogen. The refrigerant in this system is consumed differently from the circulating fluid in closed mechanical systems.

Refrigerants

There are several refrigerants available for refrigeration systems. The selection of a proper refrigerant is based on physical, thermodynamic, and chemical properties of the fluid. Environmental considerations are also important in refrigerant selection, since leaks within the system produce deleterious effects on the atmospheric ozone layer. Some refrigerants, including halocarbons, have been banned to avoid potential hazardous effects. For industrial applications, ammonia is commonly used, while chlorofluoromethane and tetrafluoroethane are also recommended as refrigerants.

Freezing Capacity

Freezing equipment selection is based on the requirements for freezing a certain quantity of food per hour. For any type of freezer, freezing capacity is defined as the ratio of the quantity of the product that can be loaded into the freezer to the holding time of the product in that particular freezer. The first parameter, the amount of food product loaded into the freezer, is affected by both the dimensions of the product and the mechanical constraints of the freezer. The denominator has an important role in freezing systems and is based on the calculation of the amount of heat removed from the product per hour, which varies depending on the type of product frozen.

Freezing Systems

There is a variety of freezing systems available for freezing, and for most products, more than one type of freezer can be used. Therefore, in selecting a freezing system initially, a cost-benefit analysis should be conducted based on three important factors: economics, functionality, and feasibility. Financial considerations mainly involve capital investment and the production cost of selected equipment. Product losses during freezing operation should be included in cost estimation since generating higher cost freezers may have other benefits in terms of reducing product losses. Functional factors are mostly based on the suitability of the selected freezer for particular products. The mode of process, either in-line or batch, should be considered based on the fact that computerised systems are becoming more important for ease of handling and lowering production costs. Mechanical constraints for the freezer should also be considered since some types of freezers are not physically suitable for freezing certain products. Lastly, the feasibility of the process should be considered in terms of plant location or location of the processing area, as well as cleanability and hygienic design, and desired product quality.

These factors and initial considerations can help eliminate several choices in freezer selection, but the relative importance of factors may change depending on the process. For developing countries where the freezing application is relatively new, the cost factor becomes more important than other factors due to the decreased production rates and need for lower capital investment costs.

FREEZING EQUIPMENT

The industrial equipment for freezing can be categorised in many ways, namely as equipment used for batch or in-line operation, heat transfer systems (air, contact, cryogenic), and product stability. The rate of heat transfer from the freezing medium to the product is important in defining the freezing time of the product. Therefore, the equipment selected for freezing process characterises the rate of freezing.

Air-blast Freezers

The air blast freezer is one the oldest and commonly used freezing equipment due to its temperature stability and versatility for several product types. In general, air is used as the freezing medium in the freezing design, either as still air or forced air. Freezing is accomplished by placing the food in freezing rooms called sharp freezers. Still, air freezing is the cheapest way of freezing and has the added advantage of a constant temperature during frozen storage, which allows usage for unprocessed bulk products like beef quarters and fish. However, it is the slowest method of freezing due to the low surface heat transfer coefficient of circulating air inside the room.

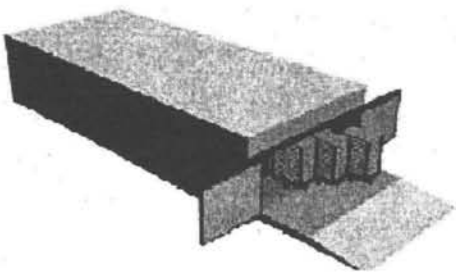

Figure 1. Air blast freezer

Freezing time in sharp freezers is largely dependent on the temperature of the freezing chamber and the type, initial temperature, and size of product. An improved version of the still air freezer is the forced air freezer, which consists of air circulation by convection inside the freezing room. However, even modification of the sharp freezer with extra refrigeration capacity and fans for increased air circulation does not help control the air flow over the products during slow freezing.

There are a considerable number of designs and arrangements for air blast freezers, primarily grouped in two categories depending on the mode of process, as either inline or batch. Continuous freezers are the most suitable systems for mass production of packaged products with similar freezing times, in which the product is carried through on trucks or on conveyors. The system works on a semi-batch principle when trucks are used, since they remain stationary during the process except when a new truck enters one end of the tunnel, thus moving the others along to release a finished one at the exit. The batch freezers are more flexible since a variety of products can be frozen at the same time on individual trolleys. Over-loading may be a problem for these types of freezers, thus the process requires closer supervision than continuous systems.

Tunnel freezers

In tunnel freezers, the products on trays are placed in racks or trolleys and frozen with cold air circulation inside the tunnel. In order to allow air circulation, optimum space is provided between layers of trolley, which can be moved continuously in and out of the freezer manually or by forklift trucks.

Figure 2. Trolley in a tunnel freezer

This freezing system is suitable for all types of products, although there are some mechanical constraints including the requirement of high manpower for handling, cleaning, and transportation of trays.

Belt Freezers

Belt freezers were first designed to provide continuous product flow with the help of a wire mesh conveyor inside the blast rooms. A poor heat transfer mechanism and the mechanical problems were solved in modern belt freezers by providing a vertical airflow to force air through the product layer. Airflow has good contact with the product only when the entire product is evenly distributed over the conveyor belt. In order to decrease required floor space, the belts can be arranged in a multi-tier belt freezer or a spiral belt freezer. Spiral belt freezers consist of a belt that can be bent laterally around a rotating drum to maximise belt surface area in a given floor space. This type of design has the advantage of eliminating product damage in transfer points, especially for products that require gentle handling. Both packed and unpacked products with long freezing times (10 min to 3 hr) can be frozen in spiral belt freezers due to the flexibility of the equipment.

Fluidised Bed Freezers

The fluidised bed freezer, a fairly recent modified type of air-blast freezer for particular product types, consists of a bed with a perforated bottom through which cold air is blown vertically upwards.

The system relies on forced cold air from beneath the conveyor belt, causing the products to suspend or float in the cold air stream. The use of high air velocity is very effective for freezing unpacked foods, especially when they can be completely surrounded by flowing air, as in the case of fluidised bed freezers.

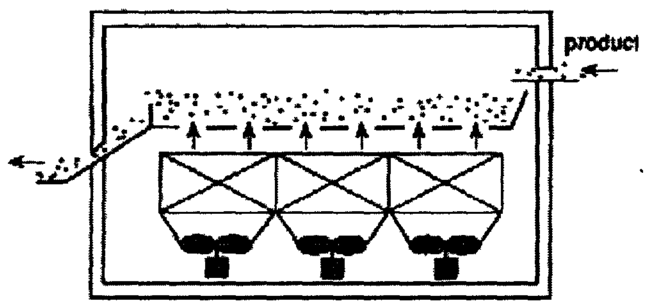

Figure 3. Simple working principle of a fluidized bed freezer

The use of fluidisation has several advantages compared with other methods of freezing since the product is individually quick frozen (IQF), which is convenient for particles with a tendency to stick together. The idea of individually quick frozen foods (IQF) started with the first technological developments aimed at quick freezing. The need for an effective means of freezing small particles with the potential for lumping during the process is the objective of IQF freezing. Small vegetables, prawns, shrimp, french-fried potatoes, diced meat, and fruits are some of the products now frozen with this technology.

Contact Freezers

Contact freezing is the one of the most efficient ways of freezing in terms of heat transfer mechanism. In the process of freezing, the product can be in direct or indirect contact with the freezing medium. For direct contact freezers, the product being frozen is fully surrounded by the freezing medium, the refrigerant, maximising the heat transfer efficiency. A schematic illustration is given in Figure 4. For indirect contact freezers, the product is indirectly exposed to the freezing medium while in contact with the belt or plate, which is in contact with the freezing medium.

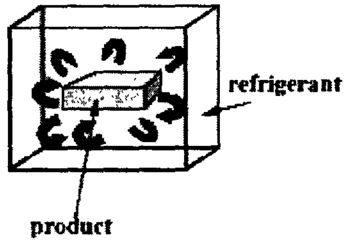

Figure 4. Direct contact freezer

Immersion Freezers

The immersion freezer consists of a tank with a cooled freezing media, such as glycol, glycerol, sodium chloride, calcium chloride, and mixtures of salt and sugar. The product is immersed in this solution or sprayed while being conveyed through the freezer, resulting in fast temperature reduction through direct heat exchange. Direct immersion of a product into a liquid refrigerant is the most rapid way of freezing since liquids have better heat conducting properties than air. The solute used in the freezing system should be safe without taste, odour, colour, or flavour, and for successful freezing, products should be greater in density than the solution. Immersion freezing systems have been commonly used for shell freezing of large particles due to the reducing ability of product dehydration when the outer layer is frozen quickly. A commonly seen problem in these freezing systems is the dilution of solution with the product, which can change the concentration and process parameters. Thus, in order to avoid product contact with the liquid refrigerant, flexible membranes can be used.

Indirect contact freezers

In this type of freezer, materials being frozen are separated from the refrigerant by a conducting material, usually a steel plate. Indirect contact freezers generally provide an efficient medium for heat transfer, although the system has some limitations, especially when used for packaged foods due to resistance of package to heat transfer. Additionally, corrosive effects may occur due to interaction of metal packages with heat transfer surfaces.

Plate freezers

The most common type of contact freezer is the plate freezer. In this case, the product is pressed between hallow metal plates, either horizontally or vertically, with a refrigerant circulating inside the plates.

Contact belt freezers

This type of freezer is designed with single-band or double-band for freezing of thin product layers. The design can be either straight forward or drum. Typical products frozen in belt freezers are, fruit pulps, egg yolk, sauces and soups.

Cryogenic freezers

Cryogenic freezing is a relatively new method of freezing in which the food is exposed to an atmosphere below -60 °C through direct contact with liquefied gases such as nitrogen or carbon dioxide. This type of system differs from other freezing systems since it is not connected to a refrigeration plant; the refrigerants used are liquefied in large industrial installations and shipped to the food-freezing factory in pressure vessels. Thus, the small size and mobility of cryogenic freezers allow for flexibility in design and efficiency of the freezing application. Low initial investment and rather high operating costs are typical for cryogenic freezers.

Liquid Nitrogen freezers

Liquid nitrogen, with a boiling temperature of -196 °C at atmospheric pressure, is a by-product of oxygen manufacture. The refrigerant is sprayed into the freezer and evaporates both on leaving the spray nozzles and on contact with the products. The system is designed in a way that the refrigerant passes in counter current to the movement of the products on the belt giving high transfer efficiency. The refrigerant consumption is in the range of 1.2-kg refrigerant per kg of the product. Typical food products used in this system are, fish fillets, seafood, fruits, berries.

Liquid carbon dioxide freezers

Liquid carbon dioxide exists as either a solid or gas when stored at atmospheric pressure. When the gas is released to the atmosphere at -70 °C, half of the gas becomes dry-ice snow and the other half stays in the form of vapor. This unusual property of liquid carbon dioxide is used in a variety of freezing systems, one of which is a pre-freezing treatment before the product is exposed to nitrogen spray.

Packaging

Proper packaging of frozen food is important to protect the product from contamination and damage while in transit from the manufacturer to the consumer, as well as to preserve food value, flavour, colour, and texture. There are several factors considered in designing a suitable package for a frozen food. The package should be attractive to the consumer, protected from external contamination, and effective in terms of processing, handling, and cost. Proper selection is based on the type of package and material. There are typically three types of packaging used for frozen foods: primary, secondary, and tertiary. The primary package is in direct contact with the food and the food is kept inside the package up to the time of use. Secondary packaging is a form of multiple packaging used to handle packages together for sale. Tertiary packaging is used for bulk transportation of products.

Packaging materials should be moisture-vapor-proof to prevent evaporation, thus retaining the highest quality in frozen foods. Oxygen should also be completely evacuated from the package using a vacuum or gas-flush system to prevent migration of moisture and oxygen. Glass and rigid plastic are examples of moisture-vapor-proof packaging materials. Many packaging materials, however, are not moisture-vapor-proof, but are sufficiently moisture-vapor-resistant to retain satisfactory quality in foods. Most bags, wrapping materials, and waxed cartons used in freezing packaging are moisture-vapor-resistant. In general, the containers should be leakage free while easy to seal. Durability of the material is another important factor to consider, since the packaging material must not become brittle at low temperatures and crack.

A range of different packaging materials, mainly grouped as rigid and non-rigid containers, can be used for primary packaging. Glass, plastic, tin, and heavily waxed cardboard materials are in the rigid container group and usually used for packaging of liquid food products. Glass containers are mostly used for fruits and vegetables if they are not water-packed. Plastics are the derivatives of the oil-cracking industry. Non-rigid containers include bags and sheets made of moisture-vapor-resistant heavy aluminum foil, polyethylene or laminated papers. Bags are the most commonly used packaging materials for frozen fruits and vegetables due to their flexibility during processing and handling. They can be used with or without outer cardboard cartons to protect against tearing.

Shape and size of the container are also important factors in freezing products. Serving size may vary depending on the type of product and selection should be based on the amount of food determined for one meal. For shape of the container, freezer space must be considered since rigid containers with flat tops and bottoms stack well in the freezer, while round containers waste freezer space.

Frozen Storage and Distribution

The quality of the final product depends on the history of the raw material. Using the lowest possible temperature is essential for frozen storage, transport, and distribution in achieving a high-quality product, since deteriorative processes are mainly temperature dependent. The lower the product temperature is, the slower the speed of reaction is leading to loss of quality. The temperatures of supply chains in freezing applications from the factory to the retail cabinet should be carefully monitored. The temperature regime covering the freezing process, the cold-store temperatures (£ -18 °C), distribution temperatures (£ -15 °C), and retail display (£ -12 °C) are given as legal standards.

FREEZING FRUITS AND VEGETABLES IN SMALL SCALE OPERATIONS

The preservation of fruits and vegetables by freezing is one of the most important methods for retaining high quality in agricultural products over long-term storage. In particular, the freshness qualities of raw fruits and vegetables can be retained for long periods, extending well beyond the normal season of most horticultural crops. The potential application of freezing preservation of fruits and vegetables, including tropical products, has been increasing recently in parallel with developments in developing countries.

Freezing Fruits

The effect of freezing, frozen storage, and thawing on fruit quality has been investigated over several decades. Today frozen fruits constitute a large and important food group. The quality demanded in frozen fruit products is mostly based on the intended use of the product. If the fruit is to be eaten without any further processing after thawing, texture characteristics are more important when compared to use as a raw material in other industries. In general, conventional methods of freezing tend to destroy the turgidity of living cells in fruit tissue. Different from vegetables, fruits do not have a fibrous structure that can resist this destructive effect. Additionally, fruits to be frozen are harvested in a fully ripe state and are soft in texture. On the contrary, a great number of vegetables are frozen in an immature state. Fruits have delicate flavours that are easily damaged or changed by heat, indicating they are best eaten when raw and decrease in quality with processing. In the same way, attractive colour is important for frozen fruits. Chemical treatments or additives are often used to inactivate the deteriorative enzymes in fruits. Therefore, proper processing is essential for all steps involved, from harvesting to packaging and distribution.

Production and harvesting

The characteristics of raw materials are of primary importance in determining the quality of the frozen product. These characteristics include several factors such as genetic makeup, climate of the growing area, type of fertilisation, and maturity of harvest.

The ability to withstand rough handling, resistance to virus diseases, molds, uniformity in ripening, and yield are some of the important characteristics of fruits in terms of economical aspects considered in production. The use of mechanical harvesting generally causes bruising of fruits and results in a wide range of maturity levels for fruits.

In contrast, hand-picking provides gentler handling and maturity sorting of fruits. However in most cases, it is non-economical compared to mechanical harvesting due to high labor cost.

As a rule, harvesting of fruits at an optimum level for commercial use is difficult. Simple tests like pressure tests are applied to determine when a fruit has reached optimum maturity for harvest. Colour is also one of the characteristics used in determining maturity since increased maturation causes a darker colour in fruits. A combination of colour and pressure tests is a better way to assess maturity level for harvesting.

Controlled atmosphere storage is a common method of storage for some fruits prior to freezing. In principle, a controlled atmosphere high in carbon dioxide and low in oxygen content slows down the rate of respiration, which may extend shelf life of any respiring fruit during storage. Due to the fact that these fruits do not ripen appreciably after picking, most fruits are picked as near to eating-ripe maturity as possible.

Pre-process handling and operations

Freezing preservation of fruits can only help retain the inherent quality present initially in a product since the process does not improve the quality characteristics of raw materials. Therefore, quality level of the raw materials prior to freezing is the major consideration for successful freezing. Washing and cutting generally results in losses when applied after thawing. Thus, fruits should be prepared prior to the freezing process in terms of peeling, slicing or cutting. Freezing preservation does not require specific unit operations for cleaning, rinsing, sorting, peeling, and cutting of fruits.

Fruits that require peeling before consumption should be peeled prior to freezing. Peeling is done by scalding the fruit in hot water, steam or hot lye solutions. The effect of peeling on the quality of frozen products has been studied for several fruits, including kiwi, banana, and mango. The rate of freezing can be increased by decreasing the size of products frozen, especially for large fruits. An increase in the freezing rate results in smaller ice crystals, which decreases cellular damage in fruit tissue. Banana, tomato, mango, and kiwi are some examples of large fruits commonly cut into smaller cubes or slices prior to freezing.

The objective of blanching is to inactivate the enzymes causing detrimental changes in colour, odour, flavour, and nutritive value, but heat treatment causes loss of such characteristics in fruits. Therefore, only a few types of fruits are blanched for inactivation of enzymes prior to freezing. The loss of water-soluble minerals and vitamins during blanching should also be minimised by keeping blanching time and temperature at an optimum combination.

Effect of ingredients

Addition of sugars is an extremely important pretreatment for fruits prior to freezing since the treatment has the effect of excluding oxygen from the fruit, which helps to retain colour and appearance. Sugars when dissolved in solutions act by withdrawing water from cells by osmosis, resulting in very concentrated solutions inside the cells. The high concentration of solutes depresses the freezing point and therefore reduces the freezing within the cells, which inhibits excessive structural damage. Sugar syrups in the range of 30-60 percent sugar content are commonly used to cover the fruit completely, acting as a barrier to oxygen transmission and browning. Several experiments have shown the protective effect of sugar on flavour, odour, colour, and nutritive value during freezing, especially for frozen berries.

Packaging

Fruits exposed to oxygen are susceptible to oxidative degradation, resulting in browning and reduced storage life of products. Therefore, packaging of frozen fruits is based on excluding air from the fruit tissue. Replacement of oxygen with sugar solution or inert gas, consuming the oxygen by glucose-oxidase and/or the use of vacuum and oxygen-impermeable films are some of the methods currently employed for packaging frozen fruits. Plastic bags, plastic pots, paper bags, and cans are some of the most commonly used packaging materials (with or without oxygen removal) selected, based on penetration properties and thickness.

There are several types of fruit packs suitable for freezing: syrup pack, sugar pack, unsweetened pack, and tray pack and sugar replacement pack. The type of pack is usually selected according to the intended use for the fruit. Syrup-packed fruits are generally used for cooking purposes, while dry-packed and tray-packed fruits are good for serving raw in salads and garnishes.

Syrup pack

The proportion of sugar to water used in a syrup pack depends on the sweetness of the fruit and the taste preference of the consumer. For most fruits, 40 percent sugar syrup is recommended. Lighter syrups are lower in calories and mostly desirable for mild-flavoured fruits to prevent masking the flavour, while heavier syrups may be used for very sour fruits.

Syrup is prepared by dissolving the sugar in warm water and cooling the solution down before usage. Just enough cooled syrup is used to cover the prepared fruit after it has been settled by jarring the container. In order to keep the fruit under the syrup, a small piece of crumpled waxed paper or other water resistant wrapping material is placed on top; the fruit is pressed down into the syrup before closing, then sealed and frozen. Pectin can be used to reduce sugar content in syrups when freezing berries, cherries, and peaches. Pectin syrups are prepared by dissolving 1 box of powdered pectin with 1 cup of water. The solution is stirred and boiled for 1 minute; 1/2 cup of sugar is added and dissolved; the solution is then cooled down with the addition of cold water. Previously prepared fruit is put into a 4 to 6 quart bowl and enough pectin syrup is added to cover the fruit with a thin film. The pack is sealed and promptly frozen.

Sugar packs

In preparing a sugar pack, sugar is first sprinkled over the fruit. Then the container is agitated gently until the juice is drawn out and the sugar is dissolved. This type of pack is generally used for soft sliced fruits such as peaches, strawberries, plums, and cherries, by using sufficient syrup to cover the fruit. Some whole fruits may also be coated with sugar prior to freezing.

Unsweetened packs

Unsweetened packs can be prepared in several ways, either dry-packed, covered with water containing ascorbic acid, or packed in unsweetened juice. When water or juice is used in syrup and sugar packs, fruit is submerged by using a small piece of crumpled water-resistant material. Generally, unsweetened packs yield a lower quality product when compared with sugar packs, with the exception, some fruits such as raspberries, blueberries, scalded apples, gooseberries, currants, and cranberries maintain good quality without sugar.

Tray packs

Unsweetened packs are generally prepared by using tray packs in which a single layer of prepared fruit is spread on shallow trays, frozen, and packaged in freezer bags promptly. The fruit sections remain loose without clumping together, which offers the advantage of using frozen fruit piece by piece.

Sugar replacement packs

Artificial sweeteners can be used instead of sugar in the form of sugar substitutes. The sweet taste of sugar can be replaced by using these kinds of sweeteners, however the beneficial effects of sugar like colour protection and thick syrup can not be replaced. Fruits frozen with sugar substitutes will freeze harder and thaw more slowly than fruits preserved with sugar.

Freezing Vegetables

Freezing is often considered the simplest and most natural way of preservation for vegetables. Frozen vegetables and potatoes form a significant proportion of the market in terms of frozen food consumption. The quality of frozen vegetables depends on the quality of fresh products, since freezing does not improve product quality. Pre-process handling, from the time vegetables are picked until ready to eat, is one of the major concerns in quality retention.

The choice of the right cultivar and maturity before crop is harvested are the two most important factors affecting raw material quality. Raw material characteristics are usually related to the vegetable cultivar, crop production, crop maturity, harvesting practices, crop storage, transport, and factory reception.The choice of crop cultivars is mostly based on their suitability for frozen preservation in terms of factory yield and product quality. Some of the characteristics used as selection criteria are as follows:

- Suitability for mechanical harvesting
- Uniform maturity
- Exceptional flavour and uniform colour and desirable texture
- Resistance to diseases
- High yield

Although cultivar selection is a major factor affecting the quality of the final product, many practices in the field and factors during growth of crop can also have a significant effect on quality. Those practices include site selection for growth, nutrition of crop, and use of agricultural chemicals to control pests or diseases. The maturity assessment for harvesting is one of the most difficult parts of the production. In addition to conventional methods, new instruments and tests have been developed to predict the maturity of crops that help determining the optimum harvest time, although the maturity assessment differs according to crop variety.

At optimum maturity, physiological changes in several vegetables take place very rapidly. Thus, the determination of optimum harvesting time is critical. Some vegetables such as green peas and sweet corn only have a short period during which they are of prime quality. If harvesting is delayed beyond this point, quality deteriorates and the crop may quickly become unacceptable. Most of the vegetables are subjected to bruising during harvesting.

Vegetables at peak flavour and texture are used for freezing. Postharvest delays in handling vegetables are known to produce deterioration in flavour, texture, colour, and nutrients. Therefore, the delays between harvest and processing should be reduced to retain fresh quality prior to freezing. Cooling vegetables by cold water, air blasting, or ice will often reduce the rate of post-harvest losses sufficiently, providing extra hours of high quality retention for transporting raw material to considerable distances from the field to the processing plant.

Blanching is the exposure of the vegetables to boiling water or steam for a brief period of time to inactivate enzymes. Practically every vegetable needs to be blanched and promptly cooled prior to freezing, since heating slows or stops the enzyme action, which causes vegetables to grow and mature. After maturation, however, enzymes can cause loss in quality, flavour, colour, texture, and nutrients. If vegetables are not heated sufficiently, the enzymes will continue to be active during frozen storage and may cause the vegetables to toughen or develop off-flavours and colours. Blanching also causes wilting or softening of vegetables, making them easier to pack. It destroys some bacteria and helps remove any surface dirt.

Blanching in hot water at 70 to 105 °C has been associated with the destruction of enzyme activity. Blanching is usually carried out between 75 and 95 °C for 1 to 10 minutes, depending on the size of individual vegetable pieces. Blanched vegetables should be promptly cooled down to control and minimise the degradation of soluble and heat-labile nutrients. The enzymes used as indicators of effectiveness of the blanching treatment are peroxidase, catalase, and more recently lipoxygenase. Peroxidase inactivation is commonly used in vegetable processing, since peroxidase is easily detected and is the most heat stable of these enzymes.

Vegetables can be blanched in hot water, steam, and in the microwave. Hot water blanching is the most common way of processing vegetables. The operation time can vary depending on the intended product use. For water blanching, vegetables are put in a basket and then placed in a kettle of boiling water covered with a lid. Timing begins immediately. Steam blanching takes longer than the water method, but helps retain water-soluble nutrients such as water-soluble vitamins. For steam blanching, a single layer of vegetables is placed on a rack or in a basket at 3-5 cm above water boiling in a kettle. A tightly fitted lid is placed on the kettle and timing is started. Microwave blanching is usually recommended for small quantities of vegetables prior to freezing. Due to the non-uniform heating disadvantage of microwaves, research is still being conducted to obtain better results with microwave blanching.

There are several factors to consider in packaging frozen vegetables, which include protection from atmospheric oxygen, prevention of moisture loss, retention of flavour, and rate of heat transfer through the package. There are two basic packing methods recommended for frozen vegetables: dry pack and tray pack. In the dry pack method, the blanched and drained vegetables are put into meal-sized freezer bags and packed tightly to cut down on the amount of air in the package. Proper headspace (approximately 2 cm) is left at the top of rigid containers before closing. For freezer bags, the headspace is larger. Provision for headspace is not necessary for foods such as broccoli, asparagus, and brussels sprouts, as they do not pack tightly in containers. In the tray pack method, chilled, well-drained vegetables are placed in a single layer on shallow trays or pans. Trays are placed in a freezer until the vegetables become firm, then removed. Vegetables are filled into containers. Tray-packed foods do not freeze in a block but remain loosely distributed so that the amount needed can be poured from the container and the package reclosed.

FORMULATION AND PROCESSING OF SELECTED FROZEN FOOD PROTOTYPES

Food prototypes based on fruits and vegetables are used to demonstrate the freezing application on specific food products.

Selecting a Formulation for Mixed Fruits

One of the most common commercially frozen fruit products is mixed frozen berries. The mixtures typically contain combinations of raspberries, blackberries, blueberries, and strawberries. There is a wide range of mixtures available in the market for frozen berry combinations. Raspberries and blackberries for example, which are known to freeze well and retain their wholeness and shape, dependent on the structure of the fruit, are strongly associated with their cultivar. The processing requirements for different varieties of berries do not change significantly. Therefore, a mixture of raspberries and blackberries is chosen in this case as a fruit formulation to simplify the freezing process.

- Full-flavoured, ripe berries of like size preferably with tender skins are selected.
- Berries are sorted, washed, and drained.
- Berries are packed into containers and covered with cold 40 percent sugar syrup, with proper headspace.
- Polyethylene freezer bags are sealed and frozen.

Selecting a Formulation for Mixed Vegetables

Frozen mixed vegetables constitute a large portion of the frozen vegetable market and are now available in an ever-increasing variety of mixtures. The mixtures include three or more types of vegetables, properly prepared and blanched. The USDA standards for frozen mixed vegetables describe this item as a mixture containing three or more of the basic vegetables - beans, carrots, corn, and peas. When three vegetables are used, none of the vegetables should be more than 40 percent of the total weight; the individual percent decreases with increased number of vegetable types.

In a mixed frozen vegetable product, vegetables of different sizes are present in the mixture. Therefore, during pre-freeze treatments, especially blanching, care must be taken to be sure all vegetables are blanched properly.

Procedure for processing mixed vegetables

- A mixture of four 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 are selected.
- The vegetables are sorted, washed and peeled.
- They are cut into uniform size and blanched in hot water for 5 minutes, and immediately cooled after blanching.
- Packed and frozen.

Recommendations for the Processing Site

Initial selection of the processing site should be based on significant considerations. The design of the general processing plant has great importance in assuring quality of the final product and the effectiveness of the process. Some recommendations related to the location, and the general plant layout, are summarised in the following section.

Location

- Areas free from objectionable odours, smoke, flies, ash, and dust or other sources of contamination shall be considered in choosing the location for the food processing plant.
- Frozen food preparation plants shall be completely separate from areas used as living or sleeping quarters by solid partitions with no connecting openings.

General Plant Layout

- Product preparation and processing departments shall be of sufficient size to permit the installation of all necessary equipment with proper space for plant operations.
- The proper flow of the product shall be arranged in the plant, without backtracking, from the time raw materials are received until the frozen, packaged article is shipped from the plant.
- Raw material storage rooms and areas where pre-freezing operations (e.g., washing and peeling of fruits and vegetables, and preparation of meats) are carried out shall be separated from rooms or areas where frozen food is formulated, processed, and packaged.
- Doors connecting various rooms or openings to the outside shall be tight-fitted, solid, and kept in a closed position by self-closing devices.

- Facilities for efficient quick-freezing of the product shall be provided and conveniently located near the food processing and packaging departments. Proper freezer storage shall be provided with convenient access to the quick freezing facilities.
- A separate room for storing inedible materials such as fruit and vegetable peels, pending removal from the plant, shall be provided in a location convenient to the various preparation and processing areas. This waste storage room shall be of sufficient size to permit proper storage.
- The discharge from the exhaust system, if used, shall be located far away from fresh air inlets into the plant. Packaging and labeling material shall be stored in a separately enclosed space convenient to the packaging department.

Employees shall not be permitted to eat in food processing or packaging areas. Well located, properly ventilated dressing rooms and toilet rooms of ample size with self-closing doors shall be provided for employees.

RAW MATERIALS AND REQUIRED EQUIPMENT

The formulations given as examples are selected based on the proper illustration of the freezing process without complicated operations. Therefore, simple formulations with a reduced number of ingredients are used as food products. In the same manner, required equipment is chosen based on a reduced production rate in order to simplify the calculations.

Ingredients for the Proposed Formulations

The main ingredients in prototype fruit-based and vegetable-based formulations are as follows:

- Fruit-based formulation : Raspberry, blackberry, sugar syrup (40 percent)
- Vegetable-based formulation: Carrot, green beans, cauliflower, and onions

Freezing Equipment

Production rate is an important consideration in selection of proper equipment for the freezing operation. To simplify the process parameters of the selected prototype formulations, a lower production rate is used. 1 000 kg of frozen product (fruits or vegetables) per month was found suitable in a small-scale operation where usage of a domestic freezer is generally more convenient than an industrial freezer. Several types of domestic freezers are available on the market but the selection was based on economical considerations. Chest freezers are relatively more economical than other types of domestic freezers in terms of energy usage for small-scale operations. Considering the production rate per month and capacity, an optimum domestic freezer, the Zanussi ZCF146 chest freezer with internal volume of 414 lt, was chosen to handle freezing of the fruits and vegetables.

Processing Equipment

The equipment required in pre-freezing operations and packaging include proper kitchen utensils for washing and cutting, hot water kettles for blanching, and proper devices for packaging. In general, the highest investment cost in the freezing process is the freezer operation. The utensils are only a small percentage of the initial investment.

Frozen Storage

Following the freezing operation, frozen products are maintained in frozen storage, which is also an important step in the quality retention of frozen food products. During frozen storage, the amount of ice in the system generally remains constant for any given temperature, where the number of ice crystals decreases due to increase in average crystal size. Fluctuations in storage temperature and temperature gradient within the product cause moisture migration, relocating the water within the product and undesirable recristalisation which may afect texture and general quality. Therefore, it is important to maintain and monitor the efficiency of frozen storage for retention of high quality within the frozen products.

Cold stores are generally maintained at - 30 °C and the cost of the facility is mostly based on the size of the storage room. The main cost of a storage facility is due to the construction of the building, preparation of the site, and provision of the services. However, public cold stores also provide service for small-scale operations and are relatively less costly than private ones.

REFERENCES

Bentley, Amy. *Eating for Victory: Food Rationing and the Politics of Domesticity.*

Hauther,W. & Worth, M., 2008. *Zapped! Irradiation and the Death of Food,* Food & Water Watch Press, Washington, DC.

Mitchell, F.G., Guillon, R., R.A.. Parsons. 1972. *Commercial Cooling of Fruits and Vegetables. U.C. Extension Manual* 43, University of California, Division of Agricultural Sciences, Oakland, California 94608.

Shephard, Sue. *Pickled, Potted, and Canned: How the Art and Science of Food Preserving Changed the World.*

Zachariassen KE, Kristiansen E. 2000. "Ice nucleation and antinucleation in nature". *Cryobiology* 41 (4): 257–279.

11

Preparing Products for Market

After harvest, fruits and vegetables need to be prepared for sale. This can be undertaken on the farm or at the level of retail, wholesale or supermarket chain. Regardless of the destination, preparation for the fresh market comprises four basic key operations:

1. Removal of unmarketable material,
2. Sorting by maturity and/or size,
3. Grading,
4. Packaging.

Any working arrangement that reduces handling will lead to lower costs and will assist in reducing quality losses. Market preparation is therefore preferably carried out in the field. However, this is only really possible with tender or perishable products or small volumes for nearby markets. Products need to be transported to a packinghouse or packing shed in the following cases: for large operations, distant or demanding markets or products requiring special operations like washing, brushing, waxing, controlled ripening, refrigeration, storage or any specific type of treatment or packaging.

These two systems are not mutually exclusive. In many cases part field preparation is completed later in the packing shed. Because it is a waste of time and money to handle unmarketable units, primary selection of fruits and vegetables is always carried out in the field. In this way products with severe defects, injuries or diseases are removed.

Lettuce is an example of field preparation where a team of three workers cut, prepare and pack. For distant markets, boxes prepared in the field are delivered to packhouses for palletising, precooling, and sometimes cold storage before shipping. Mobile packing sheds provide an alternative for handling large volumes in limited time. Harvest crews feed a mobile grading and packing line. On completion of loading, the consignment is shipped to the destination market and replaced by an empty truck. In mechanised harvesting, the product is transported to the packhouse where it is prepared for the market. In many cases, harvest crews make use of an inspection line for primary selection on the field.

THE PACKHOUSE

A packinghouse allows special operations to be performed. Another advantage is that products can be prepared continuously for 24 hours regardless of the weather. With its capacity to process large volumes, farmers associations, cooperatives, or even community organisations can take advantage of these opportunities.

The size and degree of complexity of a packing shed depends on the following factors: crop(s) and volume to be processed, capital to be invested, its objectives such as handling of owner's production or to provide service to others. Packing sheds range from a straw shelter to highly automated facilities. In some cases storage rooms as well as offices for commercial sales are annexed to packing sheds.

A packhouse can be defined as a place protected from weather for both, product and personnel. It is organised in such a way that product is prepared in a centralised handling operation. To some extent, this is similar to a factory assembly line, where raw material from the field undergoes a sequence of activities resulting in the final packaged product.

Packinghouse Design

A packinghouse needs to be located close to the production area and within easy access to main roads or highways. It also needs to have one entrance to facilitate and control supply and delivery. Moreover, it needs to be large enough for future expansion or additional new facilities. Sufficient space outside is also required to avoid congestion of vehicles entering and leaving. Buildings should be designed to ensure sufficient shade during most of the day in the loading and unloading areas. They also need good ventilation in summer and protection in winter.

Packinghouses are usually built with cheap materials. However, it is important to create a comfortable environment both for produce and workers. This is because product exposed to unfavorable conditions can lead to rapid deterioration in quality. Also, uncomfortable working conditions for staff can lead to unnecessary rough handling.

A packinghouse should have adequate room for easy circulation with ramps to facilitate loading and unloading. Doors and spaces should be sufficiently large to allow the use of forklifts.The reception area should be large enough to hold product equivalent to one working day. The main reason for this is to keep the packinghouse in operation in the event of an interruption in the flow of product from the field (rain, machine breakdown, etc).

Electricity is critical for equipment, refrigeration and particularly lighting. Because packhouses usually work extended hours or even continuously during harvest time, lighting (both, intensity and quality) is critical in identifying defects on inspection tables. Lights should be below eye level to prevent glare and eyestrain. Light intensity should be around 2 000-2 500 lx for light coloured products but 4 000-5 000 for darker ones. The working area together with the whole building should have lighting. This is in order to avoid the contrasts caused by shaded areas, resulting in temporary blindness when the eyes are raised. Dull colours and non-glossy surfaces are a requirement for equipment, conveyor belts and outfits. In this way, defects are not masked because of the reflection of light. It also helps to reduce eye fatigue.

A good supply of water is important for washing product, trucks, bins and equipment, as well as for dumping. In some cases it may also be necessary for hydro cooling. Provision of an adequate waste water disposal system is as important as a good source.

Administration offices should be located on clean and quiet areas and if possible elevated. This is so that the entire operation is visible. Packinghouses should have facilities or laboratories for quality analysis.

After working out the details of the building layout, it is important to prepare a diagram for the movement of product throughout the packinghouse and activities to be undertaken for the entire operations. Handling must be minimised and movement of product should always be in one direction without crossovers. It may be possible to undertake operations concurrently, such as working simultaneously on different sizes or maturity stages.

Packinghouse Operations

Reception

Preparation and packing operations should be designed to minimise the time between harvest and delivery of the packaged product. Reception is one area where delays frequently occur and the product should be protected from the sun as much as possible. Product is normally weighed or counted before entering the plant and in some cases samples for quality analysis are taken. Records should be kept, particularly when providing a service to other producers.

Preparation for the fresh market starts with dumping onto packinghouse feeding lines. Dumping may be dry or in water. In both cases it is important to have drop decelerators to minimise injury as well as control the flow of product. Water dipping produces less bruising and can be used to move free-floating fruits. However, not all products tolerate wetting. A product with a specific density lower than water will float, but with other products salts (sodium sulfate, for example) are diluted in the water to improve floatation.

Removal of rejects

After dumping, the first operation that usually follows is the removal of unmarketable material. This is because handling of plant material that cannot be sold is costly. This is performed prior to sizing and grading. Primary selection is one of the four basic operations for market preparation carried out in the field. This step involves the removal of over mature, too small, severely damaged, deformed or rotting units.

Very small produce is usually mechanically removed by mesh screens, pre-sizing belts or chains. Bruised, rotted, off-shaped units, wilted or yellow leaves are usually removed by hand. Garlic and onions are topped to remove the dry foliage attached to the bulbs by specific equipment and in many crops soil and loose parts are removed by brushing. In crops where water dipping is possible, differential floatation could be used to separate rejects. In addition to this, detergents and brushes can be used to remove soil, latex, insects, pesticides etc. Clean fruits should be dried with sponges or hot air.

Culls as well as other plant parts from cutting, peeling, trimming, bruised and spoiled fruits can be used for animal feeding. Although they provide a good source of energy and are extremely tasty, their high water content makes them bulky and expensive to transport. In addition to this, their nutritional value is less than other food sources. This is because of their low protein and dry matter contents. Their inclusion in the diet must be in the right proportions to avoid digestive problems. Another disadvantage is that in many cases they are highly perishable and cannot be stored. This means that they cannot be gradually introduced into the animal's diet. When not used for animal feeding, they can be disposed as sanitary fillings or organic soil amendments.

Sizing

Sizing is another basic operation undertaken in a packhouse and can be carried out before or after sorting by colour. Both operations should always be carried out before grading. This is because it is easier to identify units with defects on a uniform product, either in terms of size or colour.

There are two basic systems - according to weight or dimensions (diameter, length or both). Spherical or almost spherical products like grapefruits, oranges, onions, and others, are probably the easiest to sort by size. Several mechanisms are available from mesh screens to diverging belts or rollers with increased spaces between them. Sizing can also be performed manually using rings of known diameter. Sorting by weight is carried out in many crops with weight sensitive trays. These automatically move fruit onto another belt aggregating all units of the same mass.

Grading

Amongst the four basic operations, this is probably the most important. It consists of sorting product in grades or categories of quality. Two main systems exist: static and dynamic. Static systems are common in tender and/or high value crops. Here the product is placed on an inspection table where sorters remove units which do not meet the requirements for the grade or quality category. The dynamic system is probably much more common. Here product moves along a belt in front of the sorters who remove units with defects. Main flow is the highest quality grade. Often second and third grade quality units are removed and placed onto other belts. It is much more efficient in terms of volume sorted per unit of time. However, personnel should be well trained. This is because every unit remains only a few seconds in the worker's area of vision. There are two types of common mistakes: removing good quality units from the main flow and more frequently, not removing produce of doubtful quality.

Rejects mainly on aesthetic grounds provide a second or even third quality grade. These can be marketed in less demanding outlets or used as raw material for processing.

Small scale processing, however, needs to be able to achieve a standard of quality similar or even better than large industries. This is not always possible because industrial plants tend to use specific varieties and processes. In addition to this, surpluses for the fresh market and sub-standard products do not provide uniform raw material. The industrial yield is low and this together with the low technology in the manufacturing process can result in a product of variable quality. At this point, it is important to highlight that the quality of a processed product will depend both upon, the quality of the raw material and the manufacturing process.

Special operations

These operations are commodity specific. They are different from basic operations because they are carried out on every crop independent of size and sophistication of the packinghouse.

Colour sorting

These are common in fruits and fruit vegetables and can be undertaken electronically. Fruits are usually harvested within a range of maturity that needs to be uniform for sale. Harvesting within a narrow range of maturity reduces colour sorting. However, this is only possible for low-volume operations.

Waxing

Some fruits such as apples, cucumbers, citrus, peaches, nectarines and others, are waxed for the following reasons: to reduce dehydration, improve their postharvest life by replacing the natural waxes removed by washing and to seal small wounds produced during handling. Waxes are also used as carriers of some fungicides or just to increase shine and improve appearance. Different types and formulae of waxes are available.

These can be applied as sprays or foams, or by immersion and dripping or in other ways. Uniform distribution is important. Soft brushes, rollers or other methods are used to ensure that application on the surface of fruit is thorough and texture is even. Heavy application can block fruit gas exchange and produce tissue asphyxia. Internal darkening and development of off-flavors and off-odors are some of the characteristics. It is very important that waxes are approved for human consumption.

Degreening

The main causes of greening are climatic conditions before harvest. For example, citrus often reaches commercial maturity with traces of green colour on the epidermis (flavedo). Although not different from fruits with colour, consumers sense that they are not ripe enough and have not reached their full flavor. Degreening consists of chlorophyll degradation to allow the expression of natural pigments masked by the green colour. In purpose built chambers, citrus fruits are exposed from 24 to 72 hours (depending on degree of greening) to an atmosphere containing ethylene (5-10 ppm) under controlled ventilation and high relative humidity (90-95%). Conditions for degreening are specific to the production area. Artés Calero recommends temperatures of 25-26 °C for oranges, 22-24 °C for grapefruit and lemon and 20-23 °C for mandarins.

Controlled ripening

Maturity at harvest is the key factor for quality and postharvest life. When shipped to distant markets, fruits need to be harvested slightly immature to reduce bruising and losses during transport. Prior to distribution and retail sales, however, it is necessary to speed up and achieve uniform ripening. The main reason for this is so that product reaches consumers at the right stage of maturity. As with degreening, ethylene is used but at higher concentrations. Banana provides a typical example of this type of operation. It can however, also be carried out on tomatoes, melons, avocados, mangoes and other fruits (Table 1).

Table 1. Conditions for controlled ripening of some fruits.

	Ethylene concentration (ppm)	*Ripening temperature °C*	*Exposure time to these conditions (hr.)*
Avocado	10-100	15-18	12-48
Banana	100-150	15-18	24
Honeydew melon	100-150	20-25	18-24
Kiwifruit	10-100	0-20	12-24
Mango	100-150	20-22	12-24
Stone fruits	10-100	13-25	12-72
Tomato	100-150	20-25	24-48

Controlled ripening is performed in purpose built rooms where temperature and relative humidity can be controlled and ethylene removed when the process has been completed. The process involves initial heating to reach the desired pulp temperature. This is followed by an injection of ethylene at the desired concentration. Under these conditions, the product is maintained for a certain amount of time followed by ventilation in order to remove accumulated gases. On completion of the treatment, the temperature is reduced to the desired level for transportation and/or storage. Ethylene concentration and exposure time are a function of temperature, which accelerates the process.

Pest and disease control

Different treatments are performed to prevent and control pests and diseases at postharvest level. Fungicides belonging to different chemical groups are widely used in citrus, apples, bananas, stone fruits and other fruits. Most have a fungistatic activity. This means that they inhibit or reduce germination of spores without complete suppression of the disease. Chlorine and sulfur dioxide are amongst those most widely used.

Chlorine is probably the most widely used sanitiser. It is used in concentrations from 50 to 200 ppm in water to reduce the number of microorganisms present on the surface of the fruit. However, it does not stop the growth of a pathogen already established. Table grapes are usually fumigated with sulfur dioxide to control postharvest diseases at a concentration of 0,5% for 20 minutes followed by ventilation. During storage, periodic (every 7-10 days) fumigations are performed in concentrations of 0.25%. During transport, pads impregnated with sodium metabisulfite can be used inside packages. These slowly generate sulfur dioxide in contact with the humidity released by fruits.

Gas fumigation is the most important method for eliminating insects, either adults, eggs, larvae or pupae. Methyl bromide was probably the most widely used fumigant for many years but it is banned in most countries. It has been replaced by temperature (high and low) treatments, controlled atmospheres, other fumigants or irradiation.

It is also possible to prevent some postharvest physiological disorders with chemical treatments. For example, calcium chloride (4-6%) dips or sprays for bitter pit in apples. Other methods include dipping or drenching fruits in chemical solutions to avoid storage scalds or other disorders. Similarly, the addition of low concentrations of 2.4-D to waxes assists in keeping citrus peduncles green.

Temperature treatments

Cold can be used in low temperature tolerant fruits (apples, pears, kiwifruit, table grapes, etc.) and other potential carriers of quarantine pests and/or their ovipositions. Exposure to any of the following combinations of temperatures and time is provided in the following recommendations (Table 2).

Table 2. Combinations of temperature and exposure time for fruit fly quarantine treatments.

Time (days)	*Maximun temperature (°C)*	
	Ceratitis capitata	*Anastrepha fraterculus*
10	0,0	
11	0,6	0,0
12	1.1	
13		0.6
14	1.7	
15		1.1
16	2.2	
17		1.7

Heat treatments like hot water dips or exposure to hot air or vapor have been known for many years for insect control (and for fungi, in some cases). When restrictions were extended to bromine based fumigants, however, heat treatments were reconsidered as quarantine treatments in fruits such as mango, papaya, citrus, bananas, carambola and vegetables like pepper, eggplant, tomato, cucumber and zucchinis. Temperature, exposure and application methods are commodity specific and must be carried out precisely in order to avoid heat injuries, particularly in highly perishable crops. On completion of treatment, it is important to reduce temperature to recommended levels for storage and/or transport.

Hot water immersion requires that fruit pulp temperature is between 43 and 46,7 °C for 35 to 90 minutes. This depends on commodity, insect to be controlled and its degree of development. Dipping in hot water also contributes to reduced microbial load in plums, peaches, papaya, cantaloupes, sweet potato and tomato but does not always guarantee good insect control. For the export of mangoes from Brazil, it is recommended that dipping is performed at 12 cm depth in water at 46,1 °C and for 70-90 minutes.

Many tropical crops are exposed to hot and humid air (40-50 °C up to 8 hours) or water vapor to reach a pulp temperature which is lethal to insects. Hot air is well tolerated by mango, grapefruit, Navel oranges, carambola, persimmon and papaya. Similarly, vapor treatments have been approved by the USDA-APHIS for clementines, grapefruits, oranges, mango, pepper, eggplant, papaya, pineapple, tomatoes and zucchinis.

Sprout suppression

In potatoes, garlic, onion and other crops, sprouting and root formation accelerate deterioration. They also determine the marketability of these products. This is because consumers strongly reject sprouting or rooting products.

After development, bulbs, tubers and some root crops enter into a "rest" period. This is characterised by reduced physiological activity with non response to environmental conditions. In other words, they do not sprout even when they are placed under ideal conditions of temperature and humidity. Different studies show that during rest, endogenous sprout inhibitors like abscisic acid predominate over promoters like gibberellins, auxins and others. This balance changes with the length of storage to get into a "dormant" period. They will then sprout or form roots if placed under favorable environmental conditions. There are no clear-cut boundaries between these stages. Instead, there is a slow transition from one to the other as the balance between promoters and inhibitors change. With longer storage times, promoters predominate and sprouting takes place.

Refrigeration and controlled atmospheres reduce sprouting and rooting rates but because of their costs, chemical inhibition is preferred. In onions and garlic Maleic Hydrazide is sprayed before harvest while in potatoes CIPC (3-chloroisopropyl-Nphenylcarbamate) is applied prior to storage as dust, immersion, vapor or other forms of application. As CIPC interferes with periderm formation, it must be applied after curing is completed.

Gas treatments before storage

Different studies have shown that exposure to carbon dioxide rich atmosphere (10-40% up to week) before storage, contributes towards maintaining quality in grapefruits, clementines, avocados, nectarines, peaches, broccoli and berries. Control of insects is possible with higher concentrations (60-100%). The effect of this gas is not well understood. What is known is that it has an inhibitory effect on metabolism and ethylene action and the effect is persistent after treatment. Also, at higher concentrations (> 20%)

there is difficulty in spore germination and growing of decay organisms. Similarly, exposure to very low oxygen atmosphere (< 1%) also contributes towards preserving quality and controlling insects in oranges, nectarines, papaya, apples, sweet potatoes, cherries and peaches. Lowering oxygen concentration reduces respiratory rate and the whole metabolism.

PACKAGING

The main purpose of packaging is to ensure that the product is inside a container along with packing materials to prevent movement and to cushion the produce (plastic or moulded pulp trays, inserts, cushioning pads, etc.) and for protection (plastic films, waxed liners, etc.). It needs to satisfy three basic objectives. These are to:

1. Contain product and facilitate handling and marketing by standardising the number of units or weight inside the package.
2. Protect product from injuries (impact, compression, abrasion and wounds) and adverse environmental conditions (temperature, relative humidity) during transport, storage and marketing.
3. Provide information to buyers, such as variety, weight, number of units, selection or quality grade, producer's name, country, area of origin, etc. Recipes are frequently included such as nutritional value, bar codes or any other relevant information on traceability.

A well-designed package needs to be adapted to the conditions or specific treatments required to be undertaken on the product. For example, if hydrocooling or ice-cooling need to be undertaken, it needs to be able to tolerate wetting without losing strength; if product has a high respiratory rate, the packaging should have sufficiently large openings to allow good gas exchange; if produce dehydrates easily, the packaging should provide a good barrier against water loss, etc. Semi-permeable materials make it possible for special atmospheres inside packages to be generated. This assists in maintaining produce freshness.

Categories of Packaging

There are three types of packaging:

1. Consumer units or prepackaging
2. Transport packaging
3. Unit load packaging or pallets

When weighed product reaches the consumer in the same type of container in which it is prepared - this is described as a consumer unit or prepackaging. Normally, this contains the quantity a family consumes during a certain period of time (300 g to 1,5 Kg, depending of product). Materials normally used include moulded pulp or expanded polystyrene trays wrapped in shrinkable plastic films, plastic or paper bags, clamshells, thermoformed PVC trays, etc. Onions, potatoes, sweet potatoes etc are marketed in mesh bags of 3-5 Kg. Colours, shapes and textures of packaging materials play a role in improving appearance and attractiveness.

Transport or packaging for marketing usually consists of fiberboard or wooden boxes weighing from 5 to 20 Kg or bags can be even heavier. They need to satisfy the following requirements: be easy to handle, stackable by one person; have the appropriate dimensions so that they fit into transport vehicles and materials should be constructed with biodegradable, non-contaminating and recyclable materials. Packaging intended for repeated use should be: easy to clean and dismantle so that it is possible to significantly reduce volume on the return trip; ability to withstand the weight and handling conditions they were designed for, and meet the weight specifications or count without overfilling.

In these type of packages it is common to use packaging materials which serve as dividers and immobilise the fruit. For example, vertical inserts can be used. They also assist in reinforcing the strength of the container, particularly when large or heavy units such as melons or watermelons are packed. Trays also have the same objective but they separate produce in layers. They are common in apples, peaches, plums, nectarines, etc. Plastic foam nets are used for the individual protection of large fruits like watermelons, mango, papayas, etc. It is also possible to use paper or wood wool, papers or other loose-fill materials.

In many developing countries containers made of natural fiber are still used for the packaging of fruits and vegetables. Although cheap, they cannot be cleaned or disinfected. They therefore represent a source of contamination of microorganisms when reused. Moreover, there is a risk of bruising as a result of compression. This is because they were not designed for stacking. In addition to this, the significant variations in weight and/volume makes marketing a complex business.

Finally, pallets have become the main unit load of packaging at both domestic and international level. Their dimensions correspond to those of maritime containers, trucks, forklifts, storage facilities, etc. As unit loads they reduce handling in all the steps in the distribution chain. Different sizes exist. However, the most common size internationally is 120 x 100 cm. It is sometimes made of plastic materials. Depending on the packaging dimensions, a pallet may hold from 20 to 100 units. To ensure stability, pallet loads are secured with wide mesh plastic tension netting or a combination of corner post protectors and horizontal and vertical plastic strapping. In many cases individual packages are glued to each other with low tensile strength glue that allow separate units but prevent sliding. They are also stacked crosswise or interlocked to contribute to the load stability.

There is a trend towards standardisation of sizes. This is because of the wide variety of shapes and sizes of packaging for fruits and vegetables,. The main purpose of standardisation is to maximise utilisation of the pallet's surface based on the standard size 120 x 100 cm. The ISO (International Standards Organisation) module sets 60 and 40 cm as basic horizontal dimensions divided in subunits of 40 x 30 cm and 30 x 20 cm. There are no regulations regarding the height of individual packages. However, the palletised load should not exceed 2.05 m to ensure safe handling. The trend towards the use of non-returnable containers poses an environmental challenge. To reduce the impact, packages need to be designed to meet their functional objectives, with minimal wastage of materials and need to be recyclable, after their main functional use.

REFERENCES

Humphery, Kim. *Shelf Life: Supermarkets and the Changing Cultures of Consumption.* Cambridge University Press, 1998.

Regmi, Anita (editor).*Changing Structure of Global Food Consumption and Trade.* Market and Trade Economics Division, Economic Research Service, USDA, 2001.

Smith, Andrew (Editor). "Food Marketing," in Oxford Encyclopedia of American Food and Drink, , New York: Oxford University Press, 2007.

The Economic Research Service of the USDA. *Global Food Markets: Briefing Rooms.* Retrieved from http:/ /www.ers.usda.gov/Briefing/ on 2006-09-29.

12

Prevention of Post-harvest Losses

Time and money are required to cultivate food products, and unless the farmer is providing food only for his own household, he automatically becomes part of the market economy: he must sell his produce, he must recover his costs, and he must make a profit. Estimates of the post-harvest losses of food grains in the developing world from mishandling, spoilage and pest infestation are put at 25 percent; this means that one-quarter of what is produced never reaches the consumer for whom it was grown, and the effort and money required to produce it are lost-forever. Fruit, vegetables and root crops are much less hardy and are mostly quickly perishable, and if care is not taken in their harvesting, handling and transport, they will soon decay and become unfit for human consumption. Estimates of production losses in developing countries are hard to judge, but some authorities put losses of sweet potatoes, plantain, tomatoes, bananas and citrus fruit sometimes as high as so percent, or half of what is grown. Reduction in this wastage, particularly if it can economically be avoided, would be of great significance to growers and consumers alike.

CAUSES OF POST-HARVEST FOOD LOSSES

Factors affecting post-harvest food losses of perishables vary widely from place to place and become more and more complex as systems of marketing become more complex. A farmer who is growing fruit for his family's consumption probably doesn't mind if his produce has a few blemishes and bruises. If he is producing for a market at any distance from his own locality, however, he and his workers, if he has any, must have a different attitude if he hopes to get the best money return on his work.

By knowing his market, the grower can and must judge how important are the requirements of appearance, maturity and flavour for his produce. Furthermore, the grower must decide whether the investment in packaging will in fact pay for itself in increased value of the crop. It will be of no value to buy expensive containers for his produce if the field hands pitch them around and damage the contents. It is more important for the grower to change the attitude of himself and his workers toward reducing post-harvest losses than it is for him to think that buying fancy packaging will automatically solve his problems and improve his income. The farmer must give careful attention to:

- Market demand for the products he will grow; he must know the market and his buyers
- Cultivation
- Harvesting and field handling
- Packing or packaging
- Transport
- Market handling; possibly storage or refrigeration
- Sales to consumers, wholesalers or agents
- Perishability of the produce.

The following sections will discuss these among other factors. The grower must recognise that small changes in attitudes toward the prevention of post-harvest food losses may profit him more than changes in the techniques of the marketing chain, whether containers or transport improvements, and may cost him less in the long run. He must instruct his family, field workers, and others in the methods of reducing his losses.

CONTRIBUTION OF FRESH PRODUCE TO HUMAN NUTRITION

Most people eat a mixed diet of foods from plants and animals. In most societies, starchy staple foods, particularly cereal grains, are the main source of energy in the human diet. In certain areas, especially in the humid tropics, root and tuber crops, together with plantains and similar plants, are either the staple food or a supplement to cereal staples.

Fruit and vegetables are important sources of essential minerals and vitamins in the human diet. When eaten together with some root (potato, sweet potato) and leguminous (pigeon peas, beans, lentils) crops, they provide a proportion of protein requirements as well as variety in flavour and colour.

Energy Requirements

- Starches and sugars, formed within the plant for its own use, are used as energy foods. Starch is the main component of root and tuber crops and also of plantains and green bananas.
- Oils and fats are also energy foods. Fresh produce contains only small amounts except for avocados, which contain 15-25 percent oil.

Food for Body Growth and Repair

- Proteins are essential to the building and repair of muscles and organs. They are needed in large amounts by growing children. Fresh produce is low in protein content, although on a dry-weight basis some root crops such as sweet potato and potato as well as leaves of several crops have protein contents approaching that of animal products. Cassava has very low protein content.
- Minerals are required for health but only in small amounts as compared with energy foods and proteins. Sodium, potassium, iron, calcium, phosphorus and many trace elements are essential. Vegetables contain significant amounts of calcium, iron and some other minerals.
- Vitamins are essential for the control of chemical reactions in the body. Fruit and vegetables, and to a lesser extent root crops, are important sources of vitamin C and other essentials. Table 1 lists the important vitamins derived from fresh produce.
- Fibre or "roughage" is found in large amounts in fresh produce. Though indigestible, it plays an important part in the function of digestion, and a diet containing high fibre content is shown by medical studies to reduce susceptibility to disease.

Loss of Food Value in Fresh Produce

The keeping and the preparation of fresh produce after harvest affects its nutritional value in several ways, for example:

- Dry-matter content is reduced with time as the continuation of living processes within the produce uses up stored food reserves.
- Vitamin C content decreases with time after harvest, and little may remain after two or three days.
- Cooking partially destroys vitamins C and B1. Raw fruit and vegetables are particularly valuable provided they are grown and handled hygienically.
- Peeling may cause significant loss of food value, especially in potatoes, where the protein content is just beneath the skin.
- Water used in cooking vegetables or fruit contains the dissolved minerals and trace elements of the food and should not be thrown out but used in soups or in preparing other foods.

Further information on the food value of fresh produce can usually be obtained at national nutritional councils or departments of health.

Table 1. Vitamins supplied by fruit, vegetables and root crops

Vitamin	*Name*	*Source*
A	Retinol	From carotene in dark green leaves, tomatoes, carrots, papayas
B1	Thiamine	Pulses, green vegetables, fruit (cereal grains have B. in germ and outer-seed coat)
B2	Riboflavin	Green leafy vegetables and pulses
B6	Pyridoxin	Bananas, peanuts
PP	Niacin (nicotinic acid)	Pulses, peanuts
-	Folic acid	Dark green leaves, broccoli, spinach, beets, cabbage, lettuce, avocados
C	Ascorbic acid	Dark green leaves, spinach, cauliflower, sweet pepper, citrus, guava, mango, papaya

PRE-HARVEST FACTORS IN PRODUCE MARKETING

The overall quality and condition of fresh produce cannot be improved after harvest. The final potential market value of his produce depends on the grower's decisions on what and when to plant and on the subsequent cultivating and harvesting practices. Growers in general rely on their own experience and local traditions in selecting crops and in cultivation practices, but if they want or need assistance they may need to be referred to agricultural extension officers or possibly to research and development specialists of their national department of agriculture or its equivalent.

Market Factors for the Produce

Market factors affecting farmers' decisions on the growing of specific crops are:

- potential purchasers for the produce: neighbours, townspeople, retailers, jobbers or middlemen, commission agents?
- quality requirements of the buyer: size, shape, maturity, appearance, perishability of the produce;
- pricing limitations of the buyer.

A commodity can be "too good" as well as "too bad": one that greatly exceeds market requirements may not bring higher prices and thus be a waste of labour and resources.

An important limitation of most markets is that only certain varieties of a commodity are traded and others are unacceptable. In Indonesia, for example, 242 varieties of mango have been recorded by the Agricultural Seed Experiment Station in East Java, but only seven have any commercial potential beyond certain villages. The non-marketable mangos, however, constitute about 70 percent of the total production, and the local grower can effectively increase his market share only by replacing existing trees with those of the desirable varieties. In international trade, this specification of variety is of critical importance. Countries wishing to export have little choice but to offer what will be bought by importing countries. This holds true among developing countries. For example, the Association of South East Asian Nations (ASEAN) has consciously promoted trade in fruit and vegetables, many of which are common in the various countries, but there are still distinct preferences for different cultivars between countries.

New varieties are not easily introduced into developing countries and established as profitable crops. Apart from physical conditions and cultivation practices, problems may include the overcoming of traditional human conservatism unless there are compelling economic incentives.

Influence of Production Practices

Pre-harvest production practices may seriously affect post-harvest returns in quality and quantity and result in the rejection or downgrading of produce at the time of sale. Some of them are:

Water supply (Irrigation). Growing plants need a continuous water supply for both photosynthesis (the process by which plants convert light to chemical energy and produce carbohydrates from carbon dioxide and water) and transpiration (the giving off by a plant of vapour containing waste products). Bad effects can be caused by:

- too much rain or irrigation, which can lead to brittle and easily damaged leafy vegetables and to increased tendency to decay;
- lack of rain or irrigation, which can lead to low juice content and thick skin in citrus fruit;
- dry conditions followed by rain or irrigation, which can give rise to growth cracks or secondary growth in potatoes or to growth cracks in tomatoes.

Soil fertility, use of fertilisers. Lack of plant foods in the soil can seriously affect the quality of fresh produce at harvest. On the other hand, too much fertiliser can harm the development and post-harvest condition of produce. Some of the effects are:

- lack of nitrogen can lead to stunted growth or to the yellow-red discoloration of leaves in green vegetables, e.g. cabbage;
- lack of potash can bring about poor fruit development and abnormal ripening;
- calcium-moisture imbalance can cause blossom-end rot in tomatoes and bitter pit in apples;
- boron deficiency can lead to lumpiness in papaya; hollow stem in cabbage and cauliflower; the cracking of outer skin in beets.

These are a few of the commoner soil-nutrition problems that can be readily identified at harvest. The problem of fertiliser balance in soils and its effect on crops is complex and depends also on other conditions such as temperature, moisture, acidity of the soil and reactions among different fertiliser chemicals. Severe soil-nutrition problems need reference to specialist advice, if available.

Cultivation practices. Good crop husbandry is important in achieving good yields and quality of fresh produce. Certain aspects are particularly important, such as:

- weed control-weeds are commonly alternate or alternative hosts for crop diseases and pests, and those growing in fallow land near crops are as important as those growing among the crop. Weeds also compete with crops for nutrients and soil moisture;
- crop hygiene-decaying plant residues, dead wood, and decaying or mummified fruit are all reservoirs of infection causing post-harvest decay. Their collection and removal are crucial factors in the reduction of post-harvest losses.

Agricultural chemicals. These are of two types:

- Pesticides and herbicides are used as sprays or soil applications to control weeds, disease and insect pests. They are dangerous because they can damage produce by producing spray burns if used incorrectly, and they can leave poisonous residues on produce after harvest. In most countries there are laws to control the use of pesticides, which should be used only in recommended concentrations. Strict observance of the recommended delay between the last spraying and the harvesting is required in order to keep poisonous spray residues from reaching the consumer. Advice on regulations should come from extension or other agricultural department officers.
- Growth-regulating chemicals are used in the field mainly to improve the marketability of fruit in order to control the time of fruit set and to promote uniform ripening. They are of little importance to small-scale production. Their effective use requires specialist knowledge, and they are mainly applicable to large-scale commercial production.

A critical time for growers of fruit and vegetables is the period of decision on when to harvest a crop. Normally any type of fresh produce is ready for harvest when it has developed to the ideal condition for consumption. This condition is usually referred to as harvest maturity. Confusion may arise because of the word maturity since, in the botanical sense, this refers to the time when the plant has completed its active growth and arrived at the stage of flowering and seed production. Harvest maturity thus refers to the time when the "fruit" is ready to harvest and must take into account the time required to reach market and how it will be managed en route. This time lag usually means that it is harvested earlier than its ideal maturity.

Most growers decide when to harvest by looking and sampling. Judgements are based on:

- Sight-colour, size and shape
- Touch-texture, hardness or softness
- Smell-odour or aroma
- Taste-sweetness, sourness, bitterness
- Resonance-sound when tapped.

Experience is the best guide for this kind of assessment. Newcomers to fresh produce-growing may find that learning takes time. Harvest maturity can readily be observed in some crops: bulb onions when their green tops collapse and potatoes when the green tops die off. Other crops can be more difficult: avocados remain unripe off the tree after maturity.

Large-scale commercial growers combine observation with more sophisticated measurement:

- time-recording, from flowering to harvest;
- environmental conditions, measuring accumulated heat units during the growth period;
- physical properties, including shape, size, specific gravity, weight, skin thickness, hardness, etc.;
- chemical properties (important in fruit processing, less so in vegetables), sugar/acid ratio, soluble solids content, starch and oil content;
- physiological characteristics, including respiration rate, acidity or alkalinity (pH).

The final decision on harvesting will take account of the current market value of the expected yield, and also the time during which the crop will remain in marketable condition. With seasonal crops, growers are often tempted to harvest too early or too late in order to benefit from higher prices at the beginning and end of the season.

Perishability and Produce Losses

All fruits, vegetables and root crops are living plant parts containing 65 to 95 percent water, and they continue their living processes after harvest. Their post-harvest life depends on the rate at which they use up their stored food reserves and their rate of water loss. When food and water reserves are exhausted, the produce dies and decays. Anything that increases the rate of this process may make the produce inedible before it can be used. The principal causes of loss are discussed below, but in the marketing of fresh produce they all interact, and the effects of all are influenced by external conditions such as temperature and relative humidity.

Physiological Deterioration

An increase in the rate of loss because of normal physiological changes is caused by conditions that increase the rate of natural deterioration, such as high temperature, low atmospheric humidity and physical injury. Abnormal physiological deterioration occurs when fresh produce is subjected to extremes of temperature, of atmospheric modification or of contamination. This may cause unpalatable flavours, failure to ripen or other changes in the living processes of the produce, making it unfit for use.

Mechanical Damage

Careless handling of fresh produce causes internal bruising, which results in abnormal physiological damage or splitting and skin breaks, thus rapidly increasing water loss and the rate of normal physiological breakdown. Skin breaks also provide sites for infection by disease organisms causing decay.

Diseases and Pests

All living material is subject to attack by parasites. Fresh produce can become infected before or after harvest by diseases widespread in the air, soil and water. Some diseases are able to penetrate the unbroken skin of produce; others require an injury in order to cause infection. Damage so produced is probably the major cause of loss of fresh produce.

The influences of all three causes are strongly affected by the various stages of post-harvest operations, discussed below. Furthermore, they all have great effect on the marketability of the produce and the price paid for it.

TYPES OF FRESH PRODUCE

Commodities entering the trade in fresh produce include a wide variety of plant parts from a large number of plant families and species. The words fruit, vegetables and root crops have no real botanical meaning but are terms of convenience used for horticultural and domestic purposes. As commodities, however, they may be conveniently grouped in relation to the type of edible plant parts, their response to post-harvest handling and their storage characteristics.

Roots and tubers

These are underground parts of plants, adapted for the storage of food materials. They are the means by which the crop survives unfavourable seasonal conditions, and they provide the food reserve enabling the plant to make rapid growth when conditions are favourable. They include:

Edible part

- Swollen stem tuber: Irish or white potato
- Compressed stem tuber (corm): Dasheen, tannia, eddoe
- Root tuber (from fibrous root): Sweet potato
- Root tuber (from main tap-root): Carrot, turnip

In most of these, the stored food material is starch, but in some tap-root tubers, such as carrots, it is mostly sugars.

Edible flowers

Plant breeders have produced various vegetables with dense massed flower heads that can be eaten when the flowers are immature buds. These have long been popular in temperate countries but in recent years have become well-known in the tropics, where cultivars that can be grown in warm conditions or at higher altitudes have been developed. In contrast to the massed flower head, the pineapple, one of the most widely produced tropical fruits, is formed by the fusion of a mass of immature and unfertilised flowers clustered around the plant's main stalk, which becomes the core of the fruit.

Vegetative growth (leaves, stems, shoots)

These common green vegetables are important sources of minerals, vitamins and fibre (roughage) in the diet.

Reproductive structures

These are fleshy, seed-bearing structures eaten principally for their fleshy parts. They are mostly well-known fruits having a high sugar content when ripe and are normally eaten at that stage. Some, such as tomatoes and peppers, are used as salads or vegetables. In addition, some vegetables, such as immature green seed pods of some crops, are eaten before the seeds harden.

POST-HARVEST PHYSIOLOGY OF FRESH PRODUCE

Growing green plants use the energy provided by the sunlight falling on their leaves to make sugars by combining carbon dioxide gas from the air with water absorbed from the soil through the roots. This process is known as photosynthesis. The plant either stores these sugars as they are or combines the sugar units into long chains so that they form starch. The sugars and starches, known as carbohydrates, are stored in various parts of the plant and are used later to provide the energy for its further growth and reproduction. Starches are stored by root crops over the dormant period to supply the energy for renewed growth when dormancy ends. The energy for growth in both cases is released by the process of respiration, which occurs in all plant parts before and after harvest.

What is the normal pattern of activity of fresh produce after harvest? How is this activity affected by conditions after harvest, and what effect does this have on losses?

We referred earlier to physiological deterioration as one of the causes of post-harvest loss in fresh produce. The word physiology means the study of processes that go on within living things. When fresh produce is harvested, these processes of living continue, but in modified form. Because the crop can no longer replace food materials or water, it must draw on its stored reserves, and as these are used up, the produce undergoes an ageing process that is then followed by breakdown and decay. Even if produce is not damaged or attacked by decay organisms, it will eventually become unacceptable as food because of this natural rot. The principal normal physiological processes leading to ageing are respiration and transpiration.

Respiration

Respiration is the process by which plants take in oxygen and give out carbon dioxide. Oxygen from the air breaks down carbohydrates in the plant into carbon dioxide and water. This reaction produces energy in the form of heat.

Respiration is a basic reaction of all plant material, both in the field and after harvest. It is a continuing process in the growing plant as long as the leaves continue to make carbohydrates, and cannot be stopped without damage to the growing plant or harvested produce.

Fresh produce cannot replace carbohydrates or water after harvest. Respiration uses stored starch or sugar and will stop when reserves of these are exhausted; ageing follows and the produce dies and decays.

Effect of air supply on respiration

Respiration depends on a good air supply. Air contains about 20 percent of the oxygen essential to normal plant respiration, during which starch and sugars are converted to carbon dioxide and water vapour. When the air supply is restricted and the amount of available oxygen in the environment falls to about 2 percent or less, fermentation instead of respiration occurs. Fermentation breaks down sugars to alcohol and carbon dioxide, and the alcohol produced causes unpleasant flavours in produce and promotes premature ageing.

The effect of carbon dioxide on respiration

Poor ventilation of produce because of restricted air supply leads also to the accumulation of carbon dioxide around the produce. When the concentration of this gas rises to between I and 5 percent in the atmosphere, it will quickly ruin produce by causing bad flavours, internal breakdown, failure of fruit to ripen and other abnormal physiological conditions. Thus, the proper ventilation of produce is essential.

Transpiration, or the loss of water

Most fresh produce contains from 65 to 95 percent water when harvested. Within growing plants there is a constant flow of water. Liquid water is absorbed from the soil by the roots, then passed up through the stems and finally is lost from the aerial parts, especially leaves, as water vapour.

The passage of water through the plants is called the transpiration stream. It maintains the high water content of the plant, and the pressure inside the plant helps to support it. A lack of water will cause plants to wilt and perhaps to die.

The surfaces of all plant parts are covered by a waxy or corky layer of skin or bark limiting water loss. Natural water loss from the plant occurs only through tiny pores, which are most numerous on the leaves. The pores on the plant surfaces can open or close with changing atmospheric conditions to give a controlled rate of loss of water and to keep the growing parts in a firm condition.

Fresh produce continues to lose water after harvest, but unlike the growing plant it can no longer replace lost water from the soil and so must use up its water content remaining at harvest. This loss of water from fresh produce after harvest is a serious problem, causing shrinkage and loss of weight.

When the harvested produce loses 5 or 10 percent of its fresh weight, it begins to wilt and soon becomes unusable. To extend the usable life of produce, its rate of water loss must be as low as possible.

The effect of moisture content of the air on water loss

Air spaces are present inside all plants so that water and gases can pass in and out to all their parts. The air in these spaces contains water vapour, a combination of water from the transpiration stream and that produced by respiration. Water vapour inside the plant develops pressure causing it to pass out through the pores of the plant surface. The rate at which water is lost from plant parts depends on the difference between the water vapour pressure inside the plant and the pressure of water vapour in the air. To keep water loss from fresh produce as low as possible, it must be kept in a moist atmosphere.

The effect of air movement on water loss

The faster the surrounding air moves over fresh produce the quicker water is lost. Air movement through produce is essential to remove the heat of respiration, but the rate of movement must be kept as low as possible. Well-designed packaging materials and suitable stacking patterns for crates and boxes can contribute to controlled air flow through produce.

The Influence of the type of produce on water loss

The rate at which water is lost varies with the type of produce. Leafy green vegetables, especially spinach, lose water quickly because they have a thin waxy skin with many pores. Others, such as potatoes, which have a thick corky skin with few pores, have a much lower rate of water loss.

The significant factor in water loss is the ratio of the surface area of the type of plant part to its volume. The greater the surface area in relation to the volume the more rapid will be the loss of water.

Ripening of Fruits

Fleshy fruits undergo a natural stage of development known as ripening. This occurs when the fruit has ceased growing and is said to be mature. Ripeness is followed by ageing and breakdown of the fruit. The fruit referred to here includes those used as vegetables or salads, such as aubergine, sweet pepper, tomato, breadfruit and avocado.

There are two characteristic types of fruit ripening that show different patterns of respiration:

- Non-climacteric fruit ripening-refers to those fruits which ripen only while still attached to the parent plant. Their eating quality suffers if they are harvested before they are fully ripe because their sugar and acid content does not increase further. Respiration rate slows gradually during growth and after harvest. Maturation and ripening are a gradual process. Examples are: cherry, cucumber, grape, lemon, pineapple.
- Climacteric fruit ripening-refers to fruits that can be harvested when mature but before ripening has begun. These fruits may be ripened naturally or artificially. The

start of ripening is accompanied by a rapid rise in respiration rate, called the respiratory climacteric. After the climacteric, the respiration slows down as the fruit ripens and develops good eating quality. Examples are: apple, banana, melon, papaya, tomato.

In commercial fruit production and marketing, artificial ripening is used to control the rate of ripening, thus enabling transport and distribution to be carefully planned.

The effect of ethylene on post-harvest fresh produce

Ethylene gas is produced in most plant tissues and is known to be an important factor in starting off the ripening of fruits. Ethylene is important in fresh produce marketing because:

- it can be used commercially for the artificial ripening of the climacteric fruits. This has made it possible for tropical fruits such as mangoes and bananas to be harvested green and shipped to distant markets, where they are ripened under controlled conditions;
- natural ethylene production by fruits can cause problems in storage facilities. Flowers, in particular, are easily damaged by very small amounts of the gas. Ethylene destroys the green colour of plants, so lettuce and other vegetables marketed in the mature green but unripe state will be damaged if put into storage with ripening fruit;
- ethylene production is increased when fruits are injured or attacked by moulds causing decay. This can start the ripening process and result in early ripening of climacteric fruit during transport. All produce should be handled with care to avoid injuries leading to decay. Damaged or decaying produce should not be stored;
- citrus fruit grown in tropical areas remains green after becoming fully ripe on the tree. It develops full colour after harvest only if "degreened" by the use of (manufactured) ethylene gas. The gas concentration, temperature, humidity and ventilation have to be carefully controlled in specialised rooms, so degreening is economically viable only for high-value export or domestic markets. In most tropical countries fully ripe green citrus fruit is acceptable to local populations.

POST-HARVEST DAMAGE TO FRESH PRODUCE

Physical damage to fresh produce can come from a variety of causes, the most common being:

Mechanical Injury

The high moisture content and soft texture of fruit, vegetables and root crops make them susceptible to mechanical injury, which can occur at any stage from production to retail marketing because of:

- poor harvesting practices;
- unsuitable field or marketing containers and crates, which may have splintered wood, sharp edges, poor nailing or stapling;
- overpacking or underpacking of field or marketing containers;
- careless handling, such as dropping or throwing or walking on produce and packed containers during the process of grading, transport or marketing.

Injuries caused can take many forms

- splitting of fruits or roots and tubers from the impact when they are dropped;
- internal bruising, not visible externally, caused by impact;
- superficial grazing or scratches affecting the skins and outer layer of cells;
- crushing of leafy vegetables and other soft produce.

Injuries cutting through or scraping away the outer skin of produce will:

- provide entry points for moulds and bacteria causing decay;
- increase water loss from the damaged area;
- cause an increase in respiration rate and thus heat production.

Bruising injuries, which leave the skin intact and may not be visible externally cause:

- increased respiration rate and heat production;
- internal discoloration because of damaged tissues;
- off-flavours because of abnormal physiological reactions in damaged parts.

Injuries from temperature effects

All fresh produce is subject to damage when exposed to extremes of temperature. Commodities vary considerably in their temperature tolerance. Their levels of tolerance to low temperatures are of great importance where cool storage is concerned:

- Freezing injury-all produce is subject to freezing at temperatures between 0 and -2 degrees Celsius. Frozen produce has a water-soaked or glassy appearance. Although a few commodities are tolerant of slight freezing, it is advisable to avoid such temperatures because subsequent storage life is short. Produce which has recovered from freezing is highly susceptible to decay.

— Chilling injury- some types of fresh produce are susceptible to injury at low but non-freezing temperatures. Such crops are mostly of tropical or subtropical origin, but a few temperate crops may be affected (Table 2).

Effect of chilling injury	*Symptom*
Discoloration	Internal or external or both, usually brown or black
Skin piking	Sunken spots, especially under dry conditions
Abnormal ripening (fruits)	Ripening is uneven or fails; off-flavours
Increase in decay	Activity of micro-organisms

Table 2. Susceptibillty of fruits and vegetables to chilling injury at low but non-freezing temperatures

Commodity	*Approximate lowest safe temperature °C*	*Chilling injury symtoms*
Aubergines	7	Surface scald, *Alternaria* rot
Avocados	5-13	Grey discoloration of flesh
Bananas (green/ripe)	12-14	Dull, gray-brown skin color
Beans (green)	7	Pitting, russeting
Cucumbers	7	Pitting water-soaked spots, decay
Grapefruit	10	Brown scald, piking, watery breakdown
Lemons	13-15	Pitting, membrane stain, red blotch
Limes	7-10	Pitting
Mangoes	10-13	Grey skin scald, uneven ripening
Melons: Honeydew	7-10	Pitting failure to ripen, decay
Watermelon	5	Pitting, biker flavour
Okra	7	Discoloration, water-soaked areas, piking
Oranges	7	Pitting brown stain, watery breakdown
Papaya	7	Pitting failure to ripen, off-flavour, decay
Pineapples	7-10	Dull green colour, poor flavour
Potatoes	4	Internal discoloration, sweetening
Pumpkins	10	Decay
Sweet peppers	7	Pitting *Alternaria* rot
Sweet potato	13	Internal discoloration, piking, decay
Tomatoes: Mature green	13	Water-soaked softening, decay
Ripe	7-10	Poor colour, abnormal ripening, *Alternaria* rot

Sensitivity varies with the commodity, but with each there is a temperature below which injury occurs: the lowest safe temperature (LST). Within a single commodity type, the LST may vary between varieties (Table 2). Fruit is generally less sensitive when ripe.

Symptoms of chilling injury may not develop until the produce is removed from cold storage to normal market (i.e. ambient) temperatures. When susceptible produce has to be held for some time in storage, it must be kept at a temperature just above its LST. This means that such crops will have a shorter marketing life than non-sensitive crops because respiration has continued at a relatively fast rate during storage at higher than normal cold-storage temperatures.

— High temperature injury - if fresh produce is exposed to high temperatures caused by solar radiation, it will deteriorate rapidly. Produce left in the sun after harvest may reach temperatures as high as 50 degrees Celsius. It will achieve a high rate of respiration and, if packed and transported without cooling or adequate ventilation, will become unusable. Long exposure to tropical sun will cause severe water loss from thin-skinned root crops such as carrots and turnips and from leafy vegetables.

Diseases and pests

Diseases caused by fungi and bacteria commonly result in losses of fresh produce. Virus diseases, which can cause severe losses in growing crops, are not a serious post-harvest problem.Insect pests that are mainly responsible for wastage in cereals and grain legumes are rarely a cause of post-harvest loss in fresh produce. Where they do appear, they are often locally serious, e.g. the potato tuber moth.

Diseases. Losses from post-harvest disease in fresh produce fall into two main categories.

Loss in quantity, the more serious, occurs where deep penetration of decay makes the infected produce unusable. This is often the result of infection of the produce in the field before harvest.

Loss in quality occurs when the disease affects only the surface of produce. It may cause skin blemishes that can lower the value of a commercial crop. In crops grown for local consumption, the result is less serious since the affected skin can often be removed and the undamaged interior can be used.

Fungal and bacterial diseases are spread for the most part by microscopic spores, which are widely distributed in the air and soil and on dead and decaying plant material. Produce can become infected:

— through injuries caused by careless handling, by insect or other animal damage, or through growth cracks;

— through natural pores in the above- and below-ground parts of plants, which allow the movement of air, carbon dioxide and water vapour into and out of the plant;

— by direct penetration of the intact skin of the plant. The time of infection varies with the crop and with different diseases. It can occur in the field before harvest or at any time afterwards.

Field infections before harvest may not become visible until after harvest. For example, decay of root crops caused by soil moulds will develop during storage. Similarly, tropical fruits infected at any time during their development may show decay only during ripening.

Infection after harvest can occur at any time between the field and the final consumer. It is for the most part the result of invasion of harvesting or handling injuries by moulds or bacteria.

Post-harvest diseases may be spread in the field before harvest by the use of infected seed or other planting material. Many diseases can survive by using weed plants or other crops as alternate or alternative hosts. They are also spread by means of infected soil carried on farm implements, vehicles, boots, etc. and from crop residues or rejected produce left decaying in the field. Post-harvest diseases can also be spread by:

- field boxes contaminated by soil or decaying produce or both;
- contaminated water used to wash produce before packing;
- decaying rejected produce left lying around packing houses;
- contaminating healthy produce in packages.

Pests. Although relatively few post-harvest losses of fresh produce are caused by attacks of insects or other animals, localised attacks by these pests may be serious.

- Insect damage is usually caused by insect larvae burrowing through produce, e.g. fruit fly, sweet potato weevil, potato tuber moth. Infestation usually occurs before harvest. Post-harvest spread is a problem where produce is held in store or is exposed to lengthy periods of transport.
- Rats, mice and other animal pests again are sometimes a problem when produce is stored on the farm.

Loss Assessment

There are no generally accepted methods for evaluating post-harvest losses of fresh produce. Whatever evaluation method may be used, the result can refer only to the described situation.

In the appraisal of an existing marketing operation, the accurate evaluation of losses occurring is a problem. It may be suspected that losses are too great, but there may be no figures to support this view because:

- records do not exist;
- records if available do not cover a long enough period of time;

- the figures available are only estimates made by several observers;
- records may not truly represent a continuing situation; for example, losses may have been calculated only when unusually high or low;
- loss figures may be deliberately over- or understated for commercial or other reasons in order to gain benefits or to avoid embarrassment.

Consequently, if accurate records of losses at various stages of the marketing operation have not been kept over a period of time, a reliable assessment of the potential cost-effectiveness of ways to improve handling methods is virtually impossible, and the marketing position of the grower is difficult to strengthen. It is evident that the grower who wants to reduce his post-harvest losses must maintain reliable records.

HARVESTING AND FIELD HANDLING

The quality and condition of produce sent to market and its subsequent selling price are directly affected by the care taken during harvesting and field handling. Whatever the scale of operations or the resources of labour and equipment available, the planning and carrying out of harvesting operations must observe basic principles. The objective of the grower should be:

- to harvest a good quality crop in good condition;
- to keep the harvested produce in good condition until it is consumed or sold;
- to dispose of the crop to a buyer or through a market as soon as possible after harvest.

Planning

To meet these objectives, success in harvesting and marketing must depend on planning from the earliest stages of production, particularly in regard to:

- crop selection and timing to meet expected market requirements;
- contacts with buyers so that the crop can be sold at a good price when ready for harvest;
- planning harvest operations in good time; arranging for labour, equipment and transport;
- providing full supervision at all stages of harvesting and field handling.

Labour

With small-scale family production for local markets, the labour supply will probably not be a problem. As the scale of commercial production and the distances between the rural producer and urban consumer increase, more exacting requirements will have to be met in regard to training and supervising labour. It is economically sound in terms of return to invest more in proper packing and handling of the produce before it leaves the farm. Growers will have to train their own field labour, accepting whatever support local extension workers are able to provide.

Training workers

This training should cover general aspects of produce-handling for all workers and specific training for those engaged in tasks requiring greater skill.

General training. For everyone concerned with harvesting and field handling, general training should include:

- Demonstrations of the causes and effects of damage to produce, emphasizing the need for careful handling at all times to avoid mechanical injuries from such causes as:
  1. Wooden containers with rough edges, splinters, protruding nails or staples;
  2. Overpacking containers which are to be stacked;
  3. Damaging produce with long fingernails or jewellery;
  4. Dropping or throwing into containers at a distance;
  5. Throwing, dropping or rough handling of field containers.
- An explanation of the need to avoid the contamination of harvested produce from such causes as:
  1. Placing the produce directly on to the soil, especially wet soil;
  2. Using dirty harvesting or field containers contaminated with soil, crop residues or decaying produce: containers must be kept clean;
  3. Contact with oil, gasoline, or any chemicals other than those used specifically for authorised post-harvest treatments.

Specific training. Workers allocated to specialised tasks, such as crop selection and harvesting, and the post-harvest selection, grading and packing (if applicable) of the crop should be given specific training. This will include demonstration and explanation of:

- the methods of evaluating the readiness of the crop for harvest, and the rejection of unsuitable produce at harvest, according to market requirements;
- the actual technique to be employed in harvesting produce, e.g. breaking the stem or plucking, clipping, cutting or digging;

- the use of harvest containers, and the transfer of produce to field or marketing containers;
- the selection of marketable produce at the field assembly point and (if applicable) grading for size and quality;
- the correct application of post-harvest treatment (where produce is to be packed on the farm directly into marketing packages), e.g. fungicides, wax coating;
- the method of packing market packages or other containers.

When the crop is ready for harvest, labour and transport are available, and operations organised, the decision as to when to start harvesting will depend largely on:

- weather conditions;
- the state of the market.

The flexibility of the marketing date will depend on the crops. Some, such as root crops, can be harvested and sold over a long period, or stored on the farm to await favourable prices. Others, such as soft berry fruits, must be marketed as soon as they are ready or they will spoil. When the decision to harvest has been made, the best time of day must be considered. The aim is to dispatch the produce to market in the best possible condition, that is, as cool as possible, properly packed and free from damage. The basic rules to observe are:

- harvest during the coolest part of the day: early morning or late afternoon;
- do not harvest produce when it is wet from dew or rain. Wet produce will overheat if not well ventilated, and it will be more likely to decay. Some produce may be more subject to damage when wet, e.g. oil spotting and rind breakdown in some citrus fruits;
- protect harvested produce in the field by putting it under open-sided shade when transport is not immediately available. Produce left exposed to direct sunlight will get very hot.

Produce for local markets can be harvested early in the morning. For more distant markets it may be an advantage-if suitable transport can be arranged-to harvest in the late afternoon and transport to market at night or early the next morning.

Harvesting Techniques

By hand

In developing countries, most produce for internal rural and urban markets is harvested by hand. Larger commercial producers may find a degree of mechanisation an advantage, but the use of sophisticated harvesting machinery will be limited for the most part to agro-industrial production of cash crops for processing or export or both. In most circumstances, harvesting by hand, if done properly, will result in less damage to produce than will machine-harvesting.

Hand-harvesting is usual where fruit or other produce is at various stages of maturity within the crop, that is, where there is need for repeated visits to harvest the crop over a period of time. Machine-harvesting is usually viable only when an entire crop is harvested at one time.

Root and tuber crops. Most staple roots and tubers that grow beneath the soil are likely to suffer mechanical injury at harvest because of digging tools, which may be wooden sticks, machetes (or cutlasses, pangas or bolos), hoes or forks.

Harvesting of these crops is easier if they are grown on raised beds or mounds, or "earthed up" as is common in potato-growing. This enables the digging tool to be pushed into the soil under the roots or tubers, which then can be levered upwards, loosening the soil and decreasing the possibility of damage to the crop.

Other root crops, such as taro, carrots, turnips, radishes, etc. can be loosened from the soil in a similar manner by inserting the tool into the soil at an angle and levering the roots upwards. This method can also be used for celery if it has been earthed up or buried to blanch the stems.

Vegetables. Either the whole or a part of vegetative growth can be harvested by hands only or sharp knives. Knives must be kept sharp and clean at all times or they may spread virus diseases from plant to plant. Harvesting methods vary with plant parts harvested:

- leaves only (spinach, rape, etc.) and lateral buds (Brussels sprouts): the stem is snapped off by hand;
- above-ground part of the plant (cabbage, lettuce): the main stem is cut through with a heavy knife, and trimming is done in the field (the cut stem must not be placed on the soil);
- bulbs (green onions, leeks, mature bulb onions): immature green onions can usually be pulled from the soil by hand; leeks, garlic and mature bulb onions are loosened by using a digging fork as for root crops (such as carrots) and lifted by hand. Simple tractor implements are available for undermining bulbs and bringing them to the surface.

Flower structures. Immature flower heads (cauliflower, broccoli) can be cut with a sharp knife and trimmed in the field; broccoli can be snapped off by hand and subsequently trimmed;

Mature flowers (squash, chayote, pumpkin): flowers are plucked individually by hand, or whole shoot-bearing flowers are harvested as a vegetable.

Fruits. Many ripe fruits and some immature seed-bearing structures such as legume pods have a natural break-point of the fruit stalk, which can easily be broken at harvest. Fruit and other seed-bearing structures harvested in the immature or unripe green state are more difficult to pick without causing damage to either the produce or the plant. These are best harvested by cutting them from the plant, using clippers, secateurs or sharp knives. The clippers may be mounted on long poles for tree fruits, with a bag attached to the pole to catch the fruit.

Plucking methods vary according to the kind of produce being harvested:

- ripe fruits with a natural break-point, which leaves the stalk attached to the fruit, are best removed by a "lift, twist and pull" series of movements, e.g. apple, passion fruit, tomato;
- mature green or ripe fruits with woody stalks which break at the junction of the fruit and the stalk are best clipped from the tree, leaving up to a centimetre of fruit stalk attached. If the stems are broken off at the fruit itself. disease may enter the stem scar and give rise to stem end rot, e.g. mango, citrus, avocado;
- immature fruits with fleshy stems can be cut with a sharp knife, e.g. zucchini, okra, papaya, capsicum; these can also be harvested by breaking the stem by hand, but this method may damage the plant or fruit and the rough break will be more susceptible to decay than would a clean cut.

Mechanical aids

Because the supply of fresh produce to domestic markets in developing countries comes mainly from relatively small-scale producers with limited resources, mechanical systems for "once over" crop harvesting are likely to be rare. There is scope, however, for the use of mechanical aids in modest commercial operations, especially where tractors are available. The jobs where such aids are likely to be of use are:

- in harvesting potatoes, onions and possibly some other root crops, simple tractor-drawn harvesters to lift up the crops and leave them on the soil surface;
- in transporting produce from the harvesting point to the assembly area to await transport, tractors to draw trailers of laden containers or to carry either containers on pallets or bins.

Harvesting and Field Containers

The packing of produce directly into marketing packages in the field at harvest reduces the damage caused by multiple handling and is used increasingly by commercial growers. It is not a common practice in rural areas, where produce is sent to nearby markets and elaborate packaging cannot be justified, but commercial growers can view it as cost-effective if the packaging takes produce in better condition to market, where it can command a higher price. At all stages of harvesting and handling, methods should aim at avoiding damage to produce and providing ventilation to prevent temperature rises.

Selecting field containers for harvesting

These must be of a size that can be conveniently carried by the harvest worker while moving through the field:

- harvesting bags with shoulder or waist slings can be used for fruits with firm skins like citrus and avocados. They are easy to carry and leave both hands free. They should be designed for opening at the base to allow produce to be emptied through the bottom into a field container without tipping the bag;
- plastic buckets or other containers are suitable for harvesting fruits that are more easily crushed, such as tomatoes. The containers should be smooth, with no sharp edges or projections to damage the produce;
- baskets are often used for harvesting but may have sharp edges or splinters that can injure produce. If they are not sturdy, they may bend out of shape when lifted or tipped-especially if they are large-and crush or otherwise damage the contents;
- bulk bins, usually of 250 to 500 kg capacity, are used by commercial growers, where crops such as apples or cabbages are sent to large-scale packing houses for selection, grading and packing. Bins can be carried by a fork-lift attachment on a tractor to move the produce from harvesting points to assembly areas.

When unventilated bulk bins are used in the field, produce should be left in them only briefly, and protected from sun or rain. Produce held in bulk for long will overheat and be more subject to decay. Bulk bins transported over long distances must be perforated to minimise heat build-up in the contents.

Post-harvest Hauling

Field and farm transport

Routes for the movement of produce within farm fields should be planned before crops are planted. Farm roads should be kept in good condition because great damage can be inflicted on produce carried over rough roads in unsuitable vehicles.

Containers must be loaded on vehicles carefully and stacked in such a way that they cannot shift or collapse, damaging their contents. Vehicles need good shock absorbers and low-pressure tyres and must move with care. Jolting of laden containers can aggravate damage to produce on rough roads, even at low vehicle speeds.

Transport from the farm

The destination of the produce leaving the farm will usually be one of the following:

- A local market - produce is usually in small containers carried sometimes by animals or in animal-drawn carts, but mostly by vehicles owned or hired by growers; public transport is sometimes used.
- A commercial packing house or processing plant-produce carried by trucks may be in palletised field containers, in bulk bins or in hand-loaded sacks or wooden or plastic boxes; where vehicles wait in the sun or rain for long periods before unloading, only the top part of the load should be protected by a covering; grass or leaves are not recommended for this purpose because they restrict ventilation and may be a source of disease; complete enclosing of the load with a tarpaulin is disastrous because it restricts ventilation and the temperature of the produce rises rapidly.
- A city market - this applies only where produce is packed in marketing containers on the farm.

DAMAGE SUFFERED BY PACKAGED PRODUCE

Most fresh produce ready for market is composed of large numbers of small units of similar size which must be moved in amounts conveniently handled by one person. This is best achieved by using containers of capacities from 3 to 25 kg, up to dimensions of about 60 per 40 per 30 cm. Some commodities (e.g. potatoes) may be marketed in 25 or 50 kg sacks, and other large items, such as whole bunches of bananas, are moved without packaging. Leafy vegetables can be sold loose or tied in bundles and not packaged.

Most developing countries use traditional baskets, sacks and trays to carry produce to markets. These are usually of low cost, made from readily available materials such as dried grass, palm leaves or bamboo. They serve the purpose for fresh produce carried over short distances, but they have many disadvantages in big loads carried long distances.

Large commercial quantities of produce need better packaging in order to minimise losses and achieve the most economical use of transport. The aim is to protect the produce from damage in handling, transport and storage and to provide easily handled and counted containers of uniform size.

Packages of standard size can reduce the need for repeated weighing and can facilitate handling, stacking and loading. A wide variety of package types is fabricated from paper and paper products, wood and wood products and plastics, both pliable and rigid. Each type must be considered in terms of its utility, cost and capacity to enhance the value of the produce.

Economy in packaging is always a desirable goal. A study in Thailand showed that a plastic crate, while costing five times as much as a traditional bamboo basket of similar capacity, was still useful after 20 times the number of journeys, putting the cost per journey of the plastic crate at about one-quarter of that of the bamboo basket. The crate also provided better protection of produce, easier handling and better stowing, and was easier to clean.

Perhaps improvements in the design and construction of indigenous containers might, in the context of the small-scale grower, prove to be a better solution than buying plastic crates.

Injuries

Cuts or punctures

Cause: sharp objects piercing package; splinters in bamboo or wooden containers; staples or nails protruding in containers;

Effect: deep punctures or cuts in produce, leading to water loss and rapid decay

Impact (shock)

Cause: throwing or dropping of packages; sudden starting or stopping of vehicle, causing load movement; speeding vehicle on rough road;

Effect: bursting of packaging, bruising of contents

Compression (squeezing or squashing)

Cause: flimsy or oversized containers; containers overfilled or stacked too high or both; collapse of stacked containers during transport;

Effect: bruising or crushing of contents

Vibration (shaking)

Cause: vibration of the vehicle itself and from rough roads;

Effect: wooden boxes come apart, damaging produce

From the environment

Heat damage

Cause: exposure of packages to external heat, e.g. direct sunlight, or storage near heating system; natural buildup of internal heat of produce owing to poor ventilation within package, in storage or vehicle;

Effect: fruit becomes overripe or softens; produce wilts and develops off-flavours; decay develops rapidly; cardboard cartons may become dry and brittle, easily damaged on impact;

Chilling or freezing damage

Cause: low or subzero ambient temperatures; exposure of sensitive produce to temperatures below chilling or freezing tolerance level during storage;

Effect: damage to chilling-sensitive produce; breakdown of frozen produce on thawing; plastic containers become brittle and may crack;

Moisture and free-water damage

Cause: exposure to rain or high humidity; condensation on packages and produce moved from cold store to damp atmosphere at ambient temperature; packing wet produce in cardboard containers;

Effect: softening and collapse of stacked cardboard containers; squashing of produce in collapsed containers; decay promoted in damaged produce;

Damage from light

Cause: plastic sacks and crates not treated with an ultraviolet inhibitor eventually break up when exposed to direct sunlight;

Effect: disintegration of plastic sacks damages produce when it is moved; fracturing of plastic crates can cut or bruise produce;

From other causes

Chemical contamination

Cause: contamination of containers stored near chemicals; damage to produce by containers treated with preservatives, e.g. boxes made from wood treated with pentachlorphenate (PCP); contamination of produce from boxes affected by mould growth;

Effect: flavour contamination or surface damage and discoloration of produce in contact with container; decay of produce owing to contaminating moulds; wood-rotting moulds cause collapse of boxes;

Insect damage

Cause: insects present in packed produce; wood-boring insects in wooden boxes;

Effect: consumer resistance and legal problems from presence of insects (e.g. spiders, cockroaches) in packed produce; spread of wood-destroying insects in infected boxes;

Human and animal damage

Cause: contamination and eating by rodents and birds; pilfering by humans;

Effect: rejection of damaged produce by buyers or inspectors; loss of income through loss of produce.

Cost-effectiveness Packaging

The use of packaging represents an added cost in marketing and the price of the marketed product must take account of the capital outlay and unit-packaging cost as well as expected profit. To make an exact assessment of the added value is difficult because many factors may offset the cost of packaging, for example:

- losses should be significantly reduced;
- presentation and quality of the product may make it more desirable, a competitive advantage;
- marketable life of the produce may be extended.

It is clear, however, that packaging must not exceed the willingness of the market to accept the added value of the product, i.e. the extra cost involved.

Prevention of injuries to produce

Suitable packages and handling techniques can reduce the amount of damage to which fresh produce is exposed during marketing:

- to keep the packaging itself from damaging produce during handling and transport, wooden boxes or cardboard cartons must be properly assembled; nails, staples and splinters are always a danger in wooden boxes;
- individual items of produce should be packed to avoid rubbing against each other during handling and transport; loose-fill packs are particularly susceptible to vibration damage;

- bruising results from overfilling containers or from the collapse of boxes; collapse may be caused by weak walls of boxes, by the softening of cardboard walls because of moisture or by the failure to stack boxes so that the side and end walls support those above; stacks of boxes should never exceed the height that has been recommended by the maker;
- produce in woven jute sacks or nets is especially susceptible to shock damage; sacks of 25 or 50 kg capacity are normally used for relatively low-value produce, such as root and tuber crops, and are often roughly handled on account of their weight; where possible, handling of bagged produce should be minimised by stacking sacks in unit loads on pallets or in pallet boxes.

Effect of packaging on other types damage

Heat, chilling or freezing

Packaging in general has poor insulating qualities and will have little effect on preventing damage from heat or cold. Lack of ventilation in packaging delays cooling and may contribute to high-temperature damage arising from heat generated by the produce itself. Recently developed expanded polystyrene packages have good insulating properties and are used, topped with ice, to transport vegetables with high respiration rates.

The availability and cost of such packages make them inappropriate in most developing countries.

Moisture and free water damage

High humidity and free water (e.g. rain) quickly weaken cardboard boxes, which get soggy and collapse when wet. This problem can be overcome in manufacture only by waxing the cardboard or by facing it with moisture resistant plastic. Decay of produce packed in wet sacks or in wet wooden or cardboard boxes will be accelerated.

Chemical contamination

Packaging will not protect produce from contamination by outside sources of chemicals. The containers themselves become impregnated and contribute to the contamination. Sacks and "knocked down" wooden or cardboard boxes awaiting assembly should not be stored in the same area as chemicals.

Selection of packaging for fresh produce

Packaging can be a major item of expense in produce marketing, so the selection of suitable containers for commercial-scale marketing requires careful consideration.

Besides providing a uniform-size package to protect the produce, there are other requirements for a container:

- it should be easily transported when empty and occupy less space than when full, e.g. plastic boxes which nest in each other when empty, collapsible cardboard boxes, fibre or paper or plastic sacks;
- it must be easy to assemble, fill and close either by hand or by use of a simple machine;
- it must provide adequate ventilation for contents during transport and storage;
- its capacity should be suited to market demands;
- its dimensions and design must be suited to the available transport in order to load neatly and firmly;
- it must be cost-effective in relation to the market value of the commodity for which used;
- it must be readily available, preferably from more than one supplier.

Size and shape of packages

Packages should be of a size which can be easily handled and which is appropriate to the particular marketing system. The size should be no larger than is compatible with these requirements, especially with wooden boxes. The ratio of weight of the container to that of the produce it contains is important. Where transport charges are calculated on a weight basis, heavy packaging can contribute significantly to the final cost of the saleable product.

The shape of packages is also significant because of the loading factor: the way the load is positioned on the transport vehicle for maximum capacity and stability. Round baskets, whether cylindrical or tapered, hold considerably less produce than do boxes occupying the same space. A cylindrical basket contains only 78.5 percent by volume compared with a rectangular box occupying the same space.

The need for ventilation in packages

Suitable packaging for any product will consider the need to keep the contents well ventilated to prevent the buildup of heat and carbon dioxide. The ventilation of produce in containers is a requirement at all stages of marketing, but particularly during transport and storage. Ventilation is necessary for each package, but there must also be an adequate air flow through stacked packages. A tight stack pattern is acceptable only if packages are designed to allow air to circulate through each package and throughout the stack.

Sacks and net bags must be stacked so that air can circulate through the contents. The effectiveness of ventilation during transport also depends upon the air passing through the load.

Packaging Materials

Packaging for fresh produce is of several types:

Natural materials. Baskets and other traditional containers are made from bamboo, rattan, straw, palm leaves, etc. throughout the developing world. Both raw materials and labour costs are normally low, and if the containers are well made, they can be reused. Disadvantages are:

- they are difficult to clean when contaminated with decay organisms;
- they lack rigidity and bend out of shape when stacked for long-distance transport;
- they load badly because of their shape;
- they cause pressure damage when tightly filled;
- they often have sharp edges or splinters causing cut and puncture damage.

Wood. Sawn wood is often used to make reusable boxes or crates, but less so recently because of cost. Veneers of various thicknesses are used to make lighter boxes and trays. Wooden boxes are rigid and reusable and, if made to a standard size, stack well on trucks. Disadvantages are:

- they are difficult to clean adequately for multiple use;
- they are heavy and costly to transport;
- they often have sharp edges, splinters and protruding nails, requiring some form of liner to protect the contents.

Cardboard (sometimes called fibreboard). Containers are made from solid or corrugated cardboard. The types closing with either foldover or telescopic (i.e. separate) tops are called boxes or cases. Shallower and opentopped ones are called trays. Boxes are supplied in collapsed fore, (that is, flat) and are set up by the user. The setting-up and closing of boxes requires taping, glueing, stapling or the fixing of interlocking tabs.

Cardboard boxes are lightweight and clean, and can readily be printed with publicity and information on contents, amounts and weights. They are available in a wide range of sizes, designs and strengths. Disadvantages are:

- they may, if used only once, prove an expensive recurring cost (if multiple use is intended, the boxes may be easily collapsed when empty);

- they are easily damaged by careless handling and stacking;
- they are seriously weakened if exposed to moisture;
- they can be ordered economically only in large quantities; small quantities can be prohibitively expensive.

Moulded plastics. Reusable boxes moulded from high-density polythene are widely used for transporting produce in many countries. They can be made to almost any specifications. They are strong, rigid, smooth, easily cleaned and can be made to stack when full of produce and nest when empty in order to conserve space.

Disadvantages are

- they can be produced economically only in large numbers but are still costly;
- they have to be imported into most developing countries, adding to the cost and usually requiring foreign currency for their acquisition;
- they often have many alternative uses (as washtubs, etc.) and are subject to high pilferage rates;
- they require a tight organisation and control for use in a regular go-and-return service;
- they deteriorate rapidly when exposed to sunlight (especially in the tropics) unless treated with an ultraviolet inhibitor, a factor adding to the cost.

Despite their cost, however, their capacity for reuse can make them an economical investment. The Thailand study mentioned above showed plastic containers still usable after more than 100 journeys.

Natural and synthetic fibres. Sacks or bags for fresh produce can be made from natural fibres like jute or sisal or from synthetic polypropylene or polyethylene fibres or tapes. "Bags" usually refers to small containers of up to about 5 kg capacity. They may be woven to a close texture or made in net form. Nets usually have a capacity of about 15 kg. Bags or sacks are mostly used for less easily damaged produce such as potatoes and onions, but even these crops should have careful handling to prevent injury. Disadvantages are:

- they lack rigidity, and handling can damage contents;
- they are often too large for careful handling; sacks dropped or thrown will result in severe damage to the contents;
- they impair ventilation when stacked if they are finely woven;
- they may be so smooth in texture that stacks are unstable and collapse; they are difficult to stack on pallets.

Paper or plastic film. Paper or plastic film is often used to line packing boxes in order to reduce water loss of the contents or to prevent friction damage.

Paper sacks can have walls of up to six layers of kraft (heavy wrapping) paper. They can have a capacity of about 25 kg and are mostly used for produce of relatively low value. Closure can be done by machine-stitching across the top (recommended only for large-scale crop production) or in the field by twisting wire ties around the top by means of a simple tool.

Disadvantages are:

- walls of paper are permeable by water or vapour and gases (walls may be waterproofed by incorporating plastic film or foil, but sacks then retain gases and vapour);
- heat can be slow to disperse from stacks of sacked produce, thus damaging fruit or leafy vegetables;
- limited protection to contents if sacks are mishandled.

Plastic-film bags or wraps are, because of their low cost, widely used in fruit and vegetable marketing, especially in consumer-size packs. In many developing countries, however, large polythene bags are and should not be used to carry produce, especially to market. Disadvantages are:

- they offer almost no protection from injury caused by careless handling;
- they retain water vapour thus reducing water loss from the contents; but where temperature changes occur, they cause a heavy buildup of condensation leading to decay;
- they cause a rapid buildup of heat if bags are exposed to sunlight;
- they permit only slow gas exchange; this combined with vapour and heat leads to very rapid deterioration;
- they should not be used for carrying produce; even with perforations for ventilation, plastic bags should not be used unless the package can be refrigerated.

Consumer packs wrapped in plastic are not recommended under tropical conditions except perhaps in stores with refrigerated display cabinets.

Deciding on Packaging for Fresh Produce

Before deciding on what packaging to use, the grower or packing-house operator has to consider many factors to ensure that the cost does not exceed the benefits. The decision should be made after consultation with market operators, packaging suppliers, transport operators and post-harvest extension advisers. Factors to consider are:

- the type of produce;
- the present level of produce losses that occur during the marketing process;
- the comparative costs of the present and improved packaging;
- expected reduction of losses if packaging is improved (based on research results);
- expected increase in income from reduction of losses;
- is a standard type of package available? Cost-per-unit of packages declines considerably when they are bought on a large scale; specially designed packaging is costly;
- will there be a regular supply of the new packaging?
- is adequate storage and assembly space available for the protection of packaging materials before use?
- is the change in packaging acceptable to the market?

If the introduction of new packaging does not result in increased returns, it cannot be economically feasible. Most experience shows that good produce well packaged has an advantage over produce poorly packaged, and the profits from it can cover the investment. Good packaging can therefore be held to be cost-effective in marketing.

There is no assurance that new packaging will by itself eliminate or greatly reduce post-harvest losses of fresh produce. Packaging is only one factor in the effort to improve handling at every step in the marketing process.

PACKING HOUSE CARE

Fresh produce sold through markets or by direct sales to users or agents must undergo some form of sorting and packaging. For the most part, the preparation of produce for market is carried out in a packing house, which may range from a simple, on-the-farm thatched shed to an automated regional packaging line handling large tonnages of a single commercial crop like citrus fruit or apples.

Whether it is simple or complex, the packing house provides a sheltered environment whose purpose is the assembly, sorting, selection and packaging of produce in an orderly manner with a minimum of delay and waste.

The size and design of the packing house, and the equipment and facilities required for it, will depend on the type and volume of produce, the market requirements, local infrastructure, its expected life span and its projected cost. In the planning stages, the factors to consider include:

- operations to be carried out;
- location of a suitable site;
- design of the structure and building materials available;
- equipment to be used;
- management.

Operations

Depending on the crop or crops being handled and the market being served, some or all of the following operations will be undertaken:

- reception: off-loading, checking, recording;
- sorting;
- special treatments, if required (cleaning or washing, fungicide spraying, selection, size-grading);
- packing;
- post-packaging treatments, if required (fumigation, cooling, storage);
- assembly and dispatch.

To be avoided at all costs is the all too common state of confusion where, in a confined space on a floor covered in plant trash, produce is being received, sorted, cleaned, dipped in fungicide, packed and stacked for dispatch. Where several producers supply the packing house, each delivery should be:

- labelled to identify its source and date of arrival;
- checked for quantity or weight delivered;
- sampled for quality, if necessary;
- acknowledged by a receipt to the supplier.

The reception area should be organised so that produce moves through the packing operation in the order it is received: first in, first out.

Sorting. A preliminary sorting of produce should remove unmarketable pieces and foreign matter (plant debris, soil or stones) before the produce passes on to further operations. All discarded material should be quickly hauled away from the packing house or placed in closeable bins for later removal. This is because accumulations of decaying or infested waste in or near the packing house will contaminate produce destined for market.

Cleaning and washing. The removal of soil and stones mentioned above can be done by hand-picking or by sieving. Some types of produce can be washed, brushed, or cleaned with a soft cloth.

Cleaning produce by hand-polishing or machine-brushing can remove light soil contamination or dust from produce, especially fruit. This should be done with care since damage to the skin of fresh produce will promote early decay.

Washing is required to clean produce which has acquired latex stains from injuries caused during harvesting, notably in mangoes and bananas. It is important to note that washing should be carried out only when absolutely essential. If it is necessary to wash produce, a fungicide should normally be applied immediately afterwards.

Use only clean, running water for washing. The washing of produce in recirculated or stagnant water should be avoided because it can quickly become heavily contaminated with decay organisms, leading to heavy rotting of the washed produce.

There are no acceptable or effective antibacterial agents available for treating water used to wash fresh produce. Hypochlorites or chlorine gas may be added to washing water used for commercial treatment of some products, but its use in recirculated or stagnant water cannot be recommended for small-scale washing operations because it is quickly inactivated by organic material such as plant debris in the water. The monitoring of the chlorine concentration in the wash water and its replenishment are difficult to achieve and, in any case, chlorine is of only limited effectiveness against decay.

Washed produce which is to be treated with fungicide should first be drained after washing in order to reduce the danger that residual wash water will dilute the fungicide below its effective concentration. When washing is not to be followed by fungicide treatment, the washed produce should be spread out in a single layer on raised racks of mesh or slats, in the shade but exposed to good ventilation to aid rapid drying.

Fungicide treatment

Decay caused by moulds or bacteria is a major cause of loss of fresh produce during marketing. Infection may occur before or after harvest, either through injuries or by direct penetration of the intact skin of produce. Pre-harvest infections often lie dormant until after harvest, especially in fruit, where they may develop only as the fruit ripens. Mangoes, bananas, avocados and sweet peppers are subject to latent anthracnose infections.

Post-harvest application of fungicide is usual on crops such as apples, bananas and citrus fruit which are to be stored for a long period or those which undergo long periods of transport to distant markets. As stated above, fungicides are normally applied only after the produce has been washed and drained.

Most fungicides used for post-harvest decay control are in the form of wettable powders or emulsifiable concentrations. They form suspensions in water, not solutions; this means that they settle out of suspension if the mixture is not constantly agitated during its application. Thus the concentration of fungicide applied to the crop will fall below the effective level if the suspension is not continuously stirred.

In small-scale packing operations, fungicide can be applied by:

- *Dipping*. Treatment is carried out by hand, using a suspension of fungicide agitated by hand; wire-mesh baskets can be used to dip several small pieces at one time; after dipping, produce should be drained and dried in a shaded, airy place.
- *Spraying*. This can be accomplished with a hand-operated knapsack sprayer while produce is still in trays or racks after washing and drying produce should be sprayed completely and to the point of runoff.

Larger spraying operations may require a simple mechanised spray or drenching arrangement with a mechanical mixer for the fungicide. Produce passes through the spray or drenching in perforated trays perhaps while moving on a belt or roller conveyor.

Other methods of application, such as smokes, dusts or vapour, are used only by large-scale operations where produce is to be stored.

Quality selection and size grading

Although produce will have been sorted on the farm or on its arrival at the packing house, there may be a further selection for quality and size immediately before it is packed. The scope of these operations depends on the market: will buyers be prepared to pay premium prices for quality-graded produce? Many urban customers are more demanding of quality than are rural customers. Selection and grading in a small packing house are best done by human eye and by hand, assisted by sizing rings or gauges.

Waxing

The application of wax or similar coating to enhance appearance and limit water loss from produce requires specialised equipment and has little relevance to small-scale packing.

Packaging

Packaging in small-scale operations means the filling of marketing containers by hand. Machines are used to pack durable produce like potatoes and apples in big packing houses, but they are expensive and not suitable for small volumes of different products. There are various methods of packing:

- loose-fill jumble pack is used where there is no advantage to size-grading; weighing is necessary;
- multilayer pattern pack has size-graded produce sold by count of the produce: citrus, apples, etc.
- multilayer size-graded pack used in mechanical packing has separator trays between layers; sold on per-box basis;
- single-layer packs for high-value produce may have each piece wrapped in tissue or placed in a divider holding it alone; sold on per-box basis.

Special treatments after packing

Special post-packing treatments are applied to certain crops, but this is more common in large-scale operations for urban and export markets. The principal treatments are:

Fumigation

The treatment is to control insect pests, such as fruit fly. It is a compulsory requirement for the importation of produce into many countries and requires specialised equipment and skilled operators.

Initiation of fruit ripening

This takes several days and requires treatment of the packed fruit with ethylene gas in insulated, temperature-controlled stores. The costs are high and thus limited to large operations.

Degreening of citrus fruit

Citrus fruits grown in the tropics will remain green when ripe unless subjected to low night temperatures. They will, however, develop their normal natural colour if artificially degreened by an ethylene treatment like that initiating ripening; it is not often done in small packing houses.

Assembly of packed produce for dispatch

Time is an important factor in the marketing of fresh produce; delays add to losses. Once produce has been packed, it should be dispatched to market as soon as possible. Therefore the packing-house management should give high priority to transportation arrangements. In small-scale operations, however, it may take time to assemble a full load; so when packed produce takes time to accumulate, every effort must be made to prevent its deterioration. Attention must be given to the following:

- packed containers must be protected from the sun and rain; heat and water cause rapid deterioration of produce and seriously weaken cardboard boxes;
- packed boxes must be handled carefully during stacking in order to avoid damaging the contents; damage to produce promotes water loss and decay;
- packed containers awaiting transport must be stacked so as to get ventilation; overheating leads to rapid deterioration.

Losses of fresh produce during packing operations can be minimised if produce is:

- kept as cool as possible;
- kept dry;
- protected from injury;
- kept moving quickly to market.

Planning a packing house

When seeking a location for a packing house, the following must be considered:

- is it accessible to the production areas, the proposed markets and transport routes?
- is labour available?
- are services available, e.g. electricity, water, telephone, etc.?

Before the location is decided upon, the water to be used for washing produce should be checked for quality, especially if drawn from rivers, streams or standing bodies, to ensure that it is not polluted by sewage, factory effluents, pesticides, herbicides or fertilisers.

Site characteristics. When the general location has been chosen, the following should be observed:

- the site should be level and, if possible, sheltered from exposure to strong winds;
- if it is to be a permanent packing operation, the site should have room for expansion.
- there must be room for the movement and parking of the largest number and size of vehicles expected to use the site; roadways must be at least 3.5 m wide;
- drainage must be adequate to cope with rain runoff and the water used in packing operations;
- the site should lend itself to security arrangements: fencing, watchmen, etc.

Layout, Construction and Equipment

Small-scale packing houses are likely to be handling a variety of crops at any one time and over a period of time. Where the volumes handled are relatively small, the layout of buildings and equipment should be simple and flexible.

Layout. The design will be influenced by the space available. In general, a single-level building with a receiving area at one end and a dispatching area at the other will be the most convenient arrangement. This plan separates the reception area, which will be dirty, from the packing and dispatching activities, thus reducing the risk of contamination of sorted and packed produce. It should also avoid congestion and confusion between arriving and departing vehicles. If the dimensions and shape of the site are restricted, a U-shaped layout with reception and dispatch areas beside each other is possible, but it cannot be recommended as it will certainly lead to problems of contamination and congestion, let alone problems of any future expansion.

The area of the packing house should be adequate for the easy movement of produce through three stages.

Reception. This area controls the receiving, sorting and cleaning of produce, including washing, when necessary. It is likely to be dirty with soil, dust and decaying plant material.

Ideally it should be separated from the other activities in order to limit the contamination of cleaned, sorted and packed produce.

Preparation and packing. This section will include facilities for special treatments, including drying facilities for produce washed or treated or both. The main activity will be the packing of the cleaned produce, with selection and grading facilities, if needed.

There should also be space for the storage and assembly of packing materials in dry conditions.

The whole area should be protected from the weather, but with good ventilation and lighting. The selection, grading and packing areas should be kept clean and dry.

Dispatch. This activity should be located next to the packing operation but should be kept completely clear of permanent equipment. It must be large enough to provide temporary storage of packed produce and still permit unrestricted movement of workers and produce being shifted.

The dispatch area must be clean and well ventilated.

Any separate office or quality-control activity would probably be located here.

Construction. The building materials and type of construction will be governed by the crops to be handled, expected volume, the market to be catered for and the financing available. Small-scale operations can be successful in relatively simple and inexpensive structures. The principal requirements are:

- adequate overhead protection from sun and rain. This will be helped by a wide roof overhang of at least one metre all around;
- good ventilation but protection from wind-blown rain and dust. This can usually be provided by walls which leave a wide ventilation space beneath the overhanging roof;
- hard, level flooring for safe and easy movement of people and produce.

For small-scale, on-the-farm packing, a simple structure made from cheap local materials (such as bamboo, bush poles, dried grass or other thatch) may be adequate. Such a structure may have a relatively short life, but this factor will be offset by its cost and ease of repair or replacement. If sufficient water is available, walls and roof made of dried plant materials can be periodically soaked to cool the interior of the structure.

A more durable small packing house can be built of a wooden frame with roof and walls of corrugated sheet metal over a concrete floor. In areas of strong sunlight, the heat generated in sheet-metal buildings is extreme, affecting workers and produce. If sheet metal must be used, a wide ventilation gap should be left between walls and roof, the roof itself having a wide overhang. Building walls may not be necessary if the roof is sufficiently extensive to protect produce and workers from sun and rain, and if windblown dust and rain are not problems.

Permanent packing houses should have non-slip concrete floors laid with a fall to drainage channels for easy cleaning. An antidusting surface treatment of concrete is an advantage.

Packing houses, except for those built for big commercial operations, should be free from fixed equipment installations. This allows the maximum flexibility for changing the layout as demanded by varying volumes of produce and a variety of crops.

Equipment. The equipment needed will be specific to each packing house, according to the scale of operations and crops handled. It will be simple and much of it can be made locally. It should be movable, and this means that concrete washing tanks should be avoided.

- Bins or trays manageable by one person are a convenient means of moving produce up to the point of packing. They can be of wood or of plastic, ideally of high-density polythene. Plastic containers are more expensive than wood, but they are easier to keep clean and should last longer. Several containers can be moved at one time.
- Push-carts can be any sort of two- or four-wheeled trucks like those used in markets or factories.

- Roller conveyors, supported on stands about 75 cm high, are ideal for the movement of bins or trays through the various stages; they can also be used for loading and unloading vehicles where containers have to be handled individually.
- Mechanised moving-belt conveyors can be used but are expensive and better suited to large operations.
- Hand-pushed lift trucks are valuable in larger packing houses where mechanised means are required for handling unit loads on pallets; these cannot, however, be used for lifting loaded pallets on to vehicles; to do so, requires that the loading bay be raised to the height of truck beds or that a mechanical hoist be available for loading.
- Motorised forklift trucks are used in large packing houses for moving palletised loads.

When empty (a), they nest and save space in storage or transit. When filled, they stack neatly and firmly (b) if every other crate is turned in the direction opposite to that below so that crates do not nest and cannot crush contents

Selection, grading and packing. A final selection of produce immediately before it is packed should remove any unmarketable pieces which may have passed earlier sorting. Where small volumes of produce are dealt with by hand, a simple stand is adequate for selection, grading and packing. The stand illustrated can be made to any convenient length or duplicated if larger volumes of produce are handled.

Experienced workers can select produce and often size-grade it by eye or by simple gauges, hand-held or fixed.

Selected and graded produce is placed in the packing bin, then packed into containers placed on the shelf. Packed containers then move to the dispatch assembly area.

Additional equipment

Weighing. Much produce is still bought and sold by weight, so most packing houses will require some means of weighing produce. Many types of scales are made, and it is best to study the need and the types of scales available before deciding which is most suitable.

Washing. Washing of produce can be done in fresh running water using a galvanised tank. Produce that floats can be moved along the tank by water flowing from the inlet pipe, perforated on one side, across the end of the tank. The vertical baffle near the outlet end will help to ensure that all produce in the tank is properly washed.

Drying. Produce washed or treated with fungicide needs to be dried before packing. In a small packing house this can be done on a drying rack or table made of wooden slats or plastic-covered wire mesh. Where on-the-farm packing is done, the drying table can readily be made from bamboo or bush poles.

Where a fungicide is applied from a knapsack sprayer after washing, this can be done on the drying rack, and the produce then left to dry before packing.

Water entering under pressure through perforated pipe will move floating produce along tank. The baffle near drain pipe helps to circulate water through the produce

Packing-house Management

The effective management of packing houses requires a high level of efficiency in coordinating the technical, organisational and commercial aspects of operations. Errors and delays affecting any part of the operations will be reflected in growers' returns. Operations should continue throughout the year if it is economic to do so.

Meeting market requirements. Management should be able to advise and instruct both growers and packing-house staff in order to achieve the most efficient operations and high-quality output for the best possible returns.

Procurement and control. A reliable knowledge of the size and arrival times of produce crops to the packing house is essential to its efficient operation. Pickup of harvested produce may be arranged by the packing house. Growers sending produce to a central packing house should be aware of the control of quality and the standards observed. The quality of packed produce must also be controlled in order to reduce the possibility of disputes during marketing.

Supplies of packing materials. Estimates of the coming year's needs must be made in advance. Early arrangements should be made with suppliers to obtain the most advantageous prices and delivery dates.

Accurate stock control must be observed so that supplies do not run out during packing operations.

Disposal of low-grade produce. The selection and grading of produce for market will always result in some substandard pieces. They may have a certain value but should be disposed of to the best advantage of the packing house. The management must also know how much produce is a total loss. The disposal of both the low-grade produce and the total-loss produce must be accounted for.

Staffing. The staffing of the packing house must be adequate for its efficient operation but with attention to labour costs. This means the efficient deployment of labour and the need for adequate supervision.

Permanent staff may include a manager, clerks, mechanics and maintenance workers, drivers and some skilled packers. Peak periods will require temporary workers.

Staff training. The manager's responsibility for all packing-house activities requires that he be technically qualified and able to train his foremen. He must also ensure that in-service training is provided for the packing workers.

Grower training. When a packing house is supplied by several growers, management should ensure that they are informed as to how they can achieve the quality standards set by the market. Cooperation with post-harvest extension workers is desirable. This may include formal training out of season but will be most effective if farm visits are made when harvesting and packing-house activities are in progress.

Accounting and costing of operations. Agreements must be made with growers as to payments for produce, taking into account the quality control requirements. The cost of running the packing house must be estimated per kg of produce throughput to enable costs to be minimised and growers' returns maximised.

Documentation and accounting. The manager is responsible for seeing that accurate records are maintained and proper accounts prepared. This is fundamental to the success of the packing house as a business.

PREVENTION OF LOSSES DURING TRANSPORT

Transportation is a big and often the most important factor in the marketing of fresh produce. Ideally, transport would take produce from the grower directly to the consumer, as in many developing countries. In more complex marketing systems (those serving towns, cities or distant countries)' the cost of transport contributes significantly to the price paid by the consumer, and sometimes exceeds the value of the raw product.

Losses directly attributed to transport conditions can be high. The goal of every person concerned with transport should be that the produce be kept in the best possible condition during transport and that the haulage of produce be quick and efficient. To this end, produce should be properly packaged and properly loaded on a suitable vehicle.

Causes of Loss

The damage and loss incurred during non-refrigerated transport are caused primarily by mechanical damage and by overheating.

Mechanical damage. Damage of this type occurs for many reasons, including:

- careless handling of packed produce during loading and unloading;
- vibration (shaking) of the vehicle, especially on bad roads;
- fast driving and poor condition of the vehicle;

- poor stowage, which allows packages in transit to sway; the stow may collapse;
- packages stacked too high; the movement of produce within a package increases in relation to its height in the stack.

Overheating. This can occur not only from external sources but also from heat generated by the produce within the package itself.

Overheating promotes natural breakdown and decay, and increases the rate of water loss from produce. The causes of overheating include:

- the use of closed vehicles without ventilation;
- close-stow stacking patterns blocking the movement of air between and through packages, thus hindering the dispersal of heat;
- the lack of adequate ventilation of the packages themselves;
- exposure of the packages to the sun while awaiting transport or while trucks are queuing to unload at their destination.

Reduction of Losses during Transport

The risk of deterioration of produce during transport can be reduced in several ways.

Trucks used to transport fresh produce. Most fresh produce is now moved in road vehicles, with lesser amounts by sea, air or inland waterways. The vehicles in most common use are open pick-ups or bigger trucks, either open or enclosed. The use of road vehicles is likely to increase, so users should give attention to the following:

- closed vehicles without refrigeration should not be used to carry fresh produce except on very short journeys, such as local deliveries from farmers or wholesalers to nearby retailers;
- open-sided or half-boarded trucks can be fitted with a roof on a frame. The open sides can be fitted with canvas curtains which can be rolled up or moved aside in sections to allow loading or unloading at any point around the vehicle. Such curtains can protect the produce from the elements but still allow for ventilation. Where pilfering is a problem, the sides and rear of the truck must be enclosed in wire mesh;
- a second, white-painted roof can be fixed as a radiation shield 8 or 10 cm above the main roof; this will reflect the sun's heat and help to keep produce cool;
- for the ventilation of long-distance vehicles, more elaborate air intakes can be fitted in conjunction with louvres, to ensure a positive air flow through the load;
- refrigerated trucks or road, rail or sea containers may be used for long journeys, but the cost of such transport makes it uneconomical for small-scale operations.

Handling and stowage practices. Although the shape and condition of trucks are important factors in fresh produce transportation, the loading and stowing methods in vehicles are pertinent to damage and loss:

- the best loading factor must be achieved, that is the maximum load that can be carried economically under satisfactory technical conditions: a stable and well-ventilated load;
- the size and design of packages should give adequate levels of ventilation of contents with the minimum of wasted space, and the packages should be strong enough to protect the contents;
- loading and unloading of vehicles should be properly supervised to prevent careless handling of packages; loading aids such as trolleys, roller conveyors, pallet or forklift trucks should be used where possible to reduce the handling of individual packages;
- stowage should be carefully done to avoid collapse of the stow during transport; packages should not be stacked higher than the maximum recommended by the maker, otherwise the bottom layers may collapse under the weight of those above
- packed produce should be protected from sun and rain at all times including during loading and unloading;
- packages should be loaded on dunnage (pieces of lumber or slatted racks) on the beds of vehicles, or on pallets in order to allow the circulation of air around stacks during transport;
- if the load is to be distributed to several locations, packages should be loaded in reverse order to that in which they will be unloaded, i.e. last on, first off; at the same time the load should be distributed evenly on the vehicle.

Although every care may be taken to observe all the above precautions, the standards of driving remain a difficult problem to overcome. In many cases, drivers are induced to speed in order to make more money for themselves or their employers. Whenever possible, only experienced and responsible drivers should be employed.

Other modes of transport. Fresh produce is transported by many other means, from head-loads to air-freighting. In all cases, the same conditions should be observed. Produce must be:

- kept as cool as possible;
- kept dry;
- moved to market as quickly as possible.

Rail transport. In some countries a large amount of produce is carried by rail. The advantages are:

- transport damage to produce while moving is slight as compared with that from haulage over rough roads;
- costs are lower than transport by road.

Rail transport, however, requires extra handling since road transport is needed to and from the rail journey; transport by road alone usually is a door-to-door service.

Water transport

Inland. Waterway transport is used in some countries to move produce to markets. Much of the produce carried in this way is packed in locally made crates or sacks. The vessels employed are often mixed passenger-cargo craft, and no special handling is provided for fresh produce.

Sea. Short-distance transport of fresh produce in small ships without refrigeration is common in countries of island communities (e.g. the Philippines). Ships often accommodate passengers and general cargo, and no special provision is made for fresh produce, which may be stowed in unventilated holds. Losses are high, owing to rough handling by porters, inadequate packaging and overheating in unventilated holds or near engine rooms.

There is much room for improvement in this mode of transport. A model for organised and efficient sea transport is the refrigerated shipment of commercial crops such as bananas, although a modest investment by the small-scale shipper could greatly improve performance.

Air freight. As with shipping, the international trade in the air-freighting of high-value exotic crops is generally well organised. In some countries where road links are poor (e.g. Papua New Guinea), produce is carried by air from production areas to urban markets. Costs are high and losses often heavy because of:

- poor, non-standard packages;
- careless handling and exposure to the elements at airports;
- consignments left behind in favour of passengers;
- flight delays owing to bad weather or breakdowns;
- intermittent refrigeration followed by exposure to high temperatures;
- relatively small produce shipments.

Even though changes are made in packaging and handling, it is unlikely that the overall situation will improve much until road links are established between producers and consumers.

POST-HARVEST TREATMENTS

Special Uses

The routine packing operations are cleaning, selection, grading and packing of produce. Apart from these, some crops which are seasonal and subject to long-term storage, or are highly perishable and transported over long distances to market, require special treatments in order to slow deterioration and minimise losses.

These treatments may be applied before, during or after packing and are supplementary to the routine measures, such as temperature and moisture control, which aim to reduce losses in all fresh produce.

Curing

The term "curing" is applied to the measures used to prepare starchy staple root crops and onions for long-term storage. The method of curing root crops is, however, quite different from that used on onions.

Root crop curing

The curing of root and tuber crops replaces and strengthens damaged areas of corky skin, restoring protection against water loss and infection by decay organisms. The principal crop subjected to curing is the Irish potato, but curing is also effective in some tropical root crops.

Although details vary from crop to crop, the following conditions must always be observed:

- the roots and tubers must be kept at an appropriate temperature, normally somewhat higher than ambient, in order to stimulate new skin growth;
- the atmosphere must be kept moist but without free water on the surface of the roots or tubers; no new skin will be formed in dry air on injured surfaces;
- some ventilation is needed for new skin growth, but an excessive air flow will dry the atmosphere and cause a drop in temperature;
- the temperature must be kept steady; if it falls, water will condense on the surface of the roots and tubers and will encourage bacterial soft rot.

Because all root and tuber crops are damaged to some extent during harvest and handling, curing must be carried out as soon as possible. This can be done by limiting ventilation, thus allowing the temperature to rise enough to promote curing. At the same time the air will become moist owing to the normal production of water by the roots and high rate of evaporation from injuries.

The conditions for Irish potato storage are we!! established; but those for tropical root crops are mostly based on experimental data. The storage life of sweet potatoes and of aroids like taro and cocoyam is usually rather short owing to their susceptibility to post-harvest decay. Cassava is subject to rapid internal discoloration and decay.

Curing dry bulb onions

The curing of dry bulb onions, carried out immediately after harvest, is a drying-out process. Under dry, warm conditions harvested onions are left in the field for a few days until the green tops, outer skins and roots are fully dried. Under wet conditions, it may be necessary to dry onions on racks or trays under cover. The curing of onions is necessary because:

- the necks of onions are very sensitive to decay if they remain wet, especially if the green tops are cut off before harvest;
- drying the outer skins of the bulbs reduces decay and water loss;
- roots damaged during harvesting are a common entry point for decay unless they are dried quickly.

If properly carried out, this technique will provide the necessary warm and moist atmosphere to aid in healing skin damage. It can be adapted for other root crops.

Cutting off the green tops of bulb onions is not recommended for small-scale producers because it greatly increases the risk of losses from decay if the bulbs cannot be dried quickly under controlled conditions.

In large-scale commercial production, where the green tops are cut off mechanically before harvest, drying is often carried out using artificial heat with forced ventilation. This technique is not economical for small-scale production.

Field-dried onions can be stored up to two months under ambient conditions in well-ventilated trays on pallets or in a field windbreak. Dried onions should never be allowed to come into contact with damp soil.

Inhibition of Sprouting

Sprouting of both potatoes and onions is a problem in temperate countries, where they are stored for up to eight months. Long-term storage may not be necessary in warmer climates where growers may produce more than one crop a year. Two methods are employed to reduce sprouting:

- the selection of varieties with long dormancy periods; suppliers of seed and planting material can be asked to provide information on storage characteristics of varieties produced under local conditions;

— the use of chemical sprout suppressants for potatoes and onions to be stored. Some suppressants have to be applied to the growing crop before harvest. Others such as tecnazene are mixed as a dust or granules with potatoes as they are loaded into store. Suppressants are rarely used except in large-scale production and storage; they should be used only after consultation with extension workers. Little is known about the effectiveness of sprout suppressants when used on tropical root and tuber crops.

Fungicide Application

Post-harvest application of fungicides to control decay is used on several major crops which are either stored or undergo long periods of transport to distant markets (citrus, bananas, apples, etc.). Fungicides are normally used only on produce which is washed and drained dry before packing.

Application method

Spray or mist. For small-scale operations application is by hand-held knapsack sprayer or for large-scale commercial operations by a mechanised spray rig in conjunction with a moving belt or roller conveyor. Produce is sprayed to runoff to ensure complete coverage.

Drenching. A simple mechanised recirculating system pumps fungicide in a cascade over produce passing beneath it on a belt or roller conveyor. This system has no spray nozzles to wear out or become blocked, and the high flow rate through the pump keeps the mixture agitated. It may be necessary to add a non-foaming wetting agent in the suspension to counteract possible drag-out of the fungicide if foaming occurs.

Dipping. Where small quantities of produce are to be treated, the fungicide mixture is made up in a small container and produce is dipped by hand. Excess fungicide is allowed to drain back into the bath. The fungicide suspension must be agitated constantly. Workers dipping by hand may develop skin reaction to some fungicides, and they should be supplied with rubber gloves for their protection.

Smoke or fumigant. Fungicide can be applied in the form of dust or vapour in closed containers, or in sealed bulk stores. Such treatments are relatively rare. Bulk-store fumigation requires skilled operation and is normally carried out by contractors.

Hot water. Although hot-water dips have known to be effective for the control of post-harvest decay of some tropical fruits, the treatment has not been widely adopted because of the difficulty of applying it on a commercial scale. A heated fungicide dip has been shown to control anthracnose and has been used commercially in Australia. The operation requires close technical management and allows very little margin for error. It is not generally applicable to small-scale production.

Controls on fungicide treatment

The use of fungicides after harvest is normally subject to more stringent regulation than would be applied to their use on growing crops. The range of chemicals available for post-harvest treatment of fresh produce is small, with strict limitations on both the concentrations used and the permitted levels of residues on treated produce at the retail or processing stage. Users of post-harvest fungicides must observe that the fungicide for any crop is:

- permissible (i.e. not prohibited) for use on the crop after harvest;
- effective in controlling the post-harvest diseases of that crop;
- used in accordance with the manufacturers' instructions and at their recommended concentrations (excessive residues on produce may lead to its rejection);
- agitated continuously during use to prevent its settling out.

Those in charge of operations must make sure that employees using fungicides observe all the precautions applicable to their use and that they wear the necessary protective clothing.

PREVETION OF LOSSES DURING STORAGE

Controlled conditions

The term "storage", as now applied to fresh produce, is almost automatically assumed to mean the holding of fresh fruit and vegetables under controlled conditions. Although this includes the large-scale storage of some major crops, such as potatoes, to meet a regular continuous demand and provide a degree of price stabilisation, it also meets the demands of populations of developed countries and of the richer inhabitants of developing countries, providing year-round availability of various local and exotic fruits and vegetables.

In many developing countries, however, where seasonally produced plant foods are held back from sale and released gradually, storage in a controlled environment is not possible because of the cost and the lack of infrastructural development and of maintenance and managerial skills. Even in developed countries, however, there are still many people who, for their own consumption, preserve and store fresh produce by traditional methods.

Storage Potential

Much fresh produce (i.e. that which is most perishable) cannot be stored without refrigeration, but the possibilities for extending the storage life of even the most durable fresh produce under ambient conditions are limited.

Organs of survival

The organs of survival which form the edible parts of many crops such as Irish potatoes, yams, beets, carrots and onions have a definite period of dormancy after harvest and before they resume growth, at which time their food value declines. This period of dormancy can usually be extended to give the longest possible storage if appropriate conditions are provided. This factor is called the storage potential.It is important to recognise the variation in the storage potential of different cultivars of the same crop. Experienced local growers and seed suppliers can usually provide information on this subject.

Edible reproductive parts

These are largely confined to the fruits or seeds of leguminous plants (peas and beans). In their fresh condition these products have a brief storage life which can be only slightly extended by refrigeration. They can also be dried, and then are called pulses. Pulses have a long storage life, provided they are kept dry, and do not present a storage problem of the sort affecting fresh produce.

Fresh fruit and vegetables

These include the leafy green vegetables, fleshy fruits and modified flower parts (e.g. cauliflower, pineapple). The storage potential of these is very limited under ambient conditions. They quickly deteriorate because of their fast respiration rates, which cause rapid heat buildup and the depletion of their high moisture content.Traditional methods of preservation are sun-drying or simple domestic processing into conserves and pickles. Most fresh fruit and vegetables have a storage life of only a few days under even the best environmental conditions.

Factors affecting Storage Life

The natural limits to the post-harvest life of all types of fresh produce are severely affected by other biological and environmental conditions:

Temperature. An increase in temperature causes an increase in the rate of natural breakdown of all produce as food reserves and water content become depleted. The cooling of produce will extend its life by slowing the rate of breakdown.

Water loss. High temperature and injuries to produce can greatly increase the loss of water from stored produce beyond that unavoidably lost from natural causes. Maximum storage life can be achieved by storing only undamaged produce at the lowest temperature tolerable by the crop.

Mechanical damage. Damage caused during harvesting and subsequent handling increases the rate of deterioration of produce and renders it liable to attacks by decay organisms. Mechanical damage to root crops will cause heavy losses owing to bacterial decay and must be remedied by curing the roots or tubers before storage.

Decay in storage. Decay of fresh produce during storage is mostly caused by the infection of mechanical injuries. Furthermore, many fruits and vegetables are attacked by decay organisms which penetrate through natural openings or even through the intact skin. These infections may be established during the growth of the plant in the field but lie dormant until after harvest, often becoming visible only during storage or ripening.

Ventilated stores. Naturally ventilated structures can be used for the storage of produce with a long storage potential, such as roots and tubers, pumpkins, onions and hard white cabbage. Such stores must be designed and built specifically for each intended location. Any type of building can be used provided that it allows the free circulation of air through the structure and its contents. The following essentials must be observed:

- the building should be located at a site where low night temperatures occur over the required storage period;
- it must be oriented to take maximum use of the prevailing wind for ventilation;
- the material covering the roof and walls should provide insulation from the heat of the sun; grass thatch on a bush-pole frame can be very effective, particularly if it is wetted to provide evaporative cooling;
- double-skinned walls will provide better insulation, if cost allows;
- white paint applied to surfaces of man-made materials will help to reflect the heat of the sun;
- the structure should be built in the shade of trees if they do not interfere with the prevailing air flow; beware of bush fires and of trees falling during storms;
- provide ventilation spaces below the floor and between walls and roof to give good air flow;
- if the store is subject to cold night temperatures, fit movable louvres and adjust them to limit the flow of warm air into the store during the day.

These are the basic requirements of a ventilated store. Such stores may be constructed to various levels of sophistication, using, where it is economically acceptable, fan-assisted ventilation controlled by differential thermostats. This type of store is in common use in Europe for the bulk storage of Irish potatoes and onions in locations where external winter conditions make possible the accurate control of the storage temperature.

Simple open-sided, naturally ventilated structures may be used to store seed potatoes at high altitudes in warm climates. They cannot be used for table potatoes, which will turn green, develop a bitter taste, or even become toxic if exposed to light for more than a few hours.

Clamps. These are simple, inexpensive structures used to store root crops, particularly potatoes in Europe and Latin America.

The potatoes are placed on a bed of straw I to 3 m wide, but not more than 1.5 m wide in warm climates. A ventilating duct should be placed along the bottom. The piled potatoes are covered with about 20 cm of compacted straw which can subsequently be encased in soil, applied without compaction up to 30 cm deep.

The clamp system can be modified for different climatic conditions. In warm climates extra straw casing may be used instead of soil in order to give added ventilation.

Other simple storage methods. Windbreaks are narrow, wire-mesh, basket-like structures about I m wide and 2 m high, of any convenient length, on a raised wooden base, and are used for short-term storage of dried onions in the field. The onions are covered on top with a 30 cm layer of straw, which is in turn held down by a polythene sheet fastened to the wire mesh. The windbreak is built at right angles to the prevailing wind to obtain maximum drying and ventilation.

Onions can also be woven into plaits on twine and hung in a cool dry place, where they will keep for several months.

Refrigerated and controlled-atmosphere storage. For large-scale commercial operations, refrigerated storage may be used in a cold-chain operation to carry regular consignments from production areas to urban markets and retailers. This can be a highly complex operation requiring expert organisation and management.

Cold storage can also be used for long-term storage of seasonal crops such as potatoes and onions. The storage life of some fruits, such as apples, can be extended by combining refrigeration with a controlled environment consisting of a mixture of oxygen and carbon dioxide.

These last are expensive operations with high maintenance and running costs, and demand skilled and experienced management. They have relatively little application to small-scale production in developing countries.

In most countries, the production of many perishable food crops is seasonal, making them available only during short periods of the year. During this short time, they are produced in greater quantity than the market can absorb, so the surplus of many of these crops must be processed and preserved to avoid wastage of the food and loss of income to the grower. Modern methods of food storage and preservation, such as refrigeration and freezing, are now widely used in developed countries. These methods are, however, rare in many of the developing countries, but surpluses of many seasonal local crops can be preserved for later use by various processing methods requiring only simple and inexpensive equipment.

REFERENCES

Bachmann, J. and R. Earles. 2000. "Postharvest Handling of Fruits and Vegetables". *ATTRA Horticulture Technical Note*. 19 pp.

Brackett, R.E. 1999. "Incidence, contributing factors, and control of bacterial pathogens in produce". *Postharv. Biol. Technol.* 15:305-311.

Campbell-Platt, G. 1987. *Fermented Foods of the World: Dictionary and Guide*. Stonam, Massachussetts: Butterworth Heineman.

FAO. 1989. *Prevention of Post-Harvest Food Losses: Fruit. Vegetables and Root Crops. A Training Manual.* Rome: UNFAO. 157 pp.

Lurie, S. 1998. "Postharvest heat treatments of horticultural crops". *Hort. Rev.* 22:91-121.

Moline, HE. 1984. *Postharvest Pathology of Fruits and Vegetables: Postharvest Losses in Perishable Crops.* U.C. Bulletin 1914, University of California, Division of Agriculture and Natural Resources, Oakland, California 94608.

Bibliography

Ahvenainen, R. 1996. "New approaches in improving the shelf life of minimally processed fruit and vegetables". *Trends in Food Science and Technology*. 179-197.

Aiyer, RS. et al. 1978. "No-cost method for preserving fresh cassava roots". *Cassava Newsletter* 4: 8-9. Cali, Colombia: CIAT.

Alzamora, S.E., Tapia, M.S., and López-Malo, A. 2000. *Minimally Processed Fruits and Vegetables: Fundamental Aspect and Applications*. Aspen Pub. Co., Inc., Maryland, US, 277-286.

Bachmann, J. and R. Earles. 2000. "Postharvest Handling of Fruits and Vegetables". *ATTRA Horticulture Technical Note*. 19 pp.

Bentley, Amy. *Eating for Victory: Food Rationing and the Politics of Domesticity.*

Brackett, R.E. 1999. "Incidence, contributing factors, and control of bacterial pathogens in produce". *Postharv. Biol. Technol.* 15:305-311.

Brown, M.; Bates, R.P.; McGowan, C.; Cornell, J.A. 1992, 1994. Influence of Fruit Maturity on the Hypoglycin A Level in Ackee (Blighia Sapida). Journal of Food Safety. 12 (2), 167-177.

Campbell-Platt, G. 1987. *Fermented Foods of the World: Dictionary and Guide.* Stonam, Massachussetts: Butterworth Heineman.

Cantwell, M. 2001. *Post-harvest Handling Systems: Minimally Processed Fruit and Vegetables.* Vegetable Information. University of California, Vegetable Research and Information Center.

Cook, R.L. 1998. "Post-harvest of horticultural crops. Proceedings of the World Conference on Horticulture Research". *Acta Horticulture* No. 494.

FAO. 1986. *Improvement of Post-Harvest Fresh Fruits and Vegetables Handling.* Regional Office for Asia and the Pacific. Maliwan Mansion, Phra Atit Road, Bangkok, 10200, Thailand.

Fellows, P. and Hampton, A 1992. *Small-Scale Food Processing A Guide to Appropriate Equipment.* London: Intermediate Technology Publications. 158 pp.

Hardenburg, R.E.. et al. 1986. *The Commercial Storage of Fruits. Vegetables. and Florist and Nursery Stocks.* USDA Agriculture Handbook 66. 130 pp.

Hauther,W. & Worth, M., 2008. *Zapped! Irradiation and the Death of Food,* Food & Water Watch Press, Washington, DC.

Holdsworth, S.D. 1983. The Preservation of Fruit and Vegetable Food Products. Science in Horticulture Products. Macmillan Press, London, 109-110.

Humphery, Kim. *Shelf Life: Supermarkets and the Changing Cultures of Consumption.* Cambridge University Press, 1998.

Kitinoja, L. and Gorny, J.R "Postharvest Technology for Small-Scale Produce Marketers: Economic Opportunities, Quality and Food Safety". 1999. *UC PTRIC Horticultural Series* No. 21

Leistner, L. 1992. "Food preservation by combined methods". *Food Research International.* 25, 151-158.

Liu, F.W.. 1988. "Developing practical methods and facilities for handling fruits in order to maintain quality and reduce losses". *Postharvest Handling of Tropical and Subtropical Fruit Crops,* Food and Fertilizer Technical Center for the Asian and Pacific Region, Taipei 10616, Taiwan.

Lurie, S. 1998. "Postharvest heat treatments of horticultural crops". *Hort. Rev.* 22:91-121.

Mitchell, F.G., Guillon, R., R.A.. Parsons. 1972. *Commercial Cooling of Fruits and Vegetables. U.C. Extension Manual* 43, University of California, Division of Agricultural Sciences, Oakland, California 94608.

Moline, HE. 1984. *Postharvest Pathology of Fruits and Vegetables: Postharvest Losses in Perishable Crops.* U.C. Bulletin 1914, University of California, Division of Agriculture and Natural Resources, Oakland, California 94608.

Nagy, S. and Shaw, P.E. 1980. *Tropical and Subtropical Fruits. Composition, Properties and uses.* AVI Publishing, Westport, Connecticut, 127.

Natural Resources Institute. 1994. *Manual for Horticultural Export Quality Assurance.* Chatham, UK: Natural Resources Institute.

Olaeta-Coscorroza, J.A., and Undurraga-Martínez, P. 1995. Estimación del índice de madurez en paltas. In: *Harvest and Post-harvest Technologies for Fresh Fruits and Vegetables.* Proceedings of the International Conference, Guanajuato, Mexico. February 20-24, 521-425.

Peleg, K. 1985. *Produce Handling, Packaging and Distribution.* The AVI Publishing Co., Westport, Conn, 20-53.

Proceedings on the World Conferences on Horticulture Research.1996. Global horticultural impact: fruits and vegetables in developed countries. Acta Horticulture 495, 39-66.

Rahman, M.S., Labuza, T.P. "Water activity and food preservation". 1999. In: *Handbook of Food Preservation,* edited by M. Shafiur Rahman. Marcel Dekker, Inc., New York, 339-382.

Regmi, Anita (editor).*Changing Structure of Global Food Consumption and Trade.* Market and Trade Economics Division, Economic Research Service, USDA, 2001.

Ryall, A.L. and Pentzer, W.T. 1982. *Handling, Transportation and Storage of Fruits and Vegetables.* The AVI Publishing Company, INC. Westport, CT. 2: 98-143.

Segre, A. 1998. *Global horticultural impact: Fruits and vegetables in developing countries.* World Conference on Horticultural Research, Rome, Italy, June 17-20.

Shafiur Rahman. *Handbook of Food Preservation.* Marcel Dekker, Inc., New York, 339-382.

Shephard, Sue. *Pickled, Potted, and Canned: How the Art and Science of Food Preserving Changed the World.*

Shewfelt, R.L. 1986. "Postharvest treatment for extending shelf life of fruits and vegetables". *Food Technology.*

Sloan, A.E., Labuza, T.P. 1975. "Investigating alternative humectants for use in foods". Food Product Development 9(7), 75-88.

Smith, Andrew (Editor). "Food Marketing," in Oxford Encyclopedia of American Food and Drink, , New York: Oxford University Press, 2007.

Sofos, J.N. 1989. *Sorbate Food Preservatives.* CRC Press, Boca Raton, 16-17.

Thayer, D.W. and Rajkowski, K.J. 1999. "Development in irradiation of fresh fruits and vegetables". *Journal Food Technology.* 53(11), 62-65.

The Economic Research Service of the USDA. *Global Food Markets: Briefing Rooms.* Retrieved from http://www.ers.usda.gov/Briefing/ on 2006-09-29.

Thompson, A.K. 1998. *Controlled Atmosphere Storage of Fruits and Vegetables.* Blackwell Science, Berlin, 14-17.

Walker, D. J. 1992. *World Food Programme Food Storage Manual.* Chatham, UK: Natural Resources Institute.

Wills, R.B.H., W.B. McGlasson, D. Graham, T.H. Lee, and E.G. Hall. 1989. *Post-harvest: An Introduction to the Physiology and Handling of Fruits and Vegetables.* Van Nostrand Reinhold, New York.

Zachariassen KE, Kristiansen E. 2000. "Ice nucleation and antinucleation in nature". *Cryobiology* 41 (4): 257-279.

Zagory, D. 1999. "Effects of post-processing handling and packaging on microbial populations". *Postharv. Biol. Technol.* 15:313-321.

Index