Handbook of Milk of Non-Bovine Mammals

Edited by
Young W. Park and George F.W. Haenlein

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Handbook of Milk of Non-Bovine Mammals

1
Overview of Milk of Non-Bovine Mammals

Young W. Park and George F.W. Haenlein

1 INTRODUCTION

It has been said that many countries are in the midst of a cheese revolution (16). A cheese course may now be part of the final dinner course in many restaurants, and more food stores and markets are offering a great variety of fine domestic and imported *frommage*. This is certainly the situation in Europe and America, and it is especially the case in France. During the last 30 years there has been a reawakening and rediscovery of natural, organic, farm-fresh, artisanal, and original foods for healthier and tastier eating. In this reawakening, dairy goats have also been prominently rediscovered as fitting well the new interest in healthy foods, especially goat milk products, cheeses, and yogurt. Dairy goats have reentered a niche alternative of the dairy industry even in regions in which only dairy cows rule the market. Worldwide FAO statistics also show enormously increasing numbers of goats during recent decades (+61% worldwide from 458 million head in 1980 to 738 million head in 2001) (12, 13) (see Chapter 2, Table 2.3). Dairy cows and their products have been synonymous with the concept of the dairy industry in much of the developed world, in market places and textbooks for a long time. More than 95% of dairy products have been derived from cow milk, except in countries of the Mediterranean basin. Students of dairy science learned mostly only of cows producing milk products. Archeological findings from ancient Mesopotamia, Egypt, and India show the milking mainly of cows and the making of butter and cheese (31). Even U.S. regulatory agencies and State Board of Health authorities had as their ruling dairy code the definition of milk "as being derived from cows" until recently.

This situation changed about 30 years ago, especially in America, and continues to change. Now, dairy goats have finally become accepted as a legitimate addition to the dairy industry by U.S. state regulatory authorities. Furthermore, during the last 10 years, dairy sheep have also entered America and have fast become a new and acceptable part of the dairy industry. What is a strong tradition in many Mediterranean countries and other parts of the world has finally arrived in America. Increased importation of dairy products from goat and sheep milk, even buffalo milk, from other countries to satisfy a growing interest of consumers is integrating with new domestic production from dairy goats and dairy sheep. In other parts of the world, more than just goats and sheep are important or even the principal milk producers because of steep mountains, deserts and harsh climate, poverty, economics, and long tradition. Other mammalian species besides cows are also very significant milk providers, such as camels, yaks, buffaloes, mares, reindeer, even llamas, and their contributions must not be overlooked in dairy science teaching. America has even now one or two dairy buffalo herds, and one or two commercial dairy mare herds exist in Europe and America besides the many in Asia.

Today's consumers in developing and developed countries are also more and more sophisticated in their desire to know about the composition and constituents in dairy products as they relate to human

health (9, 34). Hardly anybody paid much attention or knew much about good and bad types of fat and fatty acids until recently. Today's nutrition labels on food products indicate levels not only of protein, fat, carbohydrates, sodium, calcium, and vitamins but also of such special ingredients as saturated, unsaturated, omega-3, conjugated, and trans-fatty acids. This open knowledge leads to interest into ascertaining which dairy products may be superior to others, and which animal feeding system is best, such as pasturing versus barn feeding, and which animal species produces a more suitable or preferable human food to others. In terms of milk for infants or sick patients, answers are sought as to which milk is closest to human milk and best for babies, or which milk creates fewer allergies, which one is better tolerated by people with gastrointestinal ailments, and which dairy product causes no lactose intolerance symptoms.

2 MAMMALS IN THE ANIMAL KINGDOM

The natural law of survival in the animal kingdom is founded upon the preservation of its offspring. The highest class of animals evolved with mammary glands for the nourishment of their young after birth are called *Mammalia* (33). The fetus developing in the placenta of most mammals is born in a more or less helpless state. Upon birth, the young are nursed by their mothers with milk, which is a physiologically and nutritionally balanced secretion of the mammary gland.

The mammary glands of cows, sheep, goats, deer, camel, horses, and even whales are located in the inguinal region; those of primates and elephants are in the thoracic region, but those of pigs, rodents, and carnivores are along the ventral surface of the thorax and abdomen (37). The mammary gland, as with sebaceous and sweat glands, is a cutaneous gland. Milk is formed by synthesis and diffusion processes from the blood in the mammary gland. This lactogenesis occurs concomitantly with parturition in most mammals, although there are small quantities of precolostrum formed in the mammary gland in later stages of pregnancy (26).

Milk has been described as the most perfect food in nature. Milk is balanced for most nutrients and often has a high caloric value. It can meet the nutritional requirements of the newborn during its early critical period of body development, and provides essential nutrition for normal growth, until the newborn is able to consume and digest solid foods. All mammalian young are completely dependent on mother's milk until they begin to feed on their own and are weaned weeks after parturition.

3 EVOLUTION OF THE DAIRY INDUSTRY

In search of socioeconomically feasible and nutritionally superior sources of foods, humanity has domesticated some mammalian species and selected and bred them to produce large volumes of milk in excess of the necessary amounts to nourish the animal's own offspring. This surplus of milk production beyond nourishing the young has become the foundation of the modern dairy industry. In North America, Europe, Australia, and New Zealand, the dairy industry is one of the most integral enterprises among all agricultural production businesses.

Although the dairy cow has been the predominant domesticated animal species for dairy production in developed countries, the goat, sheep, water buffalo, yak, camel, and mare as well as some other minor mammalian species have been domesticated, kept, and bred for milk production in regions of the world where the difficult environment required special adaptation and for which many of the nonbovine mammals are better suited.

Understanding the anatomy, histology, physiology, and biochemistry of milk component synthesis and its secretory processes in the mammary gland is important for production, maintenance, and utilization of milk for human consumption. Greater knowledge of this will provide dairy producers with the essential capacity to improve management and environmental conditions of their dairy animals for higher efficiency, greater quality, and larger volumes of milk production. Such knowledge also would give dairy producers opportunities for affecting the composition of milk to meet more functionally the nutrition and health needs of people.

Milk is one of the most precious natural foods and has been a basic component of the human diet since early history. Milk drawn from the lacteal glands is highly perishable and adversely affected by improper practices of feeding and handling of the animals, handling of milk during and after milking, cooling, transportation, pasteurization, processing, packag-

ing, processing equipment, and storage (22, 30). Through understanding of the basic science of lactation in domesticated mammals, the milk production volume and quality can be maximized for effective utilization and processing of milk products for human consumption.

4 COMPOSITION AND SECRETION OF MILK OF MINOR SPECIES

In a comprehensive review of milk of mammalian species, Oftedal (27) was able to locate compositional data for at least 194 species. However, there were relatively few careful studies on nondomestic species. Only 55 species, including domesticated mammals, had systematic data for all lactation stages. It was shown that much of the available information, especially on wild species, was from opportunistic situations, in which effects of stage of lactation, compromised maternal or infant health, and sampling bias could not be tested (28).

Milk constituents are produced either directly or indirectly from blood. Even if the osmotic pressure is the same for milk and blood, markedly different compositions exist between the two physiological body fluids. Milk proteins are mainly caseins, at least in ruminants, while the principal proteins in blood plasma are albumins and globulins. In addition, milk contains more sugar (lactose), fat (lipids), calcium, phosphorus, and potassium, but often less protein, sodium, and chlorine than blood (37).

Milk contains two characteristic components, lactose and casein, besides fat, minerals, and vitamins. Even though the composition of milk is influenced by genetic, nutritional, and environmental factors, the amounts of the major and minor constituents in milk vary genetically substantially between species. In general, milk of marine mammals such as dolphins, seals, whales, and polar bears contains a high fat content (37). Many of the rapidly growing species, such as the rabbit and rat, have high protein contents in their milk, but the correlated relationships between rates of reaching maturity and levels of protein in milk are not consistently linear. The most constant component in milk is lactose, which is found in between 3 and 7% in mid-lactation milk of different species. Among marsupials, a class just below mammals but also providing milk to their young inside their pouch, the kangaroo milk contains pentoses instead of lactose, as well as proteins and other nitrogenous compounds, which are not usually associated with mammalian milk (7).

Milk composition of domesticated and some wild mammals is shown in Table 1.1. These values are average figures and can be used only for general comparisons between species.

Many data in the table, especially for nondomesticated species, are based on few analyses and have little information about the stage of lactation, when the milk samples were taken. There can even be significant differences in composition of milk between different glands of the same animal, and substantial variations do occur diurnally and from day to day.

Lactogenesis or the onset of copious milk secretion occurs concomitantly with parturition in most mammalian species. Lactogenesis takes place in two stages (14, 19). The first prepares the mammary glands for milk secretion, and this usually occurs sometime in later pregnancy. The second stage is the onset of milk secretion at the time of parturition.

In the cow, lactogenesis coincides with parturition (29). In the rat, milk is secreted into the mammary ducts four hours prior to parturition (21). On the other hand, lactogenesis is delayed for 48 or 72 hours postpartum in humans and guinea pigs, which may be attributable to the slow postpartum decrease in progesterone levels in the two species (25).

Hormones have definite influences on the initiation of the milk secretion process. The continued secretion, the amount of milk produced, and the composition of milk are controlled by several hormonal and nutritional factors within the animal. In dairy cows and goats, somatotrophin and thyroxine increase the level of milk production (33, 37) and have to be removed periodically in order for secretion of milk to continue. However, secretion of milk, that is, its removal, from the mammary gland usually requires the stimulation of the nervous system through the young's suckling or manual premilking procedures. If the milk is not evacuated from the glands, the secretory process declines and secretion stops with a complete involution of the secretory tissues. Milk secretion proceeds by a physiological feedback system. The nervous stimulus induces the release through the bloodstream of the hormone oxytocin from the pituitary gland in the brain, which causes the myoepithelial cells surrounding the milk-producing alveoli to contract, thus forcing the milk from the alveoli into the udder ducts and cisterns (33).

Table 1.1. Gross Composition (%) of Milk from Domesticated and Some Wild Mammals

Species	Fat	Protein	Lactose	Ash	Total solids	Reference
Antelope						
Impala	20.4	10.8	2.4	1.3	34.9	5
Pronghorn	13.0	6.9	4.0	1.3	25.2	10
Ass (donkey)	1.2	1.7	6.9	0.4	10.2	35
Baboon	5.0	1.6	7.3	0.3	14.2	8
Bear						
Grizzly	3.0	3.8	4.0	1.3	12.1	5
Polar	31.0	10.2	0.5	1.2	42.9	4
Bison	1.7	4.8	5.7	0.9	13.1	1
Buffalo						
Egyptian	7.7	4.3	4.7	0.8	17.5	1
Philippine	10.4	5.9	4.3	0.8	21.4	1
Camel	4.9	3.7	5.1	0.7	14.4	35
Cat	7.1	10.1	4.2	0.5	21.9	1
Cow						
Ayrshire	4.1	3.6	4.7	0.7	13.1	3
Brown Swiss	4.0	3.6	5.0	0.7	13.3	3
Guernsey	5.0	3.8	4.9	0.7	14.4	3
Holstein	3.5	3.1	4.9	0.7	12.2	3
Jersey	5.5	3.9	4.9	0.7	15.0	3
Zebu	4.9	3.9	5.1	0.8	14.7	38
Chimpanzee	3.7	1.2	7.0	0.2	12.1	5
Coyote	10.7	9.9	3.0	0.9	24.5	5
Deer	19.7	10.4	2.6	1.4	34.1	36
Dog	8.3	9.5	3.7	1.2	20.7	35
Dolphin	41.5	10.9	1.1	0.7	54.2	1
Elephant	15.1	4.2	5.1	0.7	24.1	1
Fox	6.3	6.3	4.7	1.0	18.3	39
Goat	3.5	3.1	4.6	0.8	12.1	35
Guinea pig	3.9	8.1	3.0	0.8	15.8	35
Horse	1.6	2.7	6.1	0.5	11.0	35
Human	4.5	1.1	6.8	0.2	12.6	15
(Kangaroo)[1]	2.1	6.2	trace	1.2	9.5	7
Mink	8.0	7.0	6.9	0.7	22.6	20
Monkey	3.9	2.1	5.9	0.3	12.3	35
Moose	7.0	13.5	3.6	1.6	25.7	5
Mouse	12.1	9.0	3.2	1.5	25.8	5
Mule	1.8	2.0	5.5	0.5	9.8	1
Musk ox	11.0	5.3	3.6	1.8	21.7	11
Opossum	6.1	9.2	3.2	1.6	24.5	17
Rabbit	12.2	10.4	1.8	2.0	26.4	6
Rat	14.8	11.3	2.9	1.5	31.8	1
Reindeer	22.5	10.3	2.5	1.4	36.7	1
Sea lion, CA[2]	34.9	13.6	0.0	0.6	49.1	32
Seal						
Gray	53.2	11.2	2.6	0.7	67.7	2
Hooded	40.4	6.6	?	0.9	47.9	5
Sheep	5.3	5.5	4.6	0.9	16.3	35
Swine	7.9	5.9	4.9	0.9	19.6	24
Whale	34.8	13.6	1.8	1.6	51.2	1
Yak	7.0	5.2	4.6	?	16.8	23
Zebra	4.8	3.0	5.3	0.7	13.8	1

[1]Marsupial. [2]CA = California.

5 UNIQUENESS OF THIS BOOK ON MILK OF NON-BOVINE MAMMALS

The technical and popular literature abounds with publications about the world of cow milk, while milk of other mammals has garnered little attention, at least in the English language. Therefore it was the fervent interest of Dr. Y.W. Park and Dr. G.F.W. Haenlein in producing this book to make a comprehensive and new contribution to the dairy science of the non-bovine mammals, and to overcome to some extent the paucity of published knowledge by bringing in contributions from noted scientists in foreign countries, where non-bovine mammals have an important nutritional, economic, and social role.

This book presents chapters about the production and utilization of 10 non-bovine mammals: goats, sheep, buffaloes, mares, camels, yaks, reindeer, sows, llamas, and humans. Focus on dairy goats was the initial motivator for the book, because of some unique characteristics of goat milk compared to cow milk. Goat milk has been used successfully in cases of cow milk allergies and by patients with various metabolic and gastrointestinal ailments. Goat milk proteins can differ genetically from some cow milk proteins, and goat milk fat has usually a better profile of fatty acids. Goat milk cheeses have acquired a worldwide gourmet reputation, and demand is growing.

Sheep have been milked for millenia, but mainly as part of triple-purpose breeding for fiber and meat production besides milk. Therefore official statistical records of dairy sheep populations, and sheep milk production and processing, are hard to find. Sheep milk has unique composition and is ideally suited for yogurt and cheese production (18). Sheep cheese production is well organized and promoted in some countries and in exports, where sheep cheeses are highly regarded, especially because of some official protection of origin label.

Buffalo milk is important in Asian countries mainly, but the distribution of buffalo populations and interest in buffalo milk products is spreading. India has supported officially significant research with dairy buffaloes, including at a national research institute (CIRB) specifically devoted to buffaloes at Hisar–Haryana, and the comprehensive contributions by Dr. A.J. Pandya and Dr. M.M.H. Khan to this book are particularly valuable. Buffalo milk is popular in many traditional products, which are not well known in Western countries.

Mare milk is another Asian uniqueness, with much tradition in some countries, but also with some good justification as an alternative to cow milk and treatment for humans with debilities. Research with mare milk and appreciation of its qualities is limited in the West except for a few proponents, partly because of the language barrier.

Camel milk also has unique compositional differences from cow milk, among which is an absence of beta-lactoglobulin, which makes it more similar to human milk. Dr. El-Agamy's research and comprehensive contribution to this book, especially concerning milk protein allergies, biological activities of the protective proteins in milk, lysozyme, lactoferrin, lactoperoxidase, and antiviral activities are particularly valuable.

The yak is a valuable milk-producing animal in a few Asian countries with very harsh climates, but has undeservedly received little research attention and appreciation in the West. Uniquely, yak milk is dried in several factories near yak-rearing areas in China, Nepal, and possibly also in Mongolia for popular domestic consumption. Yak butter is an important staple food from yak milk besides several types of yogurt and cheeses.

Reindeer milk has received new interest from researchers in the North, mainly because of its highest level of milk composition among the discussed mammals in this book and the unique adaptation of this ruminant mammal to the very harsh climate. Protein in reindeer milk is about three times the level in cow milk (11% verssus 3%), but lactose is uniquely less (3.5% versus 4.5%). Yet, the economics of reindeer milk production and herding management need much attention.

Sow milk is of considerable academic and research interest because of the physiological similarity of this monogastric to human milk secretion. Nutritional, physiological, and biochemical research data on sow milk can be effectively utilized and applied to related situations in human metabolism, health, and medicine. Sow milk production is also of considerable husbandry interest, because high piglet mortality and limited growth of piglets is linked to low sow milk production.

Llamas are, like camels, regurgitating herbivores, but have only three stomachs instead of the four of the true ruminants. Llamas, or any of the other three South American camelids, Alpaca, Vicuña, and Guanaco, have not been bred or used for commercial milk production, which presents a very unique

historic situation for native South Americans before the arrival of European dairy animals. The question of from where those native people obtained their necessary supplies of calcium in the absence of any milk products in their adult diet has not been answered satisfactorily. Academic interest in llama milk has been related to the need to develop satisfactory milk replacer formulae for raising newborn llamas.

Additional other minor species milks that are not included as a major chapter are discussed for a more rounded presentation in this book. Academically, there should be much stimulation from the different uniquenesses among those species.

Finally, knowledge in human milk is needed much more widely because of its superior value in infant nutrition, satisfactory health, and growth, compared to most other animal or vegetable formula substitutes. Processing of human milk is also of increasing interest as a commercial source for mothers in need of such supplementation.

No one can deny the fact that cows are the primary dairy animal species in many countries to provide humans with nutritious food through the abundance of their lacteal secretion. Goats and other minor dairy species will never be able to compete with cows in terms of volume of milk production. However, the contribution of milk from other domesticated dairy species to the survival and well being of people around the world is immense and invaluable, especially in areas where cows have difficulty surviving.

Nevertheless, the traditional dairy-cow-dominated dairy industry is and will become more diversified in domestic productions, and it is already in the market place on shelves of many food stores, where a great variety of domestic and imported dairy products from dairy goats, dairy sheep, even "mozzarella di buffalo," are now available with high quality. Consumers of such new products found in grocery stores and on restaurant menus are increasingly interested in the histories, origins, and comparative values of these diverse products from species other than dairy cows.

This book is intended to fit this evolution in the dairy market place. There has not been a book, as far as we know, covering the origin, production, composition, processing, and uniqueness of milk and its products from other domesticated mammals besides the dairy cow. This book provides comprehensive reviews of what is known in other parts of the world by dairy scientists with special knowledge in the areas of non-bovine milk. This book is intended for students in agriculture, veterinary science, even economics and political science, but in particular dairy science, to bridge the gap that has existed far too long. And this book is also aimed at the consumers who like to widen their horizon and knowledge about what they are eating, or what else might be great or beneficial to eat, and where it comes from. This book is not only for people in the developing world who want and need to better their food supply quantitatively and qualitatively, but is especially for people in the developed world who may have medical needs for alternative foods and treatment, or for gourmet-connoisseur consumers looking for a higher-quality menu.

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2
Goat Milk

2.1 Production of Goat Milk

George F.W. Haenlein

1 INTRODUCTION

The goat has been the most maligned domesticated animal and still is in many parts of the world (90), partly because of its sometimes offensive odor, especially from the buck, whose odor floats strongly around the premises and can affect the flavor of the doe's milk, if ventilation, milking practices, and cooling of the milk are improper or insufficient. For the doe this odor is an aphrodisiac enticing her libido and is part of the "buck effect" to stimulate sexual activity (65, 78). In recent years it has been convincingly demonstrated that properly milked and cooled goat milk is odor free and hard to distinguish from cow milk in odor and taste (8, 71). Thus, quality goat milk production is possible and has made great progress in recent years in dismantling the age-old prejudice by consumers. This may in part also be reflected in the phenomenal increase in dairy goat numbers around the world in recent years (Tables 2.3–2.5). Another severe prejudice has long existed among forestry officials' claim that goats are responsible for de-forestation and desertification because of their feeding preference in browsing bushes, twigs, barks, and even climbing tree limbs (13, 24, 71, 101) (Figure 2.1). However, it has been demonstrated that human management practices of overstocking and free grazing without a shepherd are to blame, and that responsible feeding of harvested tree leaves and pods is a more environmentally friendly alternative, especially since goats tolerate tannin and phenolic compounds in leaves, whereas cattle, sheep, and horses do not (74, 98, 100). In addition, goats in many parts of the world are successfully used in "integrated grazing" with cattle and sheep to clear pastures from brush and tree encroachment, thus saving and improving beef and sheep pasture grazing for higher performance per unit of land area, and also providing better protection from predators (47). In areas with traditional migratory or transhumance grazing, the herds were always a mixture of goats, sheep, and some cattle and donkeys. Goats are also used to provide brush and forest clearance for wildfire control (3, 45).

Milk production annual tonnage from goats is a relatively small amount compared to cow and buffalo milk production worldwide (Table 2.1), but it has increased in Africa, Europe, and worldwide percentage-wise. In actual milk tonnage the increases are very significant (Table 2.2), except for Central America (Table 2.5). This tonnage increase better reflects the great importance of goat milk around the world, especially when held next to the large increases of goat population numbers (Table 2.3). It also explains the conviction by dairy experts that more goat milk is consumed by more people around the world than any other milk (24), and that goat milk is a main food to sustain poor people and small farmers, to prevent mal- and undernutrition, and to aid people with cow milk allergies (38, 59, 77, 79). Foreign aid

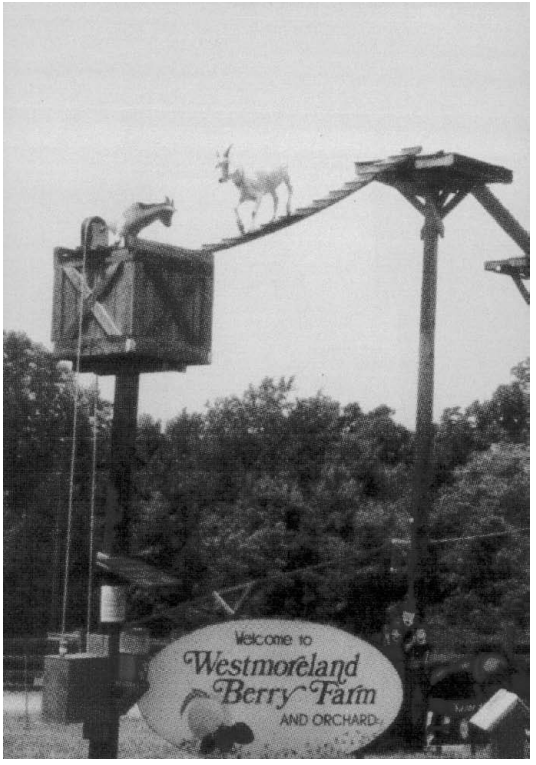

Figure 2.1. Sure-footed, fearless goats are climbing an 8 m-high board-trail to a feeding station, illustrating the ability of goats to climb tree limbs to feed on leaves. Here at the Westmoreland Berry Farm, Virginia, U.S.A., the goats attract visitors, who have fun feeding the goats small amounts of corn kernels hoisted up in a small bucket to the feeding station above. Photo Westmoreland Berry Farm, Oakgrove, VA; by permission.

Table 2.1. Milk Production by Species Relative to All Milk Produced within Continent and Trends during the Last 20 Years (20, 21)

Year	1980	2001
All milk[1]	100.0 %	100.0 %
SHEEP[2]		
World	1.7	1.3
Africa	7.0	6.6
S. America	0.1	0.07
Asia	5.1	1.9
Europe	1.9	1.3
GOATS[3]		
World	1.6	2.1
Africa	10.4	11.0
N. C. America	0.4	0.2
S. America	0.6	0.4
Asia	5.2	4.0
Europe	1.0	1.1
BUFFALOES[4]		
World	5.9	11.9
Africa	8.8	8.2
Asia	39.6	38.5
Europe	0.1	0.1
COWS		
World	90.8	84.6
Africa	73.8	74.2
N. C. America	99.6	99.8
S. America	99.3	99.5
Asia	50.1	55.6
Europe	97.2	97.5
Oceania	100.0	100.0

[1]Includes milk of cows, buffaloes, goats, and sheep.
[2]North and Central America and Oceania; no data.
[3]Oceania; no data.
[4]Americas and Oceania; no data.

project leaders in developing countries have long recognized this and focused their efforts on improving dairy goat breeding, nutrition, and milk yields (42). Within continents, Africa leads in goat milk production relative to all milk produced there (Table 2.1), but Asia leads in total annual milk tonnage, in total goat numbers, and in relative increase of goat milk production during the last 20 years (Tables 2.2–2.3). FAO data do not distinguish between dairy, cashmere, and Angora goats. The latter are of significant numbers in some Asian countries, South Africa, Turkey and Texas,U.S.A. (Table 2.5), but data of milk production tonnage help identify countries with dairy goat populations. Table 2.2 also shows that during the last 20 years the total world tonnage of goat milk has increased much beyond that of sheep milk production (12.4 million MT vs. 7.8 million MT, respectively, in 2001), but this difference probably reflects also the increased demand for fluid milk consumption, whereas sheep milk is mainly processed into cheeses. Worldwide, the numbers of people increased by 38% during the last 20 years, but goat milk production increased by 72% (Tables 2.2–2.3).

Table 2.2. Total Milk Production by Species during the Last 20 Years and Relative Proportion for Each Continent within Species (20, 21)

Year	1980 1,000 MT	2001 1,000 MT	Change, % 2001–1980	World, % 1980	World, % 2001
GOATS[1]					
World	7,236	12,455	+72	100	100
Africa	1,477	2,773	+88	20	22
N. C. America	318	165	−48	4	1
S. America	134	182	+36	2	1
Asia	3,435	7,017	+104	48	56
Europe	1,569	2,317	+48	22	19
SHEEP[2]					
World	7,980	7,808	−2	100	100
Africa	994	1,648	+66	12	21
S. America	34	35	+3	0.4	0.4
Asia	3,396	3,269	−4	42	42
Europe	3,482	2,856	−18	44	37
Mediterranean	4,289	4,523	+5	54	58
BUFFALOES[3]					
World	27,491	69,248	+152	100	100
Africa	1,248	2,051	+164	4	3
Asia	26,148	67,028	+156	95	97
Europe	96	170	+77	0.3	0.2
COWS					
World	423,034	493,828	+17	100	100
Africa	10,477	18,645	+78	2	4
N. C. America	76,540	96,638	+26	18	20
S. America	23,935	47,055	+97	6	10
Asia	33,084	96,674	+192	8	20
Europe	176,200	210,193	+19	42	43
Oceania	12,240	24,623	+101	3	5
ALL MILK					
World	465,741	583,339	+25	100	100
Africa	14,196	25,117	+77	3	4
N. C. America	76,858	96,803	+26	16	17
S. America	24,103	47,272	+96	5	8
Asia	66,063	173,988	+163	14	30
Europe	181,347	215,536	+19	39	37
Oceania	12,240	24,623	+101	3	4

[1]Oceania; no data.
[2]N. and C. America and Oceania; no data.
[3]Americas and Oceania; no data.

The Mediterranean region with some 21 countries is the major sheep milk production area of the world (Table 2.2), but not so for goat milk production, which amounted to 34% of all goat milk tonnage worldwide in 1980 but only 18% in 2001 for that region (Table 2.4). In total tonnage, Asia and Africa produced much more goat milk than did the Mediterranean region in 2001. North America does not have any FAO goat milk data listed, and Europe has more countries decreasing than increasing in

Table 2.3. Trends of Populations of Goats and People during the Last 20 Years (20, 21)

	1980	2001	Change,% 2001–1980
GOATS (Million head)			
World	458	738	+61
Africa	149	219	+47
N. C. America	13	14	+8
S. America	19	22	+16
Asia	258	465	+80
Europe	12	18	+50
Mediterranean region	44	40	−9
Oceania	0.4	0.7	+75
PEOPLE (Million head)			
World	4,450	6,134	+38
Africa	480	812	+69
N. C. America	373	493	+32
S. America	240	351	+46
Asia	2,584	3,721	+44
Europe	484	726	+50
Oceania	23	31	+35

goat milk tonnage per year (Tables 2.4 and 2.5). Thus, a general and historic disinterest in goat milk research, relative to cow milk and sheep research, in these countries may be understandable, though not forgivable, and the world literature on goat milk production, product technology, and marketing has to depend on such research from Asia and Africa.

2 MILK PRODUCTION

2.1 Breeds of Goats

The goat is one of the most versatile domestic animals in adaptation to arid and humid, tropical and cold, and desert and mountain conditions (29, 81, 97), providing people with many important products: meat, milk including yogurt and cheese, cashmere, mohair, skins, draft and pack power, and manure for crops and gardens (28, 43). Shkolnik et al. (96) studied the adaptation of the small Bedouin goat, weighing between 15 to 25 kg, to arid desert conditions. By providing watering opportunities only every two to four days, the goat's foraging range was increased greatly. Goats lost body weight during water deprivation but maintained daily milk yields of up to 2 kg nevertheless. Mason (61) lists 411 goat breeds in his world dictionary of livestock, but only about 31 as primary dairy breeds (Table 2.6). Gall (30) provides detailed description and production data of 160 goat breeds based on size of populations, productivity, and unique characteristics. Levels of milk production from surveys in 46 countries around the world are given for 89 goat breeds. Among these are four recognized as high-yielding breeds—Alpine, Saanen, Toggenburg, and Nubian—which are also called "improver" breeds for developing countries (14). The Swiss breeds, Saanen in particular, have been exported and adapted in many countries, forming new local breeds, often with new names (60). Compared to dairy sheep, genetic selection of dairy goats has succeeded in much higher milk yields, longer lactation length (Table 2.7), and better udder conformation, especially among the Swiss breeds. Milk yield production data vary much from country to country for the same breed, depending on feeding, climate, and disease adaptation. Milk composition varies between breeds but is generally lower (3.3–4.7% fat, 2.9–5.0% protein, 4.1–5.2% lactose, 11.5–15.1% total solids) than for dairy sheep, except for West African Dwarf

Table 2.4. Mediterranean Region Goat Populations, Goat Milk Production, and Trends during the Last 20 years (20, 21)

	GOAT POPULATIONS			GOAT MILK PRODUCTION		
	1980 1,000 head	2001 1,000 head	Change, % 2001–1980	1980 1,000 MT	2001 1,000 MT	Change, % 2001–1980
Portugal	747	760	+2	37	35	−6
Spain	2,120	2,830	+33	302	320	+6
France	1,065	1,200	+13	464	460	−1
Italy	989	1,375	+39	118	140	+19
Malta	6	9	+50	2	-	-
Cyprus	360	379	+5	37	29	−22
Yugoslavia 125	343	+ 174	-	-	-	
Albania	672	1,120	+67	27	80	+196
Hungary	120	150	+25	4	10	+150
Romania	378	574	+52	-	-	
Bulgaria	425	970	+128	60	215	+258
Greece	4,555	5,300	+16	425	450	+6
Turkey	18,755	8,057	−57	623	225	−64
Lebanon	413	445	+8	35	39	+11
Israel	132	68	−48	24	13	−46
Syria	1,028	979	−5	74	62	−16
Egypt	1,451	3,527	+143	8	15	+88
Tunisia	822	1,450	+76	13	12	−-8
Libya	1,400	1,950	+39	15	15	±$0
Algeria	2,763	3,500	+27	134	155	+16
Morocco	5,773	5,200	−10	27	35	+30
21 Total	44,099	40,186	−9	2,429	2,310	−6
World	457,660	738,246	+61	7,236	12,455	+72
21 Mediterranean, % of world	10	5	34	18		

goats, which may have much higher fat (7.8%), protein (5.3%), lactose (5.2%), and total solids (18.8%) contents (14, 64).

Breeds that are managed in registry herd books combined with milk recording and sire-proving schemes are generally the leaders (35, 39). Thus, individual record performances of Spanish Canaria, Malagueña, and Murciana-Granadina goats with 1,300 kg milk in 305 days (72), for Saanen in different countries milking more than 2,000 kg (16, 30), for Alpine in UK and Nordic goats in Norway more than 1,900 kg (30), and records of individual American Toggenburg (3,023 kg), Alpine (2,916 kg), Saanen (2,695 kg), LaMancha (2,454 kg), and Nubian (2,423 kg) have been reported (39).

Dairy goat breeds have been classified morphologically into three groups (62) (Table 2.6):

1. Short, erect ears (Swiss, Spanish, French and Nordic breeds) or no external ears (LaMancha) (Figure 2.7), and sabre-like horns, although some may be polled (Figure 2.2–2.5)
2. Short ears and outwardly-twisted or screw-type horns (Girgentana, Zalawadi) (Figures 2.12 and 2.13) or polled (Figures 2.8, 2.9, 2.11). Horn length may vary from 6 to 28 cm, up to 50 cm in Girgentana, and are longer in males (60).
3. Long or lop ears with different type horns (most tropical dairy breeds), and some may also be polled (Figures 2.6, 2.10, 2.14–2.16).

Table 2.5. Trends of Goat Milk Production during the Last 20 Years in Countries with Significant Amounts of Goat Milk Outside of the Mediterranean Region (20, 21)

	1980 1,000 MT	2001 1,000 MT	Change, % 2001–1980
AFRICA			
Burkina Faso	10	52	+420
Cameroon	—	42	—
Chad	15	32	+113
Ethiopia	94	95	+1
Kenya	74	96	+30
Mali	39	196	+402
Mauritania	70	101	+44
Niger	122	105	−14
Rwanda	9	14	+56
Senegal	10	17	+70
Somalia	282	390	+38
Sudan	467	1,250	+168
Tanzania	55	96	+74
TOTAL	***1,247***	***2,486***	***+99***
N. C. AMERICA			
Haiti	26	24	−8
Mexico	291	140	−52
TOTAL	***317***	***164***	***−48***
S. AMERICA			
Bolivia	14	12	−14
Brazil	89	138	+55
Chile	10	10	±0
Peru	19	19	±0
TOTAL	***132***	***179***	***+36***
ASIA			
Afghanistan	48	100	+108
Bangladesh	484	1,304	+169
China	113	255	+126
India	945	3,320	+251
Indonesia	—	200	—
Iran	222	385	+73
Iraq	80	54	−32
Jordan	15	12	−20
Kazakhstan	—	10	—
Kuwait	20	5	−75
Mongolia	12	35	+192
Nepal	31	60	+94
Oman	13	81	+523
Pakistan	407	607	+49
Saudi Arabia	81	71	−12
Tajikistan	-	25	-
U. Arab Emirates	7	27	+286
Uzbekistan	—	37	—
Yemen	141	120	−15

Table 2.5. Continued

	1980 1,000 MT	2001 1,000 MT	Change, % 2001–1980
West Bank	-	14 -	
TOTAL	***2,619***	***6,722***	***+157***
EUROPE			
Austria	14	17	+21
Czechoslovakia	22	26	+18
Germany	42	22	−48
Norway	26	21	−19
Switzerland	24	16	−33
Ukraine	—	194	—
USSR	303	305	+1
TOTAL	***431***	***601***	***+39***
GRAND TOTAL[1]	4,746	10,152	+114
WORLD	7,236	12,455	+72
% of world	66	82	

[1]No data available for Oceania.

Although most dairy sheep breeds vary little in type and appearance (Chapter 3, Figures 3.1–3.6), dairy goat breeds differ markedly, as shown in Figures 2.2–2.16. According to level of milk-producing ability (Table 2.7), success of genetic selection for superior mammary system, and size of population, it is appropriate to recognize the original dairy goat breeds in descending order of ranking by countries of origin as shown below (16), although admitting that some dairy goat breeds in countries such as the

Table 2.6. Goat Breeds with Dairy as Their Primary Use (62)

SHORT EARS, SABRE HORNS

Alpine, Chamoisée (Switzerland; Italy, U.K., U.S.A.)
Appenzell (Switzerland)
La Mancha (USA)
Malagueña (Spain)
Murciana-Granadina (Spain)
Nordic (Norway)
Oberhasli, Alpine (Switzerland; France, Germany, U.S.A.)
Poitévine (France)
Saanen (Switzerland; Bulgaria, China, Czechoslovakia, France, Germany, Israel, Poland, Russia, The Netherlands, U.K., U.S.A.)
Toggenburg (Switzerland; Germany, The Netherlands, U.K., U.S.A.)

SHORT EARS, TWISTED HORNS

Algarvia (Portugal)
Carpathian (Poland)
Corsican (France)
Garganica (Italy)
Girgentana (Italy)
Pirenaica (Spain)
Serrana (Portugal)

LOP EARS, DIFFERENT HORNS

Baladi (Egypt)
Beetal (India)
Benadir (Somalia)
Berber (Morocco)
Damascus (Syria)
Jamnapari (India)
Kamori (Pakistan)
Malabari (India)
Maltese (Italy)
Mamber (Syria)
Nubian (USA)
Sangamneri (India)
Sirohi (India)
Surti (India)

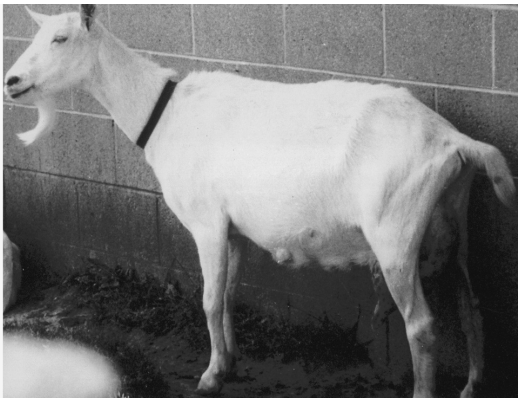

Figure 2.2. Swiss Saanen goat. Photo G.F.W. Haenlein.

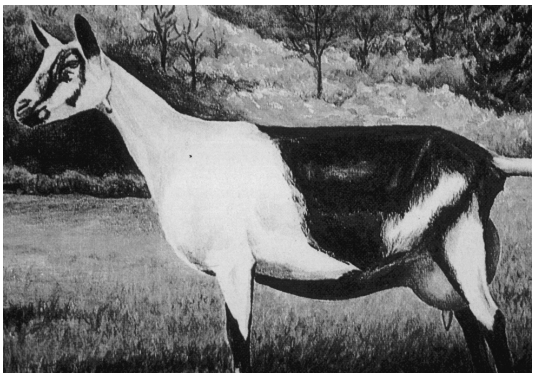

Figure 2.3. American Alpine goat. Photo American Dairy Goat Association.

Figure 2.4. American Oberhasli goat. Photo G.F.W. Haenlein.

UK, France, Germany, Norway, America, Australia, and New Zealand are distinguished by breeding success for superior type and milk production, but most of these breed populations are derivatives of imported Swiss, Spanish, or Nubian breeds:

1. Swiss breeds: Saanen, Alpine, Oberhasli, Toggenburg, Appenzell (30);
2. Mediterranean breeds:
   - Spain: Murciana-Granadina, Malagueña, Canaria, Guadarrama, Retinta Extremeña, Verata, Pirenaica, Blanca Andaluza, Blanca Celtiberica (72),
   - Italy: Maltese, Ionica, Girgentana, Garganica (89),
   - Portugal (Serrana), Greece (Native), Egypt (Nubian–Zaraibi), Syria (Damascus), Turkey (Kilis) (30);
3. Indian breeds: Jamnapari, Barbari, Beetal, Gohilwadi, Jhakrana, Kutchi, Mehsana, Surti, Zalawadi (1);
4. Other Asian and African breeds (30).

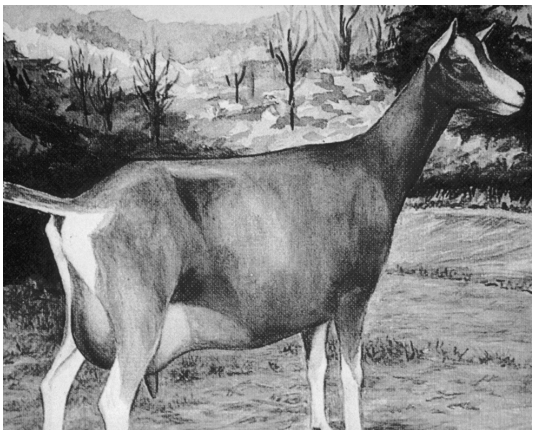

Figure 2.5. American Toggenburg goat; note the unique badger face. Photo American Dairy Goat Association, Spindale, NC.

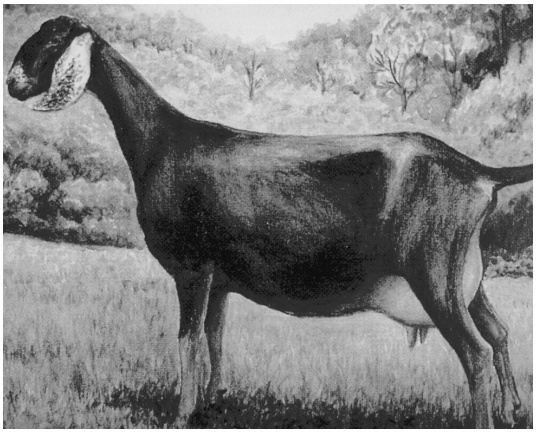

Figure 2.6. American Nubian goat. Photo G.F.W. Haenlein.

Table 2.7. Average Milk Yields and Lactation Lengths of Dairy Goats (14, 16, 30, 39, 72)

		Days	Yield, kg
CYPRUS	Damascus	210–300	460–560
FRANCE	Poitévine	230	440–600
GREECE	Native	210–250	120–200
INDIA	Barbari	150–230	110–200
	Beetal	185–210	190–210
	Jamnapari	170–270	200–230
ISRAEL	Mamber	150–210	180–240
ITALY	Garganica	190–210	180–250
	Girgentana	190–210	300–400
	Ionica	190–210	220–440
	Maltese	190–210	290–600
NORWAY	Nordic	250–300	600–700
PORTUGAL	Serrana	210–270	300–400
SPAIN	Blanca Andaluza	198	400–450
	Blanca Celtiberica	200	400–450
	Canaria	210–300	600–700
	Guadarrama	210	440–660
	Malagueña	240–270	500–700
	Murciana-Granadina	210–304	500–730
SWITZERLAND	Alpine, Chamoisée	265–290	600–820
	Appenzell	260–295	480–860
	Saanen	265–300	520–970
	Toggenburg	265–305	510–965
TURKEY	Kilis	260–280	250–330
U.S.A.	La Mancha	270–305	720–800
	Nubian	270–305	690–780
	Oberhasli	270–305	540–730

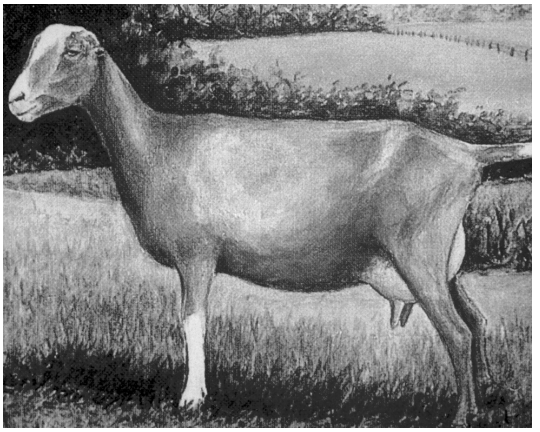

Figure 2.7. American LaMancha goat; note the unique vestigial "gopher" ear. Photo American Dairy Goat Association, Spindale, NC.

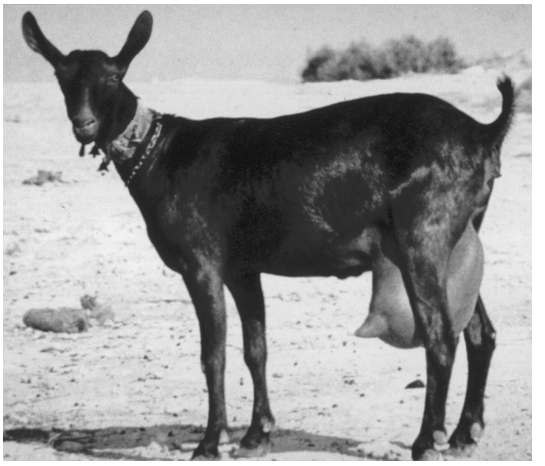

Figure 2.8. Spanish Murciana-Granadina goat. Photo Ministeró Agricultura Publ., 1980, Madrid, Spain.

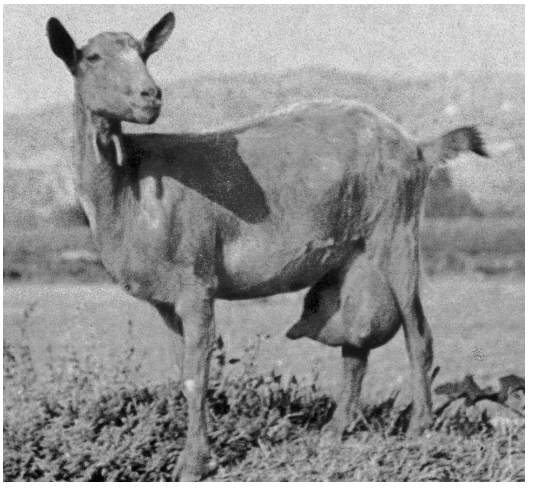

Figure 2.9. Spanish Malagueña goat. Photo Ministeró Agricultura Publ., 1980, Madrid, Spain.

Leading the world in milk production level, length of lactation, udder type quality, and population size are the four Swiss breeds, Saanen, Alpine, Toggenburg, and Oberhasli (Figures 2.2–2.5), followed by the American developed Nubian (Figure 2.6) and LaMancha (Figure 2.7). Next in value and importance are at least four original Spanish breeds, Murciana-Granadina, Malagueña, Canaria, and Guadarrama (Figures 2.8–2.11), but their udder conformation and performance still need much improvement. Other Mediterranean breeds (Figures 2.12–2.15) are producing well under the constraints of their local conditions but mostly below the leading Spanish and Swiss breeds. The remaining Asian (Figure 2.16) and African breeds, including some dwarf and disease-resistant breeds, have good potential but have not yet been selected and bred for more than their low productivity due to feeding conditions and lack of the stimulus of breed registry organizations. Most have no known statistics of average lactation length or total yield, only estimates of daily yields. The Indian Jamnapari is the leading dairy breed in that region and has been exported. It is a uniquely evolved goat and especially adapted to browsing the dominant brush vegetation in its home tract along the Jamna river (Figure 2.16). However, it is handicapped in low-level grazing because its extremely long, twisted ears hang over and cover its eyes, and because its extremely arched Roman nose causes the lower jaw to be usually overshot ("carp" mouth—brachygnatia), thus making the biting of grass at low-level grazing almost impossible; this situation appears to be endangering the breed's survival outside its home brush territory (88).

The partial (elf ear) or total absence (gopher ear) of the external ear (vestigial ear) (Figure 2.7) is a dominant genetic trait in the American LaMancha

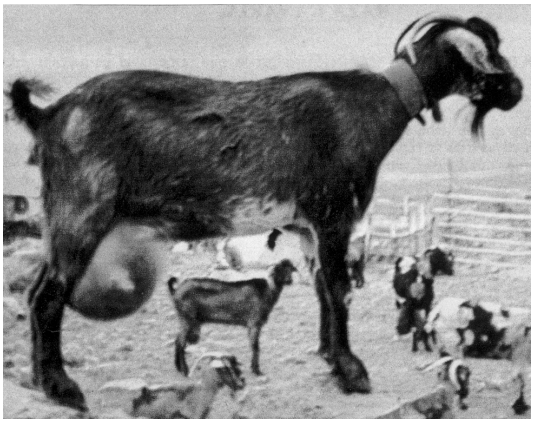

Figure 2.10. Spanish Canaria goat. Photo Ministeró Agricultura Publ., 1980, Madrid, Spain.

Figure 2.11. Spanish Guadarrama goat. Photo Ministeró Agricultura Publ., 1980, Madrid, Spain.

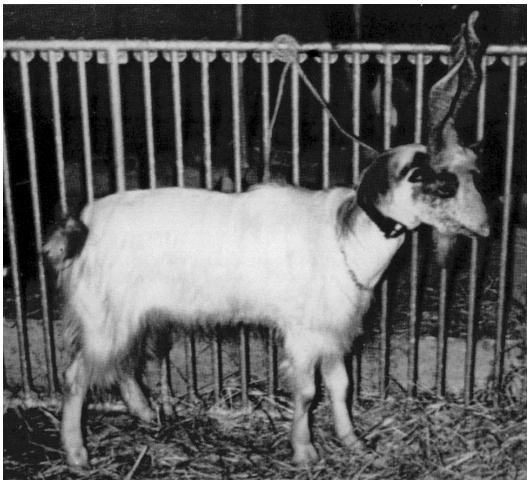

Figure 2.12. Italian Girgentana goat. Photo G.F.W. Haenlein.

Figure 2.13. Italian Garganica goat. Photo G.F.W. Haenlein.

breed (P. Sponenberg, personal communication, COGNOSAG workshop 1986) and may also occur in the Murciana-Granadina and African breeds. Lop ears are often twisted and can be 35 cm long. Goat breeds are also classified by color of hair, length of hair, color patterns, such as the "badger face" (Toggenburg) (Figure 2.5), and spotting (86). Dairy goats may have wattles on their neck, which have been linked genetically to higher prolificacy, and they may have beards in either or both genders. Polledness (PP or Pp) in dairy goats is due to a dominant gene with recessive sex-altering effects in female and male offspring, resulting in infertile intersexuals or hermaphrodites. All horned offspring (pp) are fertile, while homozygous polled (PP) females are infertile, heterozygous (Pp) females are fertile, homozygous (PP) males are 50% infertile, and heterozygous males (Pp) are fertile. Breeding polled parents (PP or Pp) results in a higher percentage of true male offspring than expected from

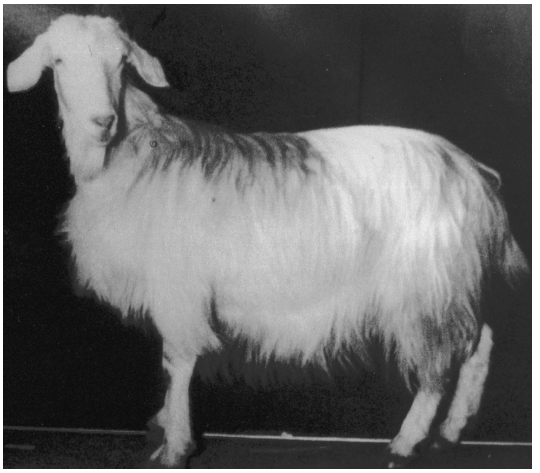

Figure 2.14. Italian Maltese goat. Photo G.F.W. Haenlein.

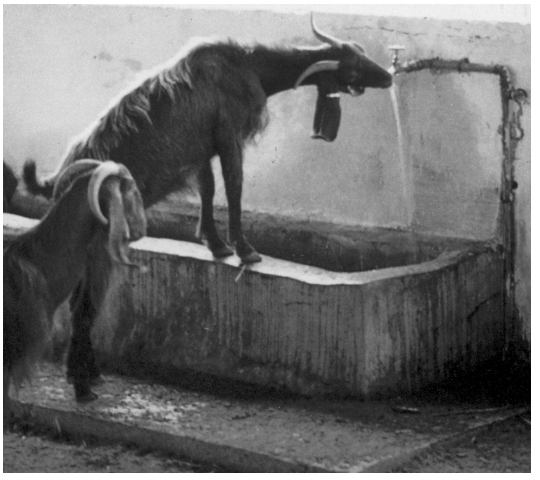

Figure 2.15. Egyptian Damascus goat. Photo G.F.W. Haenlein.

Mendelian laws of inheritance due to as much as 24% hermaphrodites (86). It has been concluded that it is not possible to obtain a fertile homozygous polled breed of goats, and selection for polledness has a negative effect on the improvement of milk production. Therefore, in France, goat breeding has favored horned sires, all bucks in artificial insemination service (AI) are horned, and the frequency of the gene for horns has increased tremendously in recent years.

Figure 2.16. Indian Jamnapari goat, one of the ancestors of the American Nubian goat; note the extremely long lop ears, Roman nose, and overshot lower jaw. Photo G.F.W. Haenlein.

Studies of biochemical polymorphisms in blood and milk of goats have shown differences between breeds and individuals, which can be related to differences in milk casein contents and cheese-making characteristics (86) (Table 2.8). Grosclaude et al. (32) found in the milk of 213 French Alpine (Oberhasli) goats that the gene α-s-1-CN A, responsible for higher total casein contents, was twice as frequent as that in the milk of 159 Saanen goats. Cheeses from goat milk with or without α-s-1-casein (gene A vs. gene 0) had differences in cheese yield, firmness of curd, and aroma (80).

Table 2.8. Casein Contents (g/liter) in Milk from Goats of Four Different Genotypes (86)

	Genotypes of α-s-1 casein			
Caseins	FF	B⁻F	AF	AB⁻
α-s-1	1.2	2.2	4.3	4.0
α-s-2	3.9	4.1	5.8	6.1
β	10.3	9.6	11.2	11.0
κ	7.3	6.5	7.7	7.7
Total	22.7	22.4	29.0	28.8

Progress in genetic selection depends on the participation by goat breeders in milk recording systems (39, 86) (Tables 2.9, 2.10). In the United States, the percentage participation is not high, but the records of the 16,000 tested dairy goats within the approximately 1 million population had exceptional averages of 860, 774, 740, 726, 960, 898 kg milk with 3.6, 3.8, 4.5, 3.8, 3.5, 3.3% fat in 305 days for the six official breeds, Alpine, LaMancha, Nubian, Oberhasli, Saanen, and Toggenburg, respectively, in 1992 (39). Progeny testing of bucks is nationally organized in the United States, and the use of artificial insemination (A.I.) is popular. Except for Norway, France, the Netherlands (Tables 2.9, 2.10), and Taiwan (69), the percentage of participation in milk recording within total milking goat populations by country appears to be less than 10% in Europe. As with dairy sheep, France has the highest number of tested dairy goats, flocks participating, does being artificially inseminated, and bucks being progeny tested for A.I. (Tables 2.9, 2.10), especially for the French Alpine (Oberhasli) breed.

Determinations of heritability of milk yield, protein percent, fat percent, their yields, and genetic correlations produced similar values (86) as for dairy sheep (Chapter 3, Table 3.10), which means that single trait selection in dairy goats can make good progress (87) but that selection for yield will decrease solids contents and vice versa. Selecting for milk yield alone can make average progress of 30 kg/year possible, whereas selection for protein or fat yield will make only 0.7 kg milk yield annual progress, but selecting for protein percent or fat percent alone will decrease milk yield by 0.6 to 0.9 kg/year.

Normally, dairy goats have only two teats, but inherited supernumerary teats can be found in several breeds. In the United States it is unethical and prohibited to remove supernumerary teats unless they interfere with good milking practices, because selection against this recessive trait is supposed to be practiced. Unique to goats (Jamnapari and their derivatives such as the Nubian) is the condition of brachygnatia or undershot upper jaw, also called "carp" mouth, while in dairy cattle the condition of the undershot lower jaw or "parrot" mouth can be encountered. The condition is determined by a recessive gene (86) and in American Nubians is undesirable and to be selected against. Myotonia of the so-called "Fainting" or nervous goats in a small U.S. population is also due to a recessive gene. Goats have 60 chromosomes (2n), whereas sheep have 54 (2n), but occasional fertile hybrids have been reported (86). Flocks of sheep and goats are traditionally herded together in many countries, and often it is

Table 2.9. Participation in Goat Milk Recording Schemes by Country in 1989 (89)

	Total goats 1,000	Recorded goats	Participation %
Austria	32	150	0.5
Bulgaria	500	690	0.1
Cyprus	100	3,000	3.0
Czechoslovakia	50	1,475	3.0
Finland	2	160	8.0
France	1,200	240,000	20.0
Germany	36	1,740	4.8
Israel	12	1,080	9.0
Italy	1,060	8,010	0.8
Netherlands	34	5,490	16.1
Norway	69	30,390	44.0
Portugal	600	400	0.1
Spain	2,300	16,000	0.7
South Africa	5,780	620	0.01
Switzerland	89	4,930	5.5
U.S.A.	1,000	16,000	1.6

Table 2.10. Participation in Milk Recording and Artificial Insemination by Goat Breeds (25)

Breed	Country	Total population	% does milk recorded	Flocks recorded	Does using AI	AI progeny bucks tested
Damascus	CYPRUS	2,500	100	18		
Alpine	FRANCE	392,000	30.7	1,200	30,000	51
Saanen	″	181,000	51.4	750	19,500	21
Skopelos	GREECE	16,000	25.0	25		
Ionica	ITALY	14,000	9.3	23		
Alpina	″	34,000	8.4	85		
Saanen	″	35,000	7.4	69		
Maltese	″	38,000	6.0	36		
Nordic	NORWAY	17.400	100	370	140	
Serrana	PORTUGAL	250,000	1.6	105		
Charnequeira	″	35,000	1.8	6		
Serpentina	″	100,000	0.5	6		
Algarvia	″	20,000	4.1	39		
Malagueña	SPAIN	194,520	3.2	62		
Murciana-Granadina	″	382,660	5.0	203	770	

hard to distinguish them, except for the way that goats always carry their short tail up.

2.2 Herd Management Systems

Dairy goats are managed the same as dairy sheep under a variety of intensive or extensive systems in different countries, depending on resources of the owner and nearness to market (11, 19, 24, 28, 69, 71). Rubino and Claps (90) described goat management systems in southern Italy, where they are typical for many other countries, in four categories:

Pastoral systems:

1. Transhumance of single goat herds with shepherd, utilizing mountain common grassland for entire seasons; goat milk is transformed into cheese and kid meat
2. Daily commuter herding of goats from many village owners mostly with one shepherd; seasonal utilization of mountain common grassland; goats are returned and housed in the village at night and are milked there for fluid milk consumption; cheese and yogurt making; kid rearing
3. Opportunistic utilization of pastures, meadows, field crops nearby and further away by single goat herds; milking at the farm for fluid milk; yogurt and cheese processing; kid rearing

Permanent at-the-farm system:

4. Exclusive utilization of farm feed resources and purchase of supplementary feeds for intensive goat milk production and kid rearing management; milk may be shipped to processing plant or transformed into yogurt and cheese at the farm for sale at the farm

The local price for goat milk determines whether it is more profitable to raise goat kids with that milk or sell the milk for cheese and yogurt production and bottling of fluid milk (40). Because it takes about 6 kg milk to produce 1 kg goat kid meat, the profitable price for goat kids per kg on the farm needs to be six times greater than the price of goat milk per kg on the farm. It has been shown that supplementary feeding of concentrates or grain mixtures for higher milk yields in addition to grazing is more profitable to goat milk producers than the extensive herd management under the conditions of various countries, as is converting the milk on farms to cheese and direct retail sales rather than delivering the milk wholesale to a processing plant (Table 2.11).

Goat milk is not marketed commercially as fluid milk in most countries (91), but serves household needs and is supplied to neighbors. Taiwan is a notable exception, where all milk from its 500,000 head dairy goat population is under intensive management and is processed by a central cooperative into glass bottles or UHT cartons and commercially marketed even by door-to-door delivery (69). In

Table 2.11. Comparative Profitability of Two Systems of Goat Farming (Greece [44]; France [57]; Italy [91]; U.S.A. [41; 105])

GREECE	Intensive farming	Extensive farming
Gross return/goat/year, $	134.94	66.24
Expenses/goat/year, $	110.89	58.69
Labor, %	39.1	51.8
Feed, %	42.8	31.6
Capital, %	12.2	13.4
Housing, %	4.4	2.1
Others, %	1.5	1.1
Net return/goat/year, $	24.05	7.55

FRANCE	Milk sold from farm	Cheese sold from milk on farm
Milk production/goat/year, kg	553	461
Price/kg milk, $	0.40	0.94
Gross return/goat, $	243.83	584.00
Production cost/goat/year, $	118.17	190.83
Net return/goat/year, $	125.66	393.17
ITALY		
Net return/goat/year, $	74.93	112.00

U.S.A.	Average herd production, kg milk/goat/year	Break-even price/kg milk
	680	0.52
	907	0.39

the United States, 4 million liters of goat milk were processed annually into powder from cooperating farms for use as infant formula in the 1990s. Another estimated 200 goat dairies sold about 480 liters weekly, half under certified raw milk license in 1985 (36). Approximately 1 million liters of goat milk were processed into artisanal farmstead cheeses by about 130 licensed goat farm dairies and by several cooperatives with a weekly volume of about 3,000 liters of farmer supplied milk in 1990 (91). In addition, more than 500,000 kg goat cheese from France alone (not counting that from other countries) was imported to satisfy the growing U.S. market demand. In France, with an annual goat cheese production of 43,500 MT, 30% was produced on 19,000 goat farms in 1985 (57). In recent years the production and marketing of goat milk products have sharply risen in many countries and worldwide, probably due to two main reasons: in developing countries, to satisfy the increasing demands for milk; in developed countries, to cater to the growing interest in quality gourmet products and to cover medical needs of people with cow milk allergies and other gastrointestinal afflictions. This means that dairy goat farmers worldwide must progress in intensification of their farming system and in their genetic selection methods toward more dairyness and fewer dual-purpose goats.

Housing for dairy goats depends on the different levels of management intensity (10, 31, 37, 71). Migratory herds, mostly in developing countries, have simple protective corrals at night as long as there is a grazing season. More intensively managed herds with supplementary feeding of hay, silage, and concentrate/grains are provided with sheltered "loose housing" barns and facilities, which may include convenient feeding troughs with head gates, automatic waterers, ventilation fans, window shading for light control, and panels for separation by age and level of milk production (82). The ground level

barns are bedded, usually with straw, or the barns may be elevated/stilted with slatted floors without bedding (31), as is commonly found in tropical countries such as Taiwan, Indonesia, and Panama. This type of housing has also been proposed for the United States (43) in order to provide good ventilation in hot summer and effective internal parasite control due to the absence of manure, from which goats reinfest themselves and then have to be treated with medications regularly. The entire dairy goat population of about 500,000 head in Taiwan is on such elevated, slatted-floor loose housing, which also provides income from the collection of pure goat manure from underneath the housing in addition to the income from goat milk and kid meat (69). Dairy goats in France under the intensive system are kept loose in bedded barns (99) when they are not out on nearby pastures. Usually detached from the sleeping and feeding barn is a facility for machine milking, cooling, and storing of the milk. The detachment is a Board of Health requirement in some countries, such as the United States, for sanitary reasons and control of odors (92, 93, 94).

2.3 Age of Doe, Parity, Lactation Length, Litter Size

There are many factors other than genetics affecting milk yield in goats, since its heritability is by most determinations around 32% (87) (Chapter 3, Table 3.10), leaving 68% of the variation to factors of the environment. Milk yields increase with age of does within breed, following a curvilinear function, which peaks between four and eight years of age (52). However, kidding season in the spring of each year also may produce higher yields than lactations beginning in autumn in some countries (102). Parity parallels the effects of age, both of which also are related to body weight. It is common practice to let dairy goats kid for their first lactation at one year of age if feeding conditions and growth permit. Major correlations of 80 to 90% exist between udder volume and milk yield based on their proportionality to the mammary alveolar surface area (28). However, high-yielding dairy goats tend to have pendulous udders in some populations (Figure 2.10), which have negative effects on yield because of injuries and mastitis. This factor makes focusing on genetic selection for better udder attachments and suspensory ligaments important.

Lactation length in dairy goats varies usually between 200 and 300 days, but they may milk very well for two years if fed well (64). An individual record of 3,975 kg milk in 23 months (687 days) (5.8 kg daily average) has been reported. Annual lactations of goats may be less important in some goat management systems than for dairy cows because goats usually have twins or triplets, thus they may not need annual kidding for herd replacement. Goats have shorter pregnancies (five months vs. nine and one-half months for dairy cattle), thus they can have longer lactation periods without the interfering, overlapping effects of new pregnancies. The lactation curve of goats is also typically flatter than that for dairy cattle, with less peak, sometimes two peaks due to pasture conditions, and greater persistency (28). Therefore, the relationship of early segments of goat lactations to total lactation milk yield has a high predictive value: for the first 69 days, 68%; for 100 days, 87%; and for 140 days into lactation, 96% (27).

Litter size has an increasing effect on milk yield of goats independent of age, body weight, and season (102). Apparently, mammary growth during pregnancy is regulated by the number of goat kids born, and plasma lactogenic activity from the placenta plays a role.

2.4 Nutrition of Doe

Goats may be kept on many different types of range land: flat fallow or stubble fields, steep mountain meadows, shrub and forest areas, or sandy or rocky deserts (22). Goats do not mind standing on their hind legs to reach leaves, even from briar and thorn bushes, or to climb tree limbs, thus greatly differing in their eating behavior from sheep and dairy cattle but somewhat resembling deer and antelopes. Comparative studies with sheep, steers, and deer have shown distinct differences in gastrointestinal dynamics between these ruminant species, which are important determinants of adaptability to grazing conditions (49, 50). Goats in one experiment had lower dry matter intake on a metabolic weight basis, combined with a longer ruminal retention time and greater organic matter digestibility than the other species, suggesting a strategy of digestion for maximal utilization of the particular diet. Goats do not prefer the same plants or parts of plants as sheep, thus they are complementary on the range, and optimal productiv-

ity of the land requires that both species graze together. Including goats in a mixed grazing scheme with cattle almost doubled the total grazing capacity of range land that contained oaks (73). Goats have demonstrated an ability to utilize tree leaves from species such as oak (*Quercus* sp.), which are generally classified as toxic to other livestock because of their high content of tannin (about 9%/dry matter) and other phytochemicals, which plant species have developed as a defense against herbivory (98). The browsing preference of goats has the additional benefit of lower rates of gastrointestinal parasite infestations compared to grazing (29). Some breeds of goats, such as the Black Bedouin, differ from other goat breeds in their ability to reduce urinary nitrogen loss through recycling when feed resources provide limited supplies of protein (96, 97).

For goats producing high milk yields above 800 kg/year, it is necessary to furnish a large amount of supplementary feeds/concentrates, and the dietary supply of energy from range land may not cover more than the energy expenditures of walking to find forages, thus making range land in this case no more than an environment to keep the animals healthy (22). It has also been shown that range land does not supply sufficient levels of some minerals, vitamins, and nutrients at different seasons of the year for goat maintenance and milk production (83), thus making supplementation necessary. Urea is a cheap and effective nitrogen supplement in proper mixtures for goats (26) or in feed blocks (4). The intensive system of "zero grazing" uses harvested green forage for indoor feeding of goats. It is labor intensive but saves the cost of investing in fencing of pastures, especially under the intensive system of rotational pastures for optimizing pasture yields. Intensive feeding systems include stored forages in the form of hay and silage (48). Use of silage, especially from corn/maize, is popular in countries with large commercial goat herds such as France (68); grass silage is used in Norway. High silage quality is necessary, however, for optimum intake by the goats, and it is preferable to have large goat herds, especially in combination with a cattle herd on the same farm, to ensure sufficient daily quantities of removal from a silo to avoid spoilage. Intensive systems of dairy goat farming can be found to prevail in northern Europe, America, Australia, New Zealand, Israel, and even around cities in Greece (6). In France, the intensive dairy goat farming system has been reported to enable 6,000 to 10,000 kg goat milk/ha forage land/year (22).

The daily availability of glucose from digested feeds is the main limiting factor of secretion of goat milk because in the udder it forms lactose, which controls largely the movement of water into milk (Chapter 3, Figure 3.12). The mammary gland takes up about 70 g glucose/kg milk formed (28). Of the glucose entering blood circulation, 60% to 85% is used by the goat mammary gland. A reduction in feed intake resulting in lower blood glucose levels will reduce milk yield quickly. In terms of energy expenditures, 83 kcal/kg milk are required. Increasing the daily supply of concentrates from 0.64 kg dry matter/day to 1.21 kg increased goat milk yield significantly from 2.91 kg/day to 3.45 kg and protein content from 2.83% to 3.01% in mid-lactation (67). Increased fat contents in the feed ration and different forage-to-concentrate ratios in the daily diet can improve milk yields and the fat composition of the milk toward fatty acid profiles, which can include higher levels of the essential unsaturated fatty acids and which are of particular human health interest (51). Separate milk processing and commercialization of such "designer" milks is still waiting to arrive in the market place but seems to have considerable potential.

Nutrient requirements of dairy goats have been formulated in several publications during the past 135 years (2, 7, 12, 17, 33, 34, 53, 54, 66, 70, 75, 84, 95, 103). Probably the most comprehensive treatment of all available world data (66) concluded in energy requirements for maintenance of goats to be at 106 kcal ME/kg W(body weight)$^{0.75}$ or 0.445 MJ ME/kgW $^{0.75}$, which compares well with 101 kcal ME/kgW $^{0.75}$ recommended by NRC (75) and 0.400–0.450 MJ ME/kgW $^{0.75}$ by Drochner et al. (17). It is not easy to compare requirements between the various research authors, because of different terminology in the old starch values or kcal or kJ, actual body weight or metabolic body weight (kgW$^{0.75}$), basis of digestible, metabolizable or net energy, or differences in systems of calculation (2, 17, 53, 75), but Table 2.12 is providing the generally most agreeable and useful data from the most up-to-date research publications from the United States, France, the UK, and Germany. For a 50 kg dairy goat producing 1 kg milk per day with a fat content of 3.5%, the recommended total energy supply in the daily ration is 12.9, 14.4, 15.3, and 12.2, respectively, for the data

Table 2.12. Daily Nutrient Requirements of Dairy Goats

	Body weight, 50 kg		70 kg	
NRC, 1981 (75)	Maintenance[1]	Milk, 1 kg 3.5% fat	Maintenance[1]	Milk, 1 kg 3.5% fat
Dry matter intake, kg	1.0	1.2		
% of body weight	1.9	1.8		
Energy, TDN, kg	0.5	0.8	0.7	1.0
digestible, DE Mcal	2.3	3.8	3.0	4.5
metabolizable, ME Mcal	1.9	3.1	2.4	3.6
metabolizable, ME MJ[2]	7.9	12.9	10.0	15.0
Crude protein, g	75	143	96	164
digestible protein, g	51	99	66	114
Calcium, g	3	5	4	6
Phosphorous, g	2	3.4	3	4.4
INRA, 1978 (28)				
Metabolizable energy, MJ	9.9	14.4	11.7	16.9
Digestible protein, g	40	96	56	110
Calcium, g	3.5	8.0	4.5	9.0
Phosphorus, g	2.5	4.5	3.5	5.5
AFRC, 1993 (2)				
Dry matter intake, kg	1.4	1.6		
Metabolizable energy, MJ	15.3	18.1		
Metabolizable protein, g	95	108		
DLG, 2003 (17)		Body weight 60 kg, milk, 1 kg 4.0% fat		
Metabolizable energy, MJ	12.2[3]	14.7		

[1]Minimal activity only.
[2]1 MJ = 1,000 kJ; 1 kJ = 0.239 kcal; 1 kcal = 4.184 kJ.
[3]Body weight 50 kg.

of the four countries (Table 2.12). For practical usage of these tables it is necessary to add data from tables of feed composition (75) and include additional calculations of rumen volume limitations for feed intake, nutrient density of feed intake, minimum long fiber contents, forage to concentrate ratio, water requirements, mineral, trace element and vitamin contents, and prices of ingredients, which is usually too much for hand calculations and calls for least-cost computer programs, which are commonplace for dairy cattle ration calculations but are not well developed for small ruminants (76).

2.5 Milking Management Practices

The term "milkability" concerns the shape and attachments fore and rear of the udder, the size and position of the teats, the tightness of the teat sphincter, and the ready let-down of milk from the alveolar gland. The gland cistern in the goat udder is relatively large compared to cow and sheep udders and therefore goats may milk out quicker, easier, and faster than cows or sheep by hand or machine (56). Shape and attachments of udder, and size and shape of teats, can be improved by genetic selection because of the relatively high heritability of these type traits (86, 87). Hand milking is common but limited to small herds. One person may milk between 20 to 40 goats per hour, with average yields of 1.5 kg. Recommendations for the installation and proper operation of milking machines have been published by Le Mens and Le Jaouen (58), Billon et al. (5), and Scruton (92, 93, 94) (Table 2.13). There has been resistance to adopting milking machines because of

Table 2.13. Recommendations for Milking Machine Settings for Dairy Goats (5, 58, 92, 93, 94)

	Range	Recommendation
Vacuum level, kPa[1]		
Claw level	35–41	39–45
Low line 38–42		
Mid line 41–46		
High line 44–48		
Pulsations/minute	60–90	85
Ratio, % rest:milk	50:70	50:50
Minimum air flow, LPM[2]		
Bucket system/unit		280
Pipeline/unit		700
Clean in place, airflow minimum, LPM		
36 mm pipeline		700
48 mm pipeline		1,120
60 mm pipeline		1,680
Number of units/ slope of line		
36 mm pipeline		
0.8% slope		3
1.0% slope		4
1.2% slope		4
1.5% slope		5
48 mm pipeline		
0.8% slope		6
1.0% slope		8
1.2% slope		10
1.5% slope		12
60 mm pipeline		
0.8% slope		12
1.0% slope		14
1.2% slope		16
1.5% slope		18

[1]kPa = kilo Pascal; 1 kPa = 7.5 mm Hg.
[2]LPM = liter/minute.

preconceived ideas that they would cause mastitis, and also for financial reasons, but larger commercial herds need machines, and the greater convenience to labor is another positive argument, even for small herds. International symposia on machine milking of small ruminants have helped disseminate research results on the proper use of milking machines and installations (9, 18, 55). Many designs of milking machines and parlors for cows have also been developed and adapted to the different size of goats by the leading companies Alfa-Laval, Westfalia, Gascoyne, Bou-matic, and others. Three groups of milking systems may be distinguished, which may use portable buckets or pipeline(s) and are single or double row in systems I or II (56):

I. Milking in the barn; parallel parking; milking from behind
II. Milking parlor; linear platform type
   a. Parallel parking; milking from behind
   b. Herringbone-type parking; milking from the side
   c. Head-to-toe parking; milking from the side
III. Milking parlor; rotary platform type
   a. Head-in; parallel parking; milking from the outside from behind
   b. Head-to-toe parking; milking from inside or outside from the side

Goats may be fed a concentrate/grain ration in either system to entice them to enter the milking system, but many commercial herds do not feed goats in the parlor. Dry milking is encouraged because of lower bacteria scores compared to washing the udder before milking, since goat udders are normally much cleaner than cow udders (56). Pipelines are preferably low lines so that the milk is not lifted from the udder to the bulk tank, thereby avoiding oxidized flavors. Commercial herds and goat purebred breeders participating in sire-proving schemes have milking facilities that include automatic take-off to eliminate overmilking, computerized milk metering for official lactation record keeping, sampling devices, and in-place-cleaning systems. Some commercial parlors can handle 50 goats in each row, managed by usually two people in order to get herds of 2,000 dairy goats milked in four hours twice a day.

Three-times-a-day milking is more common in some dairy sheep or dairy cow herds because goats, in contrast to dairy sheep, normally have a long lactation of 10 months without that extra stimulation of three-times milking. Some goat managers milk their goats even as long as two years without much loss in persistency, if pregnancy is delayed for a year (64). Three-times-a-day milking increases milk yield immediately and in the long term. Unilateral (one udder half) studies in seven British Saanen for 37 weeks showed that the thrice-daily milked gland responds in increased milk yield due to several physiological phases (104). First, an acute increase is due to the removal of a feedback inhibitor. Second, the gland develops within two weeks a greater synthetic

capacity through higher parenchyma weight and more accumulation of at least 10 key enzymes, such as CoA carboxylase, fatty acid synthetase, galactosyl transferase, glycerol acyltransferase, and thymidine incorporation into DNA. Third, there is an increase in metabolic flux. Finally, a difference in mammary alveolar cell populations occurs between the twice and the thrice-milked glands. Skipping one milking per day, such as on Sunday for social reasons, will decrease milk yield by 5% over the entire lactation and may change milk composition, or decrease by 1% when started after 150 days in the lactation (56). Once-a-day milking every day will reduce yield by about a third and shorten lactation length by at least two weeks.

2.6 Seasonal Impacts

Lactation milk yield of goats is influenced by season of kidding, especially under range pasturing management systems. Lactations starting in spring time or before the rainy season may benefit from better forage growth conditions and have a longer lactation length, but this may not apply to indoor feeding management systems. In France, about 75% of lactations start in January through March, but milk yields of lactations starting in October through December were about 200 kg higher (28). Most tropical goats have estrus all year round, in contrast to most goat breeds in temperate zones, which are seasonal breeders (15). However, this is a matter of breeds rather than of climate or latitude. It has been determined that the date of first estrus of the season in the first year is heritable at 24% and repeatable at 29% from the first to the second year (85). Thus, it is possible by selecting for this trait to advance the beginning of breeding season and achieve nonseasonal polyestrus for year-round milk production. Two kiddings per year have been reported for Black Bengal goats in Pakistan (63), but three kiddings in two years are more common in the tropics and the Caribbean (15), while one annual kidding is usual in Europe and North America.

Seasonal breeding of goats is regulated by the annual biological rhythms under the influence of the pineal gland (epiphysis) through its output of hormones and neurotransmitters (46). Melatonin is secreted by the pineal gland and is present in higher amounts in blood plasma and cerebral spinal fluid at night, following nyctohemoral cycles. It has a pro-gonadotrophic effect in short-day breeders, such as goats and sheep, and is the link to the hypothalamus, apprising it of day length. Melatonin will increase as the dark period length increases. Treating goats with melatonin can advance the onset of estrus. The main environmental influence of seasonal breeding is the photoperiodic ratio of light to dark and the light intensity during a 24-hour cycle (23). In seasonal breeding goats, it is the decreasing light-to-dark ratio that induces estrus in does and stimulates sexual behavior in bucks. Artificially decreasing day length by darkening rooms with drawn window shades in indoor management systems will advance estrus in goats. Hormonal treatments of goats with intra-vaginal sponges or injections, as commonly practiced for estrus synchronization, will also produce fertile estrus regardless of season (15).

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2.2 Goat Milk—Chemistry and Nutrition

Young W. Park

1 INTRODUCTION

Although goats produce approximately 2% of the world's total annual milk supply (45), their contribution to the nutritional and economic well being of mankind is tremendous in many parts of the world, notably in the Mediterranean countries and in the Middle East (64, 71, 108). Worldwide, more people drink the milk of goats than milk of any other single species (54, 103, 106, 108). Goat milk differs from cow or human milk in higher digestibility, distinct alkalinity, higher buffering capacity, and certain therapeutic values in human medicine and nutrition (39, 54, 104, 108, 109, 125, 141). Due to the unavailability of cow milk, goat milk and its products are important daily food sources of protein, phosphate, and calcium in developing countries (54, 104).

Interest in dairy goats and goat milk products is a part of the recent trend in health food demand and consumption in some developed countries; there is also a renewed interest in goat milk as a substitute for those who suffer from allergies or intolerance against cow milk (28, 103, 108, 134, 136, 139, 141). Goat milk cheeses also recently gained increasing popularity among certain ethnic groups, health food lovers, and private goat farmers in the United States. (103).

Unlike the cow milk industry, large-scale industrialization of dairy goat production in many countries is limited due to the low level of milk production, which is approximately 50 kg per doe per lactation annually (64, 77). The major nutrient composition of goat milk resembles cow milk, whereas goat milk has its unique chemical, biochemical, physical, and nutritional characteristics compared to other species' milk.

2 CHEMICAL COMPOSITION OF GOAT MILK

2.1 Basic Composition

The basic composition of goat milk is similar to that of cow milk. As in the case of cow milk, composition of goat milk varies with diet, breed, animals within breed, parity, environmental conditions, feeding and management conditions, season, locality, and stage of lactation (128, 137). Caprine milk, on the average, contains 12.2% total solids, consisting of 3.8% fat, 3.5% protein, 4.1% lactose, and 0.8% ash (Table 2.14), indicating that it has more fat, protein, and ash and less lactose than cow milk. It is known that significant variations occur in milk composition and yield during different seasons and stages of lactation within a milking cow, with a similar phenomenon occurring in goat milk (Figure 2.17). The fat, total solids, and protein contents of the milk are high in early lactation, fall rapidly and reach a minimum during the second to third months of lactation; they then increase toward the end of lactation. This causes an inverse relationship between the yield of milk and percentage composition of these components (128).

Goat milk contains slightly less total casein but higher non-protein nitrogen than the cow counterpart (Table 2.14). The most remarkable difference in basic composition between goat (or cow) milk and human milk exists in protein and ash contents. Goat and cow milk have substantially (three to four times) greater levels of the two components than human milk, which is species specific and directly related to growth rate of the newborn of the respective species. Differences in total solids and caloric values among goat, cow, and human milks are not significant (54, 59, 119). The prominent difference is in the proportion of energy derived from lactose and protein. Fat, protein and lactose in goat and cow milks account

Table 2.14. Basic Composition of Goat, Cow, and Human Milks (Mean Values per 100 g)

Constituents	Goat	Cow	Human
Fat (g)	3.8	3.6	4.0
Protein (g)	3.5	3.3	1.2
Lactose (g)	4.1	4.6	6.9
Ash (g)	0.8	0.7	0.2
Total Solids (g)	12.2	12.3	12.3
Calories (cal)	70	69	68

Data from Posati and Orr (119), Jenness (59), and Haenlein and Caccese (54).

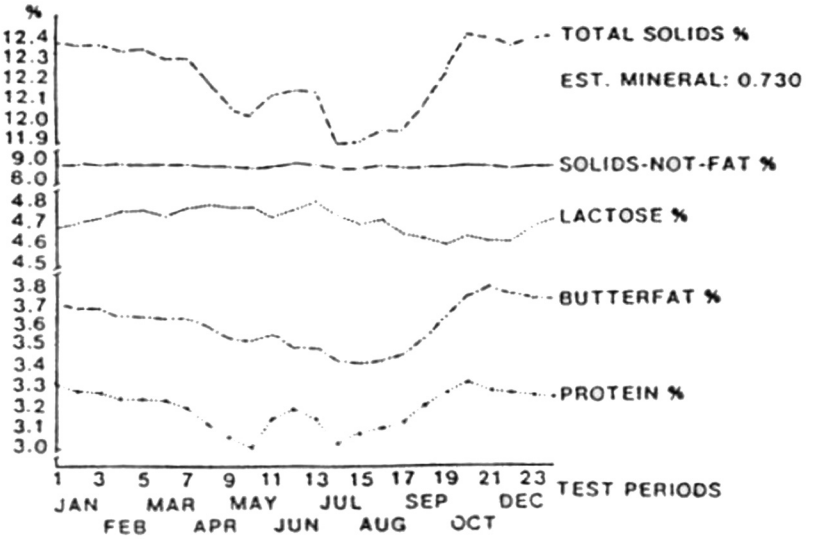

Figure 2.17. Composition of all Ontario milk, 1972. Adapted from Irvine (56).

for approximately 50, 25, and 25% of the energy, respectively, whereas human milk contributes 55, 7, and 38% (59).

2.2 Lipids

2.2.1 General Characteristics of Goat Milk Fat

One of the significant differences between goat and cow milk is found in the physico-chemical structure and composition of milk fats. The average size of goat milk fat globules is about 3.5 micrometers as compared to 4.5 micrometers for cow milk fat (43, 54, 131). Average diameters of fat globules for goat, cow, buffalo, and sheep milks were reported to be 3.49, 4.55, 5.92, and 3.30 μm, respectively (Table 2.15). Smaller fat globules make a better dispersion and more homogeneous mixture of fat in goat milk, which would provide lipases with a greater surface area of fat for enhanced digestive action. From a human health standpoint, natural homogenization of goat milk would be better for digestion than the mechanically homogenized cow milk products (28, 54). This smaller physical size of goat milk fat globules appears to be associated with poor creaming ability of goat milk. However, reports suggest that clustering of fat globules is favorably achieved by agglutinin, which is deficient in goat milk, whereby it has a weaker creaming ability than cow milk, especially at lower temperature (28, 54, 59, 67, 95).

Goat milk contains 97–99% of free lipids and 1–3% bound lipids of total milk fat (Table 2.16). The ratio of bound to free lipids is comparable to that for cow milk (24). Fractional compositions of free lipids of goat milk are similar to those of cow

Table 2.15. Frequency Distribution of Average Size Fat Globules in Milk of Goats, Buffaloes, Cows, and Sheep

Diameter	Goat	Cow	Buffalo	Sheep
(μm)			(%)	
1.5	28.4	10.7	7.9	28.7
3.0	34.7	32.6	16.6	39.7
4.5	19.7	22.1	16.4	17.3
6.0	11.7	17.9	20.3	12.1
7.5	4.4	12.2	20.9	2.0
9.0	1.0	3.1	10.5	.2
10.5	.2	1.4	1.7	. . .
12.0	. . .	.1	2.0	.1
13.5	. . .	. . .	.4	. . .
15.0	. . .	. . .	.3	. . .
16.5	. . .	. . .	. . .	. . .
18.5	. . .	. . .	.1	. . .
Average	3.49	4.55	5.92	3.30

Fahmi et al. (43).

Table 2.16. Quantitative Distribution of Lipids in Bound and Free Fractions of Goat Milk

Lipid Components	% Total Lipid
Free Lipids	97–99%
Triglycerides	96.8
Diglycerides	2.2
Monoglycerides	0.9
Bound Lipids	1–3%
Neutral lipids	46.8
Glycolipid	8.5
Phospholipid	44.7

Cerbulis et al. (24).

milk. Free lipids of goat milk contained 96.8% triglycerides, 2.2% diglycerides, and 0.9% monoglycerides, whereas bound lipids contained 46.8% neutral lipids and 53.2% polar lipids (8.5% glycolipides and 44.7% phospholipids).

In the light of skim milk fraction, goat milk displayed almost a double amount of free lipids as compared to cow counterparts, whereas the opposite trend was found for bound lipids of both goat and cow milks (Table 2.17). Polar lipids make up approximately 1.6% of the total lipids (25).

Of the polar lipid fraction, glycolipids make up 16% in goat milk as compared to the 6% in cow milk (96). Quantitative analysis of the phospholipid fraction of bound lipids of goat milk revealed that it had 35.4% phosphatidyl ethanolamine, 3.2% phosphatidyl serine, 4.0% phosphatidyl inositol, 28.2% phosphatidyl choline, and 29.2% sphingomyelin. Species differences in phospholipid fractions appear to be insignificant (Table 2.18). Holding goat milk for 1–2 days at 4°C increased the phospholipids and cholesterol in the skim milk fraction, probably as a result of damage to the fat globules (114). Owing to this reason, more neutral lipids would be retained in the skim milk.

2.2.2 Fatty Acid Composition of Goat Milk

The comparison of fatty acid composition of total lipids showed that goat milk fat has significantly higher levels of short and medium chain length fatty acids (MCT) (C4:0–C14:0) than cow and human milks (Table 2.19) (53, 59, 60, 62, 64). Goat milk has almost twice higher amounts of caproic (C6:0), caprylic (C8:0), and capric (C10:0) acids than cow milk does, which are highly correlated to "goaty" flavor (54, 59, 64). The higher levels of these short-chain acids may be attributable to the differences in polymerization of the acetate produced by the rumen bacteria in goats (136). Human milk contains an especially negligible amount of short-chain fatty acids (62).

Goat milk has a unique characteristic in the lauric:capric fatty acid (12:10) ratio, where it has a significantly lower ratio than cow milk (0.46 vs. 1.16) (57). The ratio becomes proportionally larger with increased substitution of cow milk in lieu of goat milk. The detection of the extent of adulteration of goat or sheep milk or cheese with cow milk or cheese has been used in the dairy industry (57, 101). The remarkably high concentrations of C16:0 and C18:1 (oleic) acids in goat and cow milk fats are not species specific, but rather they are common to most mammals (Table 2.19).

Significant differences in long-chain fatty acids (C16:0, C18:0, and C18:2) of goat milk were observed among different milking herds, and five branched-chain fatty acids (BCFA) (*iso*- and

Table 2.17. Comparison of Free and Bound Lipids in Fractions of Goat Milk with Cow Milk (% of Total Lipid)

		Cream		Skim milk	
	Whole milk	1200 rpm	3000 rpm	1200 rpm	3000 rpm
Goat milk					
Free	96.8	98.1	89.9	75.8	80.7
Bound	3.2	1.9	1.1	24.2	19.3
Cow milk					
Free	97.3	98.8	98.4	43.2	41.1
Bound	2.7	1.2	1.6	56.8	58.9

Cerbulis et al. (24).

Table 2.18. Distribution of Phospholipid Sub-Classes in Goat, Cow, and Human Milks

	Percent of total phospholipids		
Phospholipid fraction	Goat milk	Cow milk	Human milk
Phosphatidyl ethanolamine	35.4	35	32
Phosphatidyl choline	28.2	30	29
Sphingomyelin	29.2	24	29
Phosphatidyl inositol	4.0	5	5
Phosphatidyl serine	3.2	2	4

Data from Cerbulis et al. (24); Renner et al. (123).

anteiso-C15:0, *iso*- and *anteiso*-C17:0, and *iso*-C16:0) with >0.1% of the total fatty acid methyl esters and another 31 (the most monomethylated) with <0.1%, including 4-ethyloctanoate, were identified in caprine milk (4). Numerous BCFA (all having more than 11 carbon) were identified and quantified (88), and more than 20 volatile BCFA were identifed in caprine cheese (52). Iso and anteiso acids predominated in the BCFA of goat milk, in proportions similar to those of cow milk (64). Goat milk fat has a range of other monomethyl-branched components, mostly with methyl-substitution on

Table 2.19. Fatty Acid Composition of Total Lipid and Cholesterol Esters of Goat, Cow, and Human Milks

Fatty acid	Total lipid (g/100g fat)			Cholesterol esters (g/100g CE)	
	Goat	Cow	Human[f]	Goat[e]	Cow[f]
C4:0	2.6[a] (3.3–4.8)[b]	3.3[c] (2.5–6.2)[d]	-		
C6:0	2.9 (1.7–3.0)	1.6 (1.5–3.8)	Tr		
C8:0	2.7 (1.5–3.6)	1.3 (1.0–1.9)	Tr		
C10:0	8.4 (6.4–11.1)	3.0 (2.1–4.0)	1.3	5.2	2.9
C10:1	Tr	Tr	Tr	Tr	0.3
C12:0	3.3 (2.5–5.0)	3.1 (2.3–4.7)	3.1	4.2	4.1
C12:1	Tr	Tr	Tr	1.0	0.2
C13:0	Tr	Tr	Tr	Tr	Tr
C13:1	Tr	Tr	Tr	0.9	11.0
C14:0	10.3 (8.5–11.2)	9.5 (8.5–12.8)	5.1	9.2	6.9
C14:1	Tr	Tr (0.6–1.5)	Tr	1.4	0.5
C15:0	Tr	Tr	Tr	1.3	2.1
C15:1	Tr	Tr	Tr	Tr	2.6
C16:0	24.6(25.1–38.4)	26.5 (24.0–33.3)	20.2	39.3	26.9
C16:1	2.2 (0.7–1.7)	2.3 (1.3–2.8)	5.7	Tr	11.9
C17:0	Tr	Tr	Tr	Tr	Tr
C18:0	12.5 (5.9–14.9)	14.6 (6.2–13.6)	6.0	9.0	6.7
C18:1	28.5(15.6-28.2)	29.8 (19.7–31.2)	46.4	26.5	13.7
C18:2	2.2 (1.8–4.0)	2.5 (1.5–5.2)	13.0	2.1	10.1
C18:3	Tr	1.8	1.4	-	

[a,b]Jenness (59) and Gonc et al.(48).

[c,d]Juàrez and Ramos (64) and Martinez-Castro (87).

[e]Keenan and Patton (66), and [f]Jensen (62).

CE: Cholesterol esters, which is less than 4% of total cholesterol.

carbons 4 and 6, but they are virtually absent from cow milk, with only a trace amount of 6-methyl-hexadecanoate detected (88).

The composition of hydrocarbon fraction of goat, cow, and human milks showed that cow milk fat constituted 70 ppm of hydrocarbons and goat milk contained lower levels of squalene and phytene and was more complex in structure (26). Hydrocarbons of human milk were related more to human skin lipids than to those of cow or goat milk fat. The positional isomers of cis- and trans-octanoate in goat milk fat was 86% of the cis-C18:1 in oleate (Δ9) form, as opposed to 96% in cow milk (59, 61). Both goat and cow milk fat contain adequate amounts of essential fatty acids for human infants.

Goat milk has much higher glycerol ethers than does cow milk, which appears to be important for the nutrition of the nursing newborn (54). Goat milk also contains lower levels of orotic acid than cow milk does, which has a significant effect on the prevention of fatty liver syndrome (54, 59).

2.2.3 Conjugated Linoleic Acid in Goat Milk

Conjugated linoleic acid (CLA) has gained great attention in recent years because of its several beneficial effects on health, including anticarcinogenic activity (12, 74, 113), antiatherogenic activity (74, 75), the ability to reduce the catabolic effects of immune stimulation (33, 74), the ability to enhance growth promotion (30, 74), and the ability to reduce body fat (102, 74). CLA is a mixture of positional and geometric isomers of linoleic acid (C18:2) that contain conjugated unsaturated double bonds (40). The most biologically active isomer of CLA is *cis*-9, *trans*-11-octadecadienoic acid, which accounts for more than 82% of the total CLA isomers in dairy products (31, 40).

Feeding canola oil at 2 and 4% of grain intake to Alpine does increased CLA in milk by 88 and 210%, respectively, compared to the nontreated control group (93). It is possible to increase the CLA content of goat milk by dietary manipulation and supplementation with certain ingredients such as addition of canola oil. Because cows fed on only pasture produced milk fat with a higher CLA content than did cows receiving less feed from pasture (40), it is expected that dairy goats would produce higher CLA content in goat milk under the same feeding conditions.

Full fat rapeseed supplements resulted in substantial increases in CLA in cow milk over unsupplemented controls (74). Adding oil rich in unsaturated acids (C18:2–C18:3), which undergo saturation in the rumen, increases the C18:0 and C18:1 acid content (44). Feeding encapsulated lipids in formaldehyde-treated casein led to a marked increase in the proportion of C18:2 and C18:3 acids in the milk (64), where increase in CLA is possible although it is not tested.

2.2.4 Free Fatty Acids in Goat Milk

Free fatty acid (FFA) content of goat milk is 3.11 μ eq/ml compared with cow milk (3.0 μ eq/ml) and buffalo milk (3.4 μ eq/ml) (2). Percent fat and FFA content are highly correlated in goat milk only. The FFA content in goat milk varies with breed and stage of lactation, being maximum during mid-lactation (2).

The FFA fraction in goat milk has been related to "goaty" flavor intensity in the milk. A positive correlation exists between goaty flavor and free fatty acids (5.6 and 2.7 meq/L in samples stored for strong and weak flavor) (10). However, other factors may be involved in that flavor because samples with the same free fatty acids contents showed sometimes quite different flavor (64).

Qualitative and quantitative profiles for most branched-chain FFA were similar in cow, sheep, and goat milks, except that 4-ethyloctanoic acid was found in cow milk cheese (52). Table 2.20 shows concentrations of volatile free fatty acids and volatile total fatty acids in goat and sheep milk cheeses. Milk fat of cows contained low concentrations of 4-methyloctanoic acid, but milk fat of sheep and goats contained significant amounts of both 4-methyloctanoic and 4-ethyloctanoic acids, which contributed mutton-like and goat-like flavors, respectively (52). Quantification of free fatty acid (FFA) in goat cheeses indicated that they had higher levels of C8:0 and C10:0, characterizing a strong goaty flavor (144).

Flavor intensity increased in Italian cheese as short-chain FFA concentrations increased. FFA profiles of goat, sheep, and cow cheeses were similar, with the exception of 4-ethyloctanoic acid which was present in goat and sheep cheese, but was absent in the cow cheese (52). Concentrations of 4-methyloctanoic acid in goat Cheddar cheese increased significantly from day 1 in the 12-week

Table 2.20. Concentrations (μg/g Cheese) of Volatile Free Fatty Acids (VFFA) and Volatile Total Fatty Acids (VTFA) in Cheeses from Goat and Sheep Milk

		Goat milk cheese				Sheep milk cheese	
		VFFA			VTFA	VFFA	VTFA
Peak No.	Fatty acids	A	B	C	A	A	A
1.	Butanoic	3.50	0.72	31.8	7030	32.0	18,180
2.	2-Methylbutanoic	—[1]	—	2.26	1.18	2.48	3.2
3.	3-Methylbutanoic	0.05	—	-	20.4	20.4	22.6
4.	2-Ethylbutanoic	0.95	—	-	4.86	-	—
5.	Pentanoic	0.02	—	0.31	5.33	0.08	2.16
6.	3-Methylpentanoic	—	—	—	2.71	—	0.66
7.	4-Methylpentanoic	—	—	—	0.45	—	0.78
8.	Hexanoic	11.3	0.76	61.2	6000	40.7	7230
9.	2-Ethylhexanoic	0.18	0.18	—	0.6	0.18	0.75
10.	4-Methylpentanoic	0.05	0.05	—	3.23	0.13	1.19
11.	Heptanoic	0.33	0.03	0.90	21.6	0.51	10.9
12.	2,4-Dimethylheptanoic	0.04	0.21	—	1.43	—	—
13.	A methylheptanoic[2]	0.03	0.01	—	0.45	0.06	0.65
14.	An ethylhepanoic[2]	0.03	0.02	—	0.83	—	—
15.	An ethylheptenoic[2]	1.82	1.88	0.39	6.59	—	—
16.	Octanoic	30.9	3.69	70.3	6006	38.3	7577
17.	4-Ethylheptanoic	0.11	0.06	—	0.97	0.28	0.31
18.	4-Methyloctanoic	0.09	0.02	0.26	9.70	0.08	2.79
	A dimethyloctanoic[2]	—	—	—	—	0.09	0.22
19.	6-Methyloctanoic	0.04	0.02	—	0.12	0.08	0.28
20.	Nonanoic	0.38	0.06	1.30	19.6	0.64	13.5
21.	4-Ethyloctanoic	0.01	0.01	0.05	2.84	0.13	0.19
22.	4-Methylnonanoic	0.05	0.01	0.11	1.80	0.07	1.17
23.	8-Methylnononoic	0.41	—	—	0.63	—	—
24.	Decanoic	88.2	21.0	183	21,410	88.4	23,320
25.	A methyldecanoic[2]	—	0.09	0.13	3.15	0.08	0.72
26.	2-Ethyldecanoic	—	—	0.07	2.90	0.03	1.59
27.	9-Decenoic	2.30	0.51	4.01	63.5	2.56	53.3

[1]Not detected.
[2]Tentative identification.
Ha and Lindsay (52).

aging period (8). The 4-methlyoctanoic acid exhibited a mutton-like aroma at concentrations below 100 ppb, while 4-methyloctanoic acid blended easily with the goaty aroma of 4-ethyloctanoic acid to produce distinctive goatiness (8, 52). The threshold concentration of 4-ethyloctanoic acid for goaty aroma was 1.8 ppb (14) and 6.0 ppb (15) in diluted citric acid solution at pH 2.0. FFA content increased during storage at 4°C, where the FFAs initially consisted of short-chain acids but increased C16:0 and C18:0 after 10 days (11).

Lipolysis in goat milk increases during storage at room temperature for 4 h and 12 h (129). Goat milk had significant correlation between spontaneous lipolysis and lipoprotein lipase activity, while no correlation was found in cow milk (16, 29). Goat milk has higher sensitivity to spontaneous lipolysis than cow milk due to the difference in lipase distribution. Acid degree value (ADV) is a measure of lipolysis or degree of formation of FFA in milk and dairy products. The ADVs of goat milk cheeses steadily increased as the aging period advanced (63).

2.2.5 Cholesterol and Unsaponifiable Fat in Goat Milk

Cholesterol contents of goat, cow, and human milk were reported as 11, 14, and 14 mg/100 g milk, respectively (119), indicating that goat milk contains a lesser amount of cholesterol than other milks, even though the former has higher total fat than the latter. The reported low cholesterol value in goat milk may be of importance to human nutrition, since cholesterol is implicated with coronary heart disease. However, cholesterol in goat milk is usually in the range of 10–20 mg/100 ml milk (59). As in cow milk, most cholesterol in goat milk is in a free state with a small portion in ester forms, 52 mg/100 g fat, which constitutes less than 4% of the total cholesterol (28, 59). Fatty acid composition of cholesterol esters (Table 2.19) reveals that goat cholesterol esters have greater palmitic and oleic acid fractions than do cow counterparts (59, 64).

The level of unsaponifiable matter in goat milk is 24 mg/100 ml or 46 mg/100 g fat, which is comparable to that in cow milk (6). Most of this milk lipid fraction (91%) is cholesterol, which is about 420 mg/100 g fat (6). Significant variation in cholesterol content was observed among different breeds, and most of the cholesterol in goat milk is in free state, with only a small fraction in the ester form, 52 mg/100 g fat (6). Cholesterol esters of cow milk fat represent about one-tenth of the sterol content in cow milk (66). On the average, 66% of the free and 42% of the esterified cholesterol were associated with goat milk fat globules (66).

2.3 Carbohydrates

The major carbohydrate of goat milk is lactose, which is about 0.2-0.5% less than that of cow milk (28, 119). Lactose is a disaccharide made up of a glucose and a galactose molecule, which is synthesized in the mammary gland. Milks of most of the wild or less domesticated mammalian species usually have higher content of fat and lower content of lactose than goat milk does (54). Cow milk contains minor levels of monosaccharides and oligosaccharides, while their presence in goat milk are not known (28).

2.4 Proteins

2.4.1 Major Proteins in Goat Milk

There are five principle proteins in goat milk: β-lactoglobulin (β-Lg), α-lactalbumin (α-La), κ-casein (κ-CN), β-casein (β-CN), and α_{s2}-casein (α_{s2}-CN) (21, 54, 92). These proteins were named after their corresponding proteins of cow milk due to their homologous nature in composition and properties (143). The casein composition in goat milk is influenced by genetic polymorphism on the casein loci (136).

Electrophoretic mobility under standard conditions shows that β-casein is the major component of the casein fraction in goat milk, whereas α_{s1}-casein is the major casein in cow milk. Total casein content of goat milk is slightly lower than that of cow milk (Table 2.21). The percentages of α_{s1}- and α_{s2}-caseins in goat milk are markedly different from those in cow milk, where goat milk has much lower α_{s1} and higher α_{s2} than cow milk (27, 122). However, goat milk showed considerable variations in its α_{s1}-casein content, ranging from 2.7 g/l to only 0.12 g/l (94). Expression of α_{s1}-casein may be genetically regulated in certain breeds such as French-Alpine. Beta-casein is the most abundant protein in goat and human milks, while α_{s1} is the major protein in cow milk. Levels of α_s-casein are minimal in human milk (Table 2.21).

Percent composition of different protein fractions in goat and cow milks are summarized in Table 2.22. The result of an immunoassay showed that β-lactoglobulin contents were similar in goat and cow milk, but goat milk contained nearly twice as much α-lactalbumin as cow milk (59). However, another report revealed that the α-lactalbumin content in the two milks is about equal, and β-lactoglobulin content in goat milk is practically double the α-lactalbumin content (132).

Beta-lactoglobulins (β-Lg) in goat milk has been separated and sequenced. Goat β-lactoglobulin has three less-negatively charged and one more positively charged residues than bovine β-lactoglobulin at pH of 5 to 9 (59). The difference in ionizable groups explains the difference in titration curves for the two proteins and the slower electrophoretic mobility of goat β-lactoglobulin at alkaline pH levels (59). The α-lactalbumins play an important role in milk biochemistry because they are part of the lactose-synthetase enzyme involved in synthesis of lactose. Cow and goat α-lactalbumins have been sequenced.

2.4.2 Characteristics of Individual Proteins of Goat Milk

2.4.2.1 α_s-caseins Among cow milk proteins, the α_s-caseins have one major component, α_{s1}-casein, and several minor components (143), where the

Table 2.21. Caseins, Minor Proteins, and Enzyme Contents of Goat Milk in Comparison with Those of Cow and Human Milks

Proteins	Goat	Cow	Human
Protein (%)	3.5	3.3	1.2
Total casein (g/100ml)	2.11	2.70	0.40
α_{s1} (% of total casein)	5.6	38.0	—
α_{s2} (% of total casein)	19.2	12.0	—
β (% of total casein)	54.8	36.0	60-70.0
κ (% of total casein)	20.4	14.0	7.0
Whey protein (%) (albumin and globulin)	0.6	0.6	0.7
Nonprotein N (%)	0.4	0.2	0.5
Lactoferrin (μg/ml)	20–200	20–200	<2000
Transferrin (μg/ml)	20–200	20–200	50<
Prolactin (μg/ml)	44	50	40–160
Folate-binding protein (μg/ml)	12	8	—
Immunoglobulin			
IgA (milk:μg/ml)	30–80	140	1000
IgA (colostrum:mg/ml)	0.9–2.4	3.9	17.35
IgM (milk:μg/ml)	10–40	50	100
IgM (colostrum:mg/ml)	1.6–5.2	4.2	1.59
IgG (milk:μg/ml)	100–400	590	40
IgG (colostrum:mg/ml)	50–60	47.6	0.43
Lysozyme (μg/100ml)	25	10–35	4–40
Ribonuclease (μg/100ml)	425	1000–2000	10–20
Xanthine Oxidase (μl O_2/h/ml)	19–113	120	—

Data from Chandan et al. (27), Jenness (59), Renner et al. (123); Remeuf and Lenoir (122).

α_s-caseins possess the fastest electrophoretic mobility and are precipitated in 0.4 M $CaCl_2$ at pH 7.0 and 4°C (143). The α_s-caseins are capable of being stabilized by κ-casein against precipitation, and α_s-caseins in goat casein represent a much smaller proportion of total casein than that in bovine casein (112). This type of goat casein was found to be compositionally similar to the minor bovine casein formerly called "α_{s2}-, α_{s3}-, α_{s4}-, α_{s6}-caseins," which are later designated simply as α_{s2}-caseins (18). There is one major difference between α_{s2}- and α_{s1}-casein, which is a disulfide linkage in the former but a complete lack of disulfide or thiol in the latter (59).

Polymorphism of α_{s1}-casein controls the level of α_{s1}-casein excretion in milk, and more than 18 alleles have been identified in goat milk (136). These alleles are distributed among seven different classes of protein variants (α_{s1}-casein A–G) and associated with 4 levels of α_{s1}-casein expression ranging from 0 (null allele α_{s1}-Cn°) to 3.5 g/l per copy of each A, B or C (strong) alleles (136). The allele E (medium) is related to an intermediate content (1.1 g/l per allele), and those that are F and G (weak) are associated with low contents of α_{s1}-casein (0.5 g/l per allele) (136).

The SΔQ is an index for the degree of similarity between amino acid composition of each of the goat proteins and that of its corresponding bovine homolog (86). The amino acid compositions of bovine α_{s1}- and αs_2-caseins are markedly different (SΔQ = 82), where their respective polypeptide chains have 199 and 207 residues. Peptides formed from goat or sheep casein by proteases were less bitter than those from cow casein, suggesting that the lower bitterness in goat and sheep cheeses than in cow cheeses is attributable to the lower (or total lack of) α_{s1}-casein in the former (59, 116).

Goat casein has a negligible (or total lack of) level of α_{s1}-casein, where as little as 1% of cow milk added to goat milk could be detected by α_{s1}-casein band in gel electrophoresis (7, 59, 117). However, a recent report (94) showed that goat milk can contain considerably variable levels of α_{s1}-casein ranging

Table 2.22. Comparison of Major Protein Composition (%) of Goat Milk with Those of Cow Milk

	Goat milk	Cow milk	
Protein	Study 1	Study 1	Study 2
Total casein	2.14–3.18	2.28–3.27	2.6
α_s - casein	0.34–1.12	0.99–1.56	1.26
β - casein	1.15–2.12	0.61–1.41	0.93
κ - casein	0.42–0.59	0.27–0.61	0.33
Total whey protein	0.37–0.70	0.88–1.04	0.81
β - lactoglobulin	0.18–0.28	0.23–0.49	0.32
α - lactalbumin	0.06–0.11	0.08–0.12	0.12
Serum albumin	0.01–0.11	0.02–0.04	0.04

Study 1: Storry et al. (132).
Study 2: Jenness (59).

from 2.7 g/l to only 0.12 g/l, depending on breeds of goats. Expression of α_{s1}-casein may be genetically regulated in certain breeds such as French-Alpine.

2.4.2.2 β-caseins As shown in Tables 2.21 and 2.22, the β-caseins are the major components (54.8%) of total goat milk casein (59, 122, 123, 132). The β-casein has more numerous genetic variants than the other caseins, and their differentiation by gel electrophoresis is more complicated (143). β-caseins appear in decreasing mobilities in alkaline gel electrophoresis (9% cyanogum, 3.5 M urea) in the following order: $A^1 = A^2 = A^3 > B = B_z >$ D,E $>$ C (69). On the other hand, their order of decreasing mobility is changed in acid gels (10% cyanogum, 4.5 M urea) as: $C > B = B_z = D > A^1 = E > A^2 > A^3$.

The A variants of β-casein can be differentiated from the B, C, and D variants by alkaline gel electrophoresis, whereas A variants from each other can be differentiated by acid gel electrophoresis (143). The β-casein Bz, the genetic variant, has electrophoretically the same behavior as β-casein B, except for possessing a different peptide map for its chymotryptic digest (59, 143).

The primary structure of β-casein has been defined with a calculated molecular weight of 23,980. The positive charge at position 37 in β-casein C is thought to hinder phosphorylation of Ser_{35}, while the negative charge in all other genetic variants at position 37 may facilitate phosphorylation at Ser_{35}. β-casein E has been discovered in Italian Piedmont cattle (140) but has not been compared with the D variant, and their relative mobilities in alkaline gel have not been defined (143).

2.4.2.3 γ-caseins Through amino-acid analysis, molecular weight, peptide maps and partial amino-acid sequencing, γ-caseins have been shown to be identical with fragments of β-casein. The γ-caseins occur as four distinct polymorphs, A^1, A^2, A^3, and B, and they are related to the corresponding β-casein by cleavage of the Lys_{28} - Lys_{29} bond, (i.e., which is expressed as $\beta\text{-}A^2 \rightarrow \gamma\text{-}A^2$). This indicates that γ-casein variants consist the residues $29 \rightarrow 209$ inclusive of the corresponding variant of β-casein, which means that γ_1-casein is identical to the fragment of β-casein from residue 29 to 209 (50, 143).

It was also theoretically shown that cleavage of β-casein A^2 at Lys_{105} and Lys_{107} yields the two C-terminal fragments, which are identical with the TS-A^2 and R-caseins, whereas fragmentation of β-casein B yields segments identical with the S- and TS-B caseins (143). The fragment of β-casein from 106 to 209 is termed as γ_2-casein, while that of β-casein from 108 to 209 is termed as γ_3-casein (143).

2.4.2.4 κ-caseins The κ-casein is the only component of the goat milk caseins of which the entire sequence of amino acids has been determined (36). The sequence of κ-casein differs from its bovine counterpart in having a chain of 171 instead of 169 amino acids residues, Val and His being inserted at positions 132 and 133. As with the bovine homolog, goat κ-casein has Phe in position 105 and Met in 106 (59). Rennet enzyme hydrolyzes the κ-casein

molecule between these two residues, producing the fragments known as para-κ-casein (residues 1 to 105) and caseinomacropeptide (residues 106 to 171) (59).

The κ-caseins occur in the form of a mixture of polymers held together by intermolecular disulfide bonds (133). There are two genetic variants of κ-casein, A and B. The casein homozygous from either variant of κ-casein assayed by alkaline gel electrophoresis in the presence of percaptoethanol and ureas showed several bands with mobilities slower than β-casein (81, 143). The complexity of slower mobility of κ-casein (molecular weight about 19,000) than β-casein is attributable to the differences in carbohydrate content of these κ-caseins, which varies from zero to possibly 5 carbohydrate chains (124).

2.4.2.5 Whey Proteins There are three major whey or serum proteins other than casein fractions in milk; those are bovine serum albumin, β-lactoblobulins, and α-lactalbumins, in addition to some immunoglobulins and proteose-peptone fraction (59, 143). Because β-lactoblobulins and α-lactalbumins are generally in significant quantities in whey proteins, only these two proteins are further discussed here.

2.4.2.5.1 β-lactoglobulins Goat β-lactoglobulin (β-Lg), as with its bovine homologs, consists of a polypeptide chain of 162 amino acid residues, and it differs from bovine β-Lg B at six positions including both terminal residues (59). The N-terminal Leu of bovine β-Lg B is replaced by Ile, Asp 53→ Asn, Asp 130→ Lys, Ser 150 → Ala, Glu 158 → Gly, and Ile 162 → Val. This indicates that goat β-Lg has three less negatively charged and one more positively charged groups than bovine β-Lg at pH 5 to 9 (22, 59). Goat and cow β-Lg's are structurally different, where goat β-Lg is considerably less stable than the bovine variants to denaturation in urea, and goat and cow β-Lg's can be distinguished immunologically by microcomplement fixation technique (3, 59).

β-lactoglobulin A variant has calculated molecular weight of 18,362, and there is only one sulfhydryl group per molecule, which is distributed equally between positions 119 and 121 while a disulfide bridge is located either between positions 106 and 121 or 106 and 119 depending on the position of the sulfhydryl group (90, 118). β-lactoglobulin genetic variants A, B, C, and D are originated from point mutations, and the differences between genetic variants are from substitutions of amino acids at different positions (59).

Goat milk β-lactoglobulin has three less negatively charged and one more positively charged residues than bovine β-lactoglobulin at pH 5 to 9. This difference in ionizable groups explains the difference in titration curves and the slower electrophoretic mobility of goat β-lactoglobulin at alkaline pH levels (64).

2.4.2.5.2 α-lactalbumin Goat α-lactalbumin (α-La) is shown to be devoid of methionine, which resembles sheep α-La where all other α-La's contain one of the three methionine residues (80). Through a complete amino acid sequence analysis, 12 differences were shown between goat α-La and bovine α-La B (a variant in European cattle) in the chain of 123 residues (80). One of these differences was found at position 10, where goat α-La has Gln as in bovine α-La A (a variant in Indian cattle) instead of the Arg as in bovine α-La B (59).

Because goat α-La has immunological crossreactivity with other α-La's, it is distinguishable from bovine α-La by microcomplement fixation technique or by absorptoin of antibodies by columns of matrix-bound α-La (120). The conformation of goat α-La has been shown to be similar to that of the bovine homolog by various optical analyses, where the two species proteins have equal exposure of Tyr, Trp, and Lys groups in their conformation (59).

α-Lactalbumin is present in all milks that contain lactose because it is required for biosynthesis of lactose at meaningful rates (42). α-Lactalbumin is considered best as a modifier protein in that it changes the apparent K_m of the substrate, glucose, and does not appear to participate directly in the catalytic reaction (42). The mechanism of the action of α-lactalbumin has been elucidated: The enzyme galactosyltransferase, complexed with Mn^{2+}, transfers galactose from uridinediphosphogalactose to a carbohydrate acceptor. In the absence of α-La, the acceptor is a nonreducing N-acetyl-glucosamine residue on a glycoprotein because the transfer of galactose to glucose is slow, whereas in the presence of α-La the transfer is rapid and glucose becomes an effective substrate (42, 143).

α-Lactalbumin has its two genetic variants, A and B. The B-variant is the slower moving one in

alkaline gel electrophoresis, which is the only variant in milk of Western cattle, whereas both A and B variants are present in milk from African Fulani and African and Indian Zebu cattle (13). The major component of α-lactalbumin possesses four disulfide bonds, and the isolation of an α-lactalbumin with three disulfide bonds from an α-lactalbumin B preparation accounts for approximately 5% of the total α-lactalbumin. The sequence of amino acids in α-lactalbumin is similar to lysozymes, where a three-dimensional model of α-lactalbumin was demonstrated on the basis of the coordinates of hen's egg white lysozyme (19).

2.4.2.5.3 Bovine Serum Albumin Goat milk contains bovine serum albumin (BSA), which appears to be homologous to cow milk whey protein, which is identical to albumin from bovine blood serum. BSA has molecular weight of 66,267 and is a rod-shaped protein, containing one cysteine and 17 cystine residues and partially unfolded at low (<4) and high (>8) pH values (138). Both BSAs in milk whey and bovine blood serum are identical, except for heterogenous behavior in electrophoretic properties at pH 4.0 (143).

The BSA is heterogenous in nature and its molecule is reportedly a single peptide chain with one free sulfhydryl group at position 34 in the N-terminal peptide and probably 17 intramolecular disulfide bonds (143). The N-terminal and C-terminal amino-acid residues of BSA are aspartic acid and alanine, respectively.

2.4.2.5.4 Immunoglobulins Immunoglobulins (IgGs, IgA and IgM) are isolated from goat milk, while the literature on the characteristics and structure of goat immunoglobulins has been limited. Immunoglobulin IgG types in both goat and cow milks are much higher than in human milk, where antigen derived from bacteria and viruses introduced via the teat canal results in higher levels of IgG in the mammary gland. Human milk, however, contains greater levels of IgA and IgM type immunoglobulins than goat and cow milks (Table 2.21). Goat milk contains the IgG's in greatest concentrations as compared with other ruminants. Goat milk contains similar ranges of immunoglobulins to those of cow and sheep milk and colostrums (Table 2.21). Radioimmunoassays showed that mature goat milk contained 30 to 80 μg IgA, 10 to 40 μg IgM, 100 to 400 μg IgG/ml, and goat colostrum contained much higher than regular milk, having 0.9 to 2.4 mg IgA, 1.6 to 5.2 mg IgM, and 50 to 64 mg IgG/ml (100).

Certain aspects of structure have to be considered for the nomenclature of immunoglobulins (20, 143). The immunoglobulins are unique among the milk proteins (143) in: (i) the molecular genetics of their synthesis, (ii) their heterogeneity, and (iii) their synthesis. Immunoglobulin nomenclature is mainly based on immunochemical criteria including crossreactivity with reference proteins, typically from humans. Since the World Health Organization introduced the first nomenclature for human immunoglobulins (23), continuous revision has been made on it.

Immunoglobulin IgG1 is the principal immunoglobulin of bovine milk and colostrum, where IgG1 comprises as much as 80% of the total whey protein in colostrum and precolostral secretions (78). Most bovine IgG1 possesses a lower isoelectric distribution and greater net acidity than IgG2, thereby the former migrates more anodally during electrophoresis at alkaline pH (20, 41, 78). Bovine immunoglobulin IgG2 exists in less amount than IgG1, while both are external excretions (41, 78). The IgG2 population has a characteristic mobility in immunoelectrophoresis, polyacrylamide gel electrophoresis, and isoelectric focusing, while difficulty has been shown in separation of IgG1 and IgG2 by electrophoretic and ion-exchange methods (41, 78).

In comparison of immunoglobulins of different species, it was confirmed that antigenic homology exists between bovine IgM and its human counterpart (91). The bovine immunoglobulin IgM has been recognized in other species' milk that has similar physical, chemical, and biological characteristics of bovine IgM (20).

Bovine immunoglobulin IgA is homologous in other species, and their homologies to human counterparts are also confirmed (41, 68, 78). Bovine IgA is shown to be both physicochemically and immunochemically heterogeneous. The IgA is a major immunoglobulin in most other species' external secretion, whereas it is a remarkably minor immunoglobulin in bovine colostrum and milk (20, 143).

2.4.3 Non-Protein Nitrogen and Other Nitrogen Moieties of Goat Milk

Non-protein nitrogen (NPN) content in goat and human milk are much higher than in cow milk (104)

Table 2.23. Concentration of Total N, NPN, and Phosphate in Natural Goat and Cow Milk and Soy-Based Infant Formulas[1]

		Total N		NPN		P_2O_5	
Milk group	N[2]	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD
Goat milk							
Alpine	25	.390[c]	.032	.048[b]	.008	.166[a]	.020
Nubian	25	.556[a]	.013	.061[a]	.013	.212[a]	.015
Cow milk							
Holstein	25	.392[c]	.058	.033[c]	.002	.173[a]	.022
Jersey	25	.505[b]	.043	.038[c]	.004	.211[a]	.118
Formula milk							
Brand A	5	.227[d]	.026	.020[d]	.003	.211[a]	.008
Brand B	5	.259[d]	.016	.019[d]	.003	.192[a]	.053

[a,b,c,d]Means with different superscripts within a same column are significantly different ($P < .01$).

[1]Expressed in grams per 100 ml.

[2]Number of determinations per mean value.

Adapted from Park (104).

(Tables 2.21 and 2.23). As compared with cow milk, goat milk has higher non-protein nitrogen content, 8.7% as opposed to 5.2%, and a lower proportion of coagulable proteins and caseins, 70.9% and 75.6% compared to 73.0% and 77.8%, respectively (64). Similar but a little higher (78.3%) casein content was reported in pygmy goats (59). True protein is calculated as crude protein minus NPN, where the ratios of casein to true protein for goat and cow milks are 82.7% and 82%, respectively.

NPN is composed of several nitrogenous compounds, and its components (mg N/100 ml) in cow milk include: 0.17 ammonia N, 6.54 urea N, 0.19 creatinine, 3.55 creatin, 1.55 uric acid, 2.20 α-amino N, and 5.63 unaccountable N, respectively (60, 126). NPN contents in goat and cow milk also are different between different breeds, where Nubian has higher NPN levels than Alpine goats, and Jersey cow has higher NPN than Hostein cow (104, 105) (Table 2.23).

2.4.4 Amino Acid Composition of Goat Milk Proteins

The amino acid compositions of goat milk proteins reveal that differences between casein fractions are much greater than differences between species (goat vs. cow) within a casein fraction (Table 2.24). The α-caseins contain greater aspartate, lysine, and tyrosine than do β-caseins, while the latter has higher leucine, proline, and valine than the former. The α-La contains significantly greater aspartate than does β-Lg, whereas the opposite trend is shown for alanine and glutamate concentrations.

In a comparative investigation on amino acid composition of milks in many species of primates relative to those of non-primates, Davis et al. (35) reported that there were commonalities in the overall amino acid pattern of the milks of all species tested (Table 2.25). The most abundant amino acids were glutamate (plus glutamine, 20%), proline (10%), and leucine (10%). The amino acid pattern of human milk was more closely similar to that of great apes than to that of goats or other non-primates. Among the most abundant three amino acids, goat and other non-primate milk contained greater glutamate and proline, and less leucine than human milk. For sulfur-containing amino acids, cystine was higher and methionine was lower in primate milks than in goat and other non-primate milks (Table 2.25). Total amino acid contents in goat and other non-primate milks were substantially greater than those in human and primate milks as previously shown (Table 2.26). Other commonalities in all species milks were essential amino acids (EAA) 40%, branch-chain amino acids (BCAA) 20%, and sulfur amino acids 4% of the total amino acids. The EAA contents of goat and cow milk were greater than those of human milk, whereas the opposite trend was observed for the BCAA contents (Table 2.26). Goat, cow, and

Table 2.24. Comparison of Amino Acid Composition of Isolated Proteins of Goat Milk with Those of Cow Milk (g/100 g Protein)

Amino Acid	α-casein[a]		β-casein		κ-cn[b]	γ-cn[c]	β-Lg[d]		α-Lactalbumin	
	Goat[e]	Cow[f]	Goat	Cow	Goat	Cow	Goat	Cow	Goat	Cow
Ala	2.80	3.8	2.35	2.0	9.36	2.3	9.88	7.0	4.07	2.1
Arg	3.69	4.3	1.41	3.4	2.92	1.9	1.85	2.8	0.81	1.2
Asp	7.71	8.4	4.23	4.9	9.36	4.0	8.64	11.4	17.89	18.7
Cys	0.81	0.43	0.00	0.0	1.75	0.0	3.09	3.4	6.50	6.4
Glu	22.88	22.5	20.19	23.2	15.20	22.9	14.81	19.3	10.57	12.9
Gly	0.90	2.3	2.82	1.6	0.58	1.5	3.09	1.4	4.07	3.2
His	2.70	2.9	2.35	3.1	2.34	3.7	1.23	1.6	2.44	2.9
Ile	4.90	6.4	4.23	5.5	6.43	4.4	6.17	6.9	6.50	6.8
Leu	5.34	7.9	9.39	11.6	4.68	12.0	12.96	15.5	10.57	11.5
Lys	11.10	8.9	5.63	6.5	4.68	6.2	9.88	11.8	10.57	11.5
Met	2.07	2.5	2.82	3.4	0.58	4.1	2.47	3.2	0.00	0.95
Phe	4.64	4.6	4.23	5.8	2.34	5.8	2.47	3.5	3.25	4.5
Pro	6.88	7.5	15.49	15.1	11.11	17.0	4.94	5.1	1.63	1.5
Ser	4.80	6.3	7.04	6.8	7.60	5.5	3.70	4.0	4.88	4.8
Thr	5.57	4.9	5.63	5.1	8.77	4.4	4.94	5.0	4.88	5.5
Typ	1.47	2.2	0.47	0.83	0.58	1.2	1.23	2.7	3.25	7.0
Tyr	7.07	8.1	1.88	3.2	5.26	3.7	2.47	3.7	3.25	5.4
Val	4.68	6.3	9.86	10.2	6.43	10.5	6.17	6.1	4.88	4.7

[a]α-casein represents α_{s2}-casein for goat milk, and total α_s-casein for cow milk.
[b]κ-casein for goat milk only.
[c]γ-casein for cow milk only.
[d]β-Lg: Beta-lactoglobulin.
[e]Jenness (59).
[f]Webb and Johnson (142) unit for goat milk data were converted from residue/mole to g/100 g protein.

human milks have a satisfactory balance of EAA equalling or exceeding the FAO-WHO requirements for each amino acid to human infants (59).

2.5 Minor Proteins

Lactoferrin, transferrin, and prolactin contents of goat milk are comparable to those of cow milk (Table 2.21). Human milk contains more than 2 mg lactoferrin/ml, which amounts to 10–100 fold higher than goat milk. Goat and cow milk contain transferrin levels of 20–200 μg/ml, while human milk contains 50< μg/ml. Prolactin was determined by radioimmunoassay, and mean prolactin contents (μg/ml) of goat and cow milk were 44±5 (SE) and 50±l, respectively (82).

Goat milk has higher levels of folate-binding protein than cow milk, causing actual folate content to be lower in the former than the latter (Table 2.23; 28, 47, 123). Goat milk contains about 12 μg/ml of folate-binding protein, which is a glycoprotein with about 22% carbohydrate (47, 127), and binds 9.2 μg folic acid/mg of protein (59).

Goat milk also contains immunoglobulins IgGs, IgA, and IgM. Goat milk has similar ranges of immunoglobulins to those of cow and sheep milk and colostrums (Table 2.21). As occur in minor whey proteins, caprine milk also has proteose-peptones as do bovine and other milks. The proteose-peptone fraction has been characterized as a mixture of heat-stable acid-soluble (at pH 4.6) phosphoglycoproteins insoluble in 12% trichloroacetic acid (126)

2.6 Enzymes

Distribution of enzymes in goat milk is quite different from that in cow milk (Table 2.21; 28, 29). Ribonuclease level in cow milk is much greater than in goat milk, where this enzyme is identical to bovine pancreatic ribonuclease (64). Lysozyme concentrations of goat and cow milks are comparable

Table 2.25. Amino Acids in Primate and Nonprimate Milks[1]

Species	n	Asp	Glu	Ser	Gly	His	Arg	Thr	Ala	Pro	Tyr	Val	Met	Cys	Ile	Leu	Phe	Lys
									mg amino acid/g total amino acid									
Primate																		
Human	6	86.9	190.8	61.4	22.2	23.2	36.3	44.1	40.2	95.5	46.2	51.2	16.1	20.3	53.3	104.1	37.1	71.6
Chimpanzee	5	88.4	221.3	41.4	20.1	22.1	35.2	39.2	38.2	104.2	43.1	56.2	17.2	16.2	50.3	104.2	37.1	68.3
Gorilla	3	89.2	203.8	47.3	22.2	25.1	35.2	43.4	39.2	99.6	42.1	56.2	20.2	16.1	54.1	102.3	38.1	71.2
Baboon	5	80.4	194.6	53.1	14.1	21.2	56.2	39.1	38.2	107.6	40.1	55.3	21.2	10.2	54.1	105.3	43.2	69.6
Rhesus	6	73.8	191.5	48.3	14.1	20.2	47.4	40.2	40.2	112.4	41.1	52.2	25.2	12.3	57.3	111.3	44.1	72.6
Nonprimate																		
Cow	4	70.5	208.2	56.1	18.1	24.1	34.1	42.1	32.1	100.4	47.1	52.2	26.1	9.1	47.1	99.1	50.1	86.2
Goat	2	75.1	209.1	49.5	18.2	26.1	29.1	49.1	34.5	106.8	38.1	61.1	25.2	9.1	48.1	96.3	47.1	80.1
Sheep	6	75.2	203.4	52.1	18.1	26.1	34.1	41.1	40.1	102.2	47.2	57.2	29.1	8.1	49.1	90.4	48.1	83.3
Llama	3	71.1	220.1	41.2	14.1	29.1	36.1	44.1	25.1	102.2	40.1	55.1	31.1	7.1	55.1	99.1	46.1	83.3
Pig	3	78.5	208.5	51.3	32.1	24.1	44.1	37.1	36.2	117.3	39.1	46.1	22.1	16.1	40.2	89.4	43.3	79.3
Horse	8	95.5	217.8	52.8	16.1	22.2	60.2	39.2	37.2	91.8	45.4	47.2	22.1	11.2	39.1	93.3	43.2	73.5
Elephant	3	64.10	195.8	68.5	13.2	22.1	48.3	41.2	39.1	102.4	52.5	55.2	22.3	11.4	50.3	98.3	48.1	75.3
Cat	4	86.4	208.1	44.1	10.1	27.1	64.1	46.1	37.1	94.2	45.1	47.1	32.1	12.1	43.1	118.1	30.1	57.1
Rat	3	88.4	221.8	85.2	15.1	22.1	33.1	40.1	59.2	75.3	36.1	44.1	25.1	26.1	40.2	92.2	39.4	68.1

[1]Values are means ± SD of each amino acid (in mg) divided by the total amino acids (in g, excluding tryptophan).
Adapted from Davis et al. (35).

Table 2.26. Total Essential Amino Acids (EAA) and Total Branched-Chain Amino Acids (BCAA) in Primate and Nonprimate Milks[1,2]

Species	n	Total Amino Acids	EAA	BCAA
		g/L whole milk	mg amino acid/g —total amino acid—	
Primate				
Human	6	8.5±0.9	400±11	209±5
Chimpanzee	5	9.2±.7	392±7	209±2
Gorilla	3	11.5±2.5	408±7	212±5
Baboon	5	11.5±2.5	408±4	214±3
Rhesus	6	11.6±1.1	421±4	220±4
Nonprimate				
Cow	4	33.6±4.8	427±4	199±3
Goat	2	25.7±3.1	433±12	206±4
Sheep	6	54.1±2.4	422±5	196±5
Llama	3	29.6±6.9	443±1	209±2
Pig	3	35.0±3.5	379±11	175±7
Horse	8	15.8±3.5	377±6	178±3
Elephant	3	37.1±14.6	411±11	203±6
Cat	4	75.7±12.7	400±3	208±3
Rat	3	86.9±7.7	371±6	176±4

[1]Values are means ± SD calculated from the sum of individual essential amino acids or branched-chain amino acids (in mg) divided by the total amino acids (in g, excluding tryptophan).

[2]Branched-chain amino acids differed in primates vs. nonprimates ($P < 0.001$) and in humans and great apes vs. lower primates ($P < 0.001$).

Adapted from Davis et al. (35).

(Table 2.21); the characteristics of lysozyme content in artiodactyls' milks are in low range (112). It was shown that goat milk contains on average 25 μg of lysozyme, 425 μg of ribonuclease, and 36 μM/min of lipase/100 ml (27).

Alkaline phosphotase content in goat milk ranged from 11–13 mg/l, and the inactivation of this enzyme was reportedly at around 45°C by some authors, implying that the alkaline phosphatase test may not be effective for pasteurization of goat milk (64). Acid phosphatases (AP) also have been determined in goat and cow milks, where the activity levels of the enzyme in goat and cow milks were 0.136 and 0.076 units/g protein, respectively. Little difference was found in amino acid composition of the enzyme (AP) between goat and cow milk (72). Caprine AP (Mwt. 43,000) contained 297 residues and bovine AP (Mwt. 42,000) contained 292. Concerning carbohydrate composition of the AP, caprine AP contained 3 mannose, 1 galactose, and 2 glucosamine residues, while cow AP had 2, 2, and 4 respective residues (72).

Xanthine oxidase activity of goat milk is less than 10% of that of cow milk (28). Caprine xanthine oxidase contains higher amounts of aspartic acid, glutamic acid, proline, and glycine and lower amounts of serine than bovine xanthine oxidase (145). Goat milk xanthine oxidase has FAD as one of its cofactors and an optimum pH of 8.35. Xanthine oxidase has been associated with the control of various redox reactions in the cell and plays an important role in Fe absorption, facilitating the oxidation and combination of Fe with transferrin and coupling antibacterial effect via the lactoperoxide system (64). Xanthine oxidase also has been implicated in the spontaneous development of undesirable oxidized flavor in market milk and other dairy products, and interest in this enzyme has increased because of its possible involvement in development of atherosclerosis in humans (64). Feeding sodium molybdate caused a rapid rise in the Mo content of goat and cow milks but did not affect xanthine oxidase activity in either of their milks, which indicates that the low content of xanthine oxidase in goat milk

Table 2.27. Distribution of Lipoprotein Lipase Activity in Fresh Milk Cooled to 4° C.

	Whole milk	Skim milk	Cream	Milk serum	Caseins
Goat (n=6)					
Total activity, μ eq FFA[a]/h/ml	19.9±8.1	10.9±3.7	8.2±3.1	8.2±2.9	1.5±0.4
Percentage[b]	100	55	41 (46)	41 (46)	8 (8)
Cow (n=6)					
Total activity, μ eq FFA[a]/h/ml	94.5±13.3	72.8±3.7	3.7±0.5	11.3±1.8	51.9±2.8
Percentage[b]	100	77	4 (6)	12 (17)	55 (78)

[a]FFA = free fatty acid.
[b]Percentage of whole milk.
Adapted from Chilliard et al. (29).

does not appear to be attributed to the lack of molybdenum (59).

Goat milk contains less lipase than cow milk (29, 54). Lipase is a lipoprotein with technical applications due to its involvement in spontaneous and induced lipolysis. In contrast to that in cow milk, lipase activity in goat milk is significantly correlated with spontaneous lipolysis, possibly because of its specific lipolytic system. Lipases play a major role in flavor development in milk and dairy products during milk processing and storage. Goat milk exhibited significantly lower lipoprotein lipase activity in fresh milk cooled to 4°C than in that of its cow counterparts (Table 2.27).

Goat milk has in average 47 μmoles/s/ml of lactic dehydrogenase and 50 μmoles/s/ml of malic dehydrogenase. In electrophoresis, goat milk exhibited primarily one lactic dehydrogenase isoenzyme (LDH-1) and one malic dehydrogenase isoenzyme (M-MDH) (59). There are two enzymes that may be involved in the synthesis of glycoproteins in goat colostrum: one catalyzes the transfer of N-acetylglucosamine from uridine diphosphate N-acetylglucosamine to glycoproteins; the other is a soluble sialyl transferase that transfers sialic acid from cytidine monophosphate-sialic acid to lactose or N-acetyllactosamine (59).

2.7 Minerals

Goat milk contains about 134 mg Ca and 121 mg P/100g (Table 2.28). Human milk contains only one-fourth to one-sixth of these minerals. Although the macro-mineral levels may not fluctuate considerably, their levels can vary, depending on the breed, diet, animal, and stages of lactation. The P levels revealed slightly higher than Ca in French-Alpine and Anglo-Nubian goats (109). In underdeveloped countries, where meat consumption is low, goat milk is an important daily food source of animal protein, phosphate, and calcium due to lack of availability of cow milk (54, 104, 106). Goat milk has higher calcium, phosphorus, potassium, magnesium, and chlorine, and lower sodium and sulfur contents than cow milk (Table 2.28; 27, 54, 109, 110).

There is a close inverse relationship between lactose content and the molar sum of sodium and potassium contents of goat or other species milks (70, 109). Chloride is positively correlated with potassium and negatively with lactose, but sodium is not significantly correlated with K, Cl, and lactose. There is a close inverse relationship between lactose content and the molar sum of sodium and potassium contents of goat or other species' milks (70, 109). The major minerals in goat milk during the first seven weeks lactation showed substantial fluctuations (85). The macro minerals decreased in levels with lactation stage: Ca from 1.80–2.00 to 1.23–1.41; Mg from 0.21–0.27 to 0.10–0.13; P from 1.43–1.57 to 0.90-0.93; and Na from 0.43–0.48 to 0.30-0.37 g/l, respectively.

Potassium content (1.50–1.80 g/l) was not affected by stage of lactation, while citrate concentration in goat milk decreased during lactation. Cow milk has a more stable citrate level during lactation (70). Parity had practically no effect on mineral composition of goat milk, except for the Na level, which was 15–20% lower than in the first lactation (85). Citrate is a kind of harbinger of lactogenesis in

Table 2.28. Mineral and Vitamin Contents of Goat Milk as Compared with Those of Cow and Human Milks

Constituents	Goat	Cow	Human
	Amount in 100 g		
Mineral			
Ca (mg)	134	122	33
P (mg)	121	119	43
Mg (mg)	16	12	4
K (mg)	181	152	55
Na (mg)	41	58	15
Cl (mg)	150	100	60
S (mg)	2.89	—	—
Fe (mg)	0.07	0.08	0.20
Cu (mg)	0.05	0.06	0.06
Mn (mg)	0.032	0.02	0.07
Zn (mg)	0.56	0.53	0.38
I (mg)	0.022	0.021	0.007
Se (μg)	1.33	0.96	1.52
Vitamin			
Vitamin A (I.U.)	185	126	190
Vitamin D (I.U.)	2.3	2.0	1.4
Thiamine (mg)	0.068	0.045	0.017
Riboflavin (mg)	0.21	0.16	0.02
Niacin (mg)	0.27	0.08	0.17
Pantothenic acid (mg)	0.31	0.32	0.20
Vitamin B_6 (mg)	0.046	0.042	0.011
Folic acid (μg)	1.0	5.0	5.5
Biotin (μg)	1.5	2.0	0.4
Vitamin B_{12} (μg)	0.065	0.357	0.03
Vitamin C (mg)	1.29	0.94	5.00

Data from Posati and Orr (119), Park and Chukwu (109, 110), Jenness (59) and Haenlein and Caccese (54), Debski et al. (37).

goats (115), where its level in mammary secretion increases sharply from virtually nil to the normal 150 to 200 mg/100 ml on the day of parturition (115). The total carbon dioxide and carbonate in freshly drawn goat milk was 3.4 mM; of this CO_2, 1.9 mmoles/liter was in the form of bicarbonate ion (76).

Concentrations of trace minerals are affected by diet, breed, animals, and stages of lactation (110). Mean levels of Mn, Cu, and Fe in French-Alpine goat milk were 0.33, 5.0, and 1.7 mg/l, while Anglo-Nubian goat milk contained significantly higher levels of cu (1.36 vs 1.69 mg/l) and Zn (7.9 vs 11.9 mg/l) (110). A positive correlation was observed between levels of Co and P, K, Na, Ca, Al, and Mg in Norwegian bulk goat milk (17).

Zinc content is the greatest among the trace minerals, and Zn in goat and cow milks is greater than in human milk (110). Iron contents of goat and cow milks are significantly lower than in human milk (Table 2.28). On the other hand, goat and cow milk contain significantly greater levels of iodine than human milk, which may be important for human nutrition since iodine and thyroid hormone are closely related to the metabolic rate of physiological body functions (137).

Goat and human milk contain higher concentrations of selenium than cow milk (Table 2.25). Less than 3% of the total selenium is associated with the lipid fraction of milk. Glutathione peroxidase was higher in goat milk than in human and cow milk. Goat milk total peroxidase activity (associated with

glutathione peroxidase) was 65% as opposed to 29% for human and 27% for cow milk (37).

Goat and cow milks have an average of 12.4 and 25.9 μg/L of Mo, respectively (55). The supplementation of 1.1 mg Mo/day in the goat's diet produced 12 μg/L of Mo in milk, while 13.0 mg Mo/day elevated Mo in milk approximately 70 μg/L. It was also reported that goat, cow, and human milks contained 2.6, 1.1–2.2, 0.42 mg/L of borate, respectively (59).

2.8 Vitamins

Goat milk has a higher amount of vitamin A than cow milk. Caprine milk is whiter than bovine milk because goats convert all β-carotene into vitamin A in the milk. Goat milk supplies adequate amounts of vitamin A and niacin, and excesses of thiamin, riboflavin, and pantothenate for a human infant (Table 2.28) (47, 112). Figure 2.17 also illustrates that a human infant fed solely on goat milk is oversupplied with protein, Ca, P, vitamin A, thiamin, riboflavin, niacin, and pantothenate in relation to the FAO-WHO requirements (59). Vitamin B levels in goat and cow milks are a result of rumen synthesis, and are somewhat independent of diet (54, 84).

Goat milk, however, has a significant drawback in deficiencies of folic acid and vitamin B_{12} as compared to cow milk (32, 34, 54, 59, 111). Cow milk has five times more folate and vitamin B_{12} than goat milk, where folate is necessary for the synthesis of hemoglobin (32, 34). Vitamin B_{12} deficiency has been reportedly implicated in "goat milk anemia," which is a megaloblastic anemia in infants (112). However, the major cause of the anemia has been shown to be attributable to the folate deficiency in goat milk. Both goat and and cow milks are equally deficient in pyridoxine (B_6), vitamin C, and vitamin D, requiring these vitamins to be supplemented from other food sources (89).

It was shown that high temperature and short-time pasteurization of goat milk was the best processing method to preserve various vitamins as well as extend the shelf life of the milk (73). Losses of thiamine, riboflavin, and vitamin C were reduced if the milk was processed by HTST, flash, and UHT process than by LTLT and autoclave treatment methods (73).

3 PHYSICO-CHEMICAL CHARACTERISTICS OF GOAT MILK

3.1 Physico-Chemical Properties

There are no significant differences in the unsaponifiable matter of milk fat and acid value between goat and cow milks (Table 2.29). However, goat milk has higher iodine values than cow milk, indicating that goat milk fat contains higher unsaturated fatty acids than the cow counterpart. Saponification value is higher and refractive index is slightly

Table 2.29. Comparison of Physico-Chemical Characteristics and Micelle Structure of Goat Milk with Those of Cow Milk

Characteristics	Goat milk	Cow milk
Physico-chemical values[a]		
Unsaponifiable matter of milk fat (%)	0.41±0.02	0.41±0.02
Acid value	0.47±0.02	0.48±0.05
Iodine value	30.44±2.57	27.09±1.26
Saponification value	228.6±5.24	232.3±7.61
Reichert Meissl value	29.16±0.77	24.02±1.17
Polenske value	1.80±0.35	7.06±0.56
Refractive index	1.450±0.39	1.451±0.35
Micelle Structure[b]		
Non-centrifugal casein (% of total casein)	8.7	5.7
Average diameter (nm)	260	180
Hydration of micelle (g/g MS)	1.77	1.9
Mineralization of micelle (g/ca/100 casein)	3.6	2.9

[a]Anjaneyulu et al. (5).
[b]Remeuf and Lenoir (122).

higher in cow milk than in goat milk, whereby both indices reflect the number of carbons and saturation in the fatty acids in the milks. Analysis of the positional distribution of fatty acids in goat milk triglycerides indicates that most of the short-chain acids (C4-C8) are esterified at position *sn*-3 of the glycerol while the longer chains (C10 or greater) are at position *sn*-2, whereby triglycerides are synthesized from a pool of long-chain 1,2-diglycerides (136).

Some interesting differences are found in the Reichert Meissl value and the Polenske value between goat and cow milk (Table 2.29). Goat milk has higher Reichert Meissl value and lower Polenske value than cow milk, suggesting that goat milk fat contains higher soluble volatile fatty acids and lower insoluble volatile fatty acids than cow milk fat.

The casein content of goat milk ranges between 15.8 and 26 g/L, the proportions of NPN of the total nitrogen content between 3.1 and 13.2%, the ionized calcium levels between 0.07 and 0.19 g/L, and those of the total inorganic phosphorus between 0.45 and 1 g/L (122), where these variations are attributed to individual factors such as animal, lactation period, and sample differences (77, 112).

The relative proportions of the major components of goat casein are very much different from those of cow milk (122). Goat milk is less in α_s casein and often contains more α_{s2} casein than α_{s1} casein. Nevertheless, the latter is present in highly variable amounts depending on the individual goats (94). On the other hand, the proportions of κ casein and especially β-casein are higher in goat milk than in its cow counterpart.

3.2 Micelle Characteristics

The micelle structure of goat milk also differs from that of cow milk (Table 2.29). Caseinate micelles of goat milk contain more calcium and inorganic phosphorus, are less solvated, less heat stable, and loose β-casein more readily than bovine micelles (59). Non-centrifugal casein and the average diameter of micelles of goat milk are significantly greater than those of cow milk (122). The average mineralization level in goat milk is higher than in cow milk (Table 2.29). However, the degree of hydration in goat milk is lower, which supports the evidence of an inverse relationship between the mineralization of the micelle and its hydration (Table 2.26) (122, 130).

Goat milk contains more soluble casein than cow milk. At 20°C, goat and cow milk have 10 and 1% soluble casein; at 5°C, they have 25 and 10%, respectively (64). Low storage temperatures have a marked influence on micellar system. Cooling leads to a partial solubilization of colloidal calcium phosphate and of β-casein (99). These modifications are responsible for an alteration of cheesemaking properties of milk, especially a decrease in cheese yield. Caprine β-casein is more soluble on cooling than its bovine homolog (99).

Low casein content and probably other characteristics as α_s-casein proportions and micellular size are responsible for the weak texture of caprine yogurt. Heat stability of goat milk is considerably lower than for bovine milk. High ionic calcium content and low micellular solvation in caprine milk may contribute to heat instability (121).

3.3 Relationship Between Physico-Chemical Properties and Rennetability

The renneting time and the maximum firmness of the gel are found on a scale of 1 to 4, the setting speed on a scale of 1 to 9 (122). The weight of the serum retained in the centrifuged curd is subject to smaller variations but reaches between 1 and 2. The maximum firmness of the gel of goat milk is on average clearly lower, and the gel from goat milk with an equal casein content is not as firm as cow milk (132). Renneting time for goat milk is shorter than for cow milk, and the weak consistency of the gel explains the mediocre cheese suitability levels for goat milk (112, 122). Significant correlations exist between the casein content and the proportion of α_{s1}-casein, between the casein content and the level of colloidal calcium and inorganic phosphorus, and between the degree of hydration of the micelles and their mineralization. The renneting time is influenced mainly by the pH value of the milk (122).

The casein concentration of the milk has a strong effect on rheological properties of the rennet gel, its setting speed, and its maximum firmness (122). There is a positive correlation between the casein content and the quantity of serum retained in the centrifuged curd, as the milks richer in casein levels yield a lower quantity of serum in goat, cow, and sheep milks (132). There are also significant correlations between the levels of colloidal Ca and inorganic

phosphorus and the firmness of the gel or its setting speed (132).

4 NUTRITIONAL SIGNIFICANCE OF GOAT MILK

Goat milk has significant nutritional values in human nutrition as an alternative food for children and sick people, and also has higher nutrient bioavailability. In a nutrition trial involving 38 children (20 girls and 18 boys) aged 6 to 13 years, Mack (79) fed one-half of them 0.946 liter of goat milk and the other half 0.946 liter of cow milk daily for five months. She observed that children in the goat milk group surpassed those on cow milk in weight gain, stature, skeletal mineralization, bone density, blood plasma vitamin A, calcium, thiamine, riboflavin, niacin, and hemoglobin concentrations. Statistical differences were minimal for blood hemoglobin, various other biochemical and structural measurements between the two groups.

Most milks, including human milk, are deficient in iron contents (Table 2.28; Figure 2.18). In an iron bioavailability study of goat and cow milks using anemic rats, Park et al. (111) reported that rats fed on goat milk grew significantly better, had higher liver weights, hemoglobin iron gain, and higher iron absorption rates than those on cow milk. The anemic rats receiving the whole goat milk diet showed significantly greater hemoglobin regeneration efficiencies than those on the cow milk diet (Figure 2.19). Goat milk has been blamed for the development of "goat milk anemia" due to the deficiency of folic acid in the milk (32, 34, 51, 97, 111). "Goat milk anemia" was the designation given to a macrocytic-hyperchromic megaloblastic anemia, which was originally observed in infants fed a diet of goat milk in Europe during the 1920s and 1930s (51). This anemia responded more readily to therapy with folate than to vitamin B_{12}, where folate is necessary for synthesis of hemoglobin, and where the two vitamins are interdependent on their metabolic functions and pathways in the body tissues. Therefore, supplementation of folate to goat milk is essentially recommended before feeding it to infants. Goat milk, just as cow milk, is also cautioned to be diluted to reduce

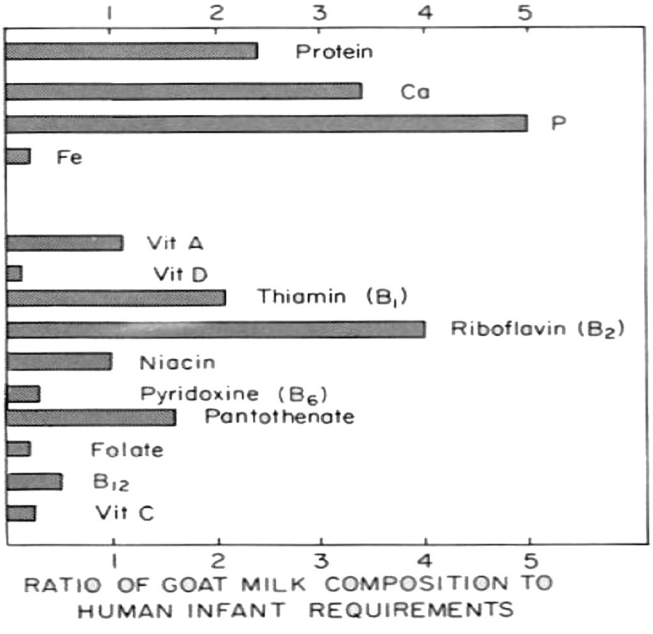

Figure 2.18. Nutrients in goat milk in relation to requirements of human infants. Adapted from Jenness (59).

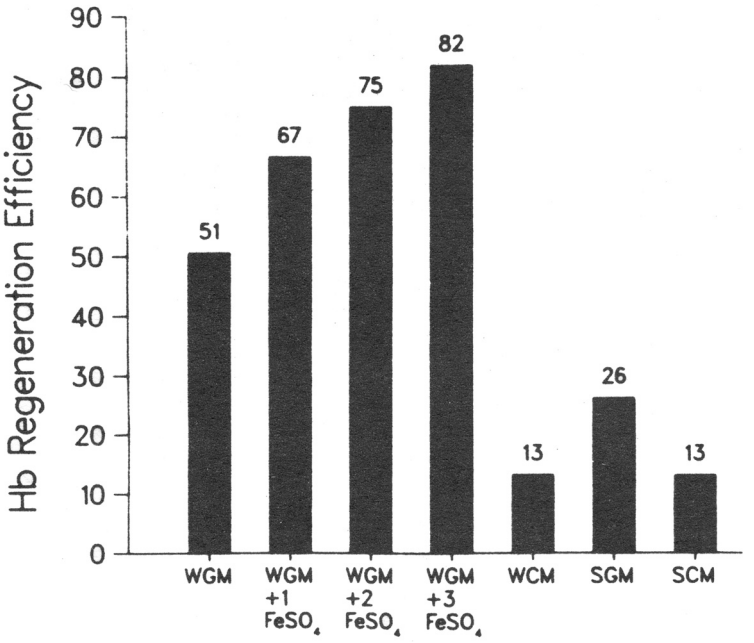

Figure 2.19. Hemoglobin regeneration efficiencies (HRE) of whole goat milk (WGM) diet, whole goat milk diet supplemented with 50, 100, or 200 ppm ferrous sulfate, whole cow milk (WCM) diet, skim goat milk diet, or skim cow milk diet fed to anemic growing rats for 10 days. HRE for WGM is significantly greater than that for WCM ($P < .01$), and SGM is greater than the SCM group $P < .05$). Adapted from Park (111).

protein level, and to be fortified with carbohydrate and certain vitamins before feeding to babies, especially under six months of age.

Some possible explanations of the nutritional advantages of goat milk over cow milk come not from its protein or mineral differences but from another overlooked component in goat milk, the lipids, more specifically the fatty acids within the lipids (9, 53). Owing to the species-specific characteristics (high amounts of short- and medium-chain fatty acids) in goat milk fat, it has been suggested that goat milk fat may have at least three significant contributions to human nutrition: (i) goat milk fat may be more rapidly digested than cow milk because lipase attacks ester linkages of short- or medium-chain fatty acids more easily than those of longer chains (27, 59, 108); (ii) these fatty acids exhibit beneficial effects on cholesterol metabolism such as hypocholesterolemic action on tissues and blood via inhibition of cholesterol deposition and dissolution of cholesterol in gallstones (49, 65); and (iii) they also have been therapeutically used for treatment of various cases of malabsorption patients suffering from steatorrhea, chyluria, hyperlipoproteinemia, and in cases of intestinal resection, coronary bypass, childhood epilepsy, premature infant feeding, cystic fibrosis, and gallstones (38, 49, 53, 58, 83, 98, 108, 135).

Fat in human milk is absorbed more readily by infants than that of cow milk (46). This is probably due to the difference in arrangement of fatty acids in the triglycerides (59). It was shown that palmitic acid (C16:0) is primarily esterified in the 2-position of the triglycerides in human milk fat, whereas the C16:0 acid is distributed nearly equally among the three positions in cow milk fat (46, 59). If palmitic acid is located in the 2-position, the digestive and absorptive processes are shown to be greatly en-

hanced. Due to the similarity of distribution of fatty acids over the positions in the triglycerides in goat and cow milks, the efficiencies of absorption of both milk fats are expected to be similar.

Several reports (27, 39, 54, 108) also suggested that goat milk proteins may be digested more efficiently than cow milk proteins because the former forms smaller, softer, and more friable curds during acidification in the stomach, which would provide stomach proteases with easier digestive actions (39, 108).

Goat milk is reported to have greater buffering capacity, which would be beneficial for treatment of stomach ulcer (39, 54, 104, 105, 107). Nubian goat milk contained significantly higher levels of major buffering entities, such as proteins, nonprotein N, and phosphate (P_2O_5), than cow milks (Holstein and Jersey) (Table 2.23) (104, 105), which appears to be important in human nutrition. Goat milk has been recommended as an ideal substitute for patients suffering from various allergies against cow milk and other food sources (108, 125, 134, 141), which is also highly important for human nutrition and health. Goat milk is a viable dairy option to fulfill the nutritional needs of infants, children, and adults, especially in developing countries.

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2.3 Goat Milk Products: Types of Products, Manufacturing Technology, Chemical Composition, and Marketing

Young W. Park and Mingruo Guo

1 INTRODUCTION

Goat milk has played a very important role in the economic viability of many developing countries of the world, as well as in the Mediterranean, Middle East, and eastern European countries, through its utilization for manufacture of cheeses and other products (48, 56). In addition to the economic, nutritional, and medical significance of goat milk in many developing countries, goat milk products also have recently gained increasing popularity among certain ethnic groups, health food lovers, gourmet lovers, goat farmers, and cheese enthusiasts in the United States (56, 78).

Worldwide average milk production from goats is approximately 50 kg per doe per lactation if one-third of all goats have milk producing capability (24). A large-scale expansion and industrialization of the dairy goat sector in many countries is difficult due to the low level of milk production, coupled with inadequate technological means and the small range of products made from the milk (48).

A variety of products may be manufactured from goat milk, including fluid products (low fat, fortified, or flavored), fermented products such as cheese, buttermilk or yogurt, frozen products such as ice cream or frozen yogurt, or butter, condensed, and dried products (67, 82). However, cheese is traditionally the main goat milk product produced and consumed in large quantities around the world. Significant amounts of fluid, evaporated and powdered goat milk products have been marketed in the United States and New Zealand for the past several decades. Although literatures have been available on goat cheeses, research data on other manufactured dairy goat products has been scarce (67, 82).

Producing high-quality raw milk is of paramount importance for successful production and marketing of dairy goat products. They must be safe to consume free of pathogenic bacteria, antibiotic, insecticide, and herbicide compounds. They should have good and no objectionable flavor, be free of spoilage bacteria, and contain legal minimum limits of all nutrients (66).

2 PRODUCTION OF QUALITY GOAT MILK AND ITS PRODUCTS

Fresh and normal goat milk from healthy and properly fed and milked animals is a white, opaque liquid with a slightly sweet taste that has practically no odor (64). Production of quality goat milk should start at every farm level because flavor and quality of the milk cannot be improved later in the processing stage. The basic principle is that the better the milk, the better the processed products.

Milk drawn from the lacteal glands is highly perishable and easily affected negatively by improper handling from many factors such as feeding, handling of animals prior to and during milking, handling of the milk during and after milking, cooling and transportation, pasteurization, processing, packaging, and processing utensils (38, 91). Quality of milk largely depends on the farm producer as well as workers at dairy processing plants.

Milk is an excellent culture medium for bacteria and is used by nature easily, and thus is rapidly liable to deterioration. A clean milking environment is just as important as the milk composition. A good-quality milk must contain no pathogens (organisms that are harmful to humans or animals) or organisms likely to damage the cheese, nor such foreign substances as antibiotics, antiseptics, or pesticide residues (38, 55, 64, 66). Furthermore, basic bacterial flora should not be too numerous.

To safeguard quality milk production, at least five major parameters are routinely monitored by various agencies in commercial milk production channels (38) as follows: (i) nutritional constituents in

milk; (ii) somatic cell counts as related to mastitis; (iii) bacteria counts as related to sanitary practices; (iv) adulteration and pesticide residue contents; and (v) flavor, taste, appearance, and temperature.

The "goaty" flavor can be avoided with good management, healthy lactating does, and sanitary milking procedures. Rancidity, or the induction of "goaty" smell, involves a chemical or mechanical reaction. If the fat globule membrane ruptures, it is exposed to the lipolytic enzyme, lipase. The lipases react with the fat molecule to yield free fatty acids. The short-chain fatty acids, capric, caproic, and caprylic acids, make up 20 to 25% of all free fatty acids in goat milk, which is considered to give goat milk its characteristic, goaty and rancid tastes.

Off-flavor in goat milk can be attributed to feeds, weeds, forages, chemicals, building materials, colostrum, estrus, mastitic milk, filthy utensils and strainer, unclean milking equipment, slow cooling, odors from bucks, barn and/or milk room. Feeding odorous feeds at least two hours before milking is recommended.

Good management of the entire farm system leads to good-quality milk. It should be followed by the recommended milking practices in a daily routine: Maintain functioning and sanitary equipment, have healthy animals, and use recommended detergent, acid, and sanitizers for cleaning and milking equipment.

3 REGULATORY REQUIREMENTS FOR QUALITY GOAT MILK PRODUCTS

The regulations for all aspects of production, processing, and marketing milk are described in the federal government (FDA) publication, called the *Grade A Pasteurized Milk Ordinance* (PMO). Each state health department establishes its minimum regulations from these standards for Grade A milk (91). Some states in the United States may adopt more stringent standards than the PMO regulations. The state of Oregon, for example, has set its somatic cell count (SCC) standard at 750,000 cells per ml, whereas the PMO standard is one million per ml.

Although goat milk contains naturally higher SCC than cow milk due to the apocrine secretory process of goats, the same regulations are enforced for both species milks. It is common to find high SCC in goat milk when actual numbers of leucocytes are relatively low (51, 87). Goat producers on the National Conference of Interstate Milk Shipments have actively pursued the problem of SCC legal thresholds (38, 51).

Many U.S. states have an Annotated Code, whereby a person shall obtain a permit from the state regulatory agency before the person may: (a) bring, send, or receive a milk product into the State for sale; (b) offer a milk product for sale; (c) give a milk product away; or (d) store a milk product (91). Specific permits are required for milk producers, milk processors, milk haulers, receiving stations, and transfer stations.

All Grade A raw milk for pasteurization and all Grade A pasteurized milk and milk products shall be produced, processed, and pasteurized to conform with the specific PMO codes. An example of regulations for the chemical, bacteriological, temperature standards, and sanitation requirements is described in Table 2.30 (15). Each U.S. state including the leading state California may have different standards for raw and Grade A pasteurized milk products while also conforming with the PMO codes. The quality control guidelines for microbiological standards in dairy foods are shown in Table 2.31 (35).

There are at least four important requirements for Grade A–quality goat milk. Those are: (i) safe to drink; (ii) good flavor; (iii) relatively free from spoilage bacteria and somatic or body cells; and (iv) composition (66). For safe milk, it must be free of pathogenic bacteria, antibiotic, insecticide, and herbicide compounds. Pasteurization is the most important practice to kill pathogens for assurance of safe milk, although it doesn't remove other contaminants. Good flavor of goat milk comes from a clean, healthy, properly managed goat herd; the ideal flavor is slightly sweet and slightly salty with complete absence of strong odors and flavors. Oxidized flavor is caused by nutritional imbalances or exposure to light. Rancid "goaty" flavor develops when the fat is partially disintegrated by enzyme action. Both are controlled by pasteurization temperature and protection of the milk from sunlight and UV light.

SCC has been accepted as a quantitative index for mastitic conditions or degree of glandular irritation in the mammary gland (87, 96). Milk with high somatic or body cells and spoilage bacteria results in

Table 2.30. Chemical, Bateriological, and Temperature Standards[a]

Grade A raw milk for pasteurization:	
Temperature	Cooled to 45° F (7° C) or less within two hours after milking, provided that the blend temperature after the first and subsequent milkings does not exceed 50° F (10° C).
Bacterial limits	Individual producer milk not to exceed 100,000 per ml prior to commingling with other producer milk. Not to exceed 300,000 per ml as commingled milk prior to pasteurization.
Antibiotics	Individual producer milk: No detectable zone with the *Bacillus subtilies* method or equivalent. Commingled milk: No detectable zone by the *Sarcina lutea* Cylinder Plate Method or equivalent.
Somatic cell count	Individual producer milk. Not to exceed 1,500,000 per ml.
Grade A pasteurized milk and milk products:	
Temperature	Cooled to 45° F (7° C) or less and maintained thereat.
Bacterial limits	20,000 per ml.*
Coliform	Not to exceed 10 per ml: Provided that, in the case of bulk milk transport tank shipments, shall not exceed 100 per ml.
Phosphatase	Less than 1 microgram per ml by the Scharer Rapid Method or equivalent.
Antibiotics	No detectable zone by the *Sarcina lutea* Cylinder Plate Method or equivalent.

*Not applicable to cultured products.

[a]Data from Colorado Department of Health (15). Colorado Grade A Pasteurized Fluid Milk and Milk Products Regulations, Denver, CO.

poor-quality products. SCC can be determined by various tests including the Wisconsin Mastitis Test and the California Masistis Test. For the fluid milk, standard milk composition refers to the levels of major nutrients such as fat, protein, lactose, and minerals. The Public Health Service, FDA, defines milk to contain a minimum of 3.25% fat and 8.25% milk solids not-fat, which is the sum of the protein, lactose, and minerals. Although this FDA standard may refer to cow milk, the same definition and regulations have been applied to goat milk.

4 TYPES OF DAIRY GOAT PRODUCTS AND THEIR MANUFACTURING TECHNOLOGIES

Many products can be manufactured from goat milk, including fluid, cultured, frozen, and dehydrated products. All manufactured products have to be made from Grade A goat milk. Standardization of milk composition, especially fat content, is essential to assure the legality of the finished product as well as its uniformity.

4.1 Fluid Goat Milk

4.1.1 General Trend and Marketing of Fluid Goat Milk

Fluid goat milk has been processed, packaged, and marketed in the United States and other countries, although little research has been documented on the product. In the United States, a beverage milk is processed with low fat milk content to meet consumer demands, where composition of the milk is adjusted to 2% fat and 10.5% milk solids-not-fat (MSNF), before being pasteurized (HTST or UHT), homogenized, and packaged in 946 ml containers (67).

Due to the smaller fat globule sizes in the goat milk, it is considered naturally homogenized. Pasteurized and homogenized goat milk products have been available in many states in the U.S. markets, including 2% fat and whole milk with or without fortification of vitamins A and D in a variety of packaging. Chocolate-flavored goat milk is also on the market in the United States (Figure 2.20). In addition, other types of dairy goat products, including goat cheeses, yogurt, and evaporated and powdered

Table 2.31. Quality Control Guidelines for Microbiological Standards in Dairy Foods

Product	Standard plate count	Coliform	Psychrotrophic SPC after 5 d at 70°	Yeast and mold	Staphylococci	Salmonella
Raw milk- Bulk takers	<1,000–50,000	<100–<1,000	<10,000–<100,000	—	—	—
Comingled Raw milk at Pasteurizer	<50,000–30,000	<100–<1,000	100,000–<800,000	—	<5,000–<100,000	—
Pasteurized Grade A fluid Products	<1,000–<10,000	<1–<5	<20,000–<69,000	—	<1	<1
Ice Cream	<20,000–50,000	<1–<10	<50		<1	<1
Cottage Cheese (dry)	<1,000–20,000	<1–<5	<10,000–<100,000	<5–<10	<1	<1
Butter	<5,000–<20,000		<50,000	<5–<10	<1	<1
Milk Powder	<20,000–<50,000	NS	NS	<10	<1	<1

Adapted from Guthrie (35).

Figure 2.20. Liquid goat milk products manufactured by Oak Knoll Dairy of Vermont, Vermont, U.S.A. Photo by M.R. Guo.

Figure 2.21. Examples of various commercial goat milk products marketed in the U.S., which include fluid milk, cheeses, yogurt, and powdered and evaporated goat milk products. Photo by Y. W. Park.

milk products, have been marketed in the United States (Figure 2.21), and large volumes of goat milk products are imported from foreign countries.

Beverage fluid milk is delivered to consumers after various heat treatments, packaging, and distribution steps. The properties of fluid milk that require the greatest attention are safety to the consumer, shelf life, and flavor. The market beverage milk has to be free of contaminants that are harmful to the consumer. Those contaminants are: (i) pathogenic microorganisms; (ii) toxicants taken up by the milking animals; (iii) antibiotics used to treat the goats; (iv) disinfectants used on the farm or in the dairy plant; (v) bacterial toxins formed during and after milking as well as during keeping of the milk; and (vi) radionuclides and so on. (110).

4.1.2 Manufacturing Processes of Fluid Goat Milk

The basic principle of manufacturing technology for fluid goat milk is similar to that of the cow milk counterpart. The major steps for manufacturing fluid goat milk would be receiving, filtering, standardizing, pasteurizing, homogenizing, cooling, packaging, storing, and distributing. An example for the basic manufacturing steps of pasteurized fluid goat milk products used at the Oak Knoll Dairy, Inc. Windsor, Vermont, is shown in Figure 2.22. The standard procedure for a commercial dairy plant for cow milk is shown in Figure 2.23, which would be equally applicable to goat milk manufacture with some modification in operation, depending upon the

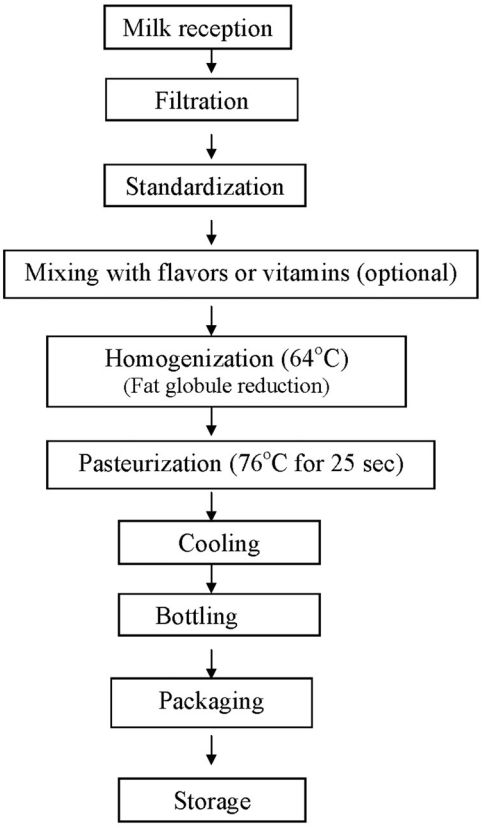

Figure 2.22. Basic flowchart of production of the pasteurized fluid goat milk products. Oak Knoll Dairy, Inc., Windsor, Vermont; courtesy of Mr. George Redick, Owner.

types of products produced, location, size of plant, preference of the facility owner, and availability of financial capitals.

4.1.2.1 Filtration (Clarification) After milk is received from the individual animal, bulk tank, or milk transporting truck, the milk is next filtered for removal of extraneous materials, which are sediment, body cells from the udder, and some bacteria. For a farmstead operation, the milk can be manually poured through the filtering device (that is, straining cloths) into milk cans (Figure 2.24). In a large-scale commercial goat dairy plant, milk can also be passed through a mechanical milk filter, shown in Figure 2.25. Removal of impurities can be effectively carried out in a mechanical clarifier, which can facilitate distributing the milk in thin layers over conical disks that revolve at high speed (Figure 2.26). Clarification routinely used in large-scale commercial cow dairy plants is by no means intended to rid the milk completely of bacteria, and the clarifier was not designed for this purpose (106). A special machine known as a Bactofuge, operating under much greater centrifugal force, has been designed for a high degree of bacterial removal. The filtered or clarified milk is now ready for pasteurization if it is to be processed as market milk.

4.1.2.2 Pasteurization Pasteurization is performed according to the U.S. FDA standards (Table 2.32) or EU standard. In general, manual and batch pasteurization of milk is performed at 145°F (62.8°C) for 30 minutes. Georgia Small Ruminant Research and Extension Center, Fort Valley State University, GA, as well as a couple of recently licensed grade A goat dairies in Georgia use the batch pasteurization method, and the fluid milk is sold whenever it is available during the milk production season and/or extra milk beyond the amount used for cheese processing. Many other states, including Texas, Wisconsin, California, New York, Pennsylvania, and Vermont, would use the low-temperature long-time pasteurization method if the processing plant were not equipped with automated pasteurization facilities. However, if the processing plant is equipped with automated processing facilities, it can use a higher-temperature and short-time processing method. An example of the UHT processing plant designed for cow milk is shown in

Table 2.32. Milk Pasteurization Methods Recognized by U.S. Public Health Service and Food and Drug Administration (FDA)

Pasteurization temperature	Time	Reference method
145° F (62.8° C)	30 minutes	LTLT
161° F (71.7° C)	15 seconds	STHT
191° F (88° C)	1 second	UHT
194° F (89° C)	0.5 second	
201° F (94° C)	0.1 second	
204° F (96° C)	0.05 second	
212° F (100°C)	0.01 second	

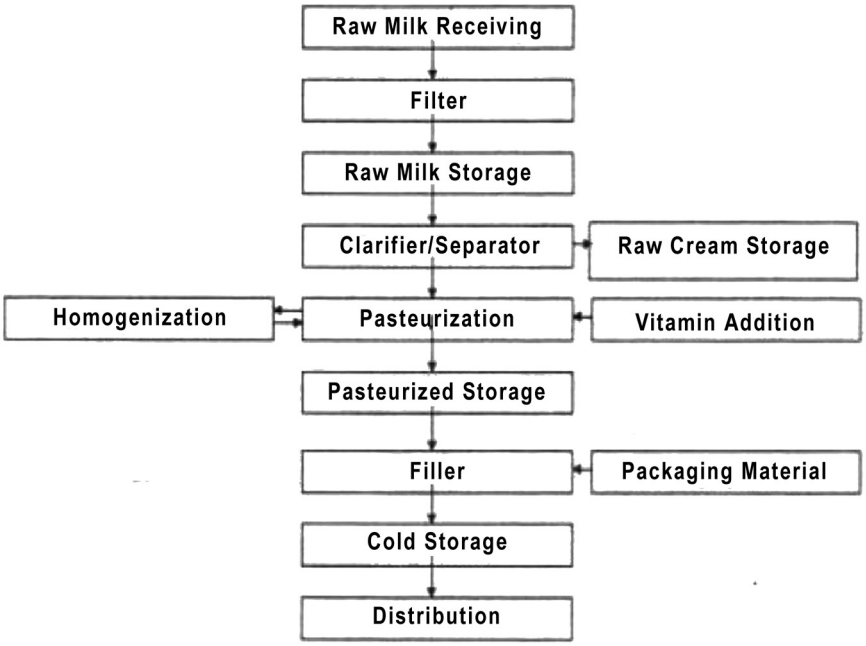

Figure 2.23. General flowchart for commercial fluid milk processing procedures. Adapted from FDA Workshop, St. Louis, MO, 2000.

Figure 2.24. Filtration of farmstead milk for further processing. Adapted from Le Jaouen (64).

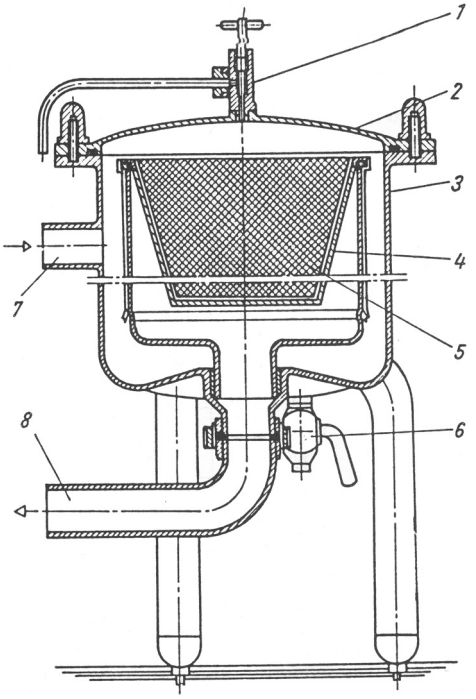

Figure 2.25. Milk filter: (1) Deaeration valve, (2) Cover, (3) Filter container, (4) Filter insert, (5) Nylon bag, (6) Discharge valve, (7) Milk inlet, (8) Milk outlet. Adapted from E. Spreer (106).

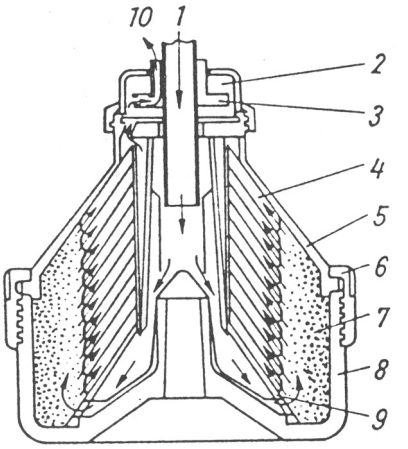

Figure 2.26. Bowl of clarifier. Adapted from E. Spreer (106). (1) Milk inlet by central pipe, (2) Paring chamber, (3) Grip, (4) Bowl assembly, (5) Bowl cover, (6) Closing ring, (7) Sludge area, (8) Bowl bottom part, (9) Distributor, (10) Outlet for clarified milk.

Figure 2.27. The HTST processing facility may have similar layout for the equipment. This processing facility could be equally used for goat milk processing if there were continuous large volumes of milk supplied from dairy goat farms.

4.1.2.3 Homogenization The farmstead goat milk processing may skip the homogenization step because it has much smaller fat globules compared to cow milk and is considered to be naturally homogenized milk. However, commercial goat dairies may adopt homogenization as a routine processing step, as in cow dairy processing plants. When homogenization is included in the processing, lower pressures may be applied due to the relatively smaller size of fat globules in goat milk. Milk is homogenized after pasteurization, or beforehand if the milk was warmed.

Milk and cream have countless fat globules that vary from 0.1 to 20 μm in diameter. The purpose of homogenization is to disintegrate the fat globules and clumps to such small size that they will no longer rise to the top of the milk as a distinct layer in time before the milk is normally consumed. The milk first undergoes homogenization and then is pushed into the second stage, during which additional homogenization takes place (106). New surface layers of milk fat globules are formed by homogenization (Figure 2.28). They are composed predominantly of micellar casein and serum protein (110). The subdivision and uniform dispersion of fat gives homogenized milk a richer taste and whiter color, as well as greater whitening power when added to coffee, than does nonhomogenized milk. In one type of homogenizer valve assembly, large fat globules in milk entering at the bottom are sheared as they are pumped under pressure through a tortuous path. They emerge at the top about one-tenth of their original diameter.

Pasteurization, homogenization, and cooling of the milk are followed by bottling or containerization

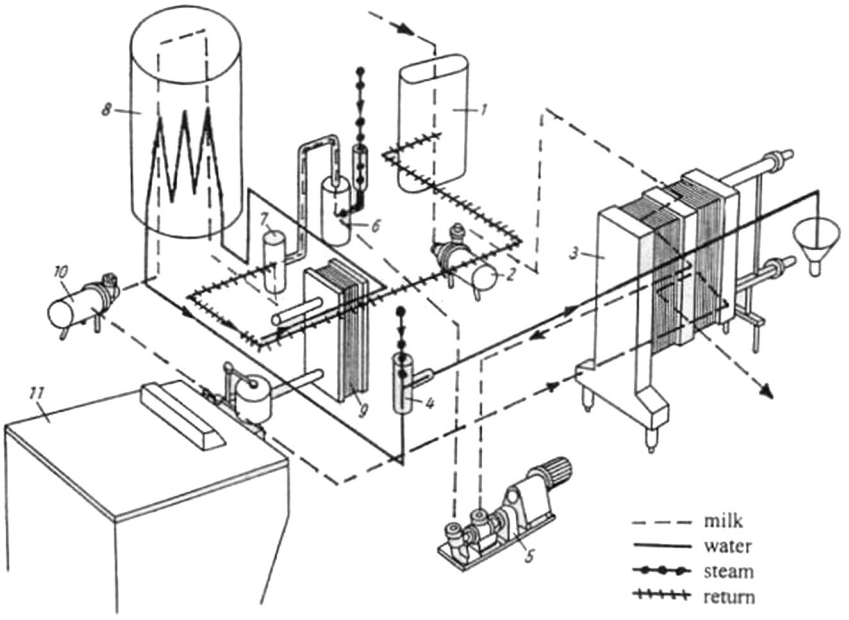

Figure 2.27. Ultra-high heat installation with direct type VT1. (1) Buffer tank with floating device, (2) Centrifugal pump, (3) Plate heat exchanger, (4) Steam injection preheater, (5) High-pressure pump, (6) Steam injection, (7) Switching valve, (8) Vacuum tank, (9) Return flow plate heat exchanger, (10) Aseptic centrifugal pump, (11) Aseptic homogenizer. Adapted from E. Spreer (106).

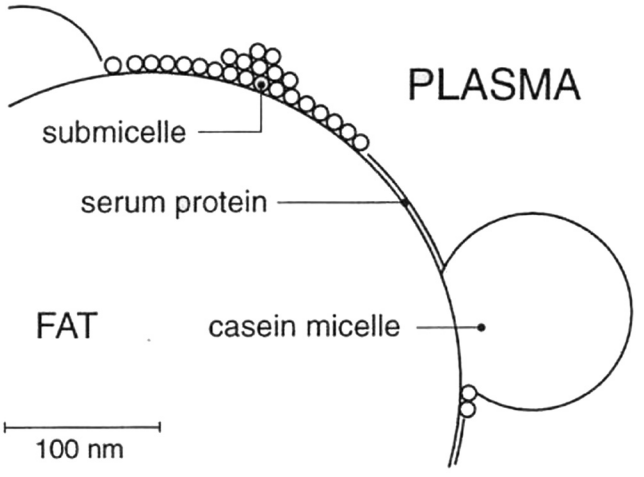

Figure 2.28. Formation of new surface layer of fat globules during homogenization. Highly schematic. Adapted from P. Walstra and R. Jenness, In: Dairy Chemistry and Physics, 1984.

in paper or plastic cartons or other types of packages. This processed and packaged fluid milk is then delivered in refrigerated trucks to retail and other outlets for marketing.

4.1.2.4 Cream Separation Cream separation is optional in goat milk, and goat milk cream is seldom available in commercial markets. The main purpose of cream separation is to standardize milk fat and to manufacture butter, ice cream and other dairy ingredients. Goat milk butter or ice cream is not marketed in large quantities in any part of the world. Little information has been available on the separation technology and utilization of goat milk cream.

Cream is made by separating skim milk from whole milk, resulting in a fat-in-water emulsion enriched with milk fat, which has been processed by an accepted heat treatment process (106). Cow milk cream is sometimes homogenized and eventually acidified. The separation is made in a centrifugal cream separator, which looks and functions quite like a milk clarifier (Figure 2.26), but has separate discharge nozzles for cream and skim milk. The skim milk's having a heavier density than the whole milk or cream is driven by centrifugal force to the outside of the bowl, while the lighter cream moves toward the center of the bowl. Skim milk may be used directly as a beverage or it may be concentrated or dried for use in manufactured foods and animal feeds. The separated cream may be used directly or it may be frozen, concentrated, dried, or further separated to produce butter oil and serum solids.

4.1.3 Heat Stability of Goat Milk During Processing

Most researchers who studied heat stability of goat milk indicated great sensitivity toward heat treatment (27, 73) and concluded that goat milk has an inability to withstand UHT treatment (114). However, a great variability in heat stability of individual milk was also observed. Heat coagulation times at 140°C were between 0.5 and 23.4 min (27), while great variations of heat coagulation temperatures (that is, temperature at which milk does not resist more than 1 min) of individual goat milk samples were from 118°C to more than 140°C (99).

This variability of heat instability of goat milk was postulated by the difference in the pH threshold between the two milks, where the threshold of goat milk is around 6.9 while that of cow milk is 6.5–6.6 (114). Goat milk at its original pH of 6.7 shows a lower heat stability compared to cow milk. The differences between micellar characteristics or salt equilibria of the two milks also might be attributable to the lower heat stability of goat milk. This explanation is based on the fact that the higher ionic calcium content and lower micelle solvation could contribute to the instability of goat milk toward heat treatment (99, 114). Several methods, including pH adjustment, addition of a calcium sequestrant, and preheating of milk, were proposed to improve heat stability of goat milk and to sustain UHT treatments for goat milk pasteurization (99, 114). Nevertheless, the problem of stability in high-temperature treated goat milk has not been completely resolved due to the rapid destabilization and flavor alteration of UHT-processed fluid goat milk.

4.2 Goat Milk Cheeses

4.2.1 Origin of Goat Milk Cheese

Goat milk cheese was originated in Mesopotamia. The milk was probably made into soft cheese first and then hard and ripened cheeses later. Caprine milk cheeses were developed later in the Mediterranean basin countries, such as Turkey, Greece, Syria, Israel, Iraq, and Iran (56). Many of these countries emerged as very large producers, consumers, and major exporters of various types of goat and sheep milk cheeses.

Greece became dominant in feta cheese production from sheep and goat milks. France, however, exceeded Greece in total goat cheese production with its early farmstead cheesemaking. France nowadays offers the best in goat milk cheeses, many of which are surface ripened. France produces many exotic types of goat cheeses, including Crottin du Chavignol, Les Pyramides, Sainte Maure, Chabis, and Chabicou (56). Other successful goat milk cheese producing countries are Norway, Spain, and Italy.

4.2.2 Interest in Goat Milk Cheeses in the United States

In the United States, no significant attention was given to production of commercial goat cheese until 1980 (80). The total volume of goat cheese produced by licensed dairies in the United States in 1980 was

about 90 metric tons, and 31 metric tons of French goat cheese was sold in the same year (52).

Goat milk cheese has gradually gained popularity among certain ethnic groups, health food lovers, and private goat farmers in the United States. Moreover, the continued shift in consumer tastes to "exotic" foreign and specialty cheeses has led to the increased volume of goat cheese importation to the United States. (78). In 1988, the amount of imported goat cheese from France alone increased to 447 metric tons, which comprised approximately 80% of the total imported caprine cheeses (9).

4.2.3 Diversity of Goat Milk Cheese Varieties

Large numbers and many different varieties of goat milk cheeses are produced worldwide, depending on diversity of locality, milk composition, and manufacturing techniques. Goat cheese would be expected to vary in composition due to the high variation in the seasonal composition of milk, modifications of manufacturing procedures, and multitude of aging time and conditions (29, 67, 78). Much of the varietal difference among cheeses is attributed to the nature of physical and chemical changes during ripening (28, 61), which are influenced by the cultures, chemicals, or flavor ingredients added to the curd during manufacturing (55, 61, 67, 78).

The Agricultural Handbook No. 54 of the USDA (101) describes over 400 varieties of goat cheeses and lists over 800 names of cheeses, made from goat milk or combinations of goat with other species milk such as cow, ewe, or buffalo (78).

The manufacture of goat cheese is referred to as a "cottage industry." A goat cheese study showed that 20 out of 30 varieties investigated were very high– or high-moisture cheeses, suggesting that slow coagulation is the major mode of fabrication (78). The cheese varieties were categorized into six types; three plain cheese—soft, semi-soft, and hard—and three spice cheeses—pepper, garlic, and herb. One third of these commercial goat cheeses were spice-added varieties. The spice additives were either blended directly into the cheese curd or rolled over the outlayer of cheeses. Herbs or chives, as well as caraway, dill, or cumin seeds, may be pressed on to the surface of cheeses (80). The vast majority of goat cheeses are of the soft-body type, and almost all French goat cheeses are of the natural drainage type associated with slow coagulation, as shown in Table 2.33 (64); Figure 2.29 shows examples of high-quality goat cheeses.

Figure 2.29. Different varieties of high-quality French soft goat milk cheeses. Source: Goat milk cheese plant, Poitiers, France.

Most goat cheese varieties, which are consumed fresh, are set by an acid (hydrochloric, lactic, vinegar, lemon, lime, and so on) coagulation process, whereas cheese varieties consumed after ripening are generally made by the enzyme (rennet, chymosin) setting process. There are numerous references to specific varieties of goat milk cheeses and to those made from a mixture of goat and ewe milk, such as Laruns, Peroil, Cabroles, Lightvan, Bryndza, Bulgarian, Akavi, Cachcaval, Canestrano, Canniotta, Gjeotst, and Feta (55).

4.2.4 Lack of Standards for Goat Cheese Classification

The classification of goat cheeses on the basis of moisture content has not been well established, and few standards are available. Even for cow cheeses, formal classifications based on rheology or softness and hardness of body use no objective measurements (55). Based on moisture content, the majority of goat cheeses evaluated in a recent study belonged to the soft cheese category (78).

Cow cheeses are defined as hard, semi-soft, and soft with the respective ranges of moisture, 30 to 40%, 39 to 50%, and 50 to 75% (111). However,

Table 2.33. Classification of French Goat Cheeses

		Rind ripened cheeses		Mold ripened cheeses	
	Fresh cheeses	Dried rind	Ash coated rind	External mold	Internal mold
Slow coagulation (15–24 hours)		Banon* Crottin de Chavignol* Maconnais Bouton de Culotte Briques du Forez Cabecou* Cabrion du Beaujolais Cachat Pigouille Rigotte*	Selles-sur-Cher* Valencay* Washed Rind Calenzana	Chabicou* Charollais Couhe-Verac Gien Levrous Lusignan Pave de Tuoraine Pouillgny Saint-Pierre Picodon* Rogeret Saint-Maixent Saint-Maure* Velencay* Vezelay Tournon Saint-Martin	
Rapid coagulation (30 minutes to 1 hour 30 minutes)	Brousse Fromaget Mato	Saint-Felicien Tomme de Montagne Sartenais		Niolo Chevre en boite (type Camembert) Chevroton Mont-d-Or Chevrotin des Aravis Chevrotin des Bauges Tomme de Chevre	Bleus de Chevre Persille des Aravis Persilles du Mont-Cenis
Whey cheeses (Brucciu, Serac, Brousse)					

*Most important varieties.
Adapted from Le Jaouen (64).

Kosikowski (55) pointed out that a classification based on moisture is scarcely adequate because it tells little about the cheese. The author classified natural cheeses as very high, high, medium, and low moisture, with the ranges of moisture as follows: 55–80, 45–55, 34–45, and 13–34%, respectively. Classification of goat cheeses is more difficult than its cow counterparts, because the former has much more diversified varieties in moisture, texture, and composition with different manufacturing procedures and localities compared to the latter.

4.2.5 Legality of Cheese Variety

Legal definition of a specific cheese is important for consumers, producers, and regulatory agencies. In certain countries, cheeses can be made from a mixed or blended milk of goats with other species such as ewe, cow, and buffalo milks. In Spain, Cyprus, and Greece, cheeses can be made from legally blended goat and sheep milks. Queso de Mezela and Saint Marcellin in Spain are cheeses made from such blended milks.

In the United States, federal regulations prohibit making cheese from such mixtures. Sheep milk, by law, is the sole source of Roquefort cheese, made for centuries in southern France. Adulteration of this milk is considered illegal. In Norway, where the most desirable whey cheese, Gjetost, is made from goat milk, supplementation with cow milk is illegal.

The mixing of goat milk with other milks and identification of products made from such mixtures is a problem in the manufacture of goat cheese. Mixing milks seems to be fairly common in certain countries as a means of extending the supply of goat milk and of reducing the cost of the finished products. The production of mixed cheese, wrongly called Tipo Manchego cheese, is a genuine invention of the Spanish cheese industries, aiming to maintain their activity throughout the year (29). There are two kinds of mixed cheese, that made of sheep milk and cow milk and that made of mixtures of sheep, goat, and cow milks.

4.2.6 Manufacturing Technology of Goat Milk Cheeses

4.2.6.1 Preparation of Goat Milk for Cheese Manufacture Because a good cheese is made only from good-quality milk, Le Jaouen (64) described that good cheese-making milk must be quality milk and must meet the following criteria: (i) it must be free of any visible impurity; (ii) it must not present any abnormal taste or odor; (iii) its acidity must be in the vicinity of or only slightly higher than that of milking time, unless it has been subject to a ripening period in which the lactic acid producing bacteria have been allowed a period of time to acidify the milk; (iv) the naturally occurring lactic acid–producing bacteria and or yeasts or the cheese starter culture bacteria that can be added to the milk must be able to survive and reproduce to the proper numbers in the milk; (v) the milk must contain no foreign substances such as antibiotics, antiseptics, cleaning products, and so on; and (vi) the milk must not be contaminated by either pathogenic microorganisms or by microorganisms that may prove undesirable for the production of cheese.

4.2.6.2 Processing Methods and Procedures of Goat Milk Cheeses

4.2.6.2.1 Soft Goat Milk Cheeses The traditional farmstead goat milk cheesemaking consists of the following nine basic steps (64): (a) filtering of the milk; (b) renneting, sometimes preceded by acidification; (c) coagulation of the milk; (d) placing of the curds into cheese moulds, sometimes preceded by pre-draining; (e) draining, sometimes interrupted by turning the cheeses over; (f) unmoulding; (g) salting; (h) drying; and (i) ripening. These procedures are traditionally used for French soft body type farmstead goat cheese manufacture.

There are also some large-scale commercial goat milk cheese processing plants in France, such as in the Poitou-Charentes, Poitiers region. A couple of commercial French goat cheese-processing procedures are displayed in Figures 2.30a and 2.30b. These caprine cheeses produced in large-scale commercial production are intended for exports to other countries. Although the basic cheesemaking procedures are similar for many goat cheese-producing countries, numerous different varieties of caprine cheeses can be made due to the variation in the composition of milk, modifications of manufacturing procedures, and multitude of aging time and conditions (29, 67, 78).

Even a licensed commercial goat dairy may modify the pasteurization procedure due to unaffordability of installation of steam and chill water systems.

Figure 2.30a. Transfer of soft curd body of goat milk cheese to the plastic hoops for draining whey in a French commercial goat milk cheese plant. Source: Goat milk cheese plant, Poitiers, France.

Figure 2.30b. Drying processes for the soft goat cheeses after removal from the plastic cheese hoops. Source: Goat milk cheese plant, Poitiers, France.

One example is a licensed grade A goat dairy located in a southern state of the United States, which has the following modified procedures for soft goat cheese manufacture: Goat milk is pasteurized at 62.8°C (145°F) for 120 minutes and by slow coagulation and natural draining, and then by hanging the cheese in cheesecloth for three days in a cool room (22°C) before packaging. The cheeses are packaged in 454 g rod shapes with polyolefin shrink wrap and then delivered to local consumers or shipped to other locations.

4.2.6.2.2 Semi-Hard and Hard Goat Cheese Processing Technology Semi-hard or hard goat milk cheese varieties such as Monterey Jack, Gouda, Cheddar, blue, and Camembert cheeses can be man-

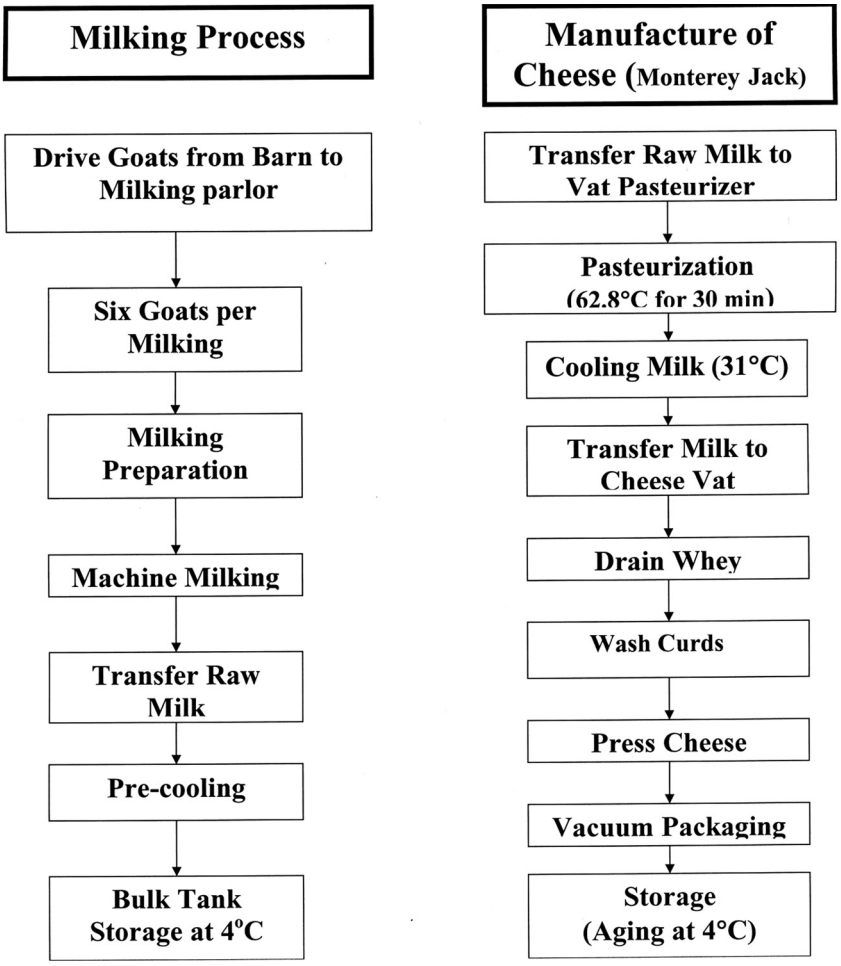

Figure 2.31. Flow diagram for milking and cheese manufacture processes. Fort Valley State University, Georgia, U.S.A.

ufactured. In the United States, a significant volume of Monterey Jack goat cheese is commercially produced and marketed.

Manufacturing procedures of Monterey Jack goat milk cheese routinely performed at the University dairy processing pilot plant of the Georgia Small Ruminant Research and Extension Center (GSR-REC), Fort Valley State University, GA, U.S.A., are shown in Figure 2.31 and described as the following detailed protocol: The bulk milk from its mixed herd of Nubian, Saanen, and Alpine goats is transferred to the vat pasteurizer. The milk is pasteurized at 62.8°C (145°F) for 30 min. The cheese is manufactured according to the modified procedure of well-documented processing methods (57, 64). Each batch of cheese is made using between 135 and 170 L of milk maintained at 88°F (31°C) in a 60-gallon (227 L) cheese vat. Lyophilized mesophilic direct vat set starter culture (R704, 50 units, Chr. Hansen, Inc., Milwaukee, WI) and 18 ml of single-strength rennet (Chymax; Chr. Hansen, Inc., Milwaukee, WI) are added to the milk and then allowed to coagulate. The curds are cut using 1.6 cm wire knives and allowed to heal for 5 minutes. The temperature is gradually raised to 39°C (102°F) over 30 minutes and the curds are cooked until firm for about 45 to

60 minutes. Two-thirds of the whey is drained, and warm water (31°C) is added to the vat to wash the curds and to bring the temperature of the whey to 88°F (31°C). The curds are soaked with the water for 5 minutes before the whey is completely drained. Curds are placed into 6 x 6 inch (15.24 x 15.24 cm) Wilson hoofs and pressed at 40 psi overnight at room temperature in a vertical cheese press (Pneumatic Press, Kusel Equip. Co., Watertown, WI). Cheeses are removed from the molds, cut into disks 5.08 cm (2 inches) in height, and vacuum packed in plastic pouches (FreshPak 500 vacuum pouches, Koch Supply, Kansas City, MO) using a vacuum packager (Koch Ultravac 250, Koch Supply, Kansas City, MO); they are then stored at 4°C in a walk-in cooler for six weeks before marketing.

4.2.6.2.3 Homemade Style Cheesemaking of Hard Goat Cheese A hard type goat milk cheese can be made at home. The following homemade cheesemaking procedures were introduced at a goat milk cheesemaking workshop conducted by the American Dairy Goat Association:

i) Ingredients needed:
   (a) 1 gallon (3.785 L) goat milk
   (b) ⅓ cup mesophilic starter culture
   (c) ½ tablet of rennet (enzyme)
   (d) Coloring agent if desired
   (e) 1 tablespoon salt
ii) Cheesemaking procedures for homemade-style hard goat cheese:

Time (hour, min)	Procedures
0.0	Add ⅓ cup starter culture to one gallon of milk in a metal pan that has been heated to 29–30° C (84–86° F), and stir well. Let stand at this temperature with occasional stirring about 1 hr depending on desired acidity (but 30 min may be used for workshop purpose).
0.30	Add ½ rennet tablet dissolved in ½ cup cold water. Stir thoroughly for 3–5 min. Color can be added at this time, but not with the rennet. Cover milk and let it set undisturbed for about 30 min at the same temperature (29–30° C). Coagulation should occur during this period, but if not, let it stand longer.
1.05	Cut curd into ⅜ to ½ inch (0.95 to 1.27 cm) cubes. If using a spatula or knife instead of a curd cutter, it must be long enough to reach the bottom of the pan. Starting at the far right of the pan, cut the curds into strips from 0.95 to 1.27 cm wide, inserting the knife to the bottom and cutting from back to front. Turn the pan and repeat the operation. Next, holding the knife at about 45° from horizontal line and starting at the inch (2.54 cm) wide strips from top to bottom of the pan. Turn the pan and repeat.
	Stir the curds slowly for about 5 min. During this time, oversized curds may be found and, if so, cut them to the required size. The mixture can be stirred, but without mashing the curds into pieces smaller than ⅜ inch (0.95 cm). The curds should be the same size, in order to reach the same degree of firmness when heating, which is an important process.
1.15	Slowly apply heat to raise the temperature to 39° C over a 20–30 min period. Hold at 39° C for another 15 min, stirring gently every 5 minutes. Cooking is complete when the curd holds its shape but falls apart without squeezing. Individual curds will be about the size of a grain of wheat and will have the general appearance of scrambled eggs.
1.45	To firm the curd, remove from heat and let curds and whey stand for about 30 min, stirring gently three or four times.
2.15	Pour curds and whey into a cheesecloth-lined colander. Thoroughly drain off whey, rolling the curds by alternately raising one end of the cloth and then the other.
	Sprinkle 1 tablespoon salt over the curd, one-half at a time, and work in with hands. Wrap the cheesecloth around the curd, making a ball, and squeeze out as much whey as possible. Then place curds in a cloth-lined mold and press overnight.

Next day:

Remove the cheese from the press, and remove cloth. Air-dry the goat cheese on board or mat in a cool place for 2 to 3 days. Turn daily.

Wax and store at about 4.4° C until optimum flavors are developed. The cheese also can be consumed immediately, if desired without flavor development.

4.2.6.2.4 Manufacturing Procedure of Goat Milk Cheddar Cheese Cheddar cheese originated many decades ago in the little village of Cheddar, England, from which it spread throughout the world (55). English Cheddar is crumbly and has a pronounced sharp, acid flavor and a higher salt content. Its American counterpart is more cohesive and waxy in texture with a generally bland flavor (55).

Strictly speaking, Cheddar cheese may not be legally made from goat milk, because the term "Cheddar cheese" has originated from cheese made only from cow milk. However, Cheddar cheese can be and has been manufactured using goat milk, even if the latter has some problems of attaining the same level of moisture content as well as the firmness in texture of the cheese due to its naturally soft curd body formation and lack of α_{s1}-casein content in goat milk, which is considered the primary casein to attain firmness of the curd. Nevertheless, the goat Cheddar cheese has been made from caprine milk including at the GSRREC, Fort Valley State University, Georgia, and other places. The manufacturing procedure for goat Cheddar cheese has been adapted from that of cow milk cheese. As an example of goat Cheddar cheese processing, steps were adapted from the University of Wisconsin, Madison, Wisconsin, which are shown in Table 2.34.

4.2.7 HACCP Plans for Goat Cheese Manufacture at the GSRREC, Fort Valley, Georgia

The Hazard Analysis and Critical Control Points (HACCP) plans are implemented in most modern food processing companies, especially in meat-processing plants. However, many local, individual dairy processing plants also implement their own HACCP plans by adapting their own specific setup and conditions to ensure the food safety of their products for consumers.

4.2.7.1 Background and Principles of the HACCP System The HACCP System is a logical, scientific approach to controlling safety problems in food production. When a company adopts HACCP, it puts controls in place at each point in the production system where safety problems could occur from biological, chemical, or physical hazards. To start a HACCP system, a company must first write an HACCP plan. There are five preparatory steps for an HACCP plan, and there are seven HACCP principles. The regulatory requirements for Sanitation Standard Operating Procedures (SSOPs) must also be met as a prerequisite to HACCP.

4.2.7.2 The Five Preliminary Steps for an HACCP Plan The five steps are as follows: (a) bring together your HACCP resources and assemble the HACCP team; (b) describe the food and its method of distribution; (c) identify the intended use and consumers of the food; (d) develop a process flow diagram; and (e) verify the diagram in the operation it is meant to represent.

4.2.7.3 The Seven HACCP Principles The seven principles are as follows: (a) conduct a hazard analysis; (b) identify critical control points; (c) establish critical limits for each critical control point; (d) establish monitoring procedures; (e) establish corrective actions; (f) establish record-keeping procedures; and (g) establish verification procedures. The HACCP plans at the GSRRREC, Fort Valley State University, Fort Valley, Georgia, are as shown in Figure 2.32.

4.2.8 Yield of Goat Milk Cheeses

Yields of cheese are dependent on manufacturing techniques in different locations, procedures, and the compositions of milk used. Due to a multitude of goat cheese processing methods in various parts of the world and with a significant variation in milk composition, there are wide variations in the yield of goat milk cheese.

4.2.8.1 Mathematical Formula for Predicting Cheese Yield A direct linear relationship has been

Table 2.34. Manufacturing Procedures for Cheddar Cheese[a,b,c]

Step in making	Time of step	Minutes to next step	Temperature °F	Acid %	Acid PH	Comments
Add starter	8:15	30	88	0.16	6.65	70 lbs strained (use manufacturers guides)
Add color	8:45	15	88	0.16	—	10 oz
Add rennet	9:00	12	88	0.17	6.60	30 oz
Coagulation	9:12	18	88	—	—	Vat covered
Cut curd	9:30	15	88	0.10	—	¼-inch knifes
Steam on	9:45	30	88	0.10	—	By heating schedule*
Steam off	10:45	45	102	0.11	6.40	Stir slowly
Drain whey	11:00	30	102	0.13	6.20	8 to 10 inches deep
End drain	11:30	15	102	0.15	6.00	18-inch trench
Pack (1st turn)	11:45	Turn	101	0.17	5.90	Blocks 7 inches wide
Pile 2 high	12:30	curd	96	0.25	5.70	Cut blocks in half
Pile 3 high	1:00	Every 15 min	93	0.32	5.50	Smooth ends
Mill	1:30	20	91	0.40	5.45	Smooth, silky
Salt	1:50	40	89	0.65	—	25 to 27 lbs
Hoop	2:30	20	88	—	—	All salt dissolved
Press	2:50	30	88	—	—	Full pressure in 15 min
Press for 5 to 20 hr at full continuous pressure						

*Heating schedule

Minutes from steam on	0	5	10	15	20	25	30
Temperature ° F	88	89	91	93	96	99	102

[a]Manufacturing Cheddar cheese from pasteurized milk (Bulletin 464). Research Division, College of Agricultural and Life Sciences, University of Wisconsin-Madison, WI. April 1971.

[b]Cheesemaking is based on 10,000 lbs of milk, 3.5% milk fat: The final cheese is expected to be 985 lbs cheese with 37–38% moisture and 33% fat.

[c]Actual cooking time may be extended longer for goat milk cheesemaking because goat milk curd is softer and needs more cooking time for more moisture to be expelled from the curds.

demonstrated between the amount of fat and protein (specifically casein) in cow milk and the yield of Cheddar cheese. Although not many research reports are available, this equation would be applicable to goat milk cheese to calculate its approximate yield. The importance of casein and fat (the major components in milk) in determining cheese yield allows the development of the following mathematical formula for predicting cheese yield by Price (97):

$$\text{Cheese yield} = \frac{[(F \times R) - (C - 0.1)] \times 1.09}{TS} = \text{g}/100\text{kg}$$

Where F = fat in milk

$$R = \frac{100 - \%\text{fat lost during cheesemaking}}{100}$$

C = % casein in milk

$$TS = \frac{100 - \%\text{ moisture of cheese}}{100}$$

The percentage of casein in cow milk can be estimated by the following formula, assuming that

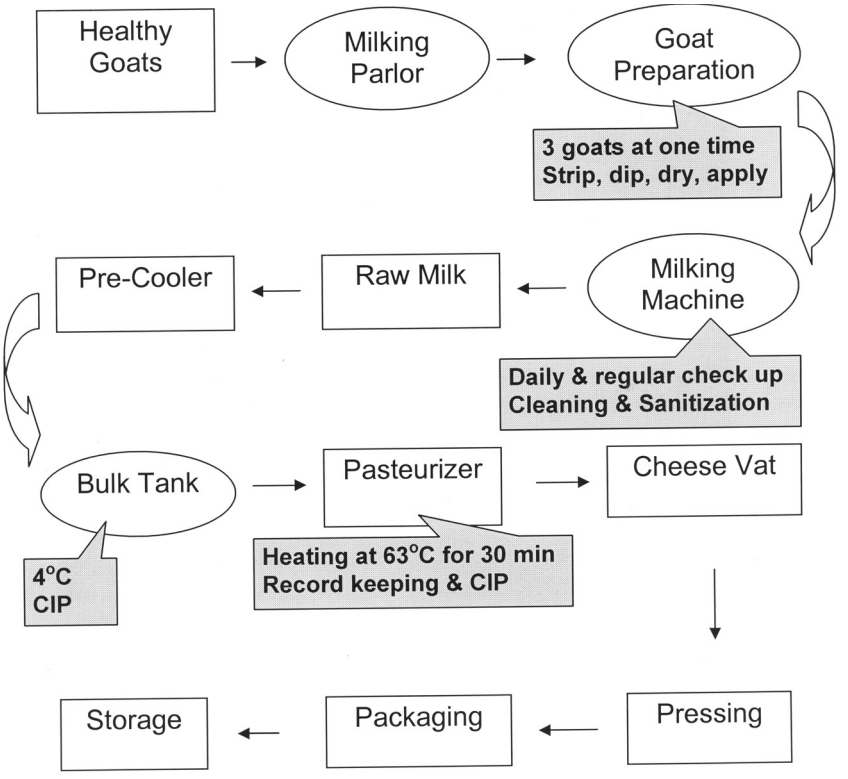

Figure 2.32. HACCP Flow Diagram of Processing. Fort Valley State University, Georgia, U.S.A..

casein constitutes a fixed percentage of total protein. This may be also applicable for goat milk:

$$\% \text{ casein} = (\% \text{ fat} \times 0.4) + 1.0$$

The yield of goat cheese is highly interrelated with moisture content of the final product (64, Table 2.35). Milk composition is significantly varied between different stages of lactation, which would affect the yield of cheese. A Canadian study clearly demonstrated that cheese yield varied directly with seasonal deviations in amounts of fat plus protein in milk (47) (Figure 2.33).

4.2.8.2 Recent Studies on Yield of Goat Milk Cheese The relationships between goat milk constituents and cheese yield have been recently studied (34). The yield of Chevre made from the sampled loads of milk was measured and adjusted to 60% moisture content. There was a definite trend in the 60% moisture-adjusted yield of Chevre during the year, which ranged from 14% in June to 20% in December and January (Figure 2.34). Milk total

Table 2.35. Moisture Content and Yield of Different Types of Goat Cheese

Type of cheese and stage of cheese	Moisture content (%)	Cheese yield
Lactic acid body		
Very fresh	80	18 kg and above
Fresh	62	14.5–15 kg
Semi-dry	58	12.5 kg
Ripened	55	11–12 kg
Dry	50	10.5 kg
Uncooked pressed body	52	8.5–10 kg

Adapted from Le Jaouen (64).

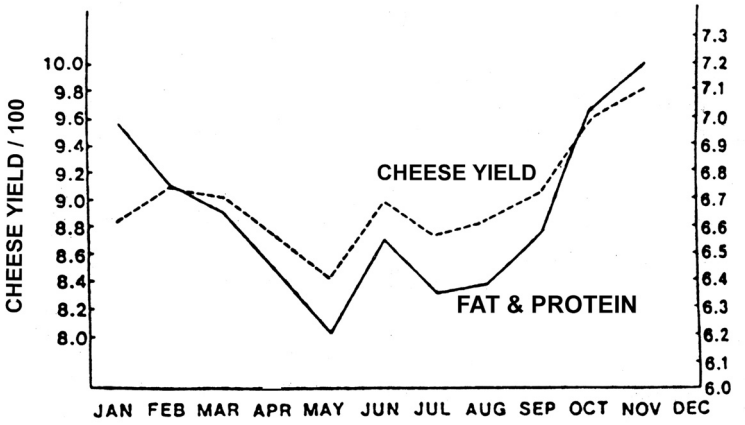

Figure 2.33. Profile of yearly cheese yield in relation to fat and protein contents of cow milk in eastern Ontario in 1972. Adapted from Irvine (47).

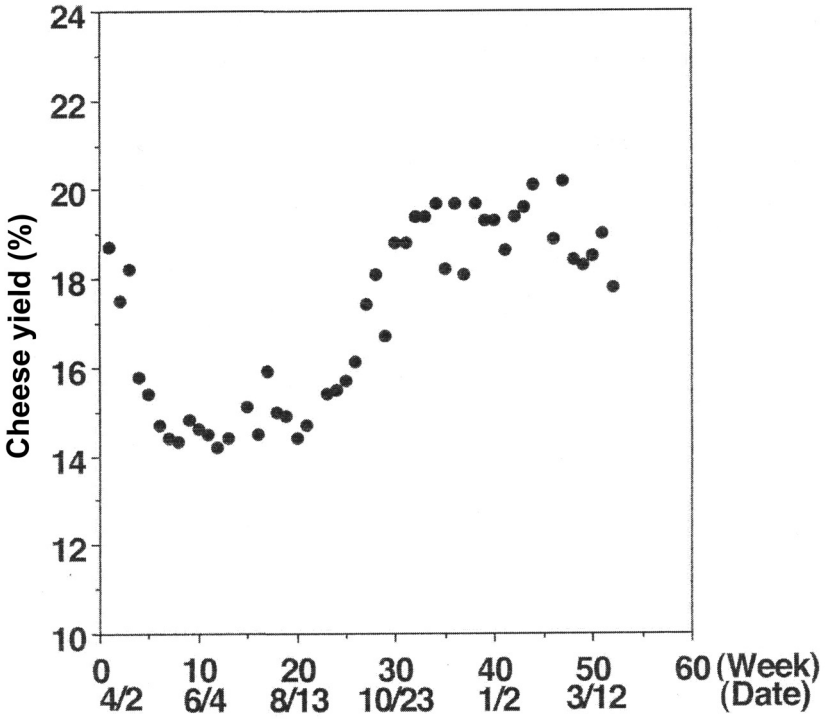

Figure 2.34. Changes in yield of Chevre during 52 weeks. Adapted from Guo et al. (34).

Table 2.36. Relationship Between Chevre Yield* (Y) and Chemical Composition of Goat's Milk

Equation	r^2	P value
$Y = 2.64\ TS^4 - 15.48$	0.81	0.01
$Y = 11.87\ CN^1 - 13.30$	0.75	0.01
$Y = 8.61\ CP^3 - 12.76$	0.79	0.01
$Y = 3.85\ F^2 + 3.31$	0.75	0.01
$Y = 170.56\ Ca^6 - 8.46$	0.64	0.01
$Y = 43.26\ A^5 - 18.90$	0.55	0.01
$Y = 2.31\ F^2 + 5.77\ CN^1 - 5.97$	0.80	0.01
$Y = 3.82\ F^2 + 0.12\ SG^7 + 0.70$	0.75	0.01
$Y = 1.22\ L^8 + 11.69$	0.01	0.50
$Y = 103.3\ P^9 + 3.73$	0.59	0.01
$Y = 0.05\ Mg^{10} + 8.86$	0.36	0.01
$Y = -0.0023\ Na^{11} + 18.697$	0.02	0.05
$Y = 0.74\ Zn^{12} + 13.52$	0.47	0.01
$Y = 30.01\ Ca^6 + 55.80\ P^9 + 0.36\ Zn^{12} + 3.78$	0.69	0.01

Moisture adjusted (60%) yield = True yield × 60/moisture × 100.
[1]CN = casein; [2]F = fat; [3]CP = crude protein; [4]TS = total solids.
[5]A = ash; [6]Ca = calcium; [7]SG = specific gravity; [8]L = lactose.
[9]P = phosphorus; [10]Mg = magnesium; [11]Na = sodium; [12]Zn = zinc.
Adapted from Guo et al. (34).

solids (TS) and crude protein (CP) contents were the most significant predictors of Chevre yield (Y). The results were:

$\%\ Y = 2.64TS - 15.48$ ($r^2 = 0.81$, $P < 0.01$), and

$\%\ Y = 8.6116CP - 12.7598$ ($r^2 = 0.79$, $P < 0.01$), respectively.

Relationships between Chevre yield (Y) and chemical compositions of goat milk for the same study are shown in Table 2.36.

4.2.9 Relationship Between Goat Cheese Yield and SCC in Milk

4.2.9.1 General Relationship Between Cheese Yield and Milk SCC Significant relationships were found among average Wisconsin mastitis tests, direct microscopic somatic cell counts (SCC), cheese yield potential in pounds (454 g) per hundred weight (cwt), and gross margin per hundred weight (for the cheese plant) for the low and high somatic cell farms (8) (Table 2.37). The difference in cheese yield potential between the high and low somatic cell count farms was 0.123 kg (0.27 pounds) cheese per hundred weight.

4.2.9.2 Consideration of Cheese Yield of Goat Milk in Contrast to Bovine Milk Research has shown that goat milk has considerably higher SCC compared to the cow milk counterpart. Somatic cell count has been accepted as a quantitative index for mastitic conditions of cows milk or for degree of glandular irritation in bovine mammary glands (87, 96). However, there has been great controversy over the relationship between SCC and mastitic infection in goat milk. Somatic cell counts in milk from normal or uninfected goats were reportedly much higher than those in milk from normal cows, especially in late stages of lactation (12, 32, 92, 105). Average SCC in goat milk ranged from 750,000 to 5.4 million cells/ml (19).

Milk secretion in the cow is of the merocrine type but in the goat it is an apocrine process, which results in a high number of round cytoplasmic particles and epithelial cells in the milk (87). Goats may shed large numbers of epithelial cells in the milk. It is common to find high SCC in goat milk, when actual numbers of leucocytes are relatively low (51). This phenomenon does not happen in cow milk due to insignificant numbers of epithelial cells. Several researchers indicated that the total SCC does not correlate with leucocyte count in goats (20, 41, 104,

Table 2.37. Impact of Somatic Cell Count on Cheese Yield Potential and Gross Margin per cwt for 12 Low and 12 High Somatic Cell Farms

	Low group	High group	Difference
Wisconsin mastitis test score	11	16	5
Somatic cells (cells/ml)	529,000	667,000	138,000
Cheese yield potential (lb/cwt)	9.52	9.26	0.27
Gross margin/cwt	$2.01	$1.78	$0.23

Source: Barbano et al. (8).

105). Non-leucocytic cell-like particles commonly existing in goat milk do not contain deoxyribonucleic acid (DNA). Methods specific to DNA gave significantly lower results than Coulter electronic cell counts or direct microscopic SCC with a nonspecific stain (20). Therefore, only counting methods specific for DNA should be employed for estimating SCC in goat milk. The direct microscopic counting with pyronin Y-methyl green stain method (77) has been exclusively recommended by the American Dairy Goat Association for enumeration of SCC in goat milk (51). In addition, the U.S. National Conference on Interstate Milk Shipments and the American Dairy Goat Association have recommended that separate standards be established in counting SCC for cow and goat milk (6, 51, 87).

Park and Humphrey (87) showed that the average SCC in their goat milk was 9.08×10^5 cells/ml, while Staphylococcus and total bacterial cell counts were 3.323×10^3 and 1.544×10^4 cells/ml, respectively, in the same milk (Table 2.38). They reported that none of the correlation coefficients (r) between somatic cell and bacterial cell counts was significant for the pooled data of Alpine and Nubian breeds, but a correlation (r) between Staphylococcus and SCC was significant. The r between SCC and % fat or protein were significant ($P<0.01$) for combined or separated breed data (Table 2.39). They confirmed that bacterial cell counts could not explain high SCC in goat milk with the present testing standards of cow milk.

The aforementioned research data indicate that cheese yield of goat milk may not be as closely related to SCC as that of bovine milk. The observations on yield of goat cheeses at the GSRREC dairy plant appeared to have some tendency in lower cheese yield with high SCC in the goat milk. Nevertheless, more research would be required to substantiate the actual relationship between cheese yield and levels of SCC in goat milk.

4.2.10 Technical Advances in Manufacture of Goat Cheeses

The goat milk cheese industry will never be able to compete with the cow cheese counterparts in terms of total volume of production, due to the lesser amount of milk production and seasonal milk sup-

Table 2.38. Statistical Summary of Total Bacterial Cell Counts (TCC), Coliform Counts (CFC), Staphylococcus Count (STC), Somatic Cell Counts (SCC), Percent Fat, and Percent Protein for the Pooled Data of Alpine and Nubian Goats

	No. of observation	Mean	Range[1]	SE
TCC ($\times 10^4$/ml)	104	1.544	0.01–34.7	0.533
CFC ($\times 10^3$/ml)	85	0.966	0.00–8.90	0.169
STC ($\times 10^3$/ml)	90	3.323	0.00–40.0	0.633
SCC ($\times 10^5$/ml)	104	9.08	0.00–62.0	1.060
Fat, %	105	4.47	1.62–7.92	0.134
Protein, %	105	3.42	2.36–5.00	0.051

[1]Zero means less than unit counts.

Adapted from Park and Humphrey (87).

Table 2.39. Correlation Coefficients among Total Bacterial Cell Counts (TCC), Coliform Counts (CFC), Staphylococcus Count (STC), Somatic Cell Counts (SCC), Percent Fat, and Percent Protein for the Combined Data of Alpine and Nubian Goats[1]

	TCC	CFC	STC	%Fat	%Protein
SCC	−0.137	−0.304	0.167	0.415**	0.412**
TCC	0.321**	0.171	0.071	0.011	
CFC	−0.136	−0.025	0.045		
STC	0.144	0.333**			
% Fat	0.655**				

[1]Number of observation is based on Table 2.9 values.
**$P < 0.01$
Adapted from Park and Humphrey (87).

ply. This inherent species-specific disadvantage of the goat cheese industry necessitates the exploration of some alternative solutions or technological development to enhance yield and quality of goat cheeses.

4.2.10.1 Ultrafiltration Technology in Goat Cheese Manufacture In 1969, Maubois, Mocquot, and Vassal introduced a new concept for manufacturing natural cheese called the MMV process (55, 56). The principle of this technique is based on selective concentration of skim or whole milk by ultrafiltration (UF) to produce a very high fat and protein liquid, called retentate.

Ultrafiltration was used for the production of retentate, precheese fraction from goat milk. The fraction was subsequently made into cheese. This resulted in an 8 to 15% increase in cheese yield, because whey proteins are retained with the curd and less rennet is required (56, 67). One of the advantages in the manufacture of a cream cheese–type product using the UF technique was the possibility of holding the precheese material in frozen storage for later use in cheese manufacture (67). The UF procedure also has been used to prepare a spray-dried retentate material that can be reconstituted and made into cheese for later use (55, 93).

Using UF technology, it is now possible to produce goat cheese even with a shortage of fluid milk supply. With the ultrafiltration technique, a large French manufacturer of Chevre cheese can now smoothe out the production variations throughout the year. A goat milk cheese-processing plant in New Zealand is being converted to UF technology. This same trend is likely to follow in the United States.

4.2.10.2 Freezing Goat Cheese or Precheese For manufacture of cheese, the precheese produced by UF is adjusted with plastic cream to the composition of natural cheese desired. It is inoculated with starter culture, rennet, color, salt, and mold spores when necessary, and then the viscous, liquid precheese is poured into plastic forms (56). In this process, the curd is formed with little or no free whey in a short time, and no cheese vats are required. Continuous cheese making became possible for certain cheese types by this MMV concept. The MMV-process technique has been presently and successfully applied to rennet cheeses, such as cream, Camembert, St. Paulin, feta, mozzarella, and fresh acid French type cheese (56).

Another means of combating seasonal goat milk supply is freezing curd and holding it in frozen storage. Cheese made from this curd generally was less desirable in flavor than that made from the fresh curd (94). However, recent research investigations conducted at the author's institution revealed that frozen-storage of plain soft and Monterey Jack goat milk cheese up to six months was possible and did not have significant influence on sensory quality of the cheeses (88). Although the concentrations of some organic acids in the frozen-stored cheeses were changed, the effects on sensory quality of the products were not deleterious for at least up to three months of storage (86), which presents the strong possibility of potential application of this technology into the extended marketing of goat products to overcome its seasonal milk supply.

4.2.10.3 Nutritional Fortification of Goat Cheeses Another technical improvement that may be applicable to goat cheese production is nutritional

fortification. Goat milk is deficient in iron, as is cow milk. Iron in ferrous sulphate form has been added to whey cheese to enhance nutritional quality of goat cheese (113). This iron supplementation technique has been successfully carried out recently for cow Cheddar cheese without having any detrimental effects on the cheese quality (115).

4.2.11 Defects of Cheese

Production of high-quality cheeses can be achieved only when the final marketed products are free of flavor and texture defects as well as free of harmful microorganisms. One problem with ripened goat milk cheese is that lipase enzymes in the cheese may activate and cause certain lipolysis during ripening, which releases significant amounts of short-chain fatty acids, such as caproic, caprylic, and capric acids, characteristic of goaty flavor. Under extreme circumstances, the cheese may be rejected by consumers due to development of a too pungent flavor. However, control of this flavor defect by enzymatic hydrolysis can be achieved through careful handling of milk, proper pasteurization, proper cheese making, and ripening techniques.

Flavor defects are identified as rancid, acid, bitter, goaty, feedy, oxidized, cooked, brothy, or yeasty flavors (43, 86). Cooked flavors arise from the release of volatile sulfides from the heat activated sulfhydryl groups of the major whey protein β-lactoglobulin. A recent study with commercial plain soft goat cheese showed that the soft cheese stored at 4°C in a refrigerator has maintained its freshness and acceptable sensory quality for up to four weeks storage (86). There are many fine qualities of goat cheese produced worldwide, and these commodities are shipped to other countries.

4.3 Yogurt

4.3.1 General Characteristics of Goat Milk Yogurt

Goat milk yogurt was one of the traditional products from countries where fermented dairy foods originated. Fermented goat milk products played a significant role in securing food for rural communities of many developing countries. There is a target market of goat yogurt for individuals who look for the special taste or health benefits, or who are allergic to cow milk protein, specifically α_{s1}-casein (33). Some individuals who simply enjoy the flavor of goat milk products, in fact many gourmet food consumers, are willing to pay high prices for certain goat milk products (39). In addition, certain consumers believe that goat milk is nutritionally superior to bovine milk. This belief certainly creates a larger market (2). Fermentation diminishes the "goaty" flavor, which is so often perceived as distasteful in the U.S. market. This taste is attributed to the aroma compounds and acids produced by the yogurt starter cultures during fermentation (21). Goat milk yogurt can be made in a similar manner to the cow counterpart. One of the main problems in manufacture of goat milk yogurt is weakness and lack of consistency in curd tension or viscosity upon agitation compared with cow yogurt. This is due to the difference in protein composition between the two milks, especially in casein contents.

4.3.2 Manufacturing Procedures of Goat Milk Yogurt

There are different yogurt products throughout the world, using different yogurt cultures and varied milk composition. The typical manufacturing steps are shown in Figure 2.35 and Table 2.40 (55, 67). The basic processing procedures of goat milk yogurt include: (i) preparation of milk; (ii) standardization (standardized to 1.0–1.7% fat); (iii) pasteurization (72°C for 20 sec, or cow yogurt 90.6°C for 40–60 sec. [HTST] or 85°C for 30 min. [vat]); (iv) cooling of the pasteurized mix to 116°F (46.7°C) and holding in vat for up to 15 min.; (v) inoculation (45°C) (carefully introduce into warm milk or milk mixes 1.25% by weight of active *Lactobacillus bulgaricus* culture and 1.25% *Streptococcus thermophilus* culture); (vi) packaging (set yogurt); (vii) incubation (permit filled containers to remain in room at 114°F (45°C) for 3–5 hrs. or until a firm, smooth gel has formed to pH 4.5); (viii) chilling (yogurt is chilled to 45°F [7.2°C] in less than 1 hr.); and (ix) storage and distribution (store the containers of yogurt at 40°F [4.4°C] or lower; the shelf life at this temperature is 30–60 days).

4.3.3 Biochemical and Microbiological Principles of Yogurt Manufacture

In yogurt production, the milk should be pasteurized and homogenized, and then cooled to the optimal

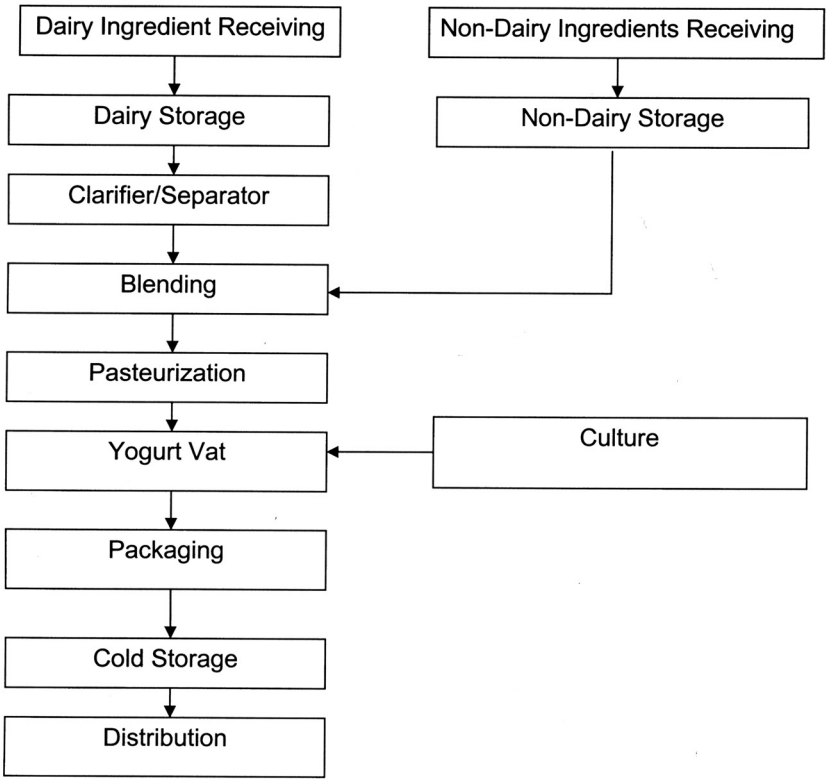

Figure 2.35. Flowchart for manufacture of yogurt. Adapted from FDA Workshop, St. Louis, MO, 2000.

growth temperature of the fermentative yogurt starter culture bacteria (depending on species, approximately 42–45°C). The next step is to add the starter culture to the warm milk. In the United States a commonly used bacterial combination of starter cultures is *Streptococcus thermophilus* with *Lactobacillus delbrueckii* subsp. *bulgaricus*. These two cultures produce lactic acid at a greater rate when used together than when used alone (108). This is caused by each organism releasing compounds into the milk that can be utilized by the other organism. Some of the compounds produced by *Streptococcus thermophilus* that stimulate the growth of *Lactobacillus delbrueckii* subsp. *bulgaricus* include formic acid (110), carbon dioxide, pyruvate, purine, adenine, and uracil (108). *Lactobacillus delbrueckii* subsp. *bulgaricus* produces the following compounds, which have been shown to stimulate *Streptococcus thermophilus* growth: glycine, histidine, and various proteolytic enzymes, which produce the nitrogen necessary for the growth of *S. thermophilus* (108). It was suggested that goat milk is better than cow milk for the growth of lactic acid bacteria due to the somewhat higher content of vitamins essential to their growth and the higher content of non-protein nitrogen (1). In many cases, other bacterial species are also added to provide probiotic benefits to consumers, such as *L. acidophilus*, *L. paracasei* subsp. *casei*, and various *Bifidobacteria* species.

Yogurt bacteria metabolize lactose in the milk and release lactic acid into the milk as a waste product (110). The starter cultures often used in yogurt are heterofermentive, indicating that they metabolize sugars by the glycolytic pathway. Lactose is a disaccharide composed of glucose and galactose. In this pathway, lactose is first transported across the cell wall and converted to galactose-6-phosphate and glucose; both of these components are then converted

Table 2.40. Manufacturing Conditions and Procedures of Cultured Goat Milk Products[a]

Products	Milk type	Culture microorganism	Type of inoculum	Rate of inoculation (%)	Incubation Temp. ° F (° C)	Incubation Time (hr)	Stop incubation at pH	Stop incubation at %TA
Buttermilk								
	Skim or low fat	*S. lactis* *S. cremoris*	Bulk start or direct set	0.5–1.0 as directed	72 (22)	14–16	4.5	0.8
		L. citrovorum *S. diacetilactis*			72 (22)	12–16	4.5	0.8
Acidophilus								
	Skim or low fat	*L. acidophilus*	Bulk start	0.5	100–111 (37–44)	18–24	3.8	1.0
Sour Dip	Half-n- Half (11% fat)	*Same as for buttermilk**	Bulk start or direct set*	1.0	72 (22)*	14–16	4.8*	0.7*
Kefir	Whole	*S. kefir* *T. kefir*	Kefir grains	As directed	72 (22) followed by 50 (10)	12	4.5	0.8
		L. caucasicus *S. lactis*				24–72		
Yogurt	Skim or low fat	*S. thermophilus* *L. bulgaricus*	Individual cultures or direct set	1.25 each or as directed	114 (45.6)	5–6	4.2	0.9

*Same conditions for sour dip and sour cream; sour cream as 18% fat.

[a]Data from Loewenstein et al. (66) and Kosikowski (55).

to glucose-6-phosphate. The glucose-6-phosphate is then metabolized by the bacteria to produce energy in the form of ATP (adenosine tri-phosphate) with water and lactic acid as by-products:

$$\text{Lactose} + 2H_3PO_4 + 4\text{ATP} \rightarrow 4 \text{ lactic acid} + 4\text{ATP} + 3H_2O$$

As the starter cultures continue to produce more acid, the initial pH 6.7 of goat milk (33, 114) decreases to 4.5 or less. This rate of decrease in pH can be affected by incubation temperature. At a higher temperature, 40–45°C, fermentation can occur as quickly as 2.5 hours, while the process can take between 16 and 18 hours at lower temperatures, 30–35°C (108).

After decrease in pH, the casein micelle structure becomes the key to yogurt production. Milk casein micelles are negatively charged and are associated with one another by calcium phosphate bridges. During the fermentation of milk, as the pH is lowered, calcium phosphate is released from the micelles, causing an increase in calcium content in the serum portion of the milk. Casein also begins to dissociate from the micelles. At pH 5.6, portions of all the major caseins (κ, β, α_s) have dissociated from the micelles. This disruption of the core structure of the casein micelles causes a loss of stability and leads to aggregation (44).

At a pH of 5.2, the casein particles begin to aggregate, due to decreased repulsive forces, which allow hydrophobic interactions to take place to form structures with empty spaces between them. Between pH 5.2 and 4.8, contraction of casein aggregates takes place, and these particles are larger than the original micelles in the milk. At pH 4.5 or below, rearrangement and aggregation of casein particles occur, leading to the formation of a protein matrix consisting of micellar chains and clusters trapping other milk components inside, where a milk gel (yogurt) is formed (108).

4.3.4 Enhancement of Texture of Goat Milk Yogurt

Various techniques have been employed to improve the texture of yogurt for many centuries. The most common method is to increase the amount of total solids in the milk. In general, the higher the level of solids in the milk, the greater the viscosity and consistency of the yogurt.

4.3.4.1 Improvement of Goat Yogurt Texture by Fortification The first method used to achieve goat yogurt texture was to boil the milk before it was used to make yogurt, which concentrates the milk and modifies the properties of the casein, which in turn improves the viscosity of the final product. Currently, there are many other methods used to increase total solids in yogurt production.

Boiling milk to increase total solids content is still a common method in rural areas where the scale of yogurt manufacture is quite small. The milk is boiled until the volume is reduced to two-thirds of its original amount. However, this procedure alters sensory characteristics and causes a loss of heat labile vitamins (108).

Another method to increase total solids content is the addition of powder ingredients. Several different additives are used to increase solid content in order to create a thicker and smoother yogurt. These include skim milk powder (high in protein), whey products, and buttermilk powder.

The most realistic and economic approach for the production of goat milk yogurt with good body texture and flavor is supplementation of goat milk with cow skim milk powder (3). It was observed that increasing the level of total solids to 15% in goat milk with cow skim milk powder increased the rate of lactic acid production, masked the goaty flavor, and decreased syneresis. Although this yogurt still had a softer body compared with cow milk yogurt, it also possessed a whiter color and displayed less of a tendency to produce syneresis when stored at 4°C, compared with cow milk yogurt. A taste panel study could not distinguish between cow milk yogurt and goat yogurt supplemented with cow skim milk powder. The goaty flavor was masked, possibly due to the addition of cow skim milk powder, which may have enhanced the flavor (acetaldehyde) producing capacity of the starter cultures. Lessened tendency to produce syneresis could be due to the presence of more acid, which produces a softer and less compact coagulum during fermentation and provides resistance of the gel to further shrinkage and syneresis during storage.

Different types of whey powder and whey protein concentrate are often added to improve yogurt texture. Whey protein is a by-product of cheese production. After casein coagulation, water, whey proteins (e.g., α-lactalbumin and β-lactoglobulin), and

other water-soluble components are drained from the cheese vats. Whey protein concentrate can commonly be found as an ingredient on the labels of commercial bovine yogurt products (31). The recommended level of addition of whey powder is 1 to 2% because adding more than this level can alter the flavor of the yogurt. Whey protein powder added at levels of 0.6 to 4% also produces an improvement in yogurt texture, while also improving some of the sensory attributes of the yogurt (108).

Sodium caseinate or micellar casein is also utilized as an additive to improve yogurt texture (54). As mentioned previously, casein forms the gel structure in yogurt, therefore the structure will become stronger if more casein is added (108). Casein is also an effective additive because casein and β-lactoglobulin interact chemically on heating, which effectively increases the concentration of gel-forming protein in the yogurt matrix and reduced syneresis through increased entrapment of serum within the interstices of the whey protein molecules attached to the surface of the casein (54).

Other methods to improve texture by increasing total solids include: concentration by vacuum evaporation, concentration by membrane filtration, and addition of non-milk proteins, such as soy protein, egg white, ground nut protein, and so on.

Another group of additives also utilized to enhance and maintain texture in yogurt are stabilizers (112). Stabilizers, also known as hydrocolloids, are polysaccharides and are common natural or synthetic gums. They improve the texture of yogurt in two ways. First, they bind water; second, they form a network of linkages between the milk constituents and themselves. This is achieved by the presence of a negatively charged group, for example, hydrogen or carboxyl radical, or by the presence of a salt, possessing the power to sequester calcium ions, which are parts of the gel structure in untreated yogurt (108).

4.3.4.2 Improvement of Goat Yogurt Texture by Enzymatic Crosslinking A new method has recently been developed to modify the texture of yogurt with an enzyme, microbial transglutaminase (MTGase). Transglutaminase is important for many biological processes in many organisms including fibrin clot stabilization, hair follicles, and cross-linking of erythrocytes (74). Research on transglutaminase was originally spurred by the desire to create meat-like texture in vegetarian foods. Animal proteins are cross-linked, which is partially responsible for the texture of meat (71). Transglutaminase is found in many sources, including animals, fish, and plants (58, 59). However, animal sources would be inappropriate for vegetarian consumers, and it is also difficult and costly to extract this enzyme from both animal and plant sources (116). Therefore, screening for enzyme-producing strains in approximately 5,000 microorganism species was carried out (5).

One organism, *Streptoverticicillium mobaranese*, demonstrated a high level of production of a transglutaminase-like enzyme, while there were only barely detectable levels produced by other microorganisms (5). This enzyme was determined to have the same cross-linking abilities as animal and plant transglutaminase (5). It has been labeled microbial transglutaminase (MTGase) (72) and is presently commercially available from Ajinomoto Inc., IA, U.S.A. (71). MTGase has been used in the food industry to cross-link many varieties of protein including whey, soy, wheat, beef myosin, and casein (116).

The physical and chemical characteristics of MTGase have been elucidated by recent studies (71, 72). The experimental molecular weight was determined to be 40 kDa. The isoelectric point is 8.9. The primary structure is comprised of 331 amino acid residues with a molecular weight of 37,842. MTGase contains a single cysteine residue essential for its catalytic activity.

The optimum temperature for MTGase activity is 50°C, but activity is sustained between 0°C and 70°C. However, activity is lost within a few minutes at temperatures below 0°C and above 70°C (71, 72). Fortunately for the commercial applicability of this enzyme, it does not require Ca^{2+} for enzymatic activity, as mammalian TGases do (5, 72). It was also discovered that most food proteins can be cross-linked by MTGase (71). MTGase was approved as a GRAS, Generally Recognized As Safe, substance in June 1997 (71). In yogurt, it has been approved at levels of 30 ppm or below (4).

MTGase catalyzes acyl-transfer reactions, which covalently cross-link the lysine and glutamine ends of various protein molecules, forming larger protein complexes from small protein substrates (62, 71, 76, 116). Most often a cross-link is catalyzed between glutamine and lysine, the ε-(γ-glutamyl) lysine cross-link (26). The protein cross-linkings not only

improve the yogurt structure but also produce non-protein nitrogen, which could contribute to increased growth of *S. thermophilus*.

A probiotic goat milk yogurt with improved texture by enzymatic cross-linking has been developed in the co-author's laboratory at the University of Vermont. The results show that the consistency of yogurt was greatly improved by the addition of MTGase. Scanning electron micrographs revealed that the microstructure of the yogurt treated with MTGase became increasingly dense as the MTGase level was increased from 0 to 2 and 4 units per gram protein. Enzymatic cross-linking did not have a significant impact on the survival of the probiotic cultures, *L. acidophilus*, *L. casei*, and *Bifidobacteria* ($P>0.05$) or on the chemical composition of the yogurt, including total solids, ash, lactose, protein, fat, and mineral content ($P>0.05$). Enzymatic cross-linking by MTGase appears to be an effective method to improve goat milk yogurt consistency (25).

4.3.5 Therapeutic Properties of Yogurt

Yogurt is made from the symbiotic growth of two bacteria: *Streptococcus thermophilus* and *Lactobacillus delbrueckii* ssp. *bulgaricus*. These bacteria cannot survive gastric passage or colonize the gut. For this reason, yogurt-containing bacteria such as *Lactobacillus acidophilus* and *Bifidobacteria* are popular due to their potential therapeutic benefits (98).

There are two main genera of bacteria that are known for their therapeutic properties in the human body: *Lactobacilli* (*L. acidophilus* being the most well known) and *Bifidobacteria* (14). Both are natural inhabitants of the human body, although each inhabits a specific location and provides a number of unique benefits. These bacteria, which when consumed survive and inhabit various areas of the digestive tract, have been labeled probiotic bacteria. They possess the ability to create positive changes in the equilibrium populations and metabolic activity of the indigenous microbiota of the human digestive tract (14) and therefore improve the overall health of the host.

Lactobacilli are gram-positive, catalase-negative rods that often occur in long-chains; they are typically microaerophilic, as in the case of *L. casei*, but many true anaerobic strains exist (49). *Lactobacilli* are natural inhabitants of the terminal ileum, where they attach themselves to epithelial cells (14). There they can prevent the attachment and growth of bacteria involved in many intestinal infections (108). They also metabolize lactose, which has been shown to protect lactose-intolerant individuals from experiencing adverse symptoms (108).

Bifidobacteria are the dominant bacteria in the stools of breast-fed infants. They are gram-positive, non-spore forming, strictly anaerobic and pleomorphic (can assume a number of different shapes) fermentative rods, often y-shaped. Their optimum growth temperature is 37–41°C, with a minimum growth temperature of 25–28°C and a maximum of 43–45°C. The optimum pH for growth of *Bifidobacteria* is 6.5–7.0. They do not grow at pH 4.5–5.0 or 8.0–8.5 (100).

Bifidobacteria are natural inhabitants of the large intestine. According to Roy (100), there are 33 species of Bifidobacteria, 12 of which have been found in humans. The main species found in the human colon are *B. adolescentis, B. bifidum, B. infantis, B. breve*, and *B. longum*. *Bifidobacteria* constitute 5–10% of total colon flora of healthy children and adults. They produce mucin, a complex polysaccharide, which eases the passage of feces and prevents attachment of harmful bacteria to the lumen. Suppression of the growth of harmful bacteria could possibly lower the risk of carcinogenic compounds being liberated during fermentation in the colon (100).

The *Bifidobacteria* also produce lactic and acetic acids in the ratio of 3:2 (90). The organic acids lower the pH in the large intestine, making conditions unfavorable for the growth of many putrefactive and pathogenic organisms. *Bifidobacteria* have been used in the treatment of diarrhea in children and constipation in the elderly. *In vitro* and animal research has demonstrated the infection prevention, immunity activation, anti-tumorigenic effects, and vitamin production of *Bifidobacteria* (90). It has been claimed that ingestion of specific *Bifidobacteria* could also contribute to reestablishment of *Bifidobacterial* flora in humans after antibiotic therapy (100).

The consensus of many sources is that at least 10^6 colony-forming units (live bacteria) of these probiotic bacteria must be contained per gram yogurt to produce health benefits (98, 100, 108). In addition to consuming yogurt with adequate live and active

bacteria, it is also important that a significant amount of yogurt, at least 200–300 ml per week, be consumed in order to receive the therapeutic benefits (108).

A number of factors have been claimed to affect the viability of probiotic bacteria in yogurt, including acid and hydrogen peroxide produced by yogurt bacteria, oxygen content in the product, and oxygen permeation through the package (103). Although *L. acidophilus* and *Bifidobacteria* can tolerate acid, a rapid decline in their numbers in yogurt has been observed. *Bifidobacteria* are not as acid tolerant (growth of the *Bifidobacterium* spp. is retarded below pH 5.0) as *L. acidophilus* (growth ceases below pH 4.0). This is especially a problem because *L. delbrueckii* ssp. *bulgaricus*, used in yogurt making, continues to produce lactic acid during fermentation and refrigerated storage. This process is known as post acidification, which is found to cause loss of viability of probiotic bacteria (103).

It is therefore important for manufacturers and retailers to confirm the viable count of these organisms in fermented milk products in the presence of other species (90) and throughout the shelf life of the product. Due to the viability problems associated with *L. acidophilus* and *Bifidobacteria* during storage, the recent trend is to add *L. casei* as an adjunct bacterium to yogurt and/or probiotic cultures (98). *L. casei* is claimed to have probiotic benefits and to be more stable than *L. acidophilus* or *Bifidobacteria*.

Yogurt has become a highly popular fermented food product for the past two to three decades. The trend of per capita consumption in the United States greatly increased from 0.12 kg in 1960 to 1.62 kg in 1984 and continues to grow (17, 70). Reports have shown that fermented dairy products are more nutritious than the milk from which they are made (7, 18, 63). The greater nutritional value of these products is attributable to the increased production or availability of certain nutrients and to the prehydrolysis of the major milk constituents by lactic starter cultures, rendering them more digestible (18, 36, 63, 75).

Yogurt has been used as a therapeutic agent. Its most common use has been in gastrointestinal disorders such as diarrhea, infantile gastroenteritis, and constipation (18, 75). Yogurt was also shown to have greater hypocholesterolemic effect than milk because the former contains hydroxymethyl glutarate, which inhibits cholesterol synthesis from acetate (68). Calcium, orotic acid, lactose, and casein have all been suggested as possible hypocholesterolemic factors (18, 45).

Qualitative and quantitative changes in vitamin, protein, carbohydrate, and bacterial content in yogurt have been reviewed (10, 30, 60). With all methods of fortification, the percent of protein in yogurt is increased, thus it will almost invariably have a higher level of protein than milk (18). Little attention has been paid to the nutritive value of the bacterial cell mass in yogurt that constitutes about 1% of the dry matter in the product, and the bacterial protein may be a rich source of essential amino acids (18, 23).

4.4 Other Goat Milk Products and Their Processing Technologies

4.4.1 Other Fermented Goat Milk Products

There are many other fermented goat milk products produced and consumed, including buttermilk, acidophilus, sour dip, and kefir. The manufacturing procedures of these other important fermented goat milk products are summarized in Table 2.40. Different culture microorganisms are used for these different types of fermented milk products, and incubation is stopped at different desired acidity, as shown in Table 2.40.

4.4.1.1 Buttermilk Buttermilk is usually made from skim milk using the by-product from churning butter out of sour cream. Goat buttermilk is made from skim milk (less than 0.5% fat); yogurt made from whole milk (3.25% fat), low fat milk (0.5 to 2.5% fat), or skim milk; sour cream must contain 18% fat in most states (67). Sour dip is made from half-n-half milk (11% fat) using the same kind of culture organisms used for buttermilk manufacture.

4.4.1.2 Acidophilus milk Acidophilus milk can be made by the activity of *Lactobacillus acidophilus*, which is capable of converting a greater proportion of the lactose to lactic acid (2%). It is pasteurized milk or low-fat milk inoculated with *Lactobacillus acidophilus*, which destroys other competing bacteria antagonistic to man in the lower intestine. These organisms have the ability to implant themselves in the large intestines, survive the

low surface tension and change nutrients (55). In the past the popularity of this product was limited by the flavor developed during fermentation. A more recent product has overcome this by adding the live organisms to pasteurized milk and refrigerating to prevent subsequent fermentation and flavor development (55). In manufacture as shown in Table 2.40, skim milk or partially defatted milk is sterilized in an autoclave at 120°C for 20 min (15 psi), then tempered to 38°C. Next, a 5% inoculation of active L. acidophilus starter is introduced. The mixture is incubated at 38°C for 18 to 24 hr until a curd forms with about 1.0% titratable acidity.

4.4.1.3 Kefir Kefir is an acidic, slightly foamy product, made from pasteurized and fat-standardized or decreamed goat milk, which has passed through a combined acidic and alcoholic fermentation of symbiotic lactic acid bacteria and yeast "kefir grains" (55). The finished product, kefir contains 0.6-0.8% lactic acid, 0.5-1.0% alcohol and carbon dioxide. The dominant microbial flora of Kefir consists of *Saccharomyces kefir, Torula kefir, Latobacillus caucasicus, Leuconostoc spp*. and lactic acid streptococci. Yeasts represent 5 to 10 % of the microbial population (55).

4.4.1.4 Ghee and butter-like products Ghee is an Indian (and Middle East) clarified butterfat product which is manufactured by fermenting whole milk into curd and churning out butter, followed by heat clarification at 105-145°C (13, 55). In the Middle East, casein is produced from skimmed milk. In Iran it is called *Kashk* or dried butter. It is used as food ingredient or in the form of meal as animal feed. In India, Chhana, Khoa and Paneer (a cheese) are also made from goat milk. Chhana is an acid- and heat-coagulated milk product.

4.4.1.5 Sweets from goat milk Sweet products made of goat milk are popular in Mexico, Norway and India. In Mexico, the *Cajeta* a thick liquid of caramelized milk with sugar added, which is popular and sold as such or dried as small tarts. In Latin American countries, other sweets made of goat milk called, "*dulces*" are produced in similar ways. In Norway, *Gjetost* is a sweet caramel-colored product with a texture in which lactose crystals may be often noted. The processing of *gjetost* is similar to the *Cajeta* except that the casein is removed while the original lactose is used instead of sugar. In India, a chhana-based sweet is made by kneading chhana and cooking in sugar syrup over medium heat. Khoa is a heat-desiccated indigenous milk product used in the preparation of a variety of sweets.

4.4.2 Evaporated and powdered goat milk products

Evaporated and powdered goat milk products are manufactured in U.S. and New Zealand, marketed around the world, but very little research data and reports are available on these products (83). Significant quantity of powdered goat milk is commercially produced especially in the United States and New Zealand. Evaporation is usually done under reduced pressure, primarily to allow boiling at a lower temperature and thus prevent damage due to heating. Figure 2.36 displays the flowcharts for manufacturing procedures of evaporated and powdered milk. The figure also shows the processing steps for the other long shelf-life products such as sterilized fluid milk and coffee creamer.

The principal components of an evaporation plant are: (a) Evaporation chambers operating as heat exchangers, (b) Equipment for the production and maintenance of a vacuum, (c) Separators for the separation of vapor and concentrate, and (d) A condenser for the vapor (16). The basic principles of the evaporation system are based on the fact that steam or vapor is condensed on one side of a metal surface in the heat exchangers, causing the liquid on the other side to evolve vapor. Evaporated goat milk would be processed using the similar evaporation facilities as performed for evaporated cow milk products. General composition of evaporated cow milk has 7.5-9.0% fat, 17.5-22% milk solids nonfat, and 25-31% total solids, while that of goat milk counterpart is shown in Table 2.41.

For powdered milk, there are two different methods of manufacture of dried milk products: roller drying and spray drying process. In the roller drying process, milk or milk concentrate is applied in a thin film on the surface of a rotating, steam-heated metal drum. During the rotation, the milk film dries and is continuously scraped off by a stationary knife located

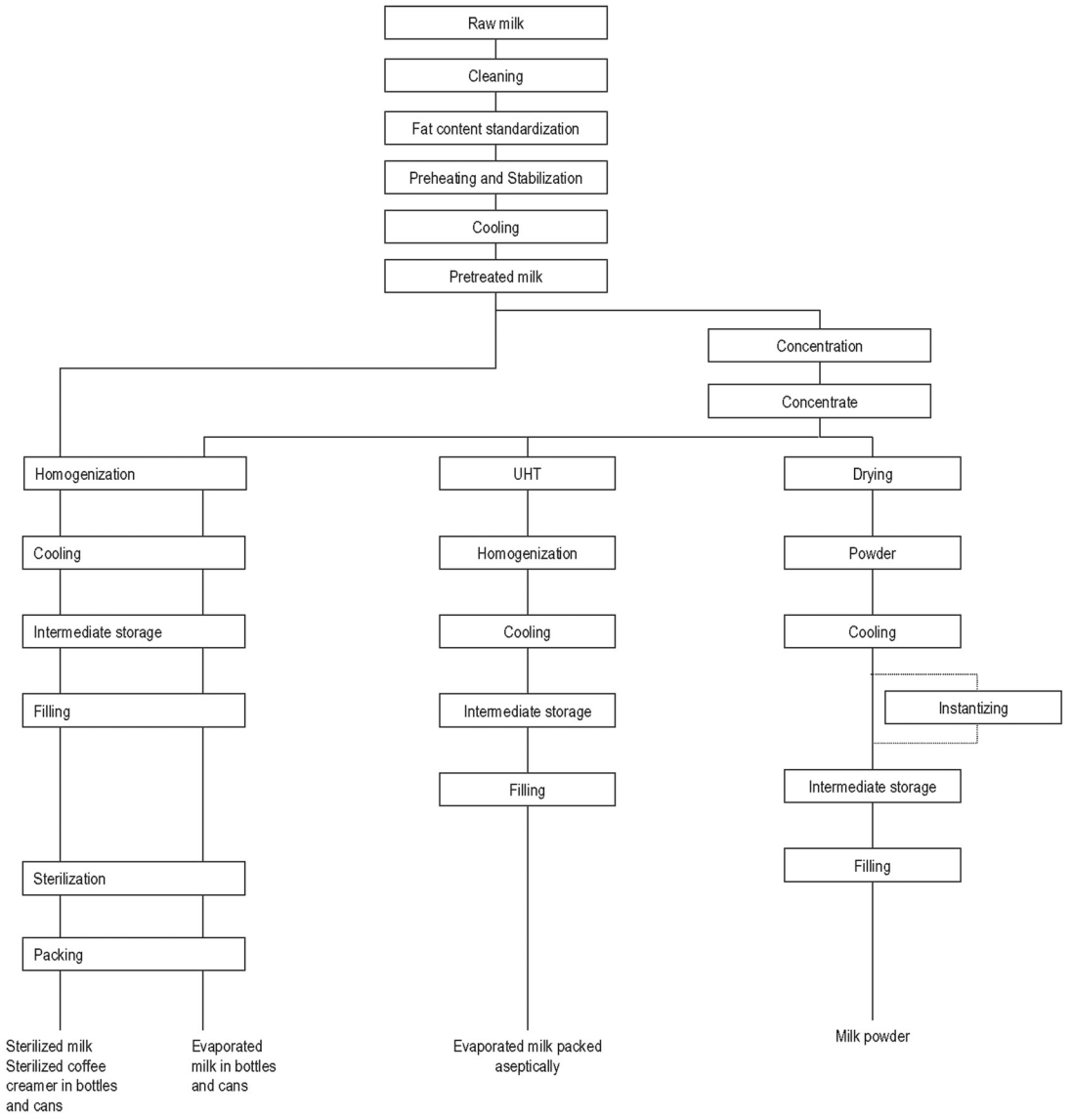

Figure 2.36. Flowchart for manufacture of evaporated and powdered milk along with sterilized fluid milk processing procedures. Adapted from E. Spreer (106).

opposite the point of application of the concentrate. The spray drying process involves the transformation of fluid state into a dried particulate by spraying the milk into a hot drying medium. Four process stages of conventional spray drying include (i) atomization of milk into a spray; (ii) spray drying air contact (mixing and flow); (iii) drying of spray (water evaporation); and (iv) separation of dried product from the air (16).

Powdered products, including whole milk, skim milk, whey, cream, ice cream mix, protein concentrates, and infant foods, are produced by several methods of drying liquid such as spray drying, drum drying, and freeze drying.

Table 2.41. Basic Nutrient Contents (%) of Commercial U.S. Goat Milk Products (Wet Basis)

Goat milk product	Total solids		Protein		Fat		Carbohydrates		Ash	
	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD
Fluid milk										
Recent study[a]	11.3	0.05	2.92	0.09	3.40	0.10	4.15	0.13	0.79	0.01
USDA[b]	13.0	0.15	3.56	0.03	4.14	0.05	4.45	-	0.82	0.01
Evaporated milk										
Recent study[a]	20.85	0.05	6.11	0.33	6.75	0.05	6.56	0.53	1.43	0.10
USDA[c]	25.86	0.08	6.81	0.03	7.56	0.01	10.04	-	1.55	0.02
Powdered milk										
Recent study[a]	94.1	0.56	27.0	0.45	28.2	1.35	32.0	0.33	6.77	0.15
USDA[d]	97.5	0.13	26.3	0.18	26.9	0.25	38.4	-	6.08	0.09
Yogurt[e]										
Plain	11.5	2.56	3.99	0.12	2.25	0.13	4.49	0.56	0.82	0.02
Blueberry	17.7	2.34	3.37	0.13	1.18	0.17	12.6	2.72	0.86	0.09
Cheese[f]										
Soft										
Plain	40.2	6.81	18.9	5.26	22.5	4.37	-	-	1.74	0.97
Herb	40.9	2.11	17.3	2.26	21.8	2.13	-	-	1.60	0.61
Hard										
Cheddar	58.3	1.76	30.3	0.56	26.6	1.13	1.40	-	3.60	0.13
Blue	74.1	1.62	20.2	0.35	31.8	1.06	-	-	3.32	0.36

[a]Means of eight fluid milk (two brands, four different lots), 12 evaporated milk (two brands, six different lots), and 10 powdered milk (two brands, five different lots) samples, respectively. Data from Park (83).

[b]Data for fluid goat milk from *USDA Handbook No. 8-1* (95).

[c]Evaporated canned milk, from *USDA Handbook No. 8-1* (95).

[d]Powdered whole canned milk, from *USDA Handbook No. 8-1* (95).

[e]Park (81).

[f]Park (78).

X = Mean; SD = Standard deviation.

4.4.3 Frozen Goat Milk Products

Ice cream was manufactured from goat milk in Georgia and Texas. However, only research data from the University of Georgia has been reported (67). The three formulations made for three flavors of goat ice cream were: (i) French vanilla mix with 14% fat, 10% MSNF, 18% sweetener (12% sucrose, 6% 36-dextrose equivalent corn syrup solids), 1.4% egg yolk solids, and 0.25% stabilizer-emulsifier; (ii) chocolate mix: 14.6% fat (0.6% cocoa fat), 9% MSNF, 20% sweetener (14% sucrose, 6% 36-DE corn syrup solids), 3% medium fat cocoa, and 0.22% stabilizer-emulsifier; (iii) premium white mix: 15% fat, 10% MSNF, 18% sweetener and 0.25% stabilizer-emulsifier.

4.4.4 Cosmetic Goat Milk Products

Recently, cosmetic products made from goat milk, such as goat milk soap and hand lotion, have been increasingly popular. These products are commercially produced in the United States and other countries such as Switzerland. An Internet search on goat milk soap shows a list of more than 5,000 references. The number of home-based goat milk soap businesses has been tremendously increased in recent years and is now estimated to generate an annual revenue of billions of dollars in the United States. Ingredients required for home-made style goat milk soapmaking include: lye, goat milk, borax, oatmeal, and pork lard or vegetable oil, among others.

5 CHEMICAL COMPOSITION OF DAIRY GOAT PRODUCTS

The basic nutrient composition of goat milk resembles cow milk, where both milks contain substantially higher protein and ash but lower lactose content than human milk (40, 50, 79). Goat milk reportedly has higher fat and ash contents in the tropics than does its cow counterparts (40, 79), although Holstein cow milk fat is similar to that in the milk of Swiss goats. On the other hand, literature on basic and other nutrient compositions of different types of manufactured goat milk products has been very limited.

Table 2.42. Profiles of Mineral Compositions among Different Commercial Goat Milk Products (ppm, Wet Basis)

Goat milk product	Major mineral									
	Ca		Mg		P		K		Na	
	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD
Fluid milk[a]	924	93	106	6.26	1113	72	1647	107	685	60.6
Concentrated milk[a]	2110	166	233	28.7	1887	117	2913	679	876	253
Powdered milk[a]	8199	786	1087	104	7939	911	15378	1237	2890	224
Yogurt[b]										
Plain	1405		149		1253		1417		736	
Blueberry	1287		148		1164		1630		732	
Cheese[c]										
Soft										
Plain	1720	1790	146	42.2	2750	1070	258	276	4160	1870
Herb	1120	336	153	39.1	2250	312	350	293	3360	1370
Hard										
Cheddar	5990	252	420	16.0	5260	1240	110	54	3610	245
Blue	8140	896	349	1.2	5750	1090	888	263	9240	684

[a]Park (83); Means of eight fluid milk (two brands, four different lots), 12 evaporated milk (two brands, six different lots), and 10 powdered milk (two brands, five different lots) samples, respectively.

[b]Park (81); the original report does not have SD values.

[c]Park (78).

5.1 Composition of Fluid Goat Milk

A recent study on the compositions of different commercial goat milk products (83) (Table 2.41) revealed that the fluid goat milk contained lower amounts of all basic nutrients than those values reported in previous studies (40, 50, 79, 95). The notably lower protein, fat, and ash contents in the fluid goat milk of the study compared to those data reported in the USDA Handbook No. 8-1 (95) apparently resulted in lower total solids content of the commercial fluid milk product. These compositional differences might have been attributable to differences in sources of original milk used for processing the products, because the nutrient compositions of goat milk can be greatly influenced by several factors, such as season, stages of lactation, breed, diet, individual animal, and environmental management conditions (22, 40, 50, 53, 78, 79, 84, 109).

Mineral concentrations of most of the major and trace minerals were proportionally higher in accordance with the total solids contents of each product, with a few exceptions (Table 2.42). The Ca concentration of the fluid milk was unusually low among the major minerals in the recent study (83). The mean Ca and P contents (ppm, wet basis) were 924 and 1113, whereas on the dry basis the corresponding minerals were 104 and 125, respectively. The normal ratio for the levels of Ca to P in milk has been considered as 1.2:1 (50), whereas the ratio of the fluid goat milk in the recent study was 0.83:1. The reason for this significantly lower Ca in the commercial fluid goat milk is not known. Mineral contents of goat milk from French-Alpine and Anglo-Nubian breeds showed higher Ca, P, K, Mg, and Cl, and lower Na and S levels than bovine milk (84).

As far as trace minerals are concerned, there were no indications of abnormal levels of Fe, Mn, Cu, Zn, and Al in the fluid milk of the recent study (Tables 2.42 and 2.43). Concentrations of these trace minerals were proportionally increased with the corresponding percentages of total solids in the different goat milk products. The mean Fe content (ppm, wet basis) of fluid goat milk in the study (83) was 0.55 mg/liter. This result is comparable to previous reports, where the levels in mature fresh goat milk were 0.56 mg/liter (22) and 0.64 mg/liter (53), respectively. However, the average Fe content of

Table 2.42. Continued

Trace mineral											
S		Fe		Mn		Cu		Zn		Al	
$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD
21.3	8.53	0.55	0.065	0.033	0.004	0.39	0.12	3.10	0.302	0.955	0.174
67.5	8.23	7.28	4.96	0.13	0.07	1.46	0.62	7.84	0.73	4.09	2.45
147.4	64.5	3.54	0.93	0.43	0.11	1.55	0.54	32.1	3.95	6.92	3.27
240		1.02		0.345		0.303		3.37		3.54	
730		1.96		0.283		1.095		4.10		4.97	
354	289	17.8	17.5	0.955	0.106	7.40	3.09	9.05	5.75	14.8	14.7
299	102	17.7	10.3	1.056	0.327	6.68	1.86	7.75	2.33	17.7	10.3
780	339	7.68	1.66	0.929	0.041	4.93	0.33	6.53	5.72	14.9	3.02
805	324	15.2	8.18	0.933	0.023	5.60	0.83	6.89	3.79	15.2	8.18

Table 2.43. Profiles of Mean Mineral Concentrations of Commercial Goat Milk Products (ppm, Dry Basis)

	Macro						Trace				
Products[a]	Ca	Mg	P	K	Na	S	Fe	Mn	Cu	Zn	Al
Fluid milk	103.9	11.93	125.2	185.3	77.06	2.40	0.062	0.004	0.044	0.349	0.107
Evaporated milk	439.9	48.50	393.4	607.4	182.6	14.07	1.518	0.027	0.304	1.635	0.853
Powdered milk	7715	1023	7471	14471	2719	138.7	3.33	0.405	1.458	30.21	6.512
Yogurt											
Plain	161	17.7	144	163	84.6	27.6	0.117	0.040	0.035	0.388	0.407
Blueberry	227	26.2	206	289	130	129	0.347	0.050	0.494	0.726	0.880
Cheese											
Plain Soft	691	58.7	1105	104	1672	142	7.16	0.384	2.97	3.64	5.95
Cheddar	3492	250	3067	64.1	2105	465	8.86	0.541	2.87	3.81	8.69

[a]Percent moisture for fluid, condensed, powdered, plain yogurt, blueberry yogurt, plain soft, and cheddar cheese were: 88.75, 79.15, 5.9, 88.5, 82.3, 59.8, and 41.8%, respectively.

Data from Park (83).

Alpine and Nubian breeds during the five-month experimental period was 1.7 ppm (mg/liter) (85). The mean Zn concentration (wet basis) in the commercial fluid goat milk was 0.31 mg/100 g (3.10 ppm; Table 2.41). This level is slightly lower than the report of Löennerdal et al. (65), where the average Zn concentrations in pasteurized cow and goat milks were 0.4 and 0.55 mg/100 ml, respectively. Zinc contents of commercial goat milk products in this study generally were higher than the other trace minerals.

5.2 Composition of Evaporated and Powdered Goat Milk

The evaporated (condensed) goat milk product had lower total solids and other basic nutrient contents compared to the evaporated cow milk products reported in the USDA Handbook No. 8-1 (Table 2.41). This result suggests that the commercial evaporated goat milk product contained higher moisture than the corresponding cow milk product. The differences in moisture between the two products might be accountable for the differences in the extent of evaporation and/or possible laboratory errors resulting from poor sampling practices such as insufficient homogenization before analysis.

The protein, fat, and ash contents of the commercial powdered goat milk were slightly higher than those of the cow milk counterparts, while the total solids contents were slightly higher in the cow product (Table 2.41). Goat milk is generally higher in protein, fat, and phosphate than is cow milk, although its composition can vary considerably with many factors including diet, breeds, and environmental management conditions (40, 79).

The evaporated milk in the recent study (83) contained unusually high iron and aluminum contents. The mean Fe content of the condensed milk was 7.28 mg/liter, which is significantly higher than that of powdered milk (Table 2.42). This high level of Fe indicates that there might be a strong possibility of Fe contamination from the metal container of the condensed product, as suggested in the previous report (78). All trace mineral and major mineral contents of fluid and evaporated milk were lower than those of the powdered milk product (Tables 2.42 and 2.43).

5.3 Composition of Goat Milk Yogurt

The commercial goat milk yogurt contained higher nutrients than the corresponding fluid milk analyzed in the recent study as expected (Table 2.41). The blueberry flavored goat milk yogurt showed greater total solids and carbohydrates, and lower fat than plain yogurt, due to the addition of the fruit to the product. Basic nutrient compositions of the five types of goat milk yogurt for the combined data of the three manufacturers, and those of separate variety data from the individual company, were studied (81). It was natural that the plain type of goat yogurt contained less ($P < 0.05$) total solids and carbohydrate contents than the fruit flavored types or varieties. On the other hand, percentages of protein and fat in plain yogurt were greater ($P < 0.05$ or 0.01) than the 4 types of fruit flavored ones. With fortification and fermentation (i.e., evaporation, skim milk powder, and increased bacterial mass) in manufacturing, the percent protein in yogurt is increased, thus it will almost invariably have a higher level of protein than milk (18). The higher protein content in yogurt is also strongly supported by the fact that bacterial cell mass constitutes approximately 1% of the dry matter in yogurt (18, 23).

Reports on fat contents of cow milk yogurt (60, 95) indicate that the products made from nonfat or low-fat milk had a range of 1.08 to 1.89%, where plain yogurt variety had slightly higher fat compared to the fruit-flavored ones. The fat contents in plain varieties of goat yogurt showed the same trend as the cow milk counterparts (81) (Table 2.41). USDA Agricultural Handbook No. 8-1 (95) showed that cow milk yogurt, especially in the fruit flavored varieties, contained 5–8% higher total solids than the goat counterparts in the study by Park (81), which may imply higher amounts of fruit added to the former than the latter.

The ash content of yogurt showed that the cherry-almond type was lower ($P < 0.05$) than the other ones, and differences among all the other types were not significant (81). However, when the individual variety from each manufacturer was compared, there were significant ($P < 0.05$) differences between varieties, showing that the blueberry variety from one company was the highest and the cherry-almond variety of the other company was the lowest (81).

There were no differences between types of yogurt products in the pooled data of levels of K, Na and S, whereas significant differences in these minerals between yogurts were observed between each variety from separate companies (81). This result

may stem from variabilities in composition of original milk, fruit additives, and processing procedures of different manufacturers. For Ca, Mg, and P concentrations, there were differences ($P < 0.05$) between varieties of yogurt for the pooled or separate manufacturer data (81) (Tables 2.42). In light of trace mineral concentration, only Fe, Zn and Al levels were different between manufacturers.

Sulfur (S) contents of yogurt products (either plain or fruit flavored) were significantly greater than those of fluid milk (Tables 2.42 and 2.43), indicating that S levels had been increased during yogurt manufacture from fluid milk. Qualitative and quantitative changes were observed in vitamin, protein, carbohydrate, and bacterial contents in yogurt (10, 30, 60). Elevated S contents in goat milk yogurts may be attributed to the increased S-containing proteins from the bacterial cell mass or additional S-containing proteins in the products synthesized by the bacterial culture during the fermentation process.

5.4 Composition of Goat Milk Cheeses

5.4.1 Basic Composition of Goat Cheeses

In a study of nutritional evaluations of more than 30 varieties of commercially manufactured goat cheeses from 11 states of the United States, most varieties of goat cheese were shown to have higher moisture contents compared to corresponding or similar types of cow cheese (Table 2.44) (78). Cheddar cheese from goat milk had higher moisture and protein and lower fat content than from its cow milk counterpart listed in the Agricultural Handbook No. 8-1 (101). Other varieties such as Blue, Camembert, and Feta cheeses had comparable levels of basic nutrients compared to the corresponding cow cheeses, with some variations.

In the same study (78) the mean percentage of moisture, fat, protein, and ash for plain soft, semi-soft, hard, pepper, garlic, and herb cheeses were reported (Table 2.44). Garlic cheeses contained significantly greater moisture than the other five groups of cheeses. Percent ash, protein, and fat were higher ($P < 0.01$) in semi-soft and hard cheeses than in soft plain and spice-added cheeses.

5.4.2 Mineral Composition of Goat Cheeses

There were wide variations in concentrations of P, K, Ca, Na, Cl, Fe, Al, and Zn among and within varieties of the 30 different cheeses (78) (Table 2.44). The spice cheeses had significantly lower macrominerals than did the plain soft cheeses. The differences in trace minerals among six types of cheeses were minimal except for Zn. The high Fe and Al contents in semi-soft and other cheeses suggest the possibility of contamination of those minerals from processing utensils during manufacturing of the farmstead cheeses. Similar observations were reported in previous studies on goat milk yogurt (81).

Among the major minerals, potassium (K) concentrations showed the most interesting and marked differences between the different goat milk products (Tables 2.42 and 2.43). The levels of K in plain goat milk yogurt and plain soft cheese were lower than in fluid milk. Furthermore, the level of K in goat milk Cheddar cheese was significantly lower than that of fluid milk. The other manufactured products having higher total solids contents explicitly displayed the higher levels of all other minerals tested in this study. These results imply that considerable amounts of K may be lost into whey during manufacturing processes of the products.

Sodium (Na) concentration revealed that both soft and hard cheeses had substantially higher levels of the mineral compared to the other products (Tables 2.42–2.44). This result suggests that significant amounts of salt (NaCl) were added to the cheese products during the manufacturing processes, as shown in the previous report (78). Other manufactured products including fluid milk appeared to contain normal levels of Na, and their concentrations increased correspondingly with the increased levels of total solids in the products.

The S contents of cheeses, especially hard cheeses such as Cheddar, were considerably greater than those of powdered products (Tables 2.42 and 2.43), suggesting that there were significant increases in S contents in cheese products even if the cheeses contained significantly less total solids than the powdered milk products. Previous reports indicated that fermented dairy products are more nutritious than the original milk from which they are made (7, 18, 63), implying that certain nutrients such as S-containing proteins may be synthesized by the bacteria during the fermentation processes of cheeses and goat yogurts.

5.4.3 Organic Acid Composition of Goat Milk Cheeses

In a recent study on organic acid composition of commercial plain soft (PS) and Monterey Jack (MJ)

Table 2.44. Nutrient Profiles of Selected Varieties of Commercial Goat Milk Cheeses (U.S. Products)

Goat cheese variety	H_2O	Fat	Protein	Ash	S	P	K	Mg	Ca	Na	Cl	Fe	Al	Mn	Cu	Zn
	g/100 g				mg/100 g							μg/g				
Fresh soft, plain	59.8	22.5	19.8	1.74	3.54	275	25.8	14.6	172	416	293	17.8	14.8	0.96	7.40	9.05
Fresh soft, garlic	64.3	18.3	16.7	1.34	4.10	247	15.2	17.2	117	331	145	13.0	38.4	0.88	8.08	14.4
Fresh soft, pepper	57.3	22.9	21.6	1.32	4.13	236	27.8	17.9	107	298	201	28.5	44.5	1.22	6.50	8.76
Fresh soft, herb	59.1	21.8	17.3	1.60	2.99	225	35.0	15.3	112	336	165	17.7	9.1	1.06	6.68	7.75
Feta	52.3	25.3	25.1	4.30	3.49	544	62.2	17.6	639	916	1260	6.1	14.9	0.97	6.46	15.5
Camembert capri	47.3	28.8	29.1	1.67	2.37	264	7.0	21.8	229	279	301	8.9	12.7	0.90	5.38	16.3
Blue	25.9	31.8	20.2	3.32	8.05	575	88.8	34.9	841	924	398	15.2	36.2	0.93	5.60	6.89
Cheddar	41.7	26.6	30.3	3.60	7.80	526	11.0	42.0	599	361	1030	7.7	14.9	0.93	4.93	6.53
Shepherd's hard	31.6	33.1	28.9	3.93	4.13	737	54.4	61.7	1035	285	114	26.7	12.3	3.98	6.56	18.7
Montasio's hard	25.9	36.8	31.9	3.52	4.87	720	42.0	55.3	990	260	96	11.0	15.9	1.06	5.99	41.3[a]
Ancho chile	42.3	29.8	22.2	4.11	3.17	688	53.3	70.5	939	464	162	24.8	16.1	1.07	6.44	9.13

[a]Extremely High Value.
Data from Park (78).

goat cheeses, Park and Lee (89) reported that there were differences ($P < 0.05$) in tartaric, formic, and uric acid contents of PS cheese between fresh and frozen-thawed treatments (Table 2.45). Freezing caused increases ($P < 0.05$) in formic and uric acids and decreases in tartaric acid in the PS cheese. The changes in organic acid contents of the soft goat cheese observed in this study are in contrast to the results reported by Califano and Bevilacqua (11), who found no significant effect of freeze-cycle on the variations in organic acid contents in their cow milk Mozzarella cheese. Effects of aging (refrigerated storage at 4°C for 28 days) on changes in organic acids in PS cheese showed that only three acids (orotic, malic, and butyric) were affected; all other acids were not influenced by the refrigerated aging (Table 2.45). Orotic acid content was highest ($P < 0.05$) at d 0 storage and reduced with advanced aging, while butyric and malic acids were elevated ($P < 0.05$) by the prolonged four weeks of refrigerated storage.

In Monterey Jack (MJ) cheese, frozen and thawed cheese had higher ($P < 0.05$) acetic, butyric, citric, malic, propionic, and pyruvic acids compared to the unfrozen control cheese (Table 2.45). Pyruvic acid was found only in MJ cheese, and its initial content was highest and gradually decreased with refrigerated aging. On the other hand, the levels of acetic, butyric, malic, and orotic acids were elevated by aging time and greatest at 28 d among the three different refrigerated storage periods. Changes in other organic acids and their unknown isomers in MJ were not significant, while a butyric-like isomer peak was in highest amount. Pyruvic and butyric acids were two distinct and solid organic acids in MJ cheese.

Table 2.45. Comparison of Mean Organic Acid Contents of Unfrozen (Fresh) and Frozen-Thaw Plain Soft with Monterey Jack Goat Milk Cheeses Aged at 4° C for Four Weeks

	Unfrozen			Frozen-thaw		
Organic acids	0 d	14 d	28 d	0 d	14 d	28 d
Plain soft goat cheese						
Tartaric acid[1,2]	1.72[a]	1.70[a]	1.70[a]	1.53[b]	1.45[b]	1.48[b]
Formic acid[1,2]	0.79[b]	0.85[b]	0.83[b]	1.28[a]	1.22[a]	1.21[a]
Orotic acid[2]	0.042[a]	0.011[b]	0.011[b]	0.043[a]	0.014[b]	0.013[b]
Malic acid[2]	1.87[b]	1.99[ab]	2.10[a]	1.82[b]	2.05[a]	1.87[b]
Lactic acid	10.72	10.83	10.98	9.58	10.77	10.45
Acetic acid[2]	5.90	6.96	7.10	7.50	6.79	6.46
Citric acid	0.52	0.67	0.72	0.71	0.73	0.65
Uric acid[1,2]	0.017[b]	0.02[b]	0.015[b]	0.029[a]	0.038[a]	0.034[a]
Propionic acid[2]	0.71	0.79	0.69	1.28	0.60	0.83
Butyric acid[2]	0.65[b]	0.81[b]	0.94[a]	0.01[c]	0.83[b]	1.24[a]
Monterey Jack goat cheese						
Formic acid[2]	2.66	2.66	2.62	2.70	2.20	2.44
Pyruvic acid[1]	1.89[b]	1.29[bc]	1.11[c]	2.04[a]	1.29[bc]	1.11[c]
Malic acid[1,2]	1.13[b]	1.00[b]	1.38[b]	1.50[ab]	1.82[ab]	2.34[a]
Lactic acid	10.45	9.56	9.16	9.28	10.00	10.24
Acetic acid[1,2]	1.78 [b]	1.86[b]	2.43[a]	1.96[b]	2.19[b]	2.82[a]
Orotic acid[2]	0.009	0.008	0.011	0.006	0.011	0.015
Citric acid[1]	1.17[ab]	0.85[b]	0.77[b]	0.91[ab]	1.31[a]	1.32[a]
Uric acid[2]	0.062	0.072	0.064	0.064	0.056	0.054
Propionic acid[1,2]	3.23[c]	3.36[c]	5.96[b]	5.43[b]	5.53[b]	7.16[a]
Butyric acid[1,2]	10.56[b]	10.58[b]	11.94[a]	10.50[b]	13.04[a]	14.04[a].

[1]Mean difference between unfrozen and frozen-thaw groups is significant ($P < 0.05$).

[2]Differences between soft and Monterey Jack cheeses are significant ($P < 0.05$ or 0.01).

[a,b,c]Means with different superscript within same row are significant ($P < 0.05$).

Adapted from Park and Lee (89).

The differences in organic acid concentrations between the two varieties of goat cheeses were significant ($P < 0.05$) for all known organic acids except for citric and lactic acids (Table 2.45). No differences were found in pH and acid degree values (ADV) between fresh and frozen-thawed PS and MJ cheeses, while lipolysis gradually increased during four weeks of refrigeration storage at 4°C.

5.5 Mineral Ratios in Goat Milk Products

With regard to mineral ratios (Ca:P, Ca:Mg, Fe:Zn, and Na:K) of goat milk products, the fluid milk and plain soft cheese revealed unusually low Ca:P ratios (0.83 and 0.625) as compared with the other products, owing to the considerably lower Ca contents of the products (Tables 2.42 and 2.43). Other products showed the Ca:P ratios closer to 1.2:1, which is considered to be the normal ratio.

Among the four mineral ratios for commercial goat milk products, Ca:Mg ratio was the highest except for the Na:K ratio in cheeses, which is in agreement with the previous report on commercial cheeses (78) (Table 2.44). In contrast, the Na:K ratios were lower than Ca:Mg and Ca:P ratios except for the cheeses, which were substantially higher than the others (Table 2.46). As for Fe:Zn ratios, the values of the evaporated milk and cheeses were significantly higher than those of the other tested goat products, which may be attributed to the possible contamination of Fe from the processing utensils as well as the metal container of the product (Table 2.46), as suggested before.

5.6 Cholesterol Contents of Goat Milk Products

Cholesterol content of goat milk was reportedly in the range of 10 to 20 mg/100 ml (50, 107). Cholesterol contents of goat, cow, and human milks are reported as 11, 14 and 14 mg/100 g, respectively (95; USDA, Handbook No. 8-1). Mean cholesterol contents of cow milk Cheddar cheese were 105

Table 2.46. Comparison of Mineral Ratios in Different Commercial Goat Milk Products

	Mineral ratio			
Goat milk products	Ca: P	Ca: Mg	Fe: Zn	Na: K
Fluid milk				
Recent rtudy[a]	0.83	8.72	0.18	0.42
USDA[b]	1.21	9.57	0.17	0.26
Evaporated milk				
Recent study[a]	1.12	9.06	1.77	0.30
USDA[c]	1.29	10.87	0.25	0.35
Powdered milk				
Recent study[a]	1.03	7.54	0.11	0.19
USDA[d]	1.18	10.73	0.14	0.28
Yogurt[e]				
Plain	1.12	9.43	0.30	0.52
Blueberry	1.11	8.70	0.07	0.45
Cheese[f]				
Plain soft	0.63	11.78	1.97	16.1
Cheddar	1.14	14.26	1.18	32.8

[a]Means of eight fluid milk (two brands, four different lots), 12 evaporated milk (two brands, six different lots), and 10 powdered milk (two brands, five lots) samples, respectively.

Data adapted from Park (83).

[b]Fluid goat milk, from *USDA Handbook No. 8-1* (95).

[c]Evaporated cow milk, from *USDA Handbook No. 8-1* (95).

[d]Powdered whole cow milk, from *USDA Handbook No. 8-1* (95).

[e]Park (81).

[f]Park (78).

mg/100 g (95) and 100 mg/100 g (42), while the range of cholesterol for Cheddar cheese was 95.6–100.8 mg/100 g (60).

Cholesterol contents (mg/100g, wet basis) of commercial fluid, evaporated, powdered milk, and Monterey Jack cheese determined by GC method in a later study (83) were: 11.0, 24.9, 119.5, and 91.7, respectively (Table 2.47). The respective cholesterol contents on dry basis for the corresponding goat milk products were: 1.25, 5.18, 112.4 and 38.7 mg/100 g, indicating that cholesterol levels of goat products were proportionally higher in dry matter contents of the products. The cholesterol content of Monterey Jack goat milk cheese by GC method was comparable to that of cow milk Cheddar cheese (Table 2.47).

Cholesterol concentrations of 15 varieties of U.S. and imported commercial goat milk cheeses were evaluated by different extraction and colorimetric determination procedures (82). The majority of the caprine milk cheeses were high moisture containing soft-type varieties, where moisture contents of the products were not exactly equated with cholesterol contents. The range of cholesterol levels in the experimental cheeses was 80 to 147 mg/100 g (wet basis), indicating that cholesterol in the goat milk cheeses was slightly higher than in cow milk cheeses. These differences in cholesterol between goat and cow milk cheeses may be due to differences in analytical procedure rather than species of milk or cheese. The imported variety having garlic and herb additives showed the greatest cholesterol level among all the tested varieties, which might be accountable for the turbidity of the sample solution in the colorimetric procedures.

Although the hard cheeses tended to have greater amounts of cholesterol, not all goat cheeses in the study showed the same phenomenon. The soft cheese, imported variety of French Royal Province with garlic and herbs (FRPGH) contained the second highest cholesterol among all cheeses tested (82). The FRPGH variety contained considerably higher moisture than the Norwegian Gjetost (NG) variety but still had greater levels of cholesterol than other hard cheeses such as Goat milk Gouda and white hard goat (WHG) milk cheese varieties. Even though the exact reason for the higher cholesterol in the FRPGH variety is not known, some chemical compounds from the additives might be extracted into the lipid extract, which in turn could interfere with the chemical reaction in the colorimetric determination (60, 69). Also, the original goat milk used for manufacturing the FRPGH might have higher levels of fat and cholesterol than the other varieties due to the animal differences in breed, diet, stage of lactation, and environmental and management conditions (85, 102, 109).

Cholesterol and fatty acid concentrations among different species were compared using the data published by the Royal Society of Chemistry, UK (42)

Table 2.47. Comparison of Fat and Cholesterol Contents (Wet Basis) in Different Manufactured Goat Milk Products in the U.S.[a]

Goat milk products	Moisture (%)		Fat (%)		Cholesterol (mg/100 g)			
					Colorimetric		GC[d]	
	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD
Fluid milk	88.75	0.24	3.40	0.15	19.5	2.58	11.0	0.80
Evaporated milk	79.2	0.68	6.75	0.25	43.9	6.20	24.85	0.75
Powdered milk	5.93	0.26	27.9	0.19	236.5	21.0	119.5	7.50
Cheese								
Plain soft[b]	67.5	0.02	17.7	0.25	120.8	3.30	—	—
Monterey Jack	51.2	1.55	26.6	1.13	124.8	2.75	94.6	0.65
Cheddar[c]	36.6	0.11	32.8	0.51	210.0	—	99.4	5.74

[a]Park (83).

[b]Park (82); Texas chevre is one of the plain soft goat milk cheese variety. Cholesterol contents by GC method were not reported.

[c]Lacroix et al. (60); cow milk Cheddar cheese.

[d]Determined by gas chromatographic method (AOAC, 1995).

$\overline{X}$ = Mean; SD = Standard deviation.

(Table 2.48). This table shows that the respective cholesterol contents of normal fluid goat, cow, sheep, and human milk are 10, 14, 11, and 16, indicating that goat milk actually has the lowest cholesterol content among these four species' milk. There is some similarity in the cholesterol values reported in the USDA Agricultural Handbook No. 8-1 (95) and others (50). Human milk appears to have the highest cholesterol among those four species' milks, and its colostrum has 31 mg/100 g. Cow milk powder has substantially higher cholesterol (120 mg/100 g) because it is a dried and concentrated product. This cholesterol value of cow milk powder is essentially at the same level of that reported by Park (83) by the GC method. However, the cholesterol content assayed by the colorimetric method by the same author was almost double the concentrations of the data analyzed by GC method as shown in Table 2.47.

In light of fatty acid composition, the normal goat, cow, sheep, and human milks contain 2.3, 2.4, 3.8, and 1.8 g/100g saturated fatty acids, respectively, suggesting that human milk has lower saturated fat than the three major dairy species' milks. The opposite trend is observed for the mono- and polyunsaturated fatty acid levels in human milk compared to the other three species' milks (Table 2.49). The significantly higher unsaturated fatty acids and cholesterol in human milk compared to the three animal species appears to be interesting and may need future investigations on certain health issues such as coronary heart diseases. Holland et al. (42) reported that goat milk has lower monounsaturated fatty acid than cow and sheep milk. However, the USDA Agricultural Handbook No. 8-1 (95) showed that goat milk has higher monounsaturated fatty acid than cow milk.

5.7 Vitamin Contents of Goat Milk Products

Research investigations and literature on vitamin concentrations of goat milk products have been very limited. The Composition of Foods published by the Royal Society of Chemistry, UK, by Holland et al. (42) contains some information of dairy goat products. It has all the nutrient and vitamin compositions of dairy and other foods including dairy goat products such as pasteurized fluid goat milk, soft goat cheese, and goat milk yogurt. Using the published information by Holland et al. (42), vitamin concentrations of some goat milk products were compared with those of other various dairy foods as shown in Table 2.49. The USDA Agricultural Handbook No. 8-1 (95) also has some limited information on vitamin contents of goat milk products. The data indicate that there are high variations in vitamin contents among different reports, especially in fluid goat milk, suggesting that the milk samples tested might have had considerable variations in compositions due to the difference in sources of milk, such as raw and pasteurized, breed of goats, diet, stages of lactation, location, and so on.

Some loss of vitamins is inevitable when milk and dairy products are processed and stored, while some

Table 2.48. Cholesterol and Fatty Acid Composition of Different Species' Milks

Species	Fatty Acids (g/100 g)			Cholesterol (mg/100 g)
	Saturated	Monounsat'd	Ployunsat'd	
Cow milk				
Whole	2.4	1.1	0.1	14
Skim	0.1	Tr	Tr	2
Dried whole	16.5	7.6	0.8	120
Goat milk	2.3	0.8	0.1	10
Sheep milk	3.8	1.5	0.3	11
Human milk				
Colostrum	1.1	1.1	0.3	31
Mature	1.8	1.6	0.5	16
Soya milk	0.3	0.4	1.1	0

Source: Data taken and organized from Holland et al. (42). The Composition of Foods, The Royal Society of Chemistry, UK.

Table 2.49. Vitamin Contents of Goat Milk Products Compared to Various Dairy Foods

Products	Vit A μg	Vit D μg	Vit E mg	Thiamin mg	Riboflavin mg	Niacin mg	Vit B_6 mg	Vit B_{12} μg	Folate μg	Pantothenate mg	Biotin μg	Vit C mg
Fluid Milk												
Goat milk pasteurized	44	0.11	0.03	0.04	0.13	0.31	0.06	0.1	1	0.41	3.0	1
Cow milk												
Whole	52	0.03	0.09	0.03	0.17	0.08	0.06	0.4	6	0.35	1.9	1
Skim												
Human milk												
Colostrum	155	N	1.30	Tr	0.03	0.05	Tr	0.1	2	0.12	Tr	7
Normal	58	0.04	0.34	0.02	0.03	0.22	0.01	0.01	5	0.25	0.7	4
Sheep milk												
Raw	83	0.18	0.11	0.08	0.32	0.41	0.08	0.6	5	0.45	2.5	5
Evaporated												
Whole cow	105	0.09	0.19	0.07	0.42	0.23	0.07	0.1	11	0.75	4.0	1
Powdered												
Whole cow	290	0.24	0.61	0.31	1.40	0.60	0.48	2.4	46	2.79	13.9	9
Skim cow	350	2.10	0.27	0.38	1.63	1.02	0.60	2.6	51	3.28	20.1	13
Cheese												
Soft goat	310	0.50	0.79	0.04	0.63	0.65	0.12	2.0	19	N	N	Tr
Cheddar (cow milk)	325	0.26	0.53	0.03	0.40	0.07	0.10	1.1	33	0.36	3.0	Tr
Camembt	230	0.18	0.65	0.05	0.52	0.96	0.22	1.1	102	0.36	7.6	Tr
Gouda	245	0.24	0.53	0.03	0.30	0.05	0.08	1.7	43	0.32	1.4	Tr
Feta	220	0.50	0.37	0.04	0.21	0.19	0.07	1.1	23	0.36	2.4	Tr
Yogurt												
Goat milk	N	N	0.03	0.04	0.17	0.27	0.06	Tr	7	0.23	0.5	1
Cow whole	28	0.04	0.05	0.06	0.27	0.18	0.10	0.2	18	0.50	2.6	1
Cow lowfat	8	0.01	0.01	0.05	0.25	0.15	0.09	0.2	17	0.45	2.9	1
Sheep, Grk	86	0.24	0.73	0.05	0.33	0.23	0.08	0.2	3	N	N	Tr

Source: Data taken and organized from Holland et al. (42). The Composition of Foods, The Royal Society of Chemistry, U.K.

vitamin contents can be increased in the products by fortification, such as vitamin A and D addition to the pasteurized fluid milk. Some vitamins also increased in the cultured dairy foods during manufacturing processes by bacterial cultures such as yogurt and cheese products. Milk products exposed for several hours to bright sunlight can lose up to 70% of its riboflavin (42). Vitamin C can also decline under those conditions from the 1–1.5 mg/100 g in the original milk to almost zero. There will be gradual losses of folate and vitamin B_{12} from UHT and sterilized milks even under ideal storage conditions because of reactions with small amounts of oxygen in the container (42).

6 MARKETING AND ITS CHALLENGES OF DAIRY GOAT PRODUCTS

6.1 Marketing Strategies for Goat Milk Products

Worldwide demand for goat milk products has been increasing, and future demand, especially in caprine cheeses, is very promising. The success of goat cheese industries will be heavily dependent upon the establishment of high-producing milking goat herds, production of high-quality milk, improved and carefully controlled cheese making and ripening techniques, appropriate packaging, and cost consciousness in the production of the final dairy goat products. Some of the key factors that must be considered for future success in marketing strategies of goat milk products were suggested by Kosikowski (56) but not limited to the following areas:

1. Consumer perception of safety and nutrition
2. Quality of flavor, body texture, and appearance
3. Availability of specialty types
4. Attractiveness of packaging
5. Relative price of cheese of other goat products
6. Establishment of proper distribution and marketing channels

Proper distribution and packaging of goat milk cheese is the most integral element in expansion of the market for cheese. Attractive packaging of caprine cheese is becoming a necessity for competing with cow milk cheese. Use of legal, permitted, packaging material containing approved antimycotic agents and proper sanitation at the plant will prevent microbial spoilage on the cheese surface and other dairy goat products.

6.2 Promotion of a Successful Dairy Goat Industry and Its Products Consumption

A successful dairy goat industry or goat cheese industry cannot be established without the highest possible levels of cooperation among goat breeders, milk producers, cheese and other dairy goat product manufacturers, distributors, and retail outlets. Effective communication of the basic information on production and consumption ecosystem is essential. The consumer must be sold on the idea that goat milk cheese or other goat products are something special—perhaps through creative packaging and shapes of the products, and especially through its unique flavor.

The survival and sustainability of the dairy goat industry is also highly dependent on the extent of supports from government, industry, and academia. However, traditionally the levels of financial supports to the dairy goat industry from such extremely important entities have been negligible. This is understandable because the volume of dairy goat production and its level of contribution to the overall national economy and agricultural production, especially in the United States, have not been significant. Nevertheless, the attainment of the strong supports from the three integral entities has to be continuously sought. Cooperative and friendly supports for the promotion of consumption of dairy goat products and its industry are crucial for its survival. The limited-resource goat farmers and dairy goat industry have faced many challenges for their survival, including the seasonality of milk production, overcoming the traditional negative perception on goat products in many developed countries, and development of superior quality dairy goat products attractive to the ordinary consumers (37, 67, 80).

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2.4 Flavor Characteristics of Goat Milk and Other Minor Species Milk Products

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1 INTRODUCTION

The dairy industry has long recognized that flavor quality is one of the most critical and important aspects of sales and marketing (65). The flavor of cow milk and dairy products has been studied extensively, but there is much less published literature and research on the flavor of goat and other minor species milk. This chapter reviews basic sensory and instrumental approaches for flavor analysis, which is followed by a review of specific studies conducted on the flavor of dairy products produced from goat, sheep, buffalo, mare, and llama milk, primarily focusing on goat and sheep milk and dairy products because this is where the majority of published research has occurred. There has not been a great deal of research conducted on the sensory characteristics of minor species dairy products, and therefore little or no information is available for some mammals (camel, yak, deer, and reindeer).

2 SENSORY TECHNIQUES

Sensory analysis is a compilation of different tools or tests. When used properly, sensory tools can be used to powerfully document and explore flavor. The history and role of sensory analysis in exploring the flavor of dairy foods has been reviewed elsewhere (18, 19, 65). In general, there are three basic groups of sensory tools for evaluating dairy foods: traditional, analytical, and affective. Traditional sensory tools include grading and quality judging. These tests are used by the dairy industry to rapidly assess overall quality based on previously defined sensory defects (7). These techniques are long standing and were established in the early 1900s before sensory science was established as a scientific area of research. Grading was established by the federal government with the foundation of the Office of Markets (currently known as the Agricultural Marketing Service) in 1913 (70). Dairy products judging developed as an educational tool for students, and the first contest was held in 1916 (7). Both techniques operate on the same premise. Products receive quality scores for appearance, flavor, and/or texture based on the presence or absence of predetermined defects (Tables 2.50 and 2.51) (7). These techniques generally utilize individuals rather than panels of people, and due to its rapid nature, replication is generally not conducted. These techniques are useful for student education and rapid assessment of quality in an industrial setting. However, defects and their intensities are not assigned equivalent score deductions and thus cannot be statistically analyzed. Grades and product scores are also not representative of all of the sensory attributes of a product. Products may receive the same grade but may have very specific differences in flavor or texture profiles (15). These qualitative and/or quantitative differences not determined by grading or judging can significantly impact research interpretations and consumer preferences. Further, grades and judging scores are not necessarily synonymous with consumer preferences (38). As a result, these traditional tests are not ideal tools for research.

Modern sensory tests that are used in research can be divided into two categories: affective and analytical (18, 36, 41). Affective tests involve consumer perception of acceptability as well as other consumer concepts. These tests are used for determining the role that sensory attributes play in consumer choice and acceptability. It is important to note that these tests evaluate *consumer* responses. As such, untrained individuals, ideally ones who are consumers of the product, should be used. Consumer responses are wide and variable. To estimate these responses with some assurance of accuracy, a large number of consumers must be polled. A minimum of 50 (untrained) individuals is recommended for these types of evaluations (36).

Analytical tests involve the use of screened or trained panelists, and their responses are treated as

Table 2.50. List of Cheese Defects Used with Judging Cheddar Cheese Flavor

Flavor defect	Definition
High acid	Excessive acid or sour taste
Bitter	Bitter taste resembling caffeine or quinine
Fruity/fermented	Aroma of fermenting or overripe fruit
Flat	Devoid of flavor
Garlic/onion	Flavor resembling garlic, onion, or leeks
Heated	Not the clean cooked flavor of pasteurized milk but a flavor resembling the odor of old or spoiled milk
Malty	Flavor similar to Grape Nuts cereal
Metallic	A flat, metal-like taste and a lingering puckery mouth feel
Moldy	Musty, reminiscent of a damp cellar
Rancid	Also called lipase, caused by short-chain fatty acids; flavor described as bitter, soapy, disagreeable
Sulfide	Also called skunky; similar to water with high sulfur content
Unclean	Dirty aftertaste that fails to clean up after the cheese is expectorated
Whey taint	Also called sour whey; the dirty sweet acidic taste and odor characteristic of fermented whey
Yeasty	Sour, bread-dough, earthy aroma characteristic of yeast

Adapted from (7).

instrumental data. Such tests include discriminatory tests and descriptive analysis. The purpose of descriptive analysis is to train a group of individuals to evaluate specific sensory properties as an instrument. Descriptive analysis is the sensory tool of choice for documenting and differentiating foods and for exploring relationships between sensory and instrumental perception. Descriptive analysis requires a descriptive technique and a language to describe the sensory properties. There are several valid approaches to descriptive analysis, and they have been reviewed (18, 48). Sensory languages can be identified for any dairy food, and descriptive sensory analysis can be conducted using any of these approaches. Panelist selection, scales and scale usage, and training are critical parts of any descriptive texture analysis approach. These specifics are reviewed elsewhere (18, 41). Descriptive analysis utilizes a panel or group of individuals (generally 8–12) rather than the one or two experts used for grading and judging. A panel of individuals is used since many factors can influence individual performance at any given time. A panel is used to correct for these variations.

One critical issue that should not be overlooked is panelist training and replication. Although descriptive analysis does not require expensive instrumen-

Table 2.51. List of Cheese Defects Used with Judging Cheddar Cheese Texture

Texture defect	Definition
Corky	Dry, hard, cork-like texture; the cheese has a stiff, rubber-like consistency when worked in the hand
Crumbly	Cheese is crumbly and falls apart when sliced or worked in the hand
Curdy	When worked, distinct curd particles are visible and may break apart in the hand; more common with stirred curd Cheddar
Pasty	When worked in the hand, cheese is sticky and pasty to the fingers
Weak	Soft; cheese is easily worked and a plug will bend without breaking
Short	Cheese plug breaks easily and is not pliable
Mealy	When worked in the hand, cheese cornmeal-like particles will be apparent
Open	Visible porous or loose texture

Adapted from (7).

tation, panelists must be trained. Training can be time consuming. Training by an experienced panel leader is required to optimize panel performance and acuity. The number of hours of training varies with the food, the number of terms, and the modality used. Analysis of appearance or texture generally requires less training than flavor. Once trained, a descriptive panel operates as an instrument. As with any instrument, data collection must be replicated (36). Each panelist should replicate *each* sample.

Sensory languages or lexicons are the basis for descriptive sensory analysis. These languages are simply sets of words to describe the sensory properties of a product or commodity. Lexicon development and attributes have been recently reviewed (18). Sensory lexicons should be representative, discriminating, descriptive, and nonredundant.

Descriptive sensory analysis has been applied for a myriad of research objectives in dairy foods in recent years. Descriptive sensory analysis has been conducted on a wide variety of cheeses (14). Table 2.52 shows an example of a defined descriptive sensory language for Cheddar cheese flavor (16, 17, 47). This language has also been adapted for sensory analysis of fresh goat cheese flavor (Table 2.53). Descriptive sensory analysis is a powerful tool for enhancing product understanding, linking flavors to specific volatile compounds, and understanding consumer responses (19). Collectively, appropriately selected and designed sensory measurements are powerful tools for evaluating sensory properties (60).

3 INSTRUMENTAL TECHNIQUES

Descriptive sensory analysis is performed to determine the flavor profile of a food. However, additional information, such as the chemical composition of the product and the compounds that contribute to

Table 2.52. Defined Descriptive Language for Cheddar Cheese Flavor

Term	Definition	References
Cooked	Aromatics associated with cooked milk	Skim milk heated to 85° C for 30 min
Whey	Aromatics associated with Cheddar cheese whey	Fresh Cheddar whey
Diacetyl	Aromatics associated with diacetyl	Diacetyl
Lactone	Aromatics associated with milk fat	Fresh coconut meat, heavy cream, δ-dodecalactone
Sulfur	Aromatics associated with sulfurous compounds	Boiled mashed egg, struck match, hydrogen sulfide bubbled through water
Brothy	Aromatics associated with boiled meat or vegetable stock	Knorr beef broth cubes, Knorr vegetable broth cubes, Wyler's low-sodium beef broth cubes, canned potatoes, methional
Free fatty acid	Aromatics associated with short-chain fatty acids	Butanoic acid
Fruity	Aromatics associated with different fruits	Fresh pineapple, canned pineapple juice
Nutty	The nut-like aromatic associated with different nuts	Lightly toasted unsalted nuts, wheat germ, unsalted Wheat Thins
Sweet	Fundamental taste sensation elicited by sugars	Sucrose (5% in water)
Salty	Fundamental taste sensation elicited by salts	Sodium chloride (0.5% in water)
Sour	Fundamental taste sensation elicited by acids	Citric acid (0.08% in water)
Bitter	Fundamental taste sensation elicited by caffeine, quinine	Caffeine (0.08% in water)
Umami	Fundamental meaty taste elicited by monosodium glutamate (msg)	Monosodium glutamate (msg, 1% in water)

Adapted from (16).

Table 2.53. Goat Cheese Lexicon and References

Term	Definition	References
Cooked/milky	Aromatics associated with cooked milk	Skim milk heated to 85° C for 30 min
Whey	Aromatics associated with Cheddar cheese whey	Fresh Cheddar whey
Diacetyl	Aromatics associated with diacetyl	Diacetyl
Milk fat/lactone	Aromatics associates with milk fat	Fresh coconut meat, heavy cream, δ-dodecalactone
Waxy/animal	Waxy/crayon-like aromatic primarily associated with cheeses made from goat or sheep's milk	4-methyl octanoic acid and 4-ethyl octanoic acid 100 ppb of each in MeOH in a sniffing jar
Brothy	Aromatics associated with boiled meat or vegetable stock	Knorr beef broth cubes, Knorr vegetable broth cubes, canned potatoes
Sweet	Fundamental taste sensation elicited by sugars	Sucrose (5% in water)
Salty	Fundamental taste sensation elicited by salts	Sodium chloride (0.5% in water)
Sour	Fundamental taste sensation elicited by acids	Citric acid (0.08% in water)

Adapted from (11).

flavor, are important as well. Instrumental analysis is a tool that can be used to determine which aroma-active compounds are present in a food. Several extraction techniques are employed to extract the volatile flavor-contributing compounds in foods, including direct solvent extraction/high vacuum distillation (DSE/HVT), solid phase microextraction (SPME), and dynamic headspace/gas chromatography (DHA/GC). Methods that are used to identify compounds include gas chromatography/olfactometry (GC/O) and gas chromatography/mass spectrometry (GC/MS). Because the aroma compounds found in foods are usually present at very low concentrations, isolation and concentration procedures are often needed in order to obtain the chemicals of interest in concentrations that can be detected (59). Traditional solvent assisted extraction techniques (DSE/HVT) are often utilized, and these are most useful in extracting the volatile and semi-volatile analytes, giving very good recovery of compounds.

SPME is a very rapid technique used in the extraction of volatile compounds (53). A fiber is inserted into the headspace of a sample, and the volatile compounds are concentrated onto it. After an exposure time, the fiber is injected onto a GC. This method is inexpensive, solvent free, and reliable (23). SPME has been used in the analysis of dairy products, including cheese (23, 37), and has been found to be a useful method in detecting volatile lipid oxidation products including alcohols, ketones, sulfur compounds, fatty acids, and aldehydes (37).

Another useful technique used to extract and identify compounds is dynamic headspace/gas chromatography (DHA/GC). Using DHA, the sample is purged with helium to release the volatiles from the food product into the headspace. Volatiles in the headspace are concentrated on a trap. After a given exposure time, the concentrated volatiles are injected onto a GC using a heated transfer line. DHA is a simple and reliable technique that can be used to concentrate analytes followed by injection onto a GC to separate and identify compounds. This method is very useful for detecting trace amounts of compounds (37, 59). Several studies have effectively utilized this technique with dairy products (22, 49, 58, 59, 71).

After the volatiles are extracted and concentrated using these methods, the sample is injected onto a GC. The GC is used to separate the analytes. A sniffing port can be placed on the end of the GC to allow olfactory detection of aroma-active compounds as they are separated on the GC (42). This technique is called GC-sniffing, or GC/O. GC/O can be used in conjunction with SPME and DHA, as well as samples, that are extracted using traditional solvent assisted methods. To confirm the identity of the com-

pounds that are sniffed, retention indices and GC/MS can be used, as can the unique aroma property of the analyte. GC/O enhances traditional GC because it allows not only determination of the concentration of an analyte but also determination of the role that the compound plays in the flavor profile of the product.

4 GOAT MILK AND THE INFLUENCE OF PROCESSING PARAMETERS ON FLAVOR

The flavor of dairy products is typically a balance of several compounds present in the correct concentration, which produce a sweet, delicate, milky flavor. The milk of minor species tends to have a more robust flavor, often characterized by a waxy/animal aroma and flavor. Dairy product flavor is caused by an array of chemical reactions including protein reactions, such as Maillard browning, proteolytic, and lipolytic reactions. In minor species dairy products, lipolysis is primarily responsible for causing flavor development, especially the characteristic waxy/animal flavor. In addition, minor species milk fat tends to have a higher concentration of branched-chain fatty acids, which play a role in the characteristic waxy/animal flavor (28). Table 2.54 lists the fatty acid composition of fat in bovine, caprine, and ovine milk.

The composition of the milk fat from different species is an important contributor to the flavor profiles of dairy products.

Goat (caprine) milk has a very characteristic flavor, typified by a waxy/animal note (11, 34). The intensity of this flavor is dependent on several factors, including breed, season, lactation period, feeding, milk yield, milk fat content, and composition (34). For example, goat milk has a more intense waxy/animal flavor in animals that are near the end of their lactation and the start of their dry period (10). There are many potential physiochemical causes of this unique flavor. Goat milk fat globules are smaller than most cow milk fat globules and have a higher proportion of C6-C10 fatty acids at the sn-3 position (12). This can influence the texture and flavor delivery of the cheese. Some research has hypothesized that the uniqueness of goat milk flavor is linked to the genetic polymorphism of the caprine α_S-casein protein, which influences not only flavor but also composition and texture of goat dairy products (13, 34). Seventy-seven percent of goat milk protein is normally casein, and the overall protein content of goat milk is generally higher than in cow milk (3.4 ± 0.5 % vs. 3.0 ± 0.2 %, respectively) (24, 31, 68). Though this difference in protein content and composition may play a role in overall goat milk flavor and texture, studies have determined that branched-chain

Table 2.54. Composition of Fatty Acids in Goat Milk and Cow Milk

Fatty acid	Cow milk	Goat milk	Sheep milk
		(μg/g of milk fat)	
butanoic acid	33000	30000	32000
2-methylbutanoic acid	60	120	85
3-methylbutanoic acid	11	38	28
pentanoic acid	200	81	99
3-methylpentanoic	30	23	10
4-methylpentanoic	16	104	32
hexanoic acid	16000	20000	22000
heptanoic acid	180	283	151
octanoic acid	13000	20000	21000
4-ethyl octanoic acid	ND	55	13
4-methyl octanoic acid	3	223	80
nonanoic acid	53	286	94
4-methylnonanoic acid	3	27	19
decanoic acid	30000	61000	65000
2-ethyldecanoic acid	ND	97	ND

Adapted from (28).

fatty acids are mainly responsible for the characteristic waxy/animal flavor associated with goat milk and its products (11, 34).

Flavors caused by these branched-chain fatty acids are a result of lipolysis (25). There are three places where lipolysis can occur. There are native lipases in the milk while still in the udder (25). Lipolysis can also occur during milking, storage, and processing due to the natural and microbial lipases. In cultured dairy products, lipolysis can occur via addition of starter cultures (25). Goat milk generally contains more fat than cow milk (68), and this higher fat content may influence flavor as well. There are differences in the free fatty acid content of goat milk based on breed, especially hexanoic, octanoic, and decanoic acids (MCFA) (1). The variations of flavor between breeds are due to different levels of lipoprotein lipases (12). These differences will give the milk slightly different flavor profiles because these MCFA are so important to the overall flavor of milk. Skim goat milk was found to have a milder flavor than full fat goat milk, which reiterates the importance of fat and free fatty acids on the characteristic flavor of goat milk as well as the impact of fat as a flavor carrier (44). The lipases found in goat milk are reported to preferentially cleave 4-ethyl octanoic acid, one of the branched-chain fatty acids, that is responsible for waxy/animal flavor in goat cheese (11, 27).

Processing can also have an impact on the intensity of the waxy/animal flavor in goat milk (Table 2.55). Heating (65°C, 1 min) reduces overall and waxy/animal flavors and reduces lipolysis through the heat inactivation of lipases (44). Cold storage and homogenization also can increase the overall and waxy/animal flavors, as well as rancidity (44). These two processing steps cause an increase in the free fatty acid content of the milk due to increased surface area after homogenization, which allows more availability for lipase action (Table 2.55) (44). The intact milk fat globule membrane provides some protection from lipase action and is disrupted by homogenization. Microbial replication can also occur during cold storage, and this can increase the level of lipases and consequently free fatty acids.

In raw, unprocessed goat milk, the free fatty acid content is typically 40 μL/mL (44). After cold storage, the free fatty acid content increases to 100 μL/mL, and after homogenization the level increases to 120 μL/mL. Cold storage specifically causes an increase in C8-C10 free fatty acids, which may influence the waxy/animal flavor. This selectivity may be due to the fact that C8-C10 free fatty acids tend to be preferentially cleaved in goat milk (27). Homogenization causes an increase in C12-C16 free fatty acids, which do not typically contribute much flavor due to their high threshold (44). It is not clear why homogenization causes an increase in C12-C16 free fatty acids. In goat milk fat, C12-C16 fatty acids are predominantly (~65%) found at the sn-2 position, while in cow milk, C12-C16 are found more evenly distributed between the sn-1 and sn-2 position (27). This distribution of fatty acids may influence the cleavage rate of the lipases during homogenization.

The flavor of goat milk is important not only for direct consumption but also in milk used as the starting material for goat cheeses or other cultured dairy

Table 2.55. Impact of Technological Processes on the Sensorial Quality of Goat Milk

		Sensorial analysis[a]		
	Lipolysis[b]	Overall flavor	Goat flavor	Rancid flavor
Raw milk (control)	0.27	6.40	4.06	0.86
Skim milk	ND	4.42	0.78	0.26
Heat-treated milk	0.18	6.24	3.06	1.08
Homogenized milk	0.80	7.30	4.90	3.06
Stored @6° C for 3 d	0.24	6.76	4.68	1.00
Stored @6° C for 6 d	0.37	6.50	4.48	1.40

Adapted from (44).

[a]On a 10-point scale.

[b]Lipolysis was determined by the BDI method (13).

products. Only high-quality milk with a low microbial count should be used for processing. Cheeses that are made from strongly flavored goat milk had more waxy/animal aroma and a higher free fatty acid content than cheeses made from mildly flavored goat milk (44). However, studies by the same authors also showed that the cheese ripening parameters (starter culture, pasteurization, and so on) influenced waxy/animal flavor more than the raw starting material.

5 GOAT CHEESE FLAVOR

Cheese is a very complex food product. The volatile flavor compounds in cheese originate from the degradation of lactose, milk lipids, and milk proteins (65). Proteolysis and lipolysis are among the most important events during cheese ripening and flavor development (63). Cheese ripening involves enzymatically catalyzed reactions, which cause flavor and textural changes (61). The main synthesis pathways for the formation of volatile components occur during ripening (33). Surface microflora also has a strong influence on the development of the characteristic flavors in goat cheese (44).

Pasteurization of milk can have an influence on the flavor of the resulting cheese (51). Pasteurization denatures the native enzymes in the milk and may partially denature whey proteins, which enhances whey-casein interactions (51). Additionally, this denaturation can increase the concentration of hydrophobic peptides, which may impart and increase bitter tastes (39). Pasteurization also decreases the concentration of non-starter lactic acid bacteria, which can play crucial roles in flavor development due to release of proteolytic, peptidolytic, and lipolytic enzymes.

5.1 The Role of Free Fatty Acids and Peptides

Sensory-perceived flavors that have been documented in goat cheeses include waxy/animal, brothy, metallic/oxidized moldy, milkfat/lactone, cooked/milky, whey, diacetyl, and the basic tastes sweet, sour, salty, bitter and "umami" (11, 16, 25, 69) (Table 2.52). "Umami" is a new term for fundamental meaty taste elicited by monosodium glutamate. Numerous types of cheese can be made from goat's milk, and each cheese will have a characteristic flavor profile (14). Table 2.53 is a lexicon of sensory attributes that are commonly found in soft goat cheeses as well as chemical or food references for each term. Table 2.56 shows the application of the language to document the flavor profiles of fresh Chevre-style goat cheeses. Goat cheese has a very characteristic waxy/animal flavor, similar to but usually more intense than the flavor observed in goat milk. During aging of goat cheese ripened by both lactic- and Camembert-type starter cultures, there was an increase in waxy/animal flavor as determined by descriptive sensory analysis (25). Frozen storage did not affect sensory profiles of fresh or Monterey Jack–type goat cheeses (53).

Previous studies with goat cheeses have mainly focused on the water-soluble components and have identified fatty acids and peptides (2, 61, 64). Many of the studies reported that the small molecular weight compounds found in the water-soluble fraction contribute only to the basic tastes (sweet, sour, salty, and bitter) of soft and hard goat cheeses (20, 21, 61, 62). These include mineral salts, organic acids, sugars, amino acids, nucleotides, biogenic amines, and peptides. Since these compounds are not volatile, their role in flavor is minimal. Nonvolatile compounds may play a role in basic taste, but their role in actual flavor will be only through their influence on flavor release and/or threshold of volatile compounds.

For most cheeses (both bovine and other species), proteolysis is the most important reaction during cheese ripening, providing texture changes and flavor development (14, 50, 65). Some small peptides contribute to sweetness, bitterness, saltiness, and

Table 2.56. Descriptive Sensory Profiles of Two Fresh Chevre-Style Goat Cheeses

Sensory attribute	Cheese 1	Cheese 2
Cooked/milky	2.7a	2.5a
Milk fat/lactone	3.3a	3.5a
Whey	1.9b	2.5a
Diacetyl	1.1b	2.0a
Waxy/animal	2.7a	2.8a
Brothy	ND	0.8a
Sweet	1.9a	1.5a
Sour	4.0a	3.8a
Salty	3.1b	4.3a
Umami	ND	1.3a

Adapted from (11).

Means in a row followed by different letters are different ($p < 0.05$).

umami flavors individually (63). Large peptides (> 500 Da) do not appear to influence basic tastes (20, 66). Engel et al. (21) used a model system of water soluble extracts of goat cheese and found that peptides did not directly impact basic tastes, but there may be some synergism between peptides and other water soluble components. Sommerer et al. (67) reported that divalent cations present in peptides may be primarily responsible for bitterness in goat cheeses.

Lactic acid content in cheeses is responsible for sourness. In a model system, lactic acid omission correlated with an absence of sourness as determined by a trained descriptive analysis panel ($p < 0.05$) (21). Mineral salts appear to be primarily responsible for saltiness. In a model system, omission of NaCl, KCl, CaCl, and MgCl, respectively, lead to decreased saltiness, with NaCl having the most effect on saltiness (21). In addition to causing saltiness, the mineral salts CaCl and MgCl contributed to bitterness in goat cheese (21).

During cheese ripening, enzymatic aging occurs, which affects flavor and texture (61). The flavors in fresh cheeses are much more delicate than those in aged cheese. Water soluble compounds, such as fatty acids, are very important to the flavor of fresh cheeses, and the short- and medium-chain fatty acids can be detected at very low concentrations, with a threshold of 5 ppm or less (61). The longer chain fatty acids have a higher perception threshold and are thought to play a lesser role in cheese flavor (61). These fatty acids do indeed contribute to sourness, but they also play a role in the aroma and volatile flavor in goat cheese.

Intact lipids do not influence the basic tastes, and contribute little direct flavor to goat cheese (20). Lipolysis by starter cultures/enzymes during ripening is considered to be the most important step in the development of sensory characteristics in soft cheeses (25, 61). Low molecular weight fatty acids tend to be the major free fatty acids present in soft cheeses, and this may give them a distinct flavor (61). The balance of these fatty acids is especially important in soft cheeses (61), due to the lack of robust, aged flavors. In soft Chevre-style goat cheese, the waxy/animal flavor is one of the predominant aromas and flavors (11) (Table 2.54). The intensity of the waxy/animal flavor is correlated with the amount of lipolysis that has occurred (25, 29). The pH of the cheese is very important, because only the protonated form of the acids is aroma active and contributes to flavor (25).

Many studies have pinpointed the compounds causing the characteristic waxy/animal flavors as being branched-chain fatty acids. In the water soluble extract, 96% of the compounds are acids, with 99.5% of these acids being straight chain and 0.45% being branched (64). These branched-chain acids are the ones responsible for the characteristic waxy/animal flavor found in goat cheese. Though these branched-chain acids are present in lower concentrations than the straight chain acids, they have low sensory thresholds (11, 34, 44). The threshold of 4-methyl octanoic acid in cheese is 300 ppb and the threshold of 4-ethyl octanoic acid is 4 ppb (8, 60). Though 4-methyl octanoic acid is present at concentrations below threshold, it does impact both the presence and intensity of the waxy/animal flavor (11).

Some compounds, which were originally thought to cause waxy/animal flavor in goat cheeses, include 3-methylbutanoic acid, octanoic acid, 4-methyl octanoic acid, 4-ethyl octanoic acid, 4-ethyl nonanoic acid, nonanoic acid, and decanoic acid (11, 28, 35). Threshold studies of these acids at pH 2.0 showed that these acids have a waxy/soapy/animal aroma (8). Gas chromatography/olfactometry (GC/O) of Chevre-style goat cheeses and subsequent model system analysis confirmed that a combination of *only* 4-methyl octanoic and 4-methyl octanoic acids at roughly 100 parts per billion (ppb) each in cheese were the source of the waxy/animal flavor (11).

There are many different types of goat cheese, but all of them contain the characteristic waxy/animal flavor. Some research has manipulated the aging parameters to see how this would influence flavor. Goat cheeses that have been ripened for 30 days and produced from different starter cultures have different flavor profiles in basic tastes and volatile flavors. However, the waxy/animal flavor was a consistent flavor note (25). After 30 days of ripening, lipolysis slows down in both raw and pasteurized milk cheeses (9). In hard goat cheeses (aged 60 days), the concentration of free fatty acids increased in raw milk cheeses but remained constant in pasteurized milk cheeses (9). Most (> 50%) of these free fatty acids were long chain, which have a minimal influence on flavor, but there were still short- and medium-chain fatty acids which had a definitive impact on flavor (9). With further aging (24 weeks)

of the raw milk cheeses, the concentration of free fatty acids increased for 12 weeks and then leveled off after that time point. This included both straight and branched-chain fatty acids (2).

5.2 Neutral/Basic Components and Volatile Flavors

Previous studies with goat cheeses have mainly focused on the water-soluble (acidic) fractions and have identified fatty acids and peptides (2, 61, 64). However, other delicate dairy flavors are also prevalent in goat cheeses, especially in unripened ones, and these flavors are important to the overall flavor profile.

Volatile flavors in the neutral/basic fraction, such as alcohols, ketones, esters, and sulfur compounds, are also important in the flavor of fresh unripened cheese (61). Table 2.57 lists several compounds, which were identified in fresh Chevre-style goat cheese. Aldehydes and alcohols play an important role in the aroma of fresh Chevre-style goat cheese (11). Methional (potato) was found to have a high odor activity in goat cheese (34). This compound may contribute to brothy notes in the cheese. Many thermally generated compounds, such as methyl ketones, vanillin, pyrrolines, thiazolines, and lactones, were found in fresh goat cheese (11). Lactone concentration increased when pasteurized milk was used to make the cheese (61). These thermally generated compounds may contribute to milk fat and cooked/milky flavors.

Ketones such as 1-octen-3-one and (Z)-1,5-octadien-3-one were also found in fresh goat cheese (11), and these may contribute to metallic flavors, which have been found in goat cheese (25). 2-phenyl acetic acid and 2-phenyl ethanol were found to be mildly aromatically potent in goat cheese and have a rosey/honey aroma (34). Other compounds, which have been found in goat cheese and may contribute to flavor, include 3-methyl indole (fecal/mothball) and limonene. Limonene is commonly found in pasture-fed animals and is in high concentrations in goat cheese (11, 32). However, at the concentrations found in goat cheese, limonene does not appear to be aroma active, though it may have an indirect flavor on goat cheese at a sub-threshold level (11). More than 80 aroma active compounds in fresh Chevre style goat cheese have been identified (11).

5.3 Other Fermented Goat Milk Products

Few studies have examined the flavor of other fermented goat milk products besides cheese. Shankleesh is a fermented de-fatted yogurt that is ripened at ambient temperatures. Sensory attributes of this product include pungency, mustiness, hardness, cohesiveness, grittiness, dryness, adhesiveness, and bitterness (68). Shankleesh that is produced from goat milk reportedly provides superior texture and flavor attributes over that which is produced from sheep or cow milk (68). Another product commonly made from goat milk is kishk. Kishk is a fermented milk product made with fermented milk and oats. When produced from goat milk instead of cow milk, it has overall lower aroma intensity and less acidity, fruitiness, cooked, cereal, and cardboard flavors, but more creaminess as determined by descriptive sensory analysis (46).

6 SHEEP MILK AND CHEESE

Sheep milk and cheese flavors are somewhat similar to the flavor of milk and other products from goats. Sheep milk has twice as many solids and almost twice as much fat as cow milk (56). This difference in composition certainly influences flavor, texture, and yield of sheep milk products. Cheese made with a combination of cow and sheep milk was lower in moisture and had a higher protein content than cheese made solely with cow milk (56). There are more low molecular weight free fatty acids (C4-C10) in sheep milk (Table 2.54), and these are important precursors in flavor development (56). Sheep milk flavor is also influenced by season, lactation period, diet, and processing (40, 43, 52). Sheep milk, more so than cow or goat milk, is a seasonal product (33). The diet that dairy ewes consume is especially important, and it has been found that sheep consuming a diet of alfalfa had an increase in dimethylsulfide, which has a sulfurous aroma (43). Roncal and Manchego ewe milk cheese had an overall lower aroma intensity when made from pasteurized milk (26, 51).

The pH of sheep milk was found to be lower in summer than in winter months, and this may impact flavor and texture of cheese made from this milk (40). The main flavor contributors in sheep milk are short- and medium-chain fatty acids (54), and these

Table 2.57. Aroma Active Compounds Found in Fresh Chevre-Style Goat Cheese Using GC/O

No.	Compound	Mean intensities[a]	Odor[b]	RI[c]		Method of identification[d]
				DB-Wax	DB-5	
1	diacetyl	3.65	Buttery	937	623	RI, odor
2	acetoin	1.50	Buttery		730	RI, odor, MS
3	hexanal	2.25	Green grassy	1020	787	RI, odor, MS
4	3-methyl thiophene	4.30	Sweet/plastic	1026		RI, odor
5	pentanoic acid	3.00	Swiss cheese	1043	920	RI, odor
6	1-hexen-3-one	3.25	Cooked/vegetable	1153		RI, odor
7	heptanal	3.70	Fatty	1181	916	RI, odor, MS
8	1-octen-3-one	4.00	Mushroom	1249	991	RI, odor
9	2-acetyl-1-pyrroline	3.00	Popcorn	1285	939	RI, odor
10	(Z)-1,5-octadien-3-one	3.60	Geranium	1312	997	RI, odor
11	acetic acid	3.50	Vinegar	1340	685	RI, odor
12	nonanal	3.75	Hay/sweet	1378	1107	RI, odor, MS
13	methional	5.25	Potato	1392	925	RI, odor, MS
14	2,5-dimethyl-3-ethylpyrazine	2.50	Potato	1441	1084	RI, odor
15	(Z,Z)-3,6-nonadienal	3.20	Fatty		1116	RI, odor
16	(E)-2-nonenal	3.65	Cucumber	1525	1170	RI, odor, MS
17	2-undecanone	3.20	Floral		1285	RI, odor, MS
18	butanoic acid	5.00	Rancid cheese	1550		RI, odor, MS
19	(E)-2-decenal	2.65	Hay/fatty	1585	1267	RI, odor
20	(Z)-2-decenal	3.55	Fatty	1596	1246	RI, odor
21	phenyl acetic acid	1.45	Sweet/floral	1602	1253	RI, odor
22	(E,E)-2,4-nonadienal	2.75	Fatty	1609	1217	RI, odor
23	benzoic acid	2.50	Sour/musty	1639	1290	RI, odor, MS
24	(E,E)-2,4-decadienal	2.50	Fried	1700	1304	RI, odor
25	2-acetyl-2-thiazoline	2.85	Popcorn	1763	1106	RI, odor
26	dodecanal	2.60	Floral	1765	1387	RI, odor, MS
27	decanol	4.25	Fatty/hay	1771	1267	RI, odor
28	indole	3.50	Musty	1796	1254	RI, odor
29	γ-butyrolactone	2.35	Coconut		1313	RI, odor, MS
30	hexanoic acid	2.75	Sweaty	1875	1060	RI, odor, MS
31	3-methyl indole (skatole)	4.10	Fecal/mothball		1440	RI, odor

32	γ-octalactone	4.40	Coconut		1547	RI, odor, MS
33	vanillin	2.50	Vanilla	1899	1412	RI, odor
34	δ-decalactone	2.85	Peach	1972	1518	RI, odor, MS
35	nonanoic acid	3.00	Dirty/sour	2072		RI, odor, MS
36	4-methyl octanoic acid	2.40	Sour/goaty/waxy	2173	1391	RI, odor
37	4-ethyl octanoic acid	4.35	Waxy/honey	2216	1438	RI, odor
38	4,5-dimethyl-3-hydroxy-2(5H)-furanone (sotolon)	1.95	Spicy, cotton candy	2234	1113	RI, odor
39	(-aminoacetophenone	3.95	Grape	2281	1346	RI, odor
40	δ-dodecalactone	2.95	Coconut		1733	RI, odor, MS
41	octanoic acid	3.50	Sweaty/waxy	2343	1307	RI, odor, MS
42	decanoic acid	1.00	Fecal/sour/waxy		2286	RI, odor, MS

Adapted from (11).

[a]Mean intensities were determined from GCO, n=4 sniffers.

[b]Odor description at the GC-sniffing port during GCO.

[c]Retention indices were calculated from GCO data.

[d]Compounds were identified by comparison with the authentic standards on the following criteria: retention index (RI) on DB-Wax and DB-5MS columns, odor property at the GC-sniffing port, and mass spectra in the electron impact mode.

must be protonated in order to contribute to flavor. As with goat milk, the net effect is a waxy/animal flavor that is absent in cows milk. Lipolysis is especially important in raw ewe cheese due to its high fat content and lipase activity from somatic cells and starter cultures (54, 55). Sheep cheese initially has very low concentrations (1–10 ppb) of free fatty acids, but after 60 days there is a 10– to 100–fold increase, with decanoic acid (sweaty/waxy) and butyric acid (rancid) having the highest concentrations (54, 55). This trend was observed for Terrincho (a semi-hard raw milk cheese) and Manchego cheese (a hard cheese) that was produced from pasteurized ewe's milk (30, 54, 55).

Moio et al. (42) identified more than 60 volatile neutral/basic compounds that contributed to the overall aroma of sheep milk. These compounds included many esters, which have a sweet, fruity aroma. Other compounds found included aldehydes, ketones, and alcohols. The main odorants, identified by gas chromatography/olfactometry, included ethyl butanoate (fruity), heptanal (green, fatty), dimethylsulfone (sulfurous), 1-octen-3-ol (mushroom), ethyl hexanoate (fruity), and octanal (green, citrus) (42). Similar compounds have been identified in Roncal cheese made from ewe's milk, including sulfur compounds and alcohols (51). One-fifth of the volatile compounds were alcohols. Many methyl ketones have also been found in Roncal cheese (51), which give a fruity, blue cheese type aroma.

Some sensory attributes that have been documented using descriptive sensory analysis of Roncal cheese made from sheep milk include fruity, animal, floral, plant, lactone, and milky (33, 51). A sensory lexicon with descriptors and references to describe and document the sensory properties (odor, flavor, texture) of ewes' milk cheeses has been published (3, 4). The lexicon was used to differentiate ewes' milk cheeses and to demonstrate specific sensory differences between raw ewes' milk cheese made with or without added starter cultures (5, 6).

7 OTHER MINOR SPECIES MILK FLAVOR

Very few studies are published that contain information about other minor species dairy product flavors. Sensory studies have been published for llama, buffaloes, and mares but not for yak, camel, deer, or reindeer. Llama milk has more sugar (6.5% vs. 4%) than cow milk does and is sweeter in taste (45). Llama milk also has less fat than other domestic ruminants (45). Because this milk contains less fat, it could be expected for it to have a lower overall aroma and flavor intensity.

The flavor of buffalo butter powder has been studied (57). It had a stale, gluey, and oxidized flavor that increased with storage. Water buffalo mozzarella has also been studied. GC/O determined that the most powerful odorant in water buffalo mozzarella was 1-octen-3-ol, which has a mushroom/earthy aroma (42). Nonanal (tallow), indole (stable), and an unknown compound (truffles) were also identified as being important character impact compounds in water buffalo mozzarella, which were not found in cow milk mozzarella (42).

Mare milk has a higher pH and is less sour than ruminant milk (52). Mare milk has a lower overall fat content but more unsaturated fatty acids and fewer saturated fatty acids. This could influence its stability and increase rancid flavors with storage. Mare milk is sweeter and has more milk fat/lactone flavors than cow milk does (52).

8 CONCLUSIONS

The dairy products of minor species have unique flavor profiles that are much different from those of milk from cows. Goat and sheep milk and their cheeses have been studied to a large extent, although little information is available on the overall volatile flavor profile of these products. Other minor species dairy products have little or no published sensory information. Flavor and texture are key attributes of food to a consumer, and further research must provide a better understanding of dairy products made from minor species milk.

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2.5 Therapeutic and Hypoallergenic Values of Goat Milk and Implication of Food Allergy

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1 INTRODUCTION

Food allergy is the clinical syndrome resulting from sensitization of an individual to dietary proteins or other food allergens present in the intestinal lumen (32, 57, 83). The types of allergic or immune response after intrusion of foreign proteins in the intestinal lumen are extremely variable, depending on the animal species, the age of the host, the quality and quantity of antigens absorbed, the location of the absorption, the pathophysiological state, the genetic background, and so on. (57). Food allergy is much more common among children than adults, and is more common among younger children than older children (34). Approximately 7% of children in the United States and probably all Western countries have symptoms of cow milk allergy, even though almost all children under age three around the world have circulating milk antibodies (25, 41, 50, 92, 100).

Cow milk allergy (CMA) is a frequent disease in infants, but its etiologic mechanisms are not clear (56, 92). Beta-lactoglobulin (MW 36,000) is the major whey protein of cow milk, not found in human breast milk and mostly responsible for cow milk allergy (56, 92). More broadly, it has been shown that casein, β-lactoglobulin, and α-lactalbumin are the major allergens in cow milk (11, 42, 130). Clinical symptomology for patients allergic to bovine milk proteins include: rhinitis, diarrhea, vomiting, asthma, anaphylaxis, urticaria, eczema, chronic catarrh, migraine, colitis, and epigastric distress (56, 92, 124).

Increased gastrointestinal absorption of antigens followed by adverse local immune reactions may constitute a major etiological factor in development of food allergies such as CMA (132). The prolonged inadvertent exposure of cow milk to infants having CMA was associated with an inflammatory response in the *lamina propria* of the intestinal membrane and a constant increase in macromolecular permeability and electrogenic activity of the epithelial layer, even in the absence of milk antigen (59, 106). These clinical disease symptoms are transient, because all the disease parameters returned to normal after several months on a cow milk-free diet (56).

Compared to cow or human milk, goat milk is reported to possess unique characteristics, such as high digestibility, distinct alkalinity, and high buffering capacity as well as certain therapeutic values in medicine and human nutrition (24, 39, 52, 90, 92, 93, 108, 131).

Many scientists have recommended goat milk as a substitute for patients who suffer from allergies to cow milk or other food sources (92, 108, 122, 129, 131). Between 40 to 100% of patients allergic to cow milk proteins tolerate goat milk well. Although some caprine milk proteins have immunological crossreactivity with cow milk proteins, infants suffering from gastrointestinal allergy and chronic enteropathy against cow milk were reportedly cured by goat milk therapy (32, 92, 108, 131). Because goat milk has a strong potential for therapeutic and hypoallergenic advantages toward those infants and patients having CMA, goat milk as a substitute for cow milk or a basis of a cow milk-free diet is of great importance for individuals with CMA, goat milk consumers, producers, and the goat milk industry in general.

2 CAUSES OF ALLERGIC RESPONSES

One reason for allergic sensitization (of atopic children by dietary antigens) is that allergic illness may be due to overstimulation of a normal immune mechanism by excess contact with an antigen. This may be attributable to a defect in intestinal mucosal handling of the antigen or in the control of the response to it (70, 120, 128). This kind of defect would allow excessive absorption of an antigen that directly stimulates IgE-secreting plasma cells at the mucosal surface, whereby these conditions may lead to sensitization (119). These concepts are supported by the

association of transient IgA deficiency with subsequent development of atopy (120, 128). Atopy is a clinical hypersensitivity state, or allergy, with a hereditary predisposition. It is a hereditary or spontaneous allergy, which is different from the specific clinical forms such as hay fever, asthma, and eczema.

The second possible reason is that normal subjects absorb enough antigen across the intestinal mucosal barrier to activate IgE-suppressor T cells, causing inhibition, not stimulation, of the IgE responses (63). This reasoning may be supported by the fact that the normal intestinal and respiratory mucosa permits the absorption of food and inhaled antigens in amounts that are unimportant nutritionally but important immunologically (17, 70, 121).

3 FOUR TYPES OF ALLERGIC REACTIONS

The true allergic reactions were classified into four types by Gell et al. (40), which were designated type I-IV on the basis of the immunologic mechanism of the reaction. They indicated that three of these types of allergic reactions (type I, III, and IV) may occur with foods. The type I reactions are characterized by a rapid onset of symptoms and are mediated by allergen-specific immunoglobulin E (IgE). These type I reactions are often called acute hypersensitivity or anaphylactic reactions (124). A good example of type I is the development of hives or perhaps anaphylactic shock after ingestion of a specific food.

The characteristics of type III reactions are recognized by responses occurring 4–6 hours after ingestion of the offending food and are mediated by immune complexes. There are some uncertainty and controversy existing with regard to the importance of the type III reactions to foods (49).

The type IV reactions are characterized by a delayed onset of symptoms that occur more than six hours after ingestion of the offending food, and by a delayed onset of the involvement of sensitized cells. An example of this type of reaction may be the contact dermatitis that develops in certain persons handling certain specific foods (124).

4 ILLUSTRATIONS OF DIFFERENT TYPES OF FOOD SENSITIVITIES AND ALLERGIES

There are several different types of food sensitivities or adverse reactions that can occur among different individuals. Taylor (124) postulated these food sensitivities into four subcategory groups on the basis of the nature of the abnormal disease processes, which are: (i) food allergies; (ii) food intolerances or metabolic disorders; (iii) idiosyncratic reactions to foods; and (iv) anaphylactoid reactions.

The first term, "food allergy," should be reserved to identify those individualistic adverse reactions to food that have an immunologic basis (124). The use of this narrower definition of the term has been supported by many scientists and allergists (35, 38, 80, 124).

The "food intolerance or metabolic disorders" are food sensitivities attributable to the existence of some genetic deficiency or induced by drugs. A good example of genetic defect is lactose intolerance, which is caused by the lack of intestinal lactase, the lactose-digesting enzyme (111). This metabolic disorder of milk lactose intolerance causes afflictions of a large proportion of certain ethnic populations. There are other types of food intolerance, such as sucrose intolerance, phenylketonuria and favism, among others. Sucrose intolerance is a much rarer syndrome than lactose intolerance; phenylketonuria is intolerance of individuals to phenylalanine; and favism is an intolerance to beans of the *Vicia faba* plant, which is accounted for by a deficiency in erythrocyte glucose-6-phosphate dehydrogenase (76). There are also food intolerances caused by drugs, such as tyramine sensitivity in patients taking monoamine oxidase-inhibiting drugs (78) and histamine sensitivity in patients on isoniazid (114).

The "idiosyncratic reactions to foods" are types of food sensitivity that have no known mechanism of action (124). These types of adverse reactions to foods are unusual and individualistic, and mechanisms of action are not easily understood. Good examples are celiac disease (an adverse response to wheat gluten) and asthma induced by sulfite or tartrazine (FD&C Yellow No.5) (124). Other types of food idiosyncrasy do not have a clear relationship between the adverse reaction and food ingestion, which include: the alleged role of food coloring agents in hyperkinetic behavior of children; the alleged role of sugar in adverse behavioral reactions; and the role of foods in migraine and irritable bowel syndrome (96, 98, 101).

The "anaphylactoid reactions" are sometimes confused with true food allergies due to their similarities in symptomology (124). The classic example

of this type is histamine poisoning associated with the ingestion of certain cheeses, or spoiled fish (4, 126), which is often called scombroid fish poisoning, that is an actual foodborne intoxication rather than a food sensitivity reaction (127). There are other types of anaphylactoid reactions (that is, strawberry allergy) that are accountable for substances producing the release of histamine *in vivo* without the mediation of IgE or other immune factors (124).

5 SYMPTOMS OF FOOD ALLERGY IN GENERAL

The three most common food allergies are manifested by allergic symptoms of the gastrointestinal tract, skin, and respiratory tract, which are listed in Table 2.58 (124). It was noted that gastrointestinal symptoms were encountered in 50–75% of patients with cow milk allergy, whereas respiratory symptoms were encountered in 10–30% and dermatologic symptoms were in approximately 50% (7). Other studies (85) showed gastrointestinal symptoms in 70% of the patients, skin symptoms in 24%, and respiratory symptoms in only 4%, indicating that respiratory reactions were less frequent occurrences than other symptom types from food allergy.

The anaphylactic shock is the most severe reaction symptom of food allergy, which is a generalized systemic shock reaction that can lead to death if not treated immediately (124). Ellis (28) suggested that anaphylactic shock may be rarely observed in general cases of allergy, while it has been implicated by ingestion of common allergenic foods including milk, eggs, fish, crustaceans, legumes, grains, nuts, sulfites, and various seeds.

Table 2.58. Symptoms of Food Allergies

Generalized	Anaphylactic shock
Gastrointestinal	Nausea
	Vomiting
	Diarrhea
	Abdominal Pain
	Oral and laryngeal edema
Cutaneous (Skin)	Urticaria
	Atopic dermatitis
	Atopic eczema
	Contact dermatitis
Respiratory	Asthma
	Rhinitis

Taylor (124).

The most often manifested gastrointestinal food allergy reactions are diarrhea, vomiting, abdominal pain, and nausea (Table 2.58). Oral and laryngeal edema also can be considered as gastrointestinal allergy symptoms. Others may include colic, steatorrhea, malabsorption conditions, stomatitis, constipation, bleeding, allergic gastroentropathy, ulcerative colitis, irritable bowel syndrome, proctitis, and Crohn's disease (124).

Cutaneous or dermatologic symptoms of food allergy include: urticaria (hives), rash, dermatitis, eczema, and angioedema (124). Some infants and children have a chronic condition of atopic dermatitis or atopic eczema. Foods are involved in the etiology of chronic urticaria, but further studies are needed for clear evidence. It has been shown that the handling of certain foods can elicit contact dermatitis in sensitive individuals (33).

Respiratory symptoms, including rhinitis and asthma, are less often encountered with food allergies than with mold or pollen allergies (2, 124). Researchers have shown that asthma has been associated with allergies to common foods such as cow milk, soybeans, peanuts, and also certain food additives including tartrazine, sulfating agents, and monosodium glutamate (2, 31, 55, 118). Rhinitis may be the most common respiratory symptom of food allergies and occurs chronically in some infants with cow milk allergy (55).

There are other various conditions that may be occasionally attributable to food allergic symptoms, although their immunological mechanisms are not clear and have not been defined or proven. These allergic symptoms include: migraine headache, behavioral disorders, otitis media, Meniere's disease (persistent ringing in the ears), sudden infant death syndrome, enuresis, sensory problems, agoraphobia, cystic fibrosis, Crohn's disease, and ulcerative colitis (124).

6 INCIDENCES OF MILK AND FOOD ALLERGIES

Food consumption presents the body with a myriad of antigens capable of causing an immunologic response. Incidence of food allergy can increase with the introduction of cow milk early in infancy (136), which is probably due to the immaturity of the immune system of the intestine during the first month of life. A clinical study of food allergy in Finland revealed that 19% of the one-year-olds, 27% of the

three-year-olds, and 8% of the six-year-olds had food allergies (67). The diagnosis of food allergy in this report was based on development of skin rash or gastrointestinal disturbances following ingestion of the offending food and the results of an elimination-challenge trial.

One of the most prevalent food allergies occurring during infancy is milk allergy. However, milk allergy is not confined to infancy but is also seen as persisting allergy in children and adults (23, 57). The type of immune response after intrusion of foreign proteins is extremely variable, depending on the animal species, the age of the host, the quality and quantity of antigens absorbed, the location of the absorption, the pathophysiological state, and genetic background, among other variables. (57).

Prolonged breast-feeding up to six months and a delay in the introduction of cow milk and solid foods lessens the risk of the appearance of allergic manifestations in babies from atopic families (37, 109). Infants with minimal exposure to cow milk showed vastly increased total and milk-specific IgE antibody levels compared with the milk-fed infants (32). Bovine milk allergy involves IgE responses, where β-lactoglobulin is a milk protein highly resistant to intestinal luminal hydrolysis and mostly responsible for cow milk allergy (57, 106, 125).

As shown in Table 2.59, various foods are capable of causing allergic symptoms (102, 131). However, cow milk is the most frequent cause of food allergy, especially in children (32, 57, 100, 106, 108, 129, 131). Apparently, more than one mechanism exists for milk allergy and more than one is involved in particular patients even when there is a single clinical manifestation (100), which has made it difficult to understand (23, 26, 57, 100).

7 MECHANISMS OF PATHOGENESIS OF FOOD ALLERGY

Pathogenesis of food allergy can be illustrated by a few important disease mechanisms, which have been investigated by many scientists for further verification. These include: (a) mechanism of antigen absorption by the gut; (b) mechanism of immune response by the host cell or animal; and (c) relationship between food allergy and intestinal permeability.

7.1 Mechanism of Antigen Absorption by the Intestinal Epithelium

This mechanism of intact protein absorption was first identified by cytochemistry, using macromolecular markers such as horseradish peroxidase (HRP) and recognized as an endocytotic-exocytotic process (20, 57). Later studies showed that enterocytes were able to process these antigens inside their lysosomal system as nonspecialized antigen-presenting cells due to their capacity to express class II histocompatibility antigen on their external membrane (10, 82).

Table 2.59. Major Causes of Food Allergy

Natural foods having allergens	
Apples	Mustard
Beef	Nuts (oil and extract)
Berries	Onion
Buckwheat	Oranges and other citrus fruits
Cane sugar	Peanut butter
Chocolate (also cola)	Peas
Cinnamon	Pork
Coconut	Potatoes
Corn	Soy
Eggs	Tomatoes
Fish (all types, including crab and shrimp)	Wheat
	Yeast
Food coloring	In adults only
Grapes (also raisins)	Alcoholic beverages
Milk	Coffee

Rapp (102).

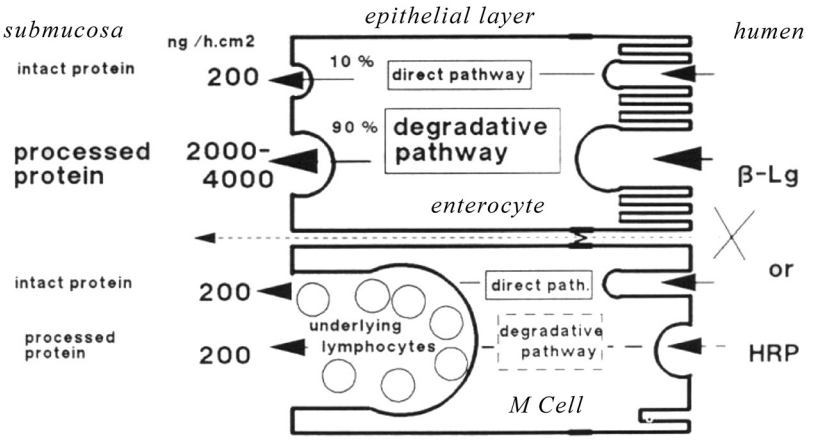

Figure 2.37. β-Lactoglobulin (β-Lg) transcytosis across the intestinal epithelium: Total transport is measured by ^{14}C-β-Lg counting and antigenic β-Lg, by enzyme-linked immunosorbent assay. As with most food-type proteins, β-Lg is absorbed along two functional pathways that comprise a main degradative pathway, implying the action of a lysosomal system and a minor pathway that allows the transport of intact proteins. Paracellular leakage is very unlikely, except in certain pathological situations such as bacterial cytotoxin interactions or high levels of lymphokines such as interferon-γ and tumor necroses factor a. The processing of the absorbed proteins allows the formation of peptides that might be implicated in lymphocyte activation. Protein absorption by Peyer's patches does not seem to increase more than absorption by the adjacent epithelium. However, the degradative pathway is greatly reduced, possibly due to the presence of M cells on the epithelium overlying the patch, because these cells have no lysosomal system. Another possibility is that degraded protein fragments are bound to the underlying lymphocytes and trapped inside the dome of the patch. HRP (horseradish peroxidase). Heyman and Desjeux (57).

Under normal physiological conditions, some amounts of macromolecules such as food antigens are constantly absorbed by the intestinal epithelium (57). It is difficult to quantify the exact amount of protein that crosses the intestinal epithelium due to a number of interactions involved before and after epithelial transport.

Using *in vitro* methods in which intestinal fragments are tested in Ussing chambers, protein transport from the intestinal epithelium has been measured quantitatively (62, 77). Two functional pathways of protein antigen absorption by transcytosis have been proposed (Figure 2.37) (57, 58, 62), of which the main one is a degradative pathway involved in lysosomal processing of the protein. This does not imply total hydrolysis of the protein but generates new antigenic determinants with MW of 2,000–4,000, which may still interact with the underlying immune cells (58). More than 90% of the protein internalized passes in this way, and the magnitude of the absorption is about 2–4 μg/hour x cm^2 (77). The second pathway of protein antigen absorption is direct transcytosis, which is a minor one. It involves the transport of the intact protein, which comprises $< 10\%$ of the total transport (57, 62).

During the basal period, degraded HRP fluxes were five times greater in sensitized animals than in controls (45). However, addition of β-lactoglobulin to the serosal side of tissues did not further increase these fluxes in either group. The intact HRP fluxes also increased in sensitized animals under basal conditions, but the increase was significant only in those sensitized orally ($P < 0.03$) (Figure 2.38). Unlike what was observed for degraded HRP fluxes, there was a large, significant increase in intact fluxes in the sensitized guinea pigs after β-lactoglobulin challenge (56).

7.2 Mechanism of Immune Response by Host Cell (Animal)

Absorption of food antigens triggers the immune system of the host cell and releases various mediators that are involved in the maintenance of the epithelial permeability dysfunctions (57). Reactions of food allergy can be classified according to

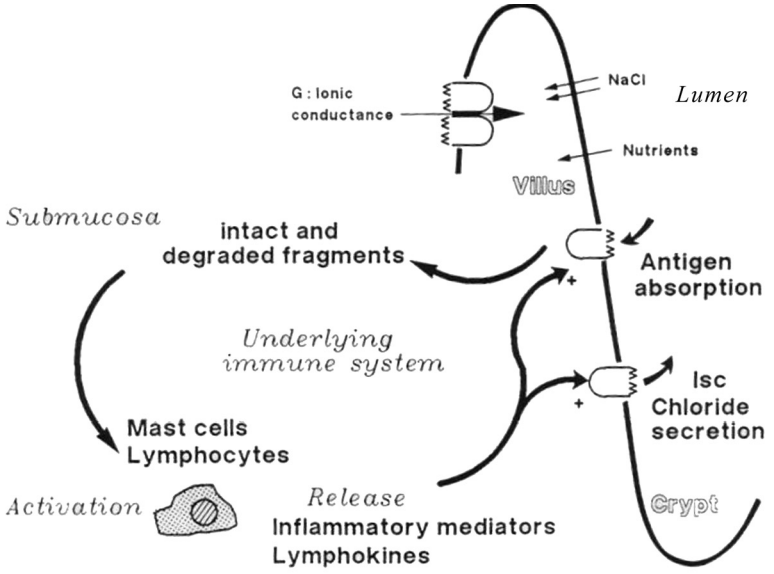

Figure 2.38. Working hypothesis for the intestinal dysfunction associated with food intolerance. The increased antigen absorption initiated a vicious circle, starting from the food protein absorption and processing that triggers the underlying immune system and the release of mediators involved in the maintenance of the epithelial permeability dysfunctions. Adapted from Heyman and Desjeux (57).

immunological mechanisms as reaginic (IgE-mediated) or nonreaginic (23, 83).

The first type of reaction is immediate hypersensitivity. IgE-specific antibodies become bound to mast cells or basophils, which react on re-exposure to the allergen, causing mediators such as histamine to be released (83, 100, 137). Mediators are stored in the body cells and released when triggered by a local stimulus (57, 100). The mediators act on local tissues, causing vasodilation, smooth muscle contraction, and secretion of mucus. Release of histamine also brings on a congestion of capillaries and flooding of intracellular spaces by lymphatic glands (83, 100). Stimulation of local nerve endings also occurs. On pathologic examination, affected areas show submucosal edema, dilated blood vessels, and eosinophilic infiltration. Mast cell degranulation and an increase in number of IgE-staining plasma cells may be seen in the intestinal interstitium (32, 81). Persons with an allergic reaction are usually more sensitive to the release of histamine and tend to produce greater numbers of antibodies to certain proteins (41). Mostly milk allergy is not reagin (IgE) mediated (23).

The second type of immunologic mechanism is considered to have several pathways: Non-reaginic antibodies react with antigen-forming complexes that in turn activate a complement system, causing inflammation and/or cytopathic effects (83). Another mechanism that is probably not immunologically mediated in food allergy may be direct intestinal mucosal toxicity of the protein or its breakdown fragments, as suggested in gluten enteropathy. The hydrolysis of the absorbed proteins allows the formation of peptides that might be implicated in lymphocyte activation (10, 57, 82). In a given patient, it is likely that several mechanisms operate simultaneously, with one predominating and the others contributing to the reaction (57, 100).

7.3 Relationship Between Food Allergy and Intestinal Permeability

Using animal models, type I, IgE-mediated immediate hypersensitivity to food proteins has shown that a challenge with a sensitizing antigen led to increased permeability to bystander proteins (12, 57, 107). Heyman et al. (56) showed that milk-sensitized

guinea pigs had higher basal HRP permeability than controls, and that a challenge with β-lactoglobulin *in vitro* further increased this elevation in permeability. In another study, the same researchers found increased basal permeability to HRP in jejunal biopsies from children having cow milk allergy (59).

It was observed that both intact and degraded-HRP fluxes were enhanced during the acute phase of the disease, but returned to normal after several months on a cow milk exclusion diet. Several studies suggested that the permeability disorders occurring during CMA are probably not the cause of food allergy but rather a consequence of abnormal immune response (57).

The intestinal secretion of electrolytes is increased during food hypersensitivity. However immediately, mast-cell activation is accountable for the electrogenic Cl^- secretion induced by histamine, serotonin, arachidonic metabolites, platelet activating factor (PAF), and neuromediators (97, 133). Researchers also showed that there is a close interaction between mast cells and the intestinal intrinsic nervous system, which further amplifies the anaphylactic intestinal dysfunction (97, 117). Therefore, it was suggested that all these mediators may stimulate the macromolecular protein absorption.

Food allergy can also be manifested by delayed symptoms, type IV delayed hypersensitivity, through the activation of T lymphocytes, which release lymphokines, such as various interleukins (ILs), tumor necrosis factor, and γ-interferon (γ-IFN), that may affect intestinal epithelial permeability (57). The stimulation of Cl^- secretion by IL-1 in rabbits was observed (18) but was inhibited by indomethacin, implying that the lymphokines might exert their stimulation by activating the arachidonic acid metabolism and prostaglandins (57).

It has been shown that lymphokines including γ-IFN can reduce the electrical resistance of T84 cell monolayers (75) and increase the intestinal permeability to inert molecules such as mannitol or inulin, which indicates epithelial cell rupture. Even though the intestinal epithelium is highly efficient in maintaining the macromolecular barrier (74), the intestinal permeability changes may maintain a vicious circle. As shown in Figure 2.38, the cycle includes antigen absorption, which triggers the immune system and the release of various mediators involved in the maintenance of these epithelial permeability dysfunctions. In addition, the lymphokines directly activate endocytosis as well as the processing of food antigens by enterocytes (57).

8 CLINICAL MANIFESTATIONS OF COW MILK ALLERGY

Cow milk allergy is considered a common disease with an estimated prevalence of 2.5% in children during the first three years of life (15), occurring in 12–30% of infants less than three months old (71), with an overall frequency in Scandinavia of 7–8% (60), even as high as 20% in some areas (87), and reported in Italy in 3% of children under two years of age (9).

The prevalence of cow milk allergy varies with countries and age of people, but exact data are lacking partly because differential diagnostic methods are difficult to perform in the apparent absence of standardized antigens (51, 68), and because cow milk contains 18 different proteins against which antibodies in animal experiments have been demonstrated (54). α-lactoglobulin is not present in human milk and has therefore been assumed to be the most offending protein in cow milk; however, comparative studies showed no difference between the allergenicity of β-lactoglobulin and caseins (14, 125). In actual clinical skin prick-tests on 21 adult and 13 infant patients with suspected cow milk allergies, α-lactalbumin caused the most positive skin reactions. Ten of the 13 infants showed positive reactions, while only five of the 21 adults reacted (68). Of these five adults, only one had a weak IgG-titer (ELISA) against α-lactalbumin. However, seven of the infants showed positive RAST tests against whole milk with different levels of IgG-titers against any or all five major milk proteins. The highest titer of 1:3,200 was found against α_s-casein and β-casein in an infant 2½ years old, which was treated against problems of resorption with a hyposensibilization therapy. Generally, IgG-titers were higher against caseins than against whey proteins.

Symptoms of milk protein allergy usually develop between two and four weeks of age, almost always appear within the first six months of life (23, 61, 83, 106, 131), and involve, as discussed earlier, gastrointestinal, respiratory, dermatologic, and systemic local tissues (61, 83, 131).

Bovine milk eosinophilic-induced colitis among children is well established (135). Clinical symptomatology to bovine milk is also expressed by

bronchospasm, erythema, and others (61) with reported frequencies of rhinitis (43%), diarrhea (43%), abdominal pain (41%), anaphylaxis (10%), and urticaria (7%) (83).

In a study of 45 children having various gastrointestinal, dermatologic and respiratory symptoms suspected to be caused by cow milk allergy, Bahna (6) gave oral challenge with whole bovine milk and skin testing supplemented with intradermal whole bovine milk, casein, and α-lactalbumin. Tests were positive in 23 subjects: Concordance (both tests positive and negative) between the results of whole milk challenge and skin testing with bovine milk was 45%, with casein 51% and α-lactalbumin 31%. Pahud et al. (89) observed that guinea pigs that had been orally sensitized to demineralized whey were sensitive to several whey proteins (β-lactoglobulin, α-lactalbumin, and immunoglobulin). They reported highest titers in cutaneous anaphylaxis with β-lactoglobulin, lower titers with other whey proteins. Demineralized whey protein lost its sensitizing capacity when it was hydrolyzed with trypsin. Among children allergic to cow milk, those who were breast fed and had minimal exposure to cow milk showed decreased titers of IgG, IgA, and IgM milk antibodies compared to those fed substantial volumes of cow milk (32).

Pathophysiological symptoms of milk allergy may be clinically manifested in two major sites: small intestine and colon. Typical symptoms of patients having pathological reaction in the small intestine are irritability, failure to gain weight, and having bulky, foul-smelling diarrhea stools (83, 137). A 72-hour fecal fat measurement for these patients often showed fat malabsorption and abnormal fat values in the stool. Observations on small-bowel biopsy may be indistinguishable from those in celiac disease. Histologic changes range from a moderate inflammatory cell infiltrate of the *lamina propria* to a totally flattened villous lesion with chronic inflammatory changes (36). Bacterial infections, viral enteritis, and malnutrition are often associated with histological intestinal lesions, which interact with pathological reactions of milk allergy in intestinal villi through increased permeability of antigen molecules (57, 62). Besides cow milk, foods that have been found to cause blunting of intestinal villi are soy, gluten, and eggs (27).

The typical clinical symptom of pathological reaction in the colon is diarrhea with occult blood and mucus in the stool. Sigmoidoscopic findings showed erythema, edema, small ulcers, and spontaneous mucosal friability in the colon (83). Histologic characteristics on rectal biopsy revealed that there was infiltration of the *lamina propria* by lymphocytes, plasma cells, eosinophils, and neutrophils, with destruction of the surface epithelium, crypt abscesses, and distortion of rectal glands (45).

In manifestation of milk allergy, one should be cautious of patients' symptomatology with reference to that of lactose intolerance. Many humans in certain parts of the world gradually lose after infancy some or all of the intestinal enzyme lactase to digest lactose. Deficiency of lactase causes clinical symptoms, which can persist in some racial groups and are often confused with common symptoms of bovine milk allergy.

9 HYPOALLERGENICITY OF GOAT MILK

9.1 Hypoallergenic Potentials of Goat Milk in Human Patients

The use of goat milk as a hypoallergenic infant food or milk substitute in infants allergic to cow milk has been reported in much anecdotal literature for those suffering from eczema, asthma, chronic catarrh, migraine, colitis, hayfever, stomach ulcer, epigastric distress, and abdominal pain due to allergenicity of cow milk protein (51, 122, 131). Children who were reactive to bovine milk but not to goat milk also reacted to bovine milk cheese but not to goat milk cheese (115). Gastrointestinal allergy in certain infants with eosinophilia also improved after administration of goat milk (108). A case of chronic enteropathy in infants due to feeding cow milk formula was reportedly cured by shifting to goat milk (79). Successful management of bovine milk allergy by substitution with goat milk formula was also reported (129).

Brenneman (13) reported that approximately 40% of allergic patients, sensitive to cow milk proteins, are able to tolerate goat milk proteins. These patients may be sensitive to cow lactalbumin, which is species specific. Other milk proteins, such as β-lactoglobulin, are mostly responsible for cow milk allergy (57, 138). Walker (131) reported that only one in 100 infants who were allergic to cow milk, did not thrive well on goat milk. Of 1,682 patients

with allergic migraine, 1,460 were due to food, 98 due to inhalants, 98 due to endogenous (bacterial) substances, and 25 due to drugs (including tobacco). Among the 1,460 patients with food allergy, 92% were due to cow milk or dairy products, 35%, wheat, 25%, fish, 18%, eggs, 10%, tomatoes, and 9%, chocolate. Some patients were allergic to more than one food.

Soy formula is the most frequent substitute for cow milk or cow milk formula for infants suspected of cow milk allergy, but approximately 20–50% of these infants will still have similar intolerance symptoms to soy formula (16, 53). Evaporated goat milk or goat milk powder has been recommended for infant formula (21, 66, 84, 122). Heat applied to manufacturing processes reduces allergic reactions (99). Heat denaturation alters the basic protein structure and thus decreases the allergenicity (73), and high-heat treatment removes the sensitizing capacity of milk (84).

Lactalbumin from goat milk shows a different skin reaction in comparison to bovine milk. Perlman (99) reported variation of skin test reactions to allergenic fractions of bovine milk and goat milk (Table 2.60). The data indicate that some proteins of bovine milk gave higher incidences of positive skin test reactions than goat milk. Inconsistency in cross-allergenicity among milks of different species may be qualitative and quantitative (100). A few reports using gel electrophoretic precipitation analysis also suggested that there was a certain immunological crossreactivity between cow and goat milk proteins (83, 95, 112, 113). However, little clinical research has shown that goat milk is not suitable for patients allergic to cow milk due to the immunological cross-reactivity between the two milk proteins, and much anecdotal evidence of goat milk values as a hypoallergenic substitute for children allergic to bovine milk exists (50, 51, 100).

9.2 Recent Studies on Hypoallergenic Properties of Goat Milk

The hypoallergenic properties of goat milk should be of great importance in human health and medicine and are of keen interest to goat milk producers and consumers, especially in developed countries in recent years. In a recent study, the treatment with goat milk resolved between 30–40% of the problem cases in children who had cow milk allergy, and in another allergy case study, 49 of 55 treated children benefited from the treatment with goat milk (9).

The wide variety of genetic polymorphisms (44) of the different caseins and whey proteins in milk adds to the complexity of the cow milk allergy situation and difficulty to determine which protein is mainly responsible for an allergic reaction. However, it has now been shown that this genetic protein diversity may actually help identify which protein is the allergen, if genetic polymorphisms of milk proteins are specifically used for clinical tests (9). Guinea pigs had allergic reactions to goat milk with α_{s1}-casein, similar to cow milk, which has only this protein polymorph, and which may explain the commonly found cross-immune reaction between cow milk and some goat milk. However, guinea pigs fed goat milk without this polymorph but instead with α_{s2}-casein showed only in 40% an allergic reaction, which led to the conclusion that goat milk lacking α_{s1}-casein is less allergenic than other goat milk. Because α_{s1}-casein content of goat milk is relatively low in some breeds, compared to α_{s2}-casein contents and in contrast to the prevalence of α_{s1}-casein in cow milk, it is logical that children with a high sensitivity

Table 2.60. Variations in Skin Test Reactions to Fractions of Cow Milk and Goat Milk

	Fractions				
Patients	α-lactalbumin	β-Lactalbumin	Casein	Bovine plasma albumin	Goat milk albumin
GF	++++	+	___	___	___
VWW	++	+	___	___	___
DK[1]	+	++++[1]	+	___	___
VDB	++++	+++	+++	Not done	+++

[1]Beta-lactalbumin heated to 100° C still gave ++ reaction but after heating to 120° C for 20 min all skin test reactions disappeared.

Perlman (99).

to α_{s1}-casein should tolerate such goat milk well (9, 16, 65).

For goat breeding programs, this new knowledge could be a challenge and rewarding, especially since selection for or against α_{s1}-casein is now practiced in some countries, because of differences in cheese yield and renneting (86, 105). Goat milk with the genetic trait of low or no α_{s1}-casein, but instead with α_{s2}-casein, has less curd yield, longer rennet coagulation time, more heat lability, and weaker curd firmness, which also may explain the benefits in digestibility in the human digestive tract (3).

From French clinical studies spanning 20 years with cow milk allergy patients, the conclusion was that substitution with goat milk was followed by "undeniable" improvements (110). In other French extensive clinical studies with children allergic to cow milk, the treatment with goat milk produced positive results in 93% of the children and was recommended as a valuable aid in child nutrition because of less allergenicity and better digestibility than cow milk (29, 46, 104).

10 THERAPEUTIC AND NUTRITIONAL ADVANTAGES OF GOAT MILK

10.1 Advantages of Goat Milk in Human Nutrition

Reports have shown that therapeutic and nutritional advantages of goat milk over cow milk can also come not only from its protein or mineral differences but also from another much overlooked component in goat milk, the lipids, more specifically the fatty acids within the lipids (5, 50, 51). Goat milk fat contains significantly greater contents of short- and medium-chain length fatty acids (C4:0-C12:0) than the cow counterpart (5, 16, 50, 51, 65).

Owing to the species-specific characteristics (high amounts of short-chain and medium-chain fatty acids: MCT) in goat milk fat, it has been suggested that goat milk fat may have at least three significant contributions to human nutrition: (i) goat milk fat may be more rapidly digested than cow milk fat because lipase attacks ester linkages of short- or medium-chain fatty acids more easily than those of longer chains (16, 64, 92); (ii) these fatty acids have the unique metabolic ability to provide energy in growing children, and exhibit beneficial effects on cholesterol metabolism such as hypocholesterolemic action on tissues and blood via inhibition of cholesterol deposition and dissolution of cholesterol in gallstones (43, 50, 69, 123); and (iii) they have been therapeutically used for treatment of various cases of malabsorption patients suffering from steatorrhea, chyluria, hyperlipoproteinemia, and in cases of intestinal resorption, coronary bypass, childhood epilepsy, premature infant feeding, cystic fibrosis and gallstones (43, 50, 92, 123). Goat butter, ghee, and related products with higher concentration of MCT than even goat milk have not been studied in relation to the physiological well-being of human subjects (5, 51).

Table 2.61. Concentration of Total N, NPN, and Phosphate in Natural Goat and Cow Milk and Soy-Based Infant Formulas[1]

Milk Group	n[2]	Total N		NPN		P_2O_5	
		$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD
Goat Milk							
Alpine	25	.390[c]	.032	.048[b]	.008	.166[a]	.020
Nubian	25	.556[a]	.013	.061[a]	.013	.212[a]	.015
Cow Milk							
Holstein	25	.392[c]	.058	.033[c]	.002	.173[a]	.022
Jersey	25	.505[b]	.043	.038[c]	.004	.211[a]	.118
Formula Milk							
Brand A	5	.227[d]	.026	.020[d]	.003	.211[a]	.008
Brand B	5	.259[d]	.016	.019[d]	.003	.192[a]	.053

[a,b,c,d]Means with different superscripts within a same column are different ($P < 0.01$).

[1]Expressed in g/100 ml.

[2]Number of determinations per mean value.

Data from Park (90).

The average size of goat milk fat globules is smaller than that of cow and other species' milks, although there are differences by breeds within species. Comparative average diameters of the fat globule for goat, cow, buffalo, and sheep milk were reported as 3.49, 4.55, 5.92, and 3.30 μm, respectively (30, 65). The smaller fat globule of goat milk has better digestibility compared to cow milk counterparts (16, 52, 116). It has also been shown that goat milk proteins are digested more readily by stomach proteases and their amino acids are absorbed more efficiently than those of cow milk, because goat milk caseins form a softer, more friable curd when acidified, which is related to differences in goat milk protein polymorphisms, especially lower contents of α_{s1}-casein (16, 52, 64, 65).

It has been found that goat milk has better buffering capacity, which is good for the treatment of ulcers (90, 91, 134). Proteins, primarily casein and phosphate systems in milk, influence the buffering capacity (BC) (134). Due to the compositional differences, milk of the Nubian goat breed showed a higher BC compared with the milk of the Alpine goat breed and Holstein and Jersey cows (90). Major buffering entities of milks were influenced by species and breeds within species (Table 2.61). Nubian goat milk had highest levels of total N, protein, non-protein N (NPN), and phosphate (P_2O_5) among the four milks of goat and cow breeds. Regardless of breed, goat milk contained significantly higher NPN than cow milk. The higher levels of nitrogen moieties and phosphate in goat milk were positively correlated with higher BC (90). Soy-based infant formulae contained less total N and NPN compared with natural goat and cow milks, and BC of the formulae were also lower than those of natural milks (Figure 2.39). This suggests that the higher BC in Nubian goat milk compared to cow milk can be of importance in human nutrition.

In anemic rats, goat milk had been shown to have a greater iron bioavailability than cow milk (94). In a comparative growth trial (72), children fed goat milk showed significantly greater nutrient bioavailability and growth parameters than those fed cow milk. Goat milk has been widely recommended as an alternative for patients suffering from various allergies, including cow milk and other foods (92, 108, 122, 131).

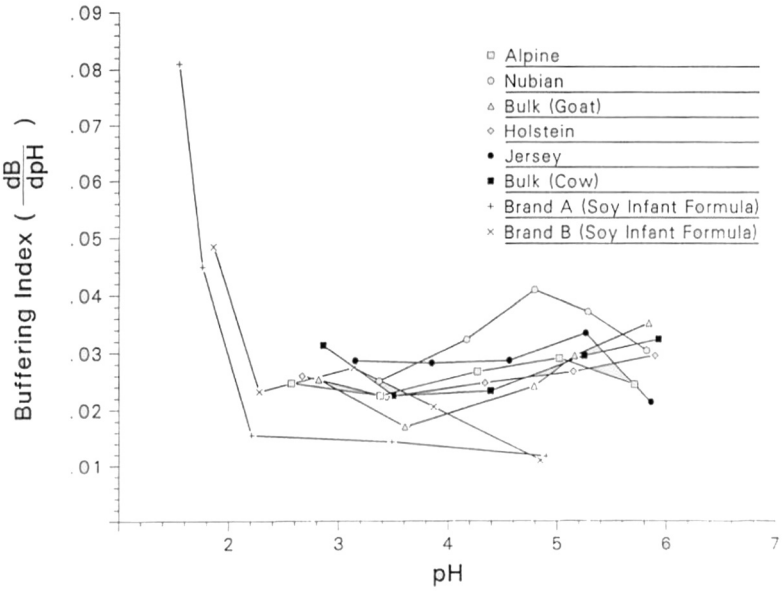

Figure 2.39. Buffering capacities of natural goat and cow milks compared with those of soy-based infant formula. Number of observations for Alpine, Nubian, Holstein, Jersey, brand A and B formula milks were 25, 25, 25, 5, and 5. Adapted from Park (90).

10.2 Recent Studies on Therapeutic and Nutritional Merits of Goat Milk

In Spanish studies with rats, which had 50% of their distal small intestine removed by resection, simulating the pathological condition of malabsorption syndrome, the feeding of goat milk instead of cow milk as part of the diet resulted in significantly higher digestibility and absorption of iron and copper, thus preventing anemia (8). Also in these studies, the utilization of fat and weight gain was improved with goat milk in the diet, compared to cow milk, and levels of cholesterol were reduced, while triglyceride, HDL, GOT and GPT values remained normal (1). It was concluded that the consumption of goat milk reduces total cholesterol levels and the LDL fraction because of the higher presence of medium-chain triglycerides (MCT) (36% in goat milk vs. 21% in cow milk), which decreases the synthesis of endogenous cholesterol. In an Algerian study of 64 infants with malabsorption syndromes, the substitution of cow milk with goat milk caused significantly higher rates of intestinal fat absorption (48).

In a study in Madagascar, 30 hospitalized undernourished children between one and five years of age were fed either cow or goat milk in addition to their regular diet (103). Malnutrition is apparently frequent among children in Madagascar, and cow milk is not affordable or available in sufficient quantities, while goat milk was cheaper to produce and more readily available. The children on goat milk outgained the cow milk children in bodyweight by 9% daily (8.53g/kg/day 1.37 vs. 7.82 1.93) over the two-week trial period, and fat absorption tended to be better in the goat milk children. Thus goat milk was again recommended as a "useful alternative to cow milk for rehabilitating undernourished children."

Although many studies have been conducted on nutritional and therapeutic values of goat milk in human subjects, further clinical and nutritional trials on human subjects are needed to substantiate and confirm the reported hypoallergenic and therapeutic significance of goat milk in human nutrition and well-being.

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3
Sheep Milk

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1 INTRODUCTION

Dairy sheep, i.e., milking ewes, are the ultimate antithesis to the expected. Sheep are supposed to grow wool and produce mutton, meat, and lambs, not milk, at least not fluid milk to be sold for human consumption. So it seems by studying animal husbandry textbooks (41, 45, 68, 95, 107, 241, 247), research journals, conference proceedings (26, 67, 111), and even the authoritative nutrient requirement books by the NRC (189, 190). However, a few countries have ongoing research projects with dairy sheep (137), and the FAO production statistical yearbooks have data on sheep milk production in some but not all countries in the world. There are no data on numbers of dairy sheep populations in the FAO yearbooks, only total numbers of all types of sheep, while separate numbers of dairy cattle populations are listed in the FAO statistics (81, 82).

Current sheep milk production in relation to total world milk production (cows, buffaloes, goats, and sheep) by continents and trends over the last 20 years are given in Table 3.1, except that there were no sheep milk data for North and Central America and Oceania; no goat milk data for Oceania; and no buffalo milk data for the Americas and Oceania. Although sheep milk production in relation to all milk production worldwide amounted to 1.7% in 1980 and 1.3% in 2001, it has been of greater significance within the continents of Africa, Asia, and Europe during these last 20 years (7.0 and 6.6; 5.1 and 1.9; 1.9 and 1.3%, respectively). Sheep milk production seems to have been declining during the last 20 years' worth, percentage-wise, of all milk, except for the 66% increase in sheep milk production in

Table 3.1. Milk Production by Species Relative to All Milk Produced within Continent and Trends During the Last 20 Years (81, 82)

Year	1980	2001
All milk[1]	100.0%	100.0 %
SHEEP[2]		
World	1.7	1.3
Africa	7.0	6.6
S.America	0.1	0.07
Asia	5.1	1.9
Europe	1.9	1.3
GOATS[3]		
World	1.6	2.1
Africa	10.4	11.0
N.C.America	0.4	0.2
S.America	0.6	0.4
Asia	5.2	4.0
Europe	1.0	1.1
BUFFALOES[4]		
World	5.9	11.9
Africa	8.8	8.2
Asia	39.6	38.5
Europe	0.1	0.1
COWS		
World	90.8	84.6
Africa	73.8	74.2
N.C.America	99.6	99.8
S. America	99.3	99.5
Asia	50.1	55.6
Europe	97.2	97.5
Oceania	100.0	100.0

[1]Includes milk of cows, buffaloes, goats and sheep.
[2]No data for North and Central America and Oceania.
[3]No data for Oceania.
[4]No data for the Americas and Oceania.

Table 3.2. Total Milk Production by Species During the Last 20 Years and Relative Proportion for Each Continent Within Species (81, 82)

	1980 1,000 MT	2001 1,000 MT	Change, % 2001−1980	World, % 1980	World, % 2001
SHEEP[1]					
World	7,980	7,808	−2	100	100
Africa	994	1,648	+66	12	21
S.America	34	35	+3	0.4	0.4
Asia	3,396	3,269	−4	42	42
Europe	3,482	2,856	−18	44	37
Mediterranean	4,289	4,523	+5	54	58
GOATS[2]					
World	7,236	12,455	+72	100	100
Africa	1,477	2,773	+88	20	22
N.C.America	318	165	−48	4	1
S.America	134	182	+36	2	1
Asia	3,435	7,017	+104	48	56
Europe	1,569	2,317	+48	22	19
BUFFALOES[3]					
World	27,491	69,248	+152	100	100
Africa	1,248	2,051	+164	4	3
Asia	26,148	67,028	+156	95	97
Europe	96	170	+77	0.3	0.2
COWS					
World	423,034	493,828	+ 17	100	100
Africa	10,477	18,645	+ 78	2	4
N. C.America	76,540	96,638	+ 26	18	20
S. America	23,935	47,055	+ 97	6	10
Asia	33,084	96,674	+192	8	20
Europe	176,200	210,193	+19	42	43
Oceania	12,240	24,623	+101	3	5
ALL MILK					
World	465,741	583,339	+25	100	100
Africa	14,196	25,117	+77	3	4
N.C.America	76,858	96,803	+26	16	17
S.America	24,103	47,272	+96	5	8
Asia	66,063	173,988	+163	14	30
Europe	181,347	215,536	+19	39	37
Oceania	12,240	24,623	+101	3	4

[1]No data for N.C. America and Oceania.
[2]No data for Oceania.
[3]No data for the Americas and Oceania.

Africa from 1980 to 2001. As Table 3.2 shows, the relative decline is most likely due to the strong increases in productivity of cow, goat, and buffalo milk on all continents. Total tonnage of sheep milk production worldwide has held steady or has been slightly declining to around 8 million MT during the last 20 years. Meanwhile, the tonnage of cow milk increased 17% to 494 million MT, of buffalo milk by 152% to 69 million MT, and of goat milk by 72% to 12 million MT. Sheep milk tonnage ranked continents in 2001 (see Table 3.2) Asia > Europe > Africa > S.America, while for goat milk it was Asia > Africa > Europe > S.America > N.C.America, for buffalo milk it was Asia > Africa > Europe, and

Table 3.3. Trends of Populations of Sheep and People During the Last 20 Years (81, 82)

	1980	2001	Change, % 2001−1980
SHEEP (Million head)			
World	1,090	1,056	− 3
Africa	181	250	+ 38
N.C. America	21	15	− 29
S.America	105	75	− 29
Asia	316	407	+ 29
Europe	122	145	+ 18
Mediterranean region	180	174	− 4
Oceania	202	164	− 19
PEOPLE (Million head)			
World	4,450	6,134	+ 38
Africa	480	812	+ 69
N.C. America	373	493	+ 32
S. America	240	351	+ 46
Asia	2,584	3,721	+ 44
Europe	484	726	+ 50
Oceania	23	31	+ 35

for cow milk it was Europe > Asia > N.C.America > S.America > Oceania > Africa. These different rankings reflect the rates of genetic and production progress made on the different continents during the last 20 years and the obvious need for better progress in the productivity of dairy sheep populations in many areas. The data in Table 3.2 also show the need to overcome problems with marketing sheep milk products, as indicated by the 18% decline of sheep milk production in Europe, where traditionally sheep dairying has been most advanced. Africa showed a significant tonnage increase in sheep milk production from 994 to 1,648 thousand MT during the last 20 years, while Asia decreased from 3,396 to 3,269 by 4%, but the Mediterranean region increased by 5% to 4,523 thousand MT.

Around the Mediterranean Sea are some 21 countries, which are unique in their use of milking sheep for the production of yogurt and cheeses of economic importance to these countries. They accounted for a majority of the total sheep milk production in the world, 54% and 58% in 1980 and 2001, respectively (Table 3.4), while they held only 16% of the world sheep population. The importance in the Mediterranean region of sheep milk production is reflected in the increase from 4,289 to 4,523 thousand MT during the last 20 years, while sheep population numbers declined by 4%. Worldwide, all milk production has increased by 25% (Table 3.2) compared to 38% for numbers of people (Table 3.3), while sheep numbers increased in Africa, Asia, and Europe by 38, 29, and 18%, respectively, yet decreased by 29% in the Americas, by 19% in Oceania, and by 3% worldwide. The Mediterranean region is historically and economically the significant sheep milk producing and processing region of the world, but trends during the last 20 years differed among its 21 countries (Table 3.4). Turkey, Bulgaria, Romania, Hungary, Yugoslavia, Cyprus, and France lost great numbers of their large sheep populations, probably more of the less profitable wool than dairy sheep, while Portugal, Spain, Italy, Malta, Albania, Greece, Lebanon, Israel, Syria, Egypt, Tunisia, Libya, Algeria, and Morocco had significant increases in sheep numbers (the FAO data do not distinguish between wool and dairy sheep).

Changes in sheep milk production tonnage from 1989 to 2001 reflect most of these plus or minus changes in sheep populations. While people numbers rose in Europe from 1980 to 2001 by 50% from 484 to 726 million head (Table 3.3), production of all milk increased only by 19%, from 181 to 215 million MT

Table 3.4. Mediterranean Region Sheep Populations, Sheep Milk Production, and Trends During the Last 20 Years (81, 82)

	Sheep numbers			Milk volume		
	1980 1,000 head	2001 1,000 head	Change, % 2001−1980	1980 1,000 MT	2001 1,000 MT	Change, % 2001−1980
Portugal	4,440	5,900	+33	83	98	+ 18
Spain	14,721	24,400	+66	211 306	+45	
France	11,452	10,000	−13	142 230	+62	
Italy	9,120	11,089	+22	606 850	+40	
Malta	5	16	+220	1	2	+100
Cyprus	517	246	−52	25	18	−28
Yugoslavia	4,443	−40	142	96	−32	
Albania	1,169	1,941	+66	42	75	+79
Hungary	2,960	1,129	−62	5	31	+520
Romania	15,766	7,800	−50	347 330	−5	7,359
Bulgaria	10,358	2,286	−78	306 100	−67	
Greece	8,040	9,000	+12	585 670	+14	
Turkey	46,199	29,435	−36	1,142 785	−31	
Lebanon	137	380	+177	14	35	+150
Israel	240	389	+62	21	21	+/−0
Syria	9,311	12,362	+33	368 483	+ 31	
Egypt	1,590	4,545	+186	20	93	+365
Tunisia	4,651	6,600	+42	13	17	+31
Libya	5,046	5,100	+1	38	56	+47
Algeria	13,111	19,300	+47	158	200	+27
Morocco	14,180	17,300	+22	20	27	+35
Total	180,372	173,661	−4	4,289	4,523	+5
World	1,090,473	1,056,184	−3	7,980	7,808	−2
Mediterranean, % of world	16	16		54	58	

(Table 3.2), and sheep milk production even declined an astonishing 18%, from 3,482 to 2,856 thousand MT in Europe. Dairy sheep together with dairy goats have been and still are widely held as "the cows of the small holder," that is, of the mountain and desert farmers, whose steep or dry terrain cannot sustain cows, and of the wandering, transhumance, and nomadic flock herders and cheese makers on the mountain meadows that are not supporting any other form of open agriculture but which are favored by hotels and skiing tourism, industries that therefore oppose any return to brush land, reforestation, and wilderness (104). Thus the decline in sheep milk production in the world's leading region of the Mediterranean probably has two alarming and challenging meanings: fewer mountain farmers and herders are making a living with dairy sheep, and fewer markets exist for sheep milk products, yogurt, and cheeses, even though these products target especially the growing upscale connoisseur and health food markets.

Countries outside the Mediterranean region have kept about 84% of all the sheep in the world (Table 3.4), but they have produced only 46% and 42% of the sheep milk worldwide during the last 20 years (1980–2001), because of the prevailing interest in wool and meat production from sheep. Nevertheless, FAO data (Table 3.5) indicate at least six countries with annual sheep milk production above 100 thousand MT: China (880), Sudan (490), Somalia (430), Iran (300), Afghanistan (165), Iraq (158); ten other countries were increasing their tonnage substantially during the last 20 years, although it is not known whether this increase in tonnage means increased sheep numbers rather than increased productivity per ewe.

Table 3.5. Trends of Sheep Milk Production During the Last 20 Years in Countries with Significant Amounts of Sheep Milk Outside of The Mediterranean Region (81, 82)

	1980 1,000 MT	2001 1,000 MT	Change, % 2001−1980
AFRICA			
Ethiopia	58	56	− 3
Kenya	21	31	+ 48
Mali	31	96	+ 210
Mauritania	56	84	+ 50
Niger	12	16	+ 33
Senegal	7	17	+ 143
Somalia	97	430	+ 343
Sudan	450	490	+ 9
S. AMERICA			
Bolivia	27	29	+ 7
Ecuador	7	6	− 14
ASIA			
Afghanistan	231	165	− 29
Bangladesh	15	23	+ 53
China	489	880	+ 80
Indonesia	-[1]	88	-
Iran	691	300	− 57
Iraq	193	158	− 18
Jordan	25	33	+ 32
Kazakhstan	-	35	-
Mongolia	14	21	+ 50
Nepal	-	13	-
Pakistan	36	31	− 14
Saudi Arabia	73	75	+ 3
Uzbekistan	-	24	-
Yemen	35	16	− 54
USSR	73	-	-
West Bank	-	34	-
Total	2,641	3,151	+ 19
World	7,980	7,808	− 2
% of world	33	40	

[1]No data available; nor for N.C. America or Oceania.

2 MILK PRODUCTION

2.1 Breed of Sheep

Among several reviews, Mason (164) listed 320 breeds of sheep, but only one, the East-Friesian, as a specialized dairy animal. Record milk yields of 1,200 kg/year for an East Friesian and 533 kg/year for an Israeli Awassi ewe have been reported (108, 251), but selected Assaf, Chios, Comisana, Lacaune, Lacha, Manchega, and Sarda ewes can also produce high milk yields (1, 109, 182, 251) (Table 3.7). In Spain, Mason (163) estimated that 4 million sheep were milked in 1964 with milk accounting for 65% and wool for 10% of the flock income. Mills (173) reported that in the Pyreneese mountains of France, about a half million ewes of the two breeds, the Basco-Bearnaise and the Manech, are milked by some 3,500 farmers earning 54% of revenue from milk, 38% from lambs, and 8% from wool. Even a pelt-dairy dual-purpose breed, such as the Karakul

in Kazakhstan, has been reported to derive 50% of their income and 36% profit from producing various cheeses from their milk (74). In the United States, the net income from a 300-ewe flock producing 68 kg milk/ewe/year was $2,806.00/flock/year and $9.35/ewe/year, compared to another 300-ewe flock producing 250 kg milk/ewe earning $74,806.00/flock/year and $249.35/ewe/year (251). Mediterranean countries such as Italy, France, Yugoslavia, Greece, Albania, Turkey, and Syria have millions of dual-purpose native sheep milked primarily for yogurt and cheese production. The sheep in Israel are supposed to be the highest milk producers in the world, partly because of about 70% participation in milk recording schemes, already in place 30 years ago, and strict selection programs (57).

The East-Friesian, Awassi, and Chios breeds have been used in many countries to improve milk production of native sheep breeds (80). The East Friesian was crossed in Israel with the fat-tail Awassi to produce a new breed, the Assaf; in Norway, the East Friesian was bred to the Dala sheep (149) to improve lamb growth and litter size. Chios were superior to breeds from temperate regions in crossing with native breeds in Lebanon, Iraq, Oman, Israel, and Egypt to increase prolificacy, age at puberty, fertility, and fecundity (1). Increases in milk production from crossing East Friesians with native breeds in Poland, Czechoslovakia, Bulgaria, Hungary, and Russia ranged from 28 to 73% and even 146% in Hungarian Merinos over a 165-day lactation (196). Awassi breeding to Booroola Merinos in Israel resulted in milk yields up to 307 kg compared to pure Awassi, giving 550 kg per lactation (1). Terrill and Slee (249) identified 36 sheep breeds with dairy as the primary use (Table 3.6). Boyazoglu (39) classified dairy sheep breeds (besides the East Friesian), mainly in the Mediterranean region, into three groups by level of milk yield potential:

- *High:* Awassi, Chios, Lacaune, Sarda
- *Average to good:* Beglika, Bergamasca, Churra, Comisana, Cyprus, Kymi, Skopelos, Lacha, Langhe, Stara Zagora, Zlatoucha
- *Low:* Barbary, Bordaleiro, Kivircik, Manchega, Manech, Mytileni, Serra da Estrela, Serres, Sopravissana, Tzigaja, Vlahiko

Milk yields of dairy sheep are not widely reported, partly because participation in milk recording schemes and organizations is not widespread for financial or logistical reasons, such as the flock's being out on faraway grazing lands. Also, milk yields of dairy sheep are usually recorded as "after suckling" lambs for 4 to 8 weeks (Table 3.7), contrary to the practice for dairy goats or dairy cattle, which have lactation lengths beginning from day of kidding or calving and continuing for preferably 305 days. Lactation length is in most sheep breeds much shorter than in dairy goats or dairy cattle, but it can be extended by milking stimulation such as three times a day milking (172). Lactation length is influenced by the seasonal breeding prevalence of many sheep breeds, but it can be altered by changing the length of daylight in barn management (139), by

Table 3.6. Sheep Breeds for Dairy as Their Primary Use (10, 39, 173, 182, 249)

BULGARIA	Massese
Karnobat	Sarda
Svishtov	Savoy
CZECHOSLOVAKIA	Sicilian
Valachian	Sopravissana
FRANCE	PAKISTAN
Basco-Bearnaise	Damani
Corsica	Gojal
Lacaune	PORTUGAL
GERMANY	Saloia
East Friesian	Serra da Estrela
GREECE	ROMANIA
Chios	Turcana
Karagouniki	Manech
Kymi	SPAIN
Lesvos	Canaria
Serron	Churra
Sekopelos	Manchegaa
Vlahiki	Talaverana
HUNGARY	TURKEY
Racka	Karaman
ITALY	Sakiz
Altamura	USSR
Calabrian	Reshetilovka
Comisana	YUGOSLAVIA
Frabosa	Istrian
Garfagnana	Karakachan
Langhe	
Lecce	

Table 3.7. Average Milk Yields and Lactation Length After Suckling Lambs (13, 39, 108, 173, 182)

		Days	Yield, kg
CZECHOSLOVAKIA	Pramenka	60–230	100–225
FRANCE	Lacaune	160–170	270
	Corsica	170	108
GERMANY	East Friesian	300–365	500–900
GREECE	Chios	170–250	135–300
	Karagouniki	160–175	120–165
	Kymi	120–265	100–170
	Sfakia	190–200	130–135
	Skopelos	160–180	150–165
ISRAEL	Awassi	240–300	440–550
	Assaf	150–210	150–350
ITALY	Comisana	-	90–175
	Langhe	-	80–150
	Massese	-	110–140
	Sarda	-	120–195
SPAIN	Canaria	200	180
	Churra	150	150
	Lacha	180	210
	Manchega	150–270	80–520
TURKEY	Awassi	120	130–205

hormone treatments (169), and by genetic selection (22). Table 3.7 gives average lactation lengths of some of the higher yielding dairy sheep breeds and their average lactation milk yields. It has been shown repeatedly, e.g. with East Friesian, Awassi, Chios, and Manchega (173, 182), that genetic selection can improve parameters of sheep milk production significantly, but for financial, nutritional, educational, and traditional reasons, average flock management is often not focused on this goal.

Sheep breeds are described by differences of types in wool (fine, coarse, hair), wool cover (clean face, clean legs, clean belly, or not), color (white, black, brown, spotted), horns (short, long, curved, four horns, polled), ears (long, short, erect, hanging), face (Roman nose, straight), tails (thin, fat, short, long), rump (fat, normal), size (large, small), udder shape and teat placement, disease resistance, and seasonal breeding (68, 108, 173, 182).

Most sheep have two functional udder halves and teats, but there are a few with four as found in the Romanov, Finnsheep, and the newly developed Wealden Four-Quarter sheep breed in the U.K. (80). Most published photos of representative dairy sheep breeds look more like they're taken by a tourist than a professional animal photographer (Figures 3.1–3.6) and do not portray ewes and their udders to their best type, as would be advantageous for promotion and sales to prospective breeder buyers and as is done so skillfully in the dairy cattle industry.

2.2 Flock Management System

Management of milk production from dairy sheep obviously depends on efficient reproductive management of the flock and successful completions of pregnancy of the ewes. Without lambing there is no milk secretion or galactopoiesis, at least not in ewes, while initiation of milk secretion just by physical massage stimulation is known from female and male goat mammary glands, even nulliparous. Lambing causes the beginning of lactation of ewes. Six systems of managing lambs and lactation have been identified (252) (Figure 3.7), although there is always some variation depending on temporary differences of the price for lambs, the price of supplementary creep feed for finishing lambs, the price and market for products made from sheep milk, the availability of hay, silage, concentrates for the ewes, and growth of pasture herbage, which will greatly

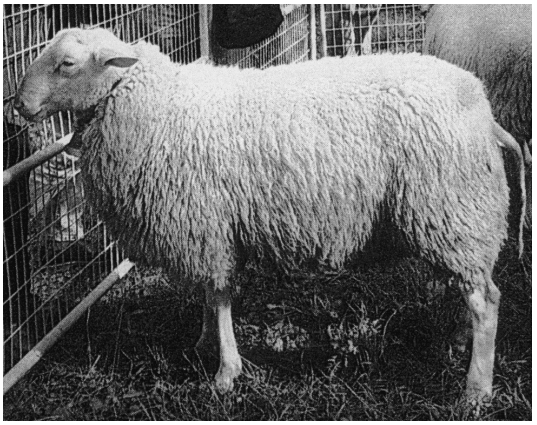

Figure 3.1. A top-quality East Friesian dairy ewe in Switzerland. Photo: O. Mills, 2000, by permission, Shepherd Publishing Ltd. and Sheep Dairy News, Malvern, Worcestershire, U.K.

Figure 3.2. Iraqi Awassi dairy ram. Photo: C. Devendra and G.B. McLeroy, 1982, by permission, Longman Publ., London, U.K.

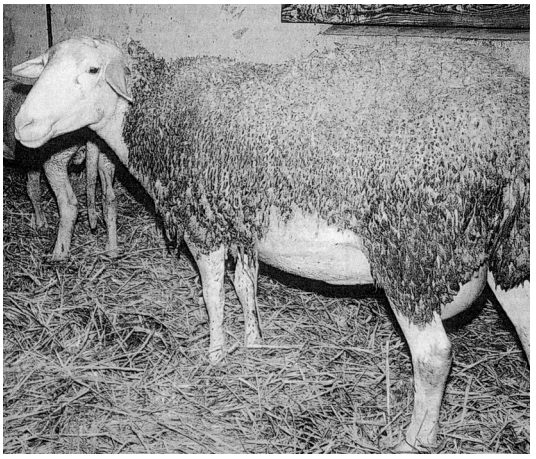

Figure 3.3. French Lacaune dairy ewe. Photo: UPRA, 1998, by permission, Shepherd Publishing Ltd. and Sheep Dairy News, Malvern, Worcestershire, U.K.

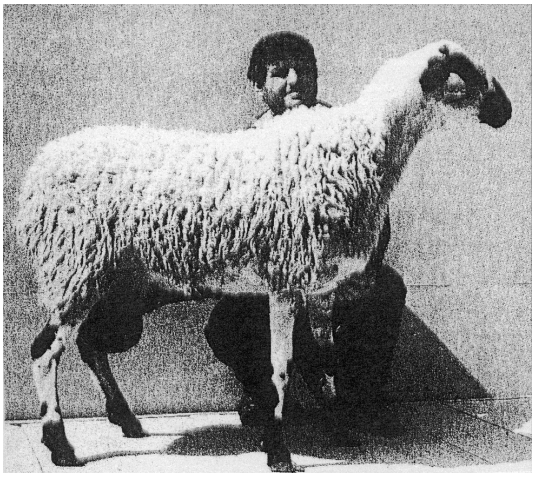

Figure 3.4. Greek Chios dairy ewe. Photo: I. Hatziminaoglou et al., 1996, by permission, Commonwealth Agricultural Bureaux International Press, Wallingford, U.K.

fluctuate between the seasons and with snow, drought, or shortages of rainfall.

System I. If the relative price for lambs exceeds that of sheep milk made into cheese and yogurt, then the prevailing management lets the lambs suckle for about four months and the ewes are not milked at all but dried up after weaning the lambs.

System II. Lambs may be suckled for about three months, after which the ewes are milked for about another month.

Figure 3.5. Spanish Manchega dairy ram. Photo: Ministerio de Agricultura Publ., 1980, Madrid, Spain.

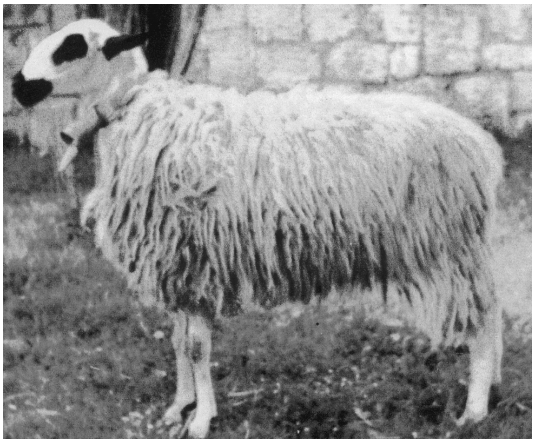

Figure 3.6. Spanish Churra dairy ewe. Photo: Ministerio de Agricultura Publ., 1980, Madrid, Spain.

System III. The traditional Mediterranean management, where sheep milk is highly priced in its products and involves early weaning of lambs at about one month of age and milking the ewes for at least another five months.

System IV. The nomadic management of sheep flocks in Asia and Africa includes mostly daytime grazing by the ewes away from their lambs, and once a day or "partial" milking starting one month after lambing.

System V. Under more intense sheep milk production, as in Israel or Cyprus, partial milking is started after the period of colostrum secretion a few days after lambing. Lambs are weaned at two months of age and full milking continues for another four months.

System VI. Under very intensive management similar to that of dairy cattle or dairy goats, as with East-Friesian in Germany or Britain, the lambs are not suckled at all but fed on a lamb nursing bar with reconstituted commercial milk replacer, and the ewes are milked for 10-month lactations.

Overall, most sheep milk is produced within a triple-purpose breed management, deriving additional but often only minor revenues from meat and wool production, besides providing food for the family and hides and manure for the gardens. Sheep milk management includes the need to consider genetic advances matched by improved nutrient supplies with the feed rations, improved veterinary and sanitary attention, perhaps some form of housing, which is minimal with most native flocks except for predator control in night corals, and possibly machine milking. Sheep milk production management differs from cow and goat milk production, which are fluid-milk oriented, while sheep milk production is not. This influences the flock owners' interest in genetic advances also quite differently, since milk yield is not of primary importance as is cheese yield, i.e., the level of protein and fat in the milk. This also influences the interest in monthly milk recording schemes for proving genetic merits of sires, i.e., of rams. As the backbone of genetic progress, milk recording is widespread and important in the dairy cattle industry, but measuring monthly individual sheep milk yield is of secondary importance to the interest in the high concentration of solids in sheep milk.

Milk recording in Europe is coordinated and promoted by the International Committee for Animal Recording (ICAR) through published proceedings of their biennial conferences (20, 52). In a 1993/1994 survey, France was the world leader in numbers of dairy sheep and flocks participating in milk recording schemes with more than two-thirds of their dairy sheep population, while other member

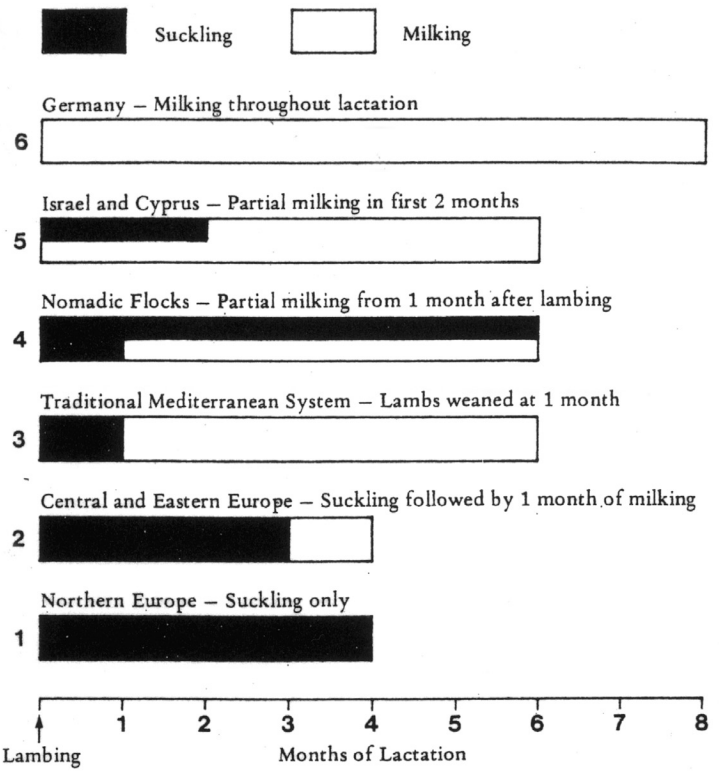

Figure 3.7. Sheep milk production systems. Source: Adopted from T.T. Treacher, 1985, by permission, Centre for Tropical Veterinary Medicine Publ., Edinburgh, U.K.

countries of ICAR tested less than 10% of their ewes (Table 3.8). By 2000, the participation in sheep milk recording schemes had markedly improved in numbers of ewes and flocks, but the percentage of the population was still less than 10% (13). In actual ewe numbers, the Lacaune was in 1993 and the Sarda in 2000 the most tested dairy sheep breed, followed by Manech, Lacha, Corsica, Karagouniki, and Comisana in 2000. The Lacaune also produced by far the most tested rams for artificial insemination (AI) use in 1993 and 2000, but considerable progress in A.I. has now been made in Spain, Italy, Greece, and Portugal, as indicated in Table 3.9.

Milk recording, use of AI, and accurate genetic evaluations of sires, dams, progeny, and pedigrees are the main tools for efficient breeding management because several studies have well established the heritability and genetic correlations of milk traits in dairy sheep populations (19) (Table 3.10). The data are similar to what has been known for these parameters in dairy cattle populations (204). Sheep milk yield was found to be 30% to 32% heritable (19, 229). This means that annual genetic progress in milk yield is predictable for dairy sheep for a certain selection differential, but simultaneous progress is not so easy in milk solids contents because of the negative correlations of milk yield with fat and protein contents (−19% to −34% and −23% to −47%, respectively). On the other hand, the rate of genetic progress in selection for solids contents alone can be faster than for milk yield because of the higher heritabilities for protein and fat contents (48% to 53% and 55% to 62%, respectively). Several studies have reported actual genetic gains in sheep milk produc-

Table 3.8. Participation in 1993 and 2000 In Sheep Milk Recording Schemes by Country (13, 19)

Country	Official recording scheme			Other recording schemes		
	Ewes, number	% of population	Flocks, number	Ewes, number	% of population	Flocks number
Belgium	-	-	-	95	9.5	3
France	259,318	21.0	798	539,005	43.6	1,648
in 2000	***281,547***	***20.2***	***807***			
Germany	1,460	2.5	270	-	-	-
Greece	54,700	0.5	675	-	-	-
in 2000	***28,050***	***7.2***	***352***			
Hungary	1,154	1.8	21	-	-	-
Israel	-	-	-	6,200	12.1	6
in 2000	***10,950***	***23.7***	***17***			
Italy	211,247	3.9	1,911	-	-	-
in 2000	***345,059***	***6.3***	***2,257***			
Netherlands	-	-	3	-	-	-
Portugal	21,448	4.3	460	-	-	-
Slovakia	-	-	-			
in 2000	***39,654***	***19.2***	***117***			
Slovenia	458	7.2	24	-	-	-
Spain	90,757	2.2	384	-	-	-
in 2000	***149,400***	***7.1***	***399***			
Switzerland	-	-	-	340	10.5	34
Tunisia	2,200	1.0	10	-	-	-

tion: for the Lacaune breed of 5.7 liters/year during the 1980s, the Manech 2.1 liters/year, the Sarda 1.6 liters/year, and the Lacha about 1 liter/year (19). Recent reports show continued progress; in the total Churra breed, the average rose from 100 to 120 liters of milk during 120-day lactations from 1987 to 1998; the same time period took the Manchega breed from a 147 to a 166 liter milk yield increase (13). Genetic parameters of dairy traits in United States nondairy sheep breeds have been reported by Sakul et al. (228).

2.3 Age of Ewe, Parity, Lactation Length, Litter Size

The relatively short generation interval of one year of small ruminants, sheep, and goats is one of their advantages compared to cows, which take 2–3 years to raise a replacement and 2–3 more years before the next generation is providing milk, while a lamb born this year can have another lamb next year, which then can milk no later than the following year. Milk yield expressed in sheep dairying, either as the amount harvested after the suckling lamb(s) have been weaned or as in cows and goats directly after parturition, follows a curvilinear function depending on age, i.e., increasing with age (47, 156, 238) up to a plateau at maturity and then decreasing again with progressing age (92, 209), just like in the physiology of cow milk production (142). Parity or number of lactation in ewes can be almost identical to age. Highest sheep milk yields are produced in the third to sixth lactation normally (213).

Lactation yield is also influenced by litter size, i.e., multiple lambs are supported by a higher rate of galactopoiesis or milk secretion (38, 157, 197). Several studies have found linearly increased daily milk yields from 1.03 to 3.2 kg/day for litters of one to five lambs suckled for 56 days (156).

Lactation length influences lactation milk yield greatly (Table 3.7). Genetic correlation between total milk yield in Churra dairy ewes and lactation length of 61% and phenotypic correlations of 25% have been reported (75). High sheep milk yields are

Table 3.9. Participation in Sheep Milk Recording Schemes by Breeds and Use of Artificial Insemination (AI) in 1993 and **2000** (13, 19)

Breed	Country	Total population	% Ewes' milk recorded	Flocks recorded	Ewes using AI	AI rams' progeny tested
Lacaune	FRANCE	725,000	21.6	376	126,000	450
″ **in 2000**	″	**825,000**	**20.1**	**384**	**135,000**	**470**
″	″	511,110[1]	70.5[1]	1,501[1]	256,000[1]	-
Manech and	″	440,000	20.8	338	40,000	130
Basco-Bearnaise	″		8.3[1]	147	15,000[1]	-
″ **in 2000**	″	**470,000**	**21.0**	**352**	**53,000**	**190**
Corsica	″	100,000	17.5	84	1,000	-
″ **in 2000**	″	**100,000**	**16.9**	**71**	**5,200**	**30**
Karagouniki	GREECE	200,000	10.0	35	6,000	20
Lesvos	″	175,000	6.2	130	-	-
Sarda	ITALY	3,700,000	2.8	854	12,000	40
in 2000	″	**4,700,000**	**4.2**	**1,168**	**23,100**	**80**
Comisana	″	990,000	8.5	723	-	-
Serra Estrela	PORTUGAL	280,000	5.5	370	-	-
Lacha	SPAIN	440,000	18.0	208	11,500	50
″ **in 2000**	″	**438,200**	**19.0**	**227**	**20,588**	**84**
Churra	″	1,700,000	1.5	87	16,000	50
″ **in 2000**	″	**750,000**	**3.6**	**72**	**14,235**	**40**
Manchega	″	1,100,000	5.4	119	15,000	50
″ **in 2000**	″	**925,000**	**4.2**	**100**	**16,974**	**43**

[1]Commercial flocks with simplified milk recording scheme.

generally from long lactations, normally eight to 10 months, but milking ewes for two years without lambing has also been practiced (174) with the goal of obtaining winter milk, which is in greater demand and higher priced therefore than spring or summer milk. Lactation length can be improved through management, increased frequency of daily milking, greater nutrient supply (46), and genetic selection, although reported heritability estimates are low, between 2 and 8% for Churra and Lacaune dairy sheep (21, 75), compared to other milk traits (Table 3.10). It means that lactation length depends mainly on "environmental" factors, which include the ewe's hormones.

Soon after weaning lamb(s) the persistency of milk secretion usually decreases sharply because the stimulation of the suckling lamb(s) on several hormones in the ewe controlling milk secretion ceases and has to be replaced by the stimulation of milking, which is more effective therefore by three times/day or more than by one or two times/day milking (186). Experimental simulation by daily oxytocin

Table 3.10. Heritability (Diagonal, Bold) and Genetic Correlations (Below Diagonal) of Sheep Milk Traits From 1,487 Officially Tested[1] Lacaune Ewes (19)

	Milk yield	Fat yield	Protein yield	Fat content	Protein content
Milk yield	**0.32**				
Fat yield	0.82	**0.29**			
Protein yield	0.92	0.91	**0.27**		
Fat content	−0.34	0.24	−0.05	**0.62**	
Protein content	0.47	−0.05	−0.10	0.75	**0.53**

[1]Monthly milk recording of two daily milkings.

injection to Mehraban ewes in Iran proved the importance of that hormone for daily milk yields, which were increased by 56% after injections beginning with day 15 of lactation and by 25% after injections beginning with the day of weaning, and lactation length was increased by 22% (278). Another hormone affecting galactopoiesis is somatotropin or growth hormone, which has been studied in dairy sheep by injecting the exogenous bovine form (bST), which differs only in one amino acid from the ovine form and is biologically active in sheep (42). Actual and 6% fat-corrected milk yields were increased in Chios and Comisana ewes (56).

Lactation yield is estimated from monthly sampling of daily yields of individual sheep. According to procedures of milk recording schemes, the total lactation yield is then calculated (19, 141). The monthly yields can be represented by curvilinear regression equations (87), which, however, can have more than one peak depending on pasture providing flush growth in spring and sometimes one more peak after good rainfall in early autumn. Relationships of sheep milk constituents were studied by Hadjipanayiotou (102) and expressed in regression equations. Total solids content was correlated at 81% with fat and protein contents.

2.4 Nutrition of Ewe

Voluntary feed intake and with it the daily supply of required nutrients is critical for the support of milk production of ewes even more than for cows because of the higher energy content of sheep milk (105 kcal/100 g versus 70 kcal for cow milk) (142). High-yielding dairy sheep need an increased energy density of their feed ration because daily voluntary feed intake is limited by the volume of the rumen, by passage rate of the feed through the digestive tract, and by palatability of the feed. Adding between 3 to 5% supplementary fat from commercial products composed of calcium soaps of long chain fatty acids can increase the caloric density of sheep diets without reducing the important fiber portion (78).

Even nondairy sheep can be made to produce fair amounts of milk with proper nutrition (192, 228). Rambouillet ewes under intensive feeding conditions produced 69 kg milk in 84 days of lactation and averaged 822 ml milk/day. Many experiments have shown that the nutritional level of the ewe before and after parturition affects milk production greatly (142). The range in milk production obtained by dietary changes in several experiments in initially similar ewes can be more than twofold (34). On the other hand, feeding extra amounts of energy and protein to ewes, which lack the genetic potential for higher milk yields, is a waste of money (239).

Not only does the quantity of milk depend on the daily feed intake, but the quality of milk can also be influenced considerably by changed dietary composition, leading to the production of nutritionally "functional" or "tailor-made" food. Milk fat is mostly affected by feed changes, especially by the ratio of forage to concentrates (85), because milk fat synthesis in the mammary gland depends on sufficient fiber supply in the daily feed intake to be fermented in the rumen to acetate, which is a primary precursor in milk fat synthesis (Figure 3.13). More than 50% concentrate in the feed ration reduces acetate production in the rumen, increases propionate production instead, and leads to decreased fat synthesis in the mammary gland and lower-than-normal levels in the milk. Feeding a commercial rumen-protected fat high in oleic and linoleic acids to Comisana ewes increased the medium- and long-chain fatty acids C16:0–C18:3 in milk fat significantly, decreased the short-chain fatty acids C4:0–C14:1, and increased the unsaturated-to-saturated fatty acid ratio considerably (224), which are changes of interest in human nutrition. On the other hand, certain dairy sheep regions, such as Roquefort, may and will impose definite feeding regulations, such as prohibition of certain feed supplements and animal treatments to preserve their traditional milk and cheese quality standards under the Protection of Origin labels (35).

Formulating a proper daily feed ration sufficient to support milk production of ewes without losing body weight (BW) requires balancing calculations of data from tables of feed composition (132, 190) and nutrient requirements (46). The difference for the requirements of just daily maintenance compared to those for producing several kg milk or nursing one or more lambs is high (2). The British recommendations for 60 kg housed ewes yielding 1 kg milk/day are 15.6 MJ metabolizable energy (ME) and 146 g metabolizable protein (MP) compared to ewes yielding 3 kg milk requiring 32.2 MJ ME and 297 g MP/day, or increases by 106% and 103%, respectively (Table 3.11). The necessary increases in voluntary dry matter intake (DMI) per day by ewes

Table 3.11. Daily Nutrient Requirements of Sheep

	Body weight, 50 kg		70 kg	
Nursing sheep (Ref: 190)	Maintenance	Nursing twins	Maintenance	Nursing twins
Dry matter intake, kg (DMI)	1.0	2.4	1.2	2.8
% of body weight	2.0	4.8	1.7	4.0
Energy, TDN, kg	0.55	1.56	0.66	1.82
Digestible, Mcal	2.4	6.9	2.9	8.0
Metabolizable, Mcal	2.0	5.6	2.4	6.6
Crude protein, g	95	389	113	420
Calcium, g	2.0	10.5	2.5	11.0
Phosphorous, g	1.8	7.3	2.4	8.1

	Body weight, 60 kg	
Lactating ewes (Ref: 2)	Milk yield, 1 kg	3 kg
Dry matter intake, kg	1.3	2.8
Metabolizable energy, MJ[1]	15.6	32.2
Metabolizable protein, g	146	297

[1]1 MJ = 1,000 kJ; 1 kJ = 0.239 kcal; 1 kcal = 4.184 kJ.

are also considerable. For maintenance of 50 kg ewes a DMI of 2% of BW is needed, but if they are also nursing twins a DMI of 4.8% of BW is required (190) (Table 3.11).

Nutrition also influences many aspects of reproduction in sheep, thus indirectly milk production (223). Quality and quantity of nutrition affects age at puberty of lambs, fertility, ovulation rate, twinning rate, embryo survival, parturition-to-rebreeding interval, testis growth, and spermatozoa production, besides persistency of lactation and peak yields.

2.5 Milking Management Practices

The majority of dairy ewes are managed under traditional systems and milked by hand. Probably because most ewes are expected to nurse their lambs for several weeks or months before they are being milked by their owners or employees, there has not been a strong interest in selecting ewes genetically for udder shapes, teat size, teat placements, and median suspensory ligament support, which would be practical for hand or machine milking, even though these type characteristics are heritable and have been tremendously improved in dairy cattle. Therefore, to modernize dairy sheep management to include machine milking, one is confronted with the reality of poor udder morphology in most ewes, pendulous udders, and teats that are sticking out on the side of the udder horizontally rather than hanging down at the base and that are of small size, all of which make machine milking often difficult. Of course, there are exceptions among the intensively managed flocks, most notably reported by French, Spanish, Italian, Greek, and Israeli researchers (58).

However, instead of concentrating on education and promoting genetic improvement of udder morphology a temporary solution has been proposed with the use of the "Sagi" hook, which is named after its inventor and lifts up the center of the udder between the teats from behind the ewe the way the median suspensory ligament of the udder is supposed to do naturally, so that milking machine teat cups can be better attached from behind and underneath and stay on during milking (173). The use of the Sagi hook has increased the yield of extracted milk by 40% to 70% in some studies in Israel and has eliminated the need of after-stripping by hand or machine. On the other hand, the promotion of udder evaluation scoring schemes for genetic improvements should be of the highest priority, and efforts are being made, especially aided by the International Symposia on Machine Milking of Small Ruminants (50, 58). Several authors have classified sheep udders into their different types for purposes of genetic selection and improvement (Figure 3.8). The most desirable type IV was identified in a Spanish survey of only 10% of 525 ewes, while the undesir-

able type II dominated 56% of the udders (90). A linear scale with 9 points for morphological appraisal ("punctuation") of five traits of sheep udders has been initiated by de la Fuentes (66). The five traits are udder depth, udder attachment, udder shape, teat placement, and teat size (Figure 3.8). Heritabilities for these five traits have been determined; they are 0.16, 0.17, 0.24, 0.24, and 0.18, respectively, and are very promising for genetic selection (13). Scoring proceeds from 1 = poor to 9 = very desirable, which has been applied to 10,762 Churra, 2,707 Lacha, and 7,171 Manchega ewes in Spain by 2001. Thanks to the new electronic age, an innovative and promising development comes from the introduction of rumen bolus microchips for electronic recording of individual sheep identifications (44, 203), and of "digital" photography of udder morphology, their evaluation with new computer software, and utilization for genetic progress (225). Udder traits were scored electronically in three flocks with 463 ewes (226), and the scores were found to be correlated with daily milk yield between 21% and 50%, and with milking kinetics between 15% and 38% (227).

Hand milking is best done by the "full hand" method, but most ewe teat sizes are too small; therefore, stripping by thumb and forefinger is more commonly practiced and also usually requires the "wet method." A few ewes are conveniently milked from the side, with the milker sitting on part of a small wooden platform on which the ewe has been placed (173). Larger flocks are milked usually from the rear by the milker squatting or sitting on a stool behind them or standing backwards over the top of the ewe, depending on tradition in different countries (Figure 3.9). The use of milking machines has been resisted by shepherds for various reasons: for taking more time than hand milking because of the small amounts of milk; because of the time needed to wash the equipment after milking; because of the cost of such investment against the low price of sheep milk products; or even because of fear that it causes mastitis. Nomadic and transhumance sheep flocks also lack electricity for operating milking machines and would have to carry extra loads of gasoline to run the motors (Figure 3.10).

The first milking machine for sheep was built in France in 1932 with the aim of improving the bacteriological quality of the milk, but not until 1958–1962 was machine milking seriously adopted at Roquefort (253). In 1986, France had more sheep

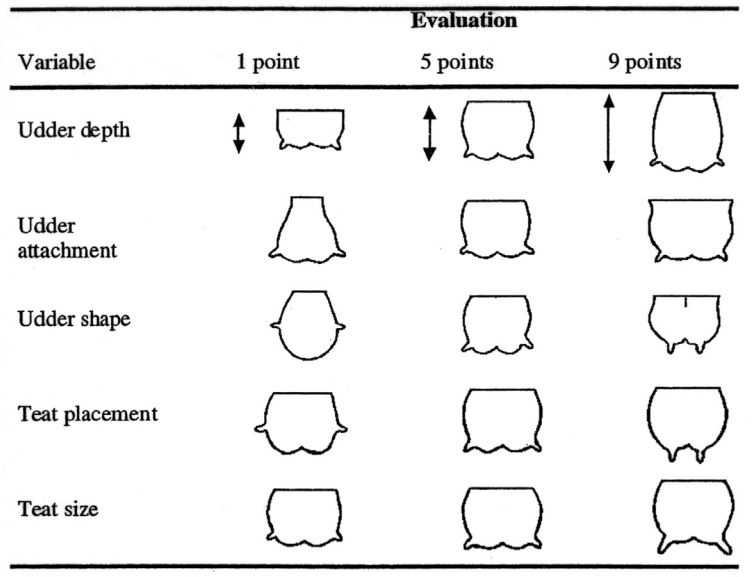

Figure 3.8. Classification of udder types in dairy sheep. Source: adopted in part from J.J. Arranz et al., 2001, Spooner Agricultural Research Station Publ., Spooner, WI, U.S.A.

Figure 3.9. Typical hand milking of a transhumance flock of dairy sheep in Romania. Photo: G. F.W. Haenlein.

milking machines (2,500) than any other country, and in the Roquefort region there was a 60% adoption level. Spain had then about 500 sheep milking machines, and Israel, Portugal, Bulgaria, and Greece also began to change from the common practice of hand milking. Machine milking is best for larger flocks in modern, more intensive management that includes housing and nearness to electricity and repair services. The major milking machine companies, Alfa Laval, Westfalia, Gascoignes, and others, have well-developed, specialized sheep milking systems that differ from the widely used cow milking systems. They differ not only in their having only two teat cups instead of four but also in using different vacuum levels, pulsations per minute, teat cup liners, vacuum reserves, and so on (33, 136, 173, 233) (Table 3.12). The cheapest and simplest milking machine system involves only a portable milking bucket with claw units attached to a portable vacuum pump, and possibly a little more sophisti-

Figure 3.10. Typical transhumance pasturing of a dairy sheep flock accompanied by donkeys carrying household equipment for the shepherds in the mountains of Romania. Photo: G.F.W. Haenlein.

Table 3.12. Recommendations for Milking Machine Settings for Dairy Sheep (33, 136, 173, 233)

	Range	Recommendation
Vacuum level, kPa[1]		
Claw level	35–51	39–45
Low line	38–42	
Mid line	41–46	
High line	44–48	
Pulsations/minute	60–180	112–120
Ratio, % rest:milk	30:70–60:40	50:50
Minimum air flow, LPM[1]		
Bucket system/unit		280
Pipeline/unit		700
Clean in place, airflow minimum, LPM		
36 mm pipeline		700
48 mm pipeline		1,120
60 mm pipeline		1,680
Number of units/slope of line		
36 mm pipeline		
0.8% slope		5
1.0% slope		6
1.2% slope		8
1.5% slope		9
48 mm pipeline		
0.8% slope		10
1.0% slope		12
1.2% slope		16
1.5% slope		18
60 mm pipeline		
0.8% slope		22
1.0% slope		24
1.2% slope		28
1.5% slope		32

[1]kPa = kilo Pascal; 1 kPa = 7.5 mm Hg.
[1]LPM = liter/minute.

cated dumping station, which then is taken to a filtering, cooling, and storage facility, which can just consist of simple milk cans of sufficient sizes stored in cold water tanks or refrigerated milk holding tanks (31). For larger commercial flocks, a milking parlor of various designs—linear, herringbone, rotary, single line, double line, heads-in, heads-out, with pipeline overhead or underneath, taking the milk to the refrigerated holding tank—any of these are a must for efficiency and for comfort of the operator (Figures 3.11–3.12). Milking 100–200 ewes/hour/operator is not unusual (252).

Machine milking of ewes, depending on breed, can proceed in two phases. Milk from the cistern of the udder is first released, followed by the alveolar milk, ejected by the effects of oxytocin (253). Other sheep release milk in a single phase, when the alveolar milk ejected by oxytocin coincides with the expulsion of the cisternal milk. It is generally agreed that cisternal milk is lower in fat content than the alveolar milk (167). The two-phase release may be aided by poor udder shapes of sheep and horizontal teat placement (13). It is common practice among many milkers to use stripping by hand or machine as a means to reduce residual milk and increase yields and fat content in the obtained milk (28), but efforts are made to eliminate stripping, as in dairy cow management (168).

Figure 3.11. Typical rotary milking parlor for dairy sheep. Photo: F. Kervina et al., 1981, by permission, Alfa-Laval Co. Publ., Tumba, Sweden.

Many milking machine pipeline systems now have also automatic take-off units on the milking units to reduce labor and the danger of over-milking of ewes. Most milking machine systems have "cleaning-in-place" systems to reduce labor after milking and assure sanitary conditions of the equipment. And most milking machine systems now accommodate temporary or permanent milk metering devices or weigh jars so that the important monthly individual milk recording can be performed for the sake of genetic selection and progress. Required vacuum and air flow are given in the cited guidelines (33, 233). Generally, milking frequency is two times/day with intervals that are convenient

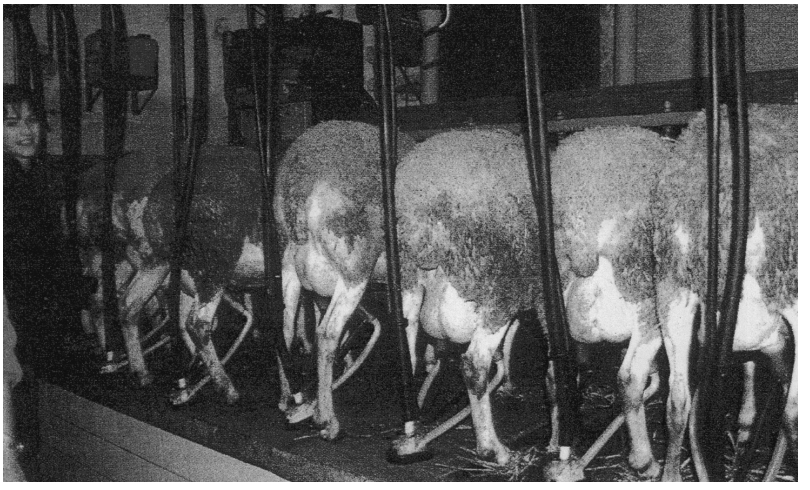

Figure 3.12. Rear view of the clean udders of Lacaune dairy ewes in a milking parlor. Photo: UPRA, 1998, by permission, Shepherd Publishing Ltd. and Sheep Dairy News, Malvern, Worcestershire, U.K.

to the operator, usually and preferably 12 hours. It is not unusual to find even in the transhumance mountain flocks that hand milking of three times/day is practiced, because it lengthens the lactation of ewes to 8–10 months/year and increases milk yield per lactation at least 12% and income in the "off-season."

In dairy sheep, as in other mammals, suckling by the lamb and milking by a farmer trigger a neuroendocrine reflex response of prolactin hormone, important for milk secretion, and of the hormone oxytocin, important for myoepithelial cell contraction and ejection of alveolar milk into the cisternal cavity. Exogenous oxytocin injection has been shown to produce between 14 and 31% more sheep milk with a higher solids content (147, 148). A lack of oxytocin effect may increase the need for hand or machine stripping at the end of milking. Machine milking has stimulated oxytocin release differently in experiments with different dairy sheep breeds and individuals, between 16% and 45% in Sarda, Lacaune, and East-Friesian and up to 90% in Churra ewes (160, 165). Overall, oxytocin release is necessary to ensure good milk yield and short milking time.

Mastitis in its clinical and subclinical occurrences affects sheep milk production and milk composition. California Mastitis Test (CMT) scoring and Somatic Cell Counts (SCC) are used in samples of sheep milk with normal appearance to determine presence or absence of subclinical mastitis. Experimentally induced subclinical mastitis from Staphylococcus epidermidis inoculations in Karagouniko and Chios ewes produced significant increases in SCC and 37% to 55% reductions in milk yield (89, 230). Prevalence of subclinical mastitis was significantly less in Spanish Manchega dairy ewes milked by machine than in those milked by hand (151). Coagulase-negative Staphylococci were the most prevalent bacteria (68%) and *S. epidermidis* was the most prevalent species. Subclinical mastitis can be of economic importance in sheep milk production; Las Heras et al. (151) found an average of 34% prevalence at times in the 22 Spanish flocks tested. In studies in Jordan, *Staphylococcus aureus* was found to be more prevalent (39%) than other species (6). Milk secretion in sheep as in goats is largely apocrine, which means that, in contrast to the merocrine cow milk secretion, cytoplasmic particles similar in size to somatic cells are normal constituents of sheep milk and can raise the SCC even without pathogenic conditions (199).

2.6 Seasonal Impacts

In response to fluctuating environmental conditions, sheep, in common with goats, have genetically evolved seasonal reproduction and lactations coinciding with the greater feed availability in spring in temperate regions with latitudes $>35°$, and in the tropics with the rainy season. Seasonal sheep breeds in the wild rely on the seasonal change of daylight length, while domestication has modified this to some extent towards breeding throughout the year as with dairy cattle. Typically, seasonal sheep breeds, goats, and deer change from being physiologically anestrous or asexual in testicular and ovarian activity to becoming sexually active with decreasing day length in autumn, and to having their parturition and lactation 150 days after conception, coinciding with new spring pasture growth. Actually, seasonality in sheep is supposed to be generated by an endogenous circannual rhythm of reproductive neuroendocrine activity, which is synchronized by the photoperiod (223). The hormone melatonin, through its duration of nocturnal secretion from the pineal gland in the brain, apparently is responsible for the translation of the day length information to the reproductive axis on the hypothalamus gland of the brain by affecting the gonadotropin-releasing hormone and thereby then the luteinizing hormone. In the tropics between 35°N and 35°S sheep are generally not seasonal but polyestrous, and the quality and availability of feed is dictating their breeding activity.

Obviously, hormone treatments are used for ewes that can change seasonal breeding habits, as can genetic selection and elevated nutritional levels such as "flushing." The use of hormones or selection within prolific sheep breeds such as Finnsheep has led to the so-called accelerated lambing system of three lambings in two years (240), but mainly for improved lamb production and not for improved milk production. Hormonal superovulation prior to mating ewes can increase serum hormone levels that stimulate better mammary ductal growth and alveolar epithelial cell multiplication during pregnancy, thus resulting in better developed mammary glands at parturition and increased milk yields (158). Thintail Javanese ewes after superovulation produced between 50 and 62% more milk depending on level

of nutrition and without change to the composition of the milk (9.1 and 9.3% fat; 2.9 and 3.1% protein, respectively).

3 MILK COMPOSITION

3.1 Gross Composition

There are many different dairy cattle breeds. In North America the major breeds are the Holstein-Friesian, Brown-Swiss, Guernsey, Ayrshire, and Jersey; in Europe they are the Simmental/Fleckvieh, Red & White, and many others besides the dual-purpose dairy cattle worldwide (45). Each breed has a more or less significant difference in the gross composition of their milk, ranging in average from 3.1% to 5.5% fat and 3.0% to 4.0% protein, but because cow milk is usually produced from cows breeding any time of the year, the milk from the herd bulk tank entering commerce varies little in composition by seasons (122). This is quite different from sheep and goat milk, which is predominantly produced by seasonally breeding ewes and does. Therefore changes in milk composition occur by seasons, because towards the end of the lactation the fat, protein, solids, and mineral contents increase, while the lactose content decreases (42, 105). Furthermore, as all flock animals are more or less at the same stage of lactation, the total milk shipped into commerce changes in composition accordingly with the advancing stage of lactation and season, and even changes in taste can be noted because of the increased mineral contents, notably salt at the seasonal end of lactation. A comparison of gross composition of sheep milk with cow milk is for all the above reasons not very precise, but as a generalization most sheep milk is higher in solids, fat, protein, lactose, and minerals than cow milk, even from Jersey milk, the cow breed with the highest milk composition, or some dual-purpose breeds (85) (Table 3.13). It is therefore also true that in general less sheep milk (6:1) than cow milk (10:1) is required to make cheese, because of the higher solids content and the interest of dairy sheep breeders who do not want to increase fluid milk volumes and rather increase cheese yield of their milk.

Composition of colostrum from sheep in the early post-partum period is also much higher than from cows; fat 13.0% and 5.1%, protein 11.8% and 7.1%, lactose 3.3% and 3.6%, minerals 0.9% and 0.9%, total solids 28.9% and 15.6%, respectively (9).

To find data of average sheep milk composition of the different dairy breeds requires much research in often only local sources; 19 breeds are listed in Table 3.13, while another 23 could have been added if milk composition had been found (Table 3.6). Besides the genetic differences, it is necessary to recognize that feeds and their composition and feeding strategies can have decisive influences on the composition of major and minor components in milk, especially fat (85, 113). Feeding calcium soaps of long chain fatty acids and a 16% crude protein ration to Pelibuey ewes increased their milk fat content but also raised their blood serum concentrations of lipid metabolites, cholesterol, triglycerides, high-density and very low-density lipoprotein (78). In recent years the use of growth hormone (bST) injections in dairy cattle has successfully increased milk yield (24). In studies with Chios dairy ewes a significant increase in milk yield of 22% over controls was obtained with bST without causing any changes in milk composition during 182 days of lactation (42), while bST treatment in late lactation Comisana ewes also increased milk yield by 22% but decreased fat contents from 8.9 to 8.2% and protein contents from 6.2 to 6.0% significantly (56).

3.2 Fat

Fat in milk has been maligned in the market place during the recent 40 years because of negative publicity from people concerned with heart disease. This has favored the development of breeds with typically low milk fat contents such as the Holstein-Friesian cow for marketing fluid milk, and it has impacted and reduced the distribution of other dairy cattle breeds drastically. The situation with dairy sheep breeds is different because so many are still low-volume yielders and deserve improvement in that trait. However, because sheep milk is not destined for fluid milk consumption in the market place, but only its solids are to be converted to cheese, no great movement toward low-fat sheep milk or cheeses has developed. One reason is that cheese flavor is very much influenced by the fermentation of milk fat during cheese ripening, and a low-fat milk produces usually not the same interesting flavor quality in cheese. Furthermore, to the surprise of many, research has found that high consumption of traditional cheeses with their high-fat contents, as in many Mediterranean countries and especially France, actu-

Table 3.13. Average Milk Composition (%) of Different Sheep Breeds (5, 10, 39, 108, 173, 201, 254)

	Fat	Protein	Total solids	Ash	Lactose
BELGIUM, BRITAIN					
Milksheep	6.80	5.16	18.60	0.95	5.69
FRANCE					
Lacaune	7.40	5.63	18.63	0.93	4.67
GERMANY					
East Friesian	6.50	5.25	17.00	0.90	4.90
GREECE					
Boutsico	7.68	6.04	19.30	0.93	4.80
Vlahiki	9.05	6.52	20.61	0.95	4.09
Karagouniki	8.70	6.60	20.31	0.93	4.08
Chios	7.90	6.20	19.08	0.92	4.06
Friesland x Local	6.40	5.71	17.59	0.87	4.61
Attikis mixed breed	7.59	5.94	18.98	0.89	4.56
Epirus	7.85	6.56	20.13	0.95	4.77
ITALY					
Sarda	6.99	5.60	18.14	0.95	4.60
NETHERLANDS					
Texel	9.27	4.53	20.13	0.95	5.38
SAUDI ARABIA					
Nadjii, Najdi	5.31	4.71	15.36	0.86	4.48
SLOVAKIA					
Tsigai	7.41	5.45	18.75	0.90	4.99
SPAIN					
Churra	7.30	5.98	18.30	0.95	4.25
Manchega	7.78	6.01	18.98	0.90	4.29
TURKEY					
Awassi	6.61	5.74	18.24	0.93	4.96
Karaman	6.65	5.94	18.28	0.97	4.26
Kivircik	7.08	5.53	17.87	0.87	4.39

ally is coinciding with low rates of heart disease and death, and less than those in, for example, the United States with its much lower consumption of cheeses including sheep cheeses (69). This cheese situation has been called the "French Paradox" and includes the "symbiotic" relationship with wine consumption.

Fat content in sheep milk is higher than in cow or goat milk, but much more important, it differs in the distribution of its lipid constituents significantly, being much higher especially in the valuable medium-chain triglycerides (MCT) (C6:0-C14:0) and monounsaturated and the essential polyunsaturated fatty acids than cow milk (Table 3.14, 3.15). The range of fatty acid percentages within sheep milk fat given in Table 3.14 reflects the influence that different feeding regimes and feed compositions can have on the lipid composition of sheep milk fat. Adding concentrates and decreasing the amount of forage in the daily sheep diet can decrease the MCT fatty acids (214). Exposure to solar radiation and high ambient temperature can change the fatty acid profiles in sheep milk toward reduced proportions of the desirable mono- and polyunsaturated fatty acids, and provision of shade in hot climates can minimize the adverse effects (237). Figure 3.13 shows the pathways leading to milk fat synthesis in ruminants from fiber, fat, and starch in feeds to acetate, lipids, and propionate. Acetate is the important and leading precursor of short-chain fatty acids in ruminants and depends on sufficient fiber sources in the daily feed intake. In

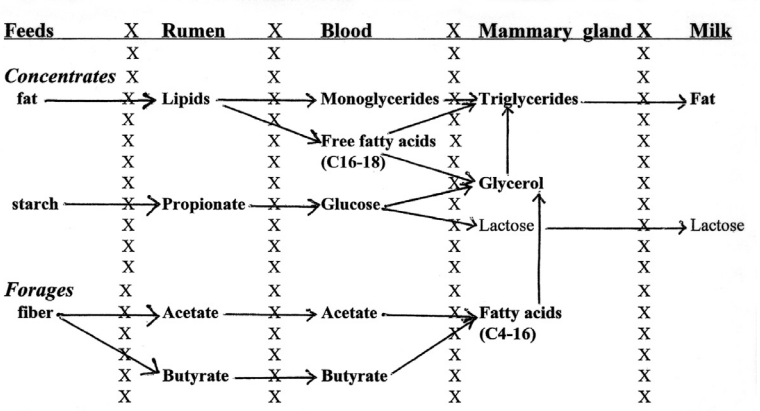

Figure 3.13. Pathways leading to the production of milk fat and lactose in ruminants. Source: Adopted in part from D.E. Bauman and C.L. Davis, 1974, Academic Press, New York, NY, U.S.A.

non-ruminants there is no acetate formation because there is no fiber fermentation in the absence of a rumen and only glucose and lipids form the precursors for milk fat. Obviously, proper supply of fiber-rich forages to sheep is critical for good levels of milk fat with the short-chain fatty acids. Bypassing the rumen has led in recent studies to interesting changes in milk fat composition. Supplementary rumen-protected fat can increase the proportion of unsaturated fatty acids (224). Adding rumen-protected methionine and lysine to the sheep ration increased the ratio of unsaturated to saturated fatty acids, the levels of C16-18, but reduced C4-12 fatty acids (236).

Fat is found in sheep milk in the form of globules of average size 4.5 μm, surrounded by a complex structure protein membrane (214). Milk fat, composed of triglycerides, is the major part of several lipids present in milk in small amounts, such as mono-, diglycerides, cholesterol, phospholipids, and sterols.

3.3 Proteins

The six major proteins found in cow milk, besides some minor proteins, can also be identified in sheep milk. The four caseins (α-s-1-CN, α-s-2-CN, β-CN, κ-CN) make up about 80% of all proteins in sheep milk from healthy udders. Caseins are the only coagulable milk proteins producing the majority of cheeses. Whey proteins in the drained liquid after cheese precipitation can also be condensed and precipitated by heating when making "whey cheeses" from that liquid, such as the Norwegian Gjetost, the Italian Ricotta, and the Greek Mizithra (10). The major whey proteins are α-lactalbumin and β-lactoglobulin, but there are also immunoglobulins, serum albumin, lactoferrin, proteose-peptones, and a few other minor proteins in small amounts in sheep milk (214). Total protein content in milk is basically determined from its nitrogen content, which is multiplied by the factor 6.38, the average nitrogen content in proteins. True protein content is the total proteins minus non-proteins, which may make up between 5–7% of total nitrogen in milk, consisting of urea (45%), amino acids (16%), creatine (2%), creatinin (2%), uric acid (2%), ammonium (1%), orotic acid, hippuric acid, and others.

So far, six of the major sheep milk proteins have been found to exist in 19 different polymorphic variants (7, 162, 177, 207):

- α-s-1 casein, A, B, C, D (Welsh), E, F
- α-s-2-casein, A, B, Fast
- β-casein, A, B, C
- κ-casein, A, B
- α-lactalbumin, A, B
- β-lactoglobulin, A, B, C

The α-s-1-casein locus seems to be most heterogeneous, and the discovered genetic variants have been given identifications from A to F according to their increasing electrophoretic mobility toward the cathode at alkaline pH (207). The different mobilities,

Table 3.14. Average Lipid Composition of Milk (100 g) and Milk Fat (%) of Two Species (105, 211, 214)

	Sheep milk, g	Cow milk, g	Sheep milk, % of cow milk	Sheep milk, % of fat	Sheep milk, % of human milk
Saturated fatty acids	4.60	2.08	221		229
Butyric, C4:0	0.20	0.11	181	3.0–5.8	2000
Caproic, C6:0	0.14	0.06	233	2.1–4.0	1400
Caprylic, C8:0	0.14	0.04	350	1.5–3.6	1400
Capric, C10:0	0.40	0.08	500	5.0–9.0	800
Lauric, C12:0	0.24	0.09	267	2.9–5.2	96
Myristic, C14:0	0.66	0.34	194	7.0–13.4	213
Pentadecanoic, C15:0				0.6–1.5	
Palmitic, C16:0	1.62	0.88	184	20.0–28.5	176
Heptadecanoic, C17:0				0.2–1.0	
Stearic, C18:0	0.90	0.40	225	6.2–13.1	310
Monounsaturated fatty acids	1.72	0.96	179		104
Decenoic, C10:1				0.1–0.3	
Myristoleic, C14:1				0.4–1.0	
Pentadecenoic, C15:1				0.2–0.6	
Palmitoleic, C16:1	0.13	0.08	162	1.0–2.8	100
Heptadecenoic, C17:1				0.2–0.7	
Oleic, C18:1	1.56	0.84	186	16.6–27.7	105
Polyunsaturated fatty acids	0.31	0.12	258		62
Linoleic, C18:2	0.18	0.08	225	2.8–4.3	49
Linolenic, C18:3	0.13	0.05	260	0.6–2.0	260
Medium chain triglycerides					
C6:0 to C14:0	1.58	0.61	259		288
Cholesterol, mg	11	13	85		55

Table 3.15. Average Lipid Composition of Two Representative Sheep Milk and Cow Milk Cheeses (211)

	Cheese, fresh, %				Cheese dry matter, %			
	Feta	Roqf.	Ched.	Swiss	Feta	Roqf.	Ched.	Swiss
Saturated fatty acids	14.95	19.26	21.09	17.78	33.37	31.78	28.31	33.37
C6:0	0.57	0.66	0.53	0.49	1.27	1.09	0.78	0.84
C8:0	0.55	0.67	0.28	0.29	1.23	1.10	0.46	0.44
C10:0	1.98	2.16	0.60	0.62	4.42	3.56	0.99	0.95
C12:0	1.16	1.30	0.54	0.52	2.59	2.14	0.83	0.85
C14:0	2.76	3.25	3.33	3.06	6.16	5.36	4.87	5.27
MCT (C6–C14), total	7.02	8.04	5.28	4.98	15.67	13.27	7.93	8.35
Monounsaturated fatty acids	4.62	8.47	9.39	7.27	10.31	13.98	11.58	14.86
Polyunsaturated fatty acids	0.59	1.32	0.94	0.97	1.32	2.18	1.54	1.48

Feta may contain some goat milk.
Roqf. = Roquefort sheep milk cheese.
Ched. = Cheddar cow milk cheese.
Swiss = cow milk cheese.

for example, for A, C, and D α-s-1-CN, are caused by different phosphorylation levels due to an amino acid substitution in the triplet code for phosphorylation and to variation in the extent of glycosylation of κ-CN. In particular, C differs from D by the substitution of Ser12 and Pro13 with Ser64, Ser66, and Asn68 (84, 214). The α-s-2-CN A variant differs from B by substitution of Asn49 with Asp49 and Lys200 with Asn200. The genetic variants A and B β-lactoglobulin differ at amino acid position 12, where A has Tyr and B has His (140). Variant C β-lactoglobulin differs from A by a single exchange Arg148 for Gln148 (77). The physiological function of α-lactalbumin is to enable lactose synthesis (177). The two genetic variants of κ-CN have been reported from only one study (162).

In general, the different genetic polymorphisms are due to different amino acid substitutions, phosphorylations, and glycosylations, causing different chain lengths and molecular weights, electrical charges, and hydrophobicity of the proteins. They also cause the milk from individual sheep and breeds to have different functional characteristics of hydration, gelation, emulsification, and reaction to enzymes such as rennet, curd firmness, and digestion, which can be exploited genetically for modified milk compositions and nutritionally functional food production. Thus, testing individual sheep for their milk protein polymorphic types has great interest academically and commercially (162, 207) (Table 3.16).

This testing can also determine differences between sheep breeds in their gene frequencies of milk protein polymorphs. The Welsh (D) variant of α-s-1-CN has been found to vary between Italian sheep breeds from 2% to 9%, and one flock of Sarda sheep was 32% heterozygous and 6% homozygous for D. Testing for milk protein polymorphs may also aid in identifying admixtures of cow and goat milk, where this is of commercial concern or prohibited (51, 131). As little as 1% cow milk admixture was easily detectable. The major fractions within total protein in cow milk are α-s-1-CN (1.0%), α-s-2-CN (0.3%), β-CN (0.9%), and κ-CN (0.3%), while α-lactalbumin and β-lactoglobulin make up 0.1% and 0.3%, respectively (150). α-s-1-CN is a minor or absent casein in goat milk. The main fractions of sheep versus cow milk casein are 52% and 37% for α-s-1-CN, 32% and 35% for β-CN, and 11% and 12% for κ-CN, respectively (9). Sheep casein also contains small amounts of γ-CN, which is a breakdown product of β-CN.

Table 3.16. Phenotype Frequency (%) of α-s-1-Casein Genotypes in the Milk of 356 Sarda Dairy Sheep (207)

Genotype	Phenotype frequency, %
AA	2
AC	8
AF	2
FF	1
BB	5
CC	22
DD	15
BC	25
CD	20

The D gene of α-s-1-CN has been found at lower levels in Lacaune than in Sarda sheep milk and may be associated with low levels of fat, total protein, casein, and poor curd forming characteristics. In Sarda sheep milk the CC phenotype had significantly higher casein contents by 3.5% than the CD type and by 8.6% than the DD type. CC milk also had higher protein-to-fat ratios, smaller casein micelle diameters, and better renneting properties (207) (Table 17). The frequency of the D (Welsh) α-s-1-CN varies widely between sheep populations from 2% to 22% (28) and thus lends itself well to genetic selection. In cow milk the α-s-1-CN A variant is sensitive to calcium, has properties more similar to those of β-CN than to the other α-s-1-CN, and may be one of the genetic polymorphs reducing the ability of milk to clot, which is of considerable interest to cheese makers (55). Homozygous AA β-lactoglobulin sheep milk had higher cheese yield and fat content than AB or BB phenotypes (206). Much more research is needed to take advantage of polymorphic differences of sheep milk proteins for commercial progress and human nutrition.

3.4 Lactose

Milk sugar, lactose, is synthesized from glucose in the mammary gland with the required active participation of the milk protein α-lactalbumin. Lactose is found in varying concentrations in the milk of all mammals except for seals (150). Lactose is of major importance for maintaining osmotic equilibrium between the blood stream and the alveolar cells of the mammary gland during milk synthesis and secretion

Table 3.17. Mean Composition And Cheese Making Characteristics of 10 Bulk Milk Samples from March to May 1995, from Three Groups of 15 Sarda Sheep Each, Differing in Cc, Cd, and Dd α-s-1-Cn Phenotypes and Balanced For β-Lactoglobulin Types (207)

	α-s-1-casein phenotypes		
	CC	CD	DD
Total solids, %	17.81	17.52	17.60
Fat, %	7.08	7.00	7.07
Total protein, %	5.44*	5.30	5.02*
Casein, %	4.41*	4.26	4.06*
α-s-1-CN, %	1.59	1.50	1.35*
α-s-2-CN, %	0.61	0.59	0.48
β-CN, %	1.75	1.76	1.75
κ-CN, %	0.43	0.42	0.46
Whey protein, %	1.03	1.04	0.96
Non-protein N, %	0.04	0.05	0.04
Protein:Fat ratio	0.80	0.79	0.74*
Total Ca, %	0.228	0.218	0.224
Total P, %	0.151	0.154	0.147
Micelle diameter, nm	194.9*	209.9*	220.5*
Clotting time, min.	13.88*	15.63	15.13
Curd firming rate, min.	5.75*	6.50	6.75
Curd firmness, mm	29.17*	28.44	27.67
Cheese yield, %	18.31*	17.86	17.52*
Whey total solids, %	9.24	9.29	9.35
Whey fat, %	1.79	1.89	1.86
Whey total N, %	0.29	0.28	0.27
Cheese, fat in DM, %	50.62	50.71	52.24*

*$P < 0.05$.

into the alveolar lumen and the duct system of the udder. Lactose contents in sheep milk as in other ruminants are lower in colostrum at the beginning of lactation and toward the end of lactation, contrary to the behavior of fat and protein contents in the milk. Compared to cow milk, lactose contents in sheep milk are at about the same level, while fat and protein levels are so much higher (Table 13). This makes sheep milk lactose actually less in proportion to their total solids compared to cow milk total solids (22–27% vs. 33–40%) (128, 214). Lactose in sheep milk as in that of other mammals is fermented in yogurt to lactic acid, which is of interest to people with "lactose intolerance," who have a deficiency of the intestinal enzyme lactase. Yogurt of any milk has less lactose, and hard cheeses have none, because lactose is in solution in the whey, which is drained from casein during cheese making. This should help clarify the widespread uncertainty among consumers. On the other hand, lactose is a valuable nutrient because it favors intestinal absorption of calcium, magnesium, and phosphorus and the utilization of vitamin D (45). Some lactose is also fermented in the intestines, thus lowering the pH and helping to inhibit the growth of undesirable putrefactive bacteria.

Lactose is a disaccharide carbohydrate, consisting of glucose and galactose, which may also be present in small free amounts. Other carbohydrates found in sheep milk are oligosaccharides, glycopeptides, glycoproteins, and nucleotide sugars in quite small amounts (150), but their functions in sheep milk have not been studied much.

3.5 Minerals and Vitamins

Sheep milk has around 0.9% total minerals or ash compared to 0.7% in cow milk. Table 3.18 gives data from different authors. They show that calcium, phosphorus, magnesium, zinc, iron, and copper contents are higher in sheep than in cow milk, while the

reverse seems to be the case on average for potassium, sodium, and manganese. The minor and trace minerals are of nutritional and possible health interest, but their levels have not received much study in sheep milk. Obviously, lead could be of concern as a contaminant from automobile exhausts on pastures along highways that sheep may be grazing. Italian studies determined that total dietary intake of lead was 15% of permissible limits, and from sheep cheese, such as Pecorino, $< 0.05\%$ of total intake (59). Cadmium, however, was found to be at significantly higher levels in sheep milk than in cow milk, possibly due to feed sources or different metabolism between the two species. Platinum is one of the components in catalytic converters in automobiles, and plants along highways have been found to be higher in platinum contents than has grass in rural areas. Platinum contents in sheep milk were considered high (59) (Table 3.18) and possibly were due to the grazing along highways, but the effects in human nutrition apparently have yet to be determined.

In general, mineral contents of sheep milk seem to vary much more than those of cow milk (221) due to feeding differences and months of the year. Discriminant analysis of mineral compositions of 360 raw milk samples showed distinct and highly significant differences for the 120 cow milk samples compared to the 120 sheep milk samples, while there was some 10% overlap between sheep and goat milk (120) samples. Two discriminant functions with eight quantitative mineral variables were used to plot the milk analyses on a graph, which showed clear separation by species for the purpose of identifying the origin of milk or milk mixtures in the market place.

Table 3.18. Mineral (Ash) Contents of Sheep and Cow Milk (59, 105, 214, 219, 221)

	Sheep milk		Cow milk
	Average	Range	Average
Calcium, mg/kg	1930	1800–2400	1190
Phosphorus, mg/kg	1580	1170–1700	930
Potassium, mg/kg	1360	960–1960	1520
Sodium, mg/kg	440	270–810	490
Magnesium, mg/kg	180	100–220	130
Chlorine, mg/kg			1030
Sulfur, mg/kg			320
Zinc, mg/kg	5.7	4.7–8.5	3.8
Iron, mg/kg	0.8	0.3–1.4	0.5
Copper, mg/kg	0.4	0.3–1.0	0.2
Manganese, mg/kg	0.07	0.04–0.1	0.3
Aluminum, mg/kg		0.5–1.8[1]	0.6
Cadmium, mg/kg		0.03–0.06	0.004
Cobalt, mg/kg		0.004–0.09	0.0008
Chromium, mg/kg		0.04–0.4	0.02
Nickel, mg/kg		0.01–0.4	0.02
Barium, mg/kg	1.7[1] ± 0.4		0.2
Lead, mg/kg	0.006 ± 0.003		0.03
Strontium, mg/kg	0.8 ± 0.2		0.4
Platinum, mg/kg	0.07 ± 0.02		
Selenium, mg/kg			0.02
Fluor, mg/kg			0.1
Iodine, mg/kg			0.08
Molybdenum, mg/kg			0.06

[1]These two columns of data may be higher than in the original raw sheep milk because of possible environmental contamination from metallic equipment and containers (Coni et al., 1999).

Vitamin contents in sheep milk are mostly higher (Table 3.20) compared to cow milk, except for carotene. Research in this area is very sparse.

3.6 Enzymes

Approximately 50 enzymes have been identified in cow milk (100, 219), but few have been studied in sheep milk (9), although some are of considerable commercial interest because of their beneficial or deleterious roles. Some enzymes originate in the mammary gland, some are constituents of leukocytes, while others enter from the blood stream into the milk during the secretory process. Lipase is important because it acts on milk fat and releases short-chain fatty acids, which produce rancid flavors, undesirable in milk but desirable in some cheeses. Lipase activity is influenced by estrus, the late stage of lactation and mastitis. Several enzymes are associated with the milk fat globule membrane, as is Xanthine oxidase, which increases in late lactation and when liberated causes oxidative flavors. Peroxidase is influenced by different feeding regimes, by estrus, season of the year, and mastitis. Catalase is increased by mastitis also and can serve as a test for udder infections. The inactivation of alkaline phosphatase is used as a measure of the efficiency of pasteurization. Several enzymes are in high concentrations in colostrum, as is Lysozyme, which also may have a role in the antibacterial activity of milk, as does Lactoferrin, another minor milk protein. The relative amounts of Proteinase and Trypsin inhibitor are important for the stability of milk and its casein content. There is great variation in enzyme levels between species (214), but sheep milk apparently has lower levels in several enzymes compared to cow milk (9).

3.7 Physicochemical Properties

The different composition of sheep milk compared to cow milk is reflected in differences in physical properties (Table 3.19). Apparently sheep milk has higher specific gravity, viscosity, refractive index, and titratable acidity, but lower freezing point than average cow milk. Cheese making, that is, renneting properties, of sheep milk are affected by these physical properties, pH, larger casein micelle, more calcium per casein weight, and other mineral concentrations in milk, as expressed by differences in coagulation time, coagulation rate, curd firmness, and amount of rennet needed (214). Also, the lipids in sheep milk have higher physical characteristics than in cow milk except for possibly the iodine number (9). Flavor constituents in sheep milk were similar to those in cow or goat milk, but differed quantitatively with overall higher levels in ewe than cow milk (175) (Table 3.19).

3.8 Nutritive Value

The superiority of sheep milk in the amounts and proportions of the desirable fatty acids is demonstrated in Table 3.15, in which a typical 100% sheep milk cheese, Roquefort, has significantly higher levels of unsaturated fatty acids and medium-chain fatty acids (MCT) than a typical 100% cow milk cheese, Cheddar or Swiss. A novel proposal has been presented by Babayan and Rosenau (15) to produce MCT-enriched cheese and aid people who must consume additional MCT as treatment for their ailments. However, it seems that this idea has not yet materialized at the market place, where it could also capitalize on the natural high levels of MCT in sheep milk. The medical and pediatric literature has much documentation of the nutritional benefits of MCT in cases of malabsorption syndromes, premature infant feeding, critical care and malnourished patients, intestinal resection, cholesterolemia, gallstones, and cystic fibrosis (14, 99, 130); MCTs also reduce cholesterol and provide direct energy (232). MCTs are the only lipid group that does not elongate and desaturate to enter into the prostaglandin cascade, thus serving as a quickly available energy source that the body rapidly oxidizes and utilizes (14). Any fatty acid of C12:0 or shorter (MCT) goes by way of the portal system directly into the liver, while everything longer goes via the lymphatic pathway through the heart, the hepatic artery into the adipose tissues. MCT concentrations in sheep milk can be increased when feeding rations that have higher proportions of grazing forage. Making sheep butter can increase even more the MCT contents to at least 25%, but this practice is not widespread presently (105). Recommended daily patient intakes of 15 g MCT could be provided by about 60 g sheep butter (71).

The nutritive value of sheep milk has not received much research attention, probably because cheese or yogurt from sheep milk rather than fluid milk

Table 3.19. Physical Properties (Ranges and Averages) of Sheep and Cow Milk and Milk Fat (5, 9, 175)

	Sheep milk	Cow milk
MILK:		
Specific gravity	1.0347–1.0384	1.0231–1.0398
Viscosity, Cp	2.86–3.93	2.0
Surface tension, dynes/cm	44.94–48.70	42.3–52.1
Refractive index, nD^{20}	1.3492–1.3497	1.3344–1.3485
Conductivity, Ω/cm	0.0038	0.0040–0.0055
Freezing point, °C	−0.570	−0.530–−0.570
Acidity, lactic acid %	0.22–0.25	0.15–0.18
pH	6.51–6.85	6.65–6.71
Volatile neutral compounds[1]		
esters	301	399
aldehydes	127	96
ketones	32	36
alcohols	27	12
sulfur compounds	250	200
lactones	1.5	1.7
N compounds	132	41
aromatic compounds	31	16
Total	901	802
CASEIN MICELLE:		
Diameter, nm	193	175
Ca mg/g casein	37	29
Volume/surface ratio	103	134
Voluminosity, ml/g	3.8	4.1
Weight-average diameter, nm	122	182
Number-average diameter, nm	59	47
FAT:		
Reichert-Meissl number	25–31	25–33
Polensky number	4.3–6.6	1.5–3
Iodine number	30–35	32–42
Saponification number	230–245	220–232
Fat globule diameter, μm	3.30	4.55

[1]Concentrations × 10^9.

consumption has been the major interest (103, 105, 119, 128). The unique qualities of sheep milk have been proposed as a natural alternative nutrition supplement in pre- and post-operative clinical nutrition in place of pharmaceutical products such as "Ensure" (106), which have experiences of artificial taste fatigue and poor patient compliance. Sheep milk has a superior nutrient profile and pleasant taste with the potential for incorporation into a wide range of domestic menus for greater patient acceptance, regaining of body weight loss, fewer post-operative complications, and improved hand-grip muscle strength. In a survey of 195 people in the U.K. who had symptoms of cow milk allergy, 83% preferred sheep milk over other cow milk substitutes such as from soybeans, rice, oats, coconuts, almonds, and even goat milk (96).

Sheep milk is an excellent source of nutrients in human nutrition (Tables 3.18, 3.19) and is superior to cow milk (w:w) in the supply of all 10 essential

Table 3.20. Average Nutrient Intake from 500 g of Sheep or Cow Milk in Comparison to Recommended Human Daily Dietary Allowances (94, 106, 188)

	Sheep milk	Cow milk	RDA
ESSENTIAL AMINO ACIDS:			
Arginine,g	0.99	0.60	
Histidine,g	0.84	0.44	
Isoleucine,g	1.69	1.00	1.4
Leucine,g	2.94	1.61	2.2
Lysine,g	2.56	1.30	1.6
Methionine,g	0.78	0.42	2.2
Phenylalanine,g	1.42	0.80	2.2
Threonine,g	1.34	0.74	1.0
Tryptophan,g	0.42	0.23	0.5
Valine,g	2.24	1.10	1.6
Total BCAA,g	6.82	3.72	
Total SAA,g	0.96	0.58	
MINERALS:			
Calcium,mg	965	595	800
Phosphorus,mg	790	465	800
Magnesium,mg	90	65	200
Sodium,mg	220	245	
Potassium,mg	680	760	800
Zinc,mg	2.85	1.90	
VITAMINS:			
Retinol, vit. A, mg	0.42	0.26	
Thiamin, vit. B_1, mg	0.40	0.20	0.8
Riboflavin, vit. B_2, mg	1.78	0.81	0.9
Pyridoxin, vit. B_6, mg	0.40	0.30	
Cobalamin, vit. B_{12}, μg	3.56	1.78	
Vitamin D, μg	0.90	0.15	
Tocopherol, vit. E, mg	0.55	0.45	
Ascorbic acid, mg	20.80	4.70	
Folic acid, μg	25	30	
Niacin, mg	2.08	0.42	14
Pantothenic acid, mg	2.04	1.57	
LIPIDS:			
Total MCT, g	8.2	3.8	
Total SFA, g	23.0	10.4	
Total MUFA, g	8.6	4.8	
Total PUFA, g	1.6	0.6	
Linoleic acid, C18:2, g	0.9	0.4	
Linolenic acid, C18:3, g	0.6	0.2	

Abbreviations: BCAA = branched-chain amino acids; SAA = sulfur amino acids; MCT = medium chain triglycerides; SFA = saturated fatty acids; MUFA = monounsaturated fatty acids; PUFA = polyunsaturated fatty acids; RDA = recommended dietary allowances where known; RDA for C18:2 and C18:3 = 2% of caloric intake as daily minimum.

amino acids. Two glasses of sheep milk (500 g) would provide the daily dietary requirements of eight of the 10 essential amino acids, as well as the needs for calcium, phosphorus, and riboflavin completely (Table 3.20). Except for folate, all vitamin contents are higher in sheep than in cow milk, as are most minerals (Table 3.18).

4 MILK HANDLING AND QUALITY

4.1 Cooling of Milk

For good-quality raw milk, milk should be drawn in sanitary milking equipment and promptly cooled to retard microbial growth and potential action by milk enzymes, for example, lipases or proteases. Grade A raw milk is required to be cooled to 7° C or less within two hours after the completion of milking (258). Regulatory requirements indicate that raw milk must be maintained at temperatures less than 7° C until pasteurization or processing. However, raw milk quality is much improved if milk is cooled and held at temperatures of 4° C or less. Normally, milk is transported from the farm to the processing plant every two days. In some cases, state regulatory agencies have given variances on raw milk storage at the farm up to three or four days. In these cases, milking procedures, cooling equipment, and sanitation must be sufficient to maintain the quality of raw milk to meet the raw milk standards set by the state or federal (U.S.) regulatory agencies. Minimum Grade A standards require raw milk to have a total bacterial count of less than 100,000 Standard Plate Count (SPC) per ml upon receipt at the processing facility (258). Proposed industry quality standards recommend limits of $<$ 10,000 Standard Plate Count (SPC) and $<$ 50 coliform per ml (183).

Unlike cow's milk, which is subject to dissociation of β-casein from the casein micelle, solubilization of calcium phosphate, and decrease in micelle size during storage at 4° C, the physicochemical properties of sheep milk are not significantly impacted by cold storage (217). Studies have shown that cold storage of cow's milk increases clotting time, reduces gel strength, and reduces curd firmness during renneting (4, 264). Slight increases in soluble calcium were reported for sheep milk after 48 hours of cold storage; however, the renneting properties were unchanged (217).

4.2 Frozen Storage

With seasonal production and low levels of milk production per ewe, raw milk typically is frozen at the farm, in some states, until sufficient quantities are accrued for further processing. Milk should be rapidly cooled and frozen as quickly, as possible, to slow microbial growth and reduce enzymatic activity. Anifantakis et al. (11) recommended freezing in thin blocks (2 cm depth) as opposed to thick blocks (7 cm depth) to obtain a quicker frozen state that was less susceptible to oxidized flavor development. Milk frozen at higher temperatures or with longer freezing times develop larger ice crystals, which tend to be more destructive to bacteria and membranes of milk fat globules (120). Young (276) had recommended freezing sheep milk in 5-liter blocks not thicker than 7 cm to obtain a stable frozen raw product.

Studies at the University of Wisconsin (273) evaluated freezing sheep milk in 13.5 kg polyethylene pails with a 2 mil polyethylene liner. One set of pails was frozen and stored in a home freezer at −15° C. The other set of pails was frozen and stored in a commercial freezer at −27° C. At three-month intervals, a pail was removed from each freezer and thawed in a cooler at 4° C. Both total bacteria and coliform counts decreased at a faster rate in milk stored at −15° C than milk stored at −27° C (Table 3.21). The larger ice crystals formed in the milk frozen at −15° C were more destructive to the bacteria than the smaller ice crystals in the milk that was flash-frozen at −27° C. The larger ice crystals in the −15° C frozen milk may have damaged some of the membranes on the milk fat globules, as evidenced by the higher acid degree values (ADV) in the milk frozen in the home freezers (Table 3.22). This increased lipolysis in frozen sheep milk was also reported by other researchers (11, 185). The major defect that developed in frozen milk stored at −15° C was protein destabilization after six months of storage (Table 3.22). Samples from the home freezer after six months showed a 20% loss of protein in the form of protein sediment at the base of containers when thawed. Samples frozen at −27° C exhibited good protein stability throughout the 12 months of storage. Additional studies on the protein destabilization in frozen milk stored in home freezers showed the primary cause for protein destabilization to be the higher calcium content in sheep

Table 3.21. Microbial Population for Frozen Ovine Milk Stored At −15° C and −27° C Up to 12 Months

Time of storage (months)	SPC (CFU/ml)		Coliforms (CFU/ml)	
	−15°C	−27°C	−15°C	−27°C
0	8200[a]	8200[a]	44[a]	44[a]
1	4100[a]	4100[a]	26[a]	10[a]
2	2500[a]	3200[a]	21[a]	9[a]
3	3400[a]	3700[a]	12[a]	12[a]
6	2200[a]	2800[a]	< 1[b]	8[a]
9	340[b]	2700[a]	< 1[b]	8[a]
12	610[b]	1800[a]	< 1[b]	5[a]

[a,b]Means (n=2) for SPC or coliforms within the same row without a common letter differ ($P < 0.05$).
Reference: (273).

milk (271). At −27° C, the stabilizing effects of high viscosity and low kinetic energy limit lactose crystallization and protein aggregation in the frozen milk (123). Based on the results of these studies and those of other researchers (11, 23, 276), it is recommended that sheep milk should be cooled and rapidly frozen and stored at −20ºC or lower for maximum protein stability. If limited to frozen storage in home freezers, frozen storage should be limited to three months maximum (271).

4.3 Aroma and Flavor

Milk quality standards require personnel receiving raw milk for processing to examine the milk by sight and smell, and to reject all milk that has an objectionable odor or is abnormal in appearance (258). Psychrotrophic bacteria, which grow under refrigeration conditions, can produce off-odors and off-flavors in raw milk. These bacteria also produce heat-stable enzymes that survive pasteurization and cause proteolysis or lipolysis in fluid milk or adversely affect the yield of cultured products (61). Sheep milk, with its high fat content, has a very rich flavor and is very susceptible to release of free fatty acids due to lipase activity. Proper cooling and sanitation are required to limit the generation of off-flavors from free fatty acids, especially when variances are granted for three- or four-day pickup of raw milk. Off-flavors may also be generated from

Table 3.22. Acid Degree Value (ADV) and Intact Protein Content for Frozen Ovine Milk Stored at −15° C and −27° C Up to 12 Months

Time of Storage (months)	ADV (ml of 1 N KOH/100 g of fat)		Intact Protein (%)	
	−15°C	−27°C	−15°C	−27°C
0	.22[a]	.22[a]	5.1[a]	5.1[a]
1	.25[a]	.26[a]	5.1[a]	5.1[a]
2	.42[a]	.32[b]	5.0[a]	5.0[a]
3	.35[a]	.29[a]	5.0[a]	5.0[a]
6	.41[a]	.31[b]	5.0[a]	4.9[a]
9	.42[a]	.28[b]	3.4[b]	4.9[a]
12	.49[a]	.35[b]	3.9[b]	5.0[a]

[a,b]Means for ADV or intact protein within the same row without a common letter differ ($P < 0.05$).
Reference: (273).

various feeds or weeds that the ewe has consumed (36, 72, 176). Branch-chain fatty acids that are associated with muttony or goaty off-flavors can result from ruminant lipid biosynthesis (101). Enzyme activity tends to be increased in late lactation, so sensory assessment of raw milk should be a requirement prior to use of the milk for processed products.

4.4 Microbiological Concerns

The quality of ready-to-eat dairy products is entirely dependent on the microbiological quality of the raw milk and proper sanitation in the manufacturing procedures (110). This is especially true if the product produced is a raw milk cheese. U.S. minimum Grade A standards require raw milk to have a total bacterial count of less than 100,000 Standard Plate Count (SPC) (< 5.0 log CFU) per ml upon receipt at the processing facility (258). Reports on total bacteria in raw sheep milk in other countries include 4.48–5.85 log SPC per ml in Spain (93) and 4.8–8.5 log CFU per ml in Italy (60). Grade A raw sheep milk, produced under good hygienic conditions, has been reported to contain less than 4.0 log CFU/ml (271).

Coliform bacteria in raw milk are commonly associated with contamination of fecal origin and the potential risk of more pathogenic fecal organisms present or environmental contaminants from dirty equipment. Coliform counts in raw sheep milk from six Italian plants ranged from 63 to 7943 CFU/ml (60), while the mean coliform count of sheep milk in a Spanish study was 309 CFU/ml (93). Autumn coliform counts were higher than spring counts and were attributed to poor cleaning practices at the farm in autumn (93). Coliform counts in raw milk produced under good hygienic conditions in the United States were reported at 44 CFU/ml (273). Generally, coliform counts above 50 CFU/ml in raw milk indicate poor milking hygiene (183). Coliform bacteria will reproduce during the cheesemaking process and can be the cause of early gas formation in fresh cheese curd. Nunez et al. (191) reported that coliform counts of one-day-old cheese was 445-fold higher than the milk going into the vat. For good-quality raw milk cheeses, the raw milk should meet the same microbial standards as pasteurized Grade A milk. Those standards are < 20,000 SPC and < 10 coliform/ml (258). If coliform counts of raw milk are above 10 CFU/ml, the milk should be fully pasteurized or at least heat treated at 64.4° C for 16 seconds (124).

In recent years, consumers have become increasingly concerned about the potential presence of pathogens in food products. Several studies have been conducted on the potential presence of pathogens in raw cow milk (116, 212, 242). Jayarao and Henning (121) reported that 26.7% of bulk tank milk samples contained one or more species of pathogenic bacteria. Over 75% of commingled cow milk samples at dairy plants were positive for *Listeria* spp or *Staphylococcus aureus* (116). In raw sheep milk, Gaya et al. (93) reported geometric mean counts of 60 CFU/ml for Enterobacteriaceae and 30 CFU/ml for fecal coliforms. Cosentino and Palmas (60) reported from 10 to 790 *Escherichia coli* per ml in raw milk at the farm. They were not able to isolate *Salmonella* spp or *Listeria* spp in their survey.

Dairy processors currently have two methods to assure the safety of sheep milk products for the consumer: (1) pasteurized milk intended for fluid or soft products, for example, fluid milk, yogurt, fresh or soft cheeses, and ice cream or (2) hold raw milk hard cheeses at a temperature of not less than 2° C for at least 60 days (257). In April 1997, FDA asked the National Advisory Committee on Microbiological Criteria for Foods whether a revision of the policy requiring a minimum 60-day aging period for raw milk hard cheese was necessary to ensure the safety of hard cheeses for U.S. consumers (70). Concerns came from a report by Reitsma and Henning (218) detailing the survival of *E. coli* 0157:H7 in aged Cheddar cheese. The Institute of Food Science and Technology (IFST) in the U.K. also issued a caution on the potential health hazards posed by pathogenic bacteria in raw milk cheeses, especially soft and semi-soft cheeses (115). FDA has run studies to determine how effective the 60-day aging period is for reducing potential pathogens in Cheddar cheese. Hard cheese was made from raw milk inoculated with 10^3 and 10^5 *E. coli* 0157:H7 and aged under standard aging conditions of 7° C. Populations of *E. coli* were reduced by 1 log at 60 days and 1–2 logs at 90 days of aging (231). Populations of *E. coli* in cheese aged for 180 days and 240 days were reduced by 2 logs and 3 logs, respectively. Currently, FDA is continuing its review of the aged raw milk cheese policy, and future revisions will be forthcoming (272). USDA and FDA did release an interim advisory, HHS and USDA

Listeria risk assessment and *Listeria* action plan (255). USDA and FDA advise pregnant women, older adults, and people with weakened immune systems that "cheeses that may be eaten include hard cheeses; semi-soft cheeses such as Mozzarella; pasteurized process cheeses such as slices and spreads; cream cheese and cottage cheese." However, persons residing in these risk groups are advised, "do not drink raw (unpasteurized) milk or eat foods that contain unpasteurized milk." Potential revision of the regulations dealing with raw milk for cheesemaking might include: (1) full pasteurization of all cheese milk; (2) heat treatment of milk for hard cheeses; (3) raw milk hard cheeses made from milk produced under Hazard Analysis Critical Control Point (HACCP) program at the farm; or (4) warning labels on all raw milk cheeses (272).

4.5 Somatic Cell Counts

Somatic cell counts (SCC) in raw milk are widely used to differentiate between healthy and infected mammary glands in ruminants. In the United states, Grade A Raw Milk Standards require that the SCC of raw sheep milk shall not exceed 750,000 cells/ml (258). The primary cause of these mastitic infections have been reported to be *Staphylococcus* and *Streptococcus* bacteria (98, 250). Stress factors, for example, lamb separation, start of machine milking, and sudden change in diet can increase the risk of infection (62). Multiple-birth sheep have higher mean SCC from weaning to drying-off than single-birth sheep (98). The mean SCC per lactation also increases significantly with parity (98) and stage of lactation (12). The threshold level for SCC in raw milk that represents healthy versus infected mammary glands in ewes ranges between 200,000 and 400,000 cells/ml (65, 98). Three quality categories have been proposed by Pirisi et al. (208) for dairy sheep based on bulk tank SCC (cells/ml): good ($<$ 500,000), average (500,000–1,000,000), and bad ($>$ 1,000,000). Infection rates within these three groups were 30, 40, and 45 %, respectively. SCC in raw milk produced under three different management systems in the U.S. ranged from 40,000 to 159,000 cells/ml (166).

Several studies on sheep milk have shown that an increase in SCC impacts critical components in milk composition. Fat content, total solids, casein and lactose contents are negatively correlated with SCC, while SCC is positively correlated with total nitrogen (TN), non-protein nitrogen (NPN), whey proteins, and pH (118, 208). Typical milk composition for three different average SCC groups is shown in Table 3.23. This change in milk composition has a significant impact on the potential cheese that can be produced from that milk. Cheese yields are typically decreased with increasing SCC (118, 208). Lower yields are attributed to lower casein and fat contents of the higher SCC milk. Rennet clotting time was increased with higher SCC while rate of curd firming and curd firmness were decreased with higher SCC (16, 118, 208). Fat and total nitrogen recoveries were higher in cheese from low SCC milk (208). Cheeses produced from high SCC milk tended to have higher levels of rancidity in the cheese (118). No major differences were noted in cheese texture between the different SCC levels. In summary, not

Table 3.23. Composition of Milk of Various Somatic Cell Counts (SCC) Used for The Manufacture of Manchego Cheese

	SCC/ml		
	$<$ 100,000	100,000–1,000,000	$>$ 1,000,000
Total solids, %	16.69	16.84	14.38
Milk fat, %	5.49	5.67	4.86
True protein[1], %	4.90	4.98	4.69
Casein[2], %	3.99	3.97	3.72
Casein/true protein, %	81.43	79.72	79.32
Casein:Fat ratio	0.73	0.70	0.77

[1](Total % N − % NPN) × 6.35.
[2](Total % N − % Non-casein N) × 6.36.
Reference: (118).

only does an elevated SCC represent an increase in potential pathogens in the raw milk but also the changes in milk composition represent significant problems with cheese yield and quality characteristics of the finished cheese.

5 PROCESSING OF SHEEP MILK

5.1 Pasteurization

Pasteurization is defined as "a process in which every particle of milk shall have been heated in properly operated equipment to 62.8° C (145° F) for 30 minutes (vat pasteurization) or 71.7° C (161° F) for 15 seconds (HTST pasteurization) and held continuously at or above that temperature for the specified time" (256). The thermal process is designed to eliminate potential pathogenic microorganisms from raw milk with minimal chemical, physical, and organoleptic changes in the milk. All fresh or soft-type processed products, for example, fluid milk, yogurt, ice cream, butter, and soft cheeses produced from sheep milk, must be produced from fully pasteurized milk in the United States. Currently, raw milk may be used to produce only aged cheeses that are aged for more than 60 days prior to the sale of the product (257). Some states, for example, Wisconsin, require that the pasteurization process must be performed by, or under the supervision of, a certified pasteurizer operator (265).

Sheep milk can be effectively pasteurized by either the vat or HTST pasteurization processes. Sensory analysis of milks indicated that there was no significant flavor difference between the HTST pasteurized milk and the raw milk, but vat pasteurized milk was sometimes described as "muttony" (277). Phosphatase is the enzyme in milk used to monitor the pasteurization process because its heat sensitivity is equivalent to the most heat-resistant pathogen, *Coxiella burnetii* (184). Sheep milk has three times higher phosphatase enzyme activity than cow's milk (9). However, the alkaline phophatase in sheep milk is more sensitive to heating, but at a degree that does not influence the results of the phosphatase test for the confirmation of effective pasteurization (9).

It is generally reported that some aged varieties of cheese produced from raw milk ripen faster and develop a more intense flavor than those made from pasteurized milk, although the quality may be more variable (152). Much of this is influenced by the nonstarter lactic acid bacteria (NSLAB) present in the raw milk. A heat treatment of 65.0–65.6° C for 16–18 seconds will destroy the majority of pathogenic microorganisms in raw milk, but it will allow the NSLAB to survive and grow during cheese ripening (124). This process is called thermalization. It does not fulfill the requirements for pasteurization and does not destroy all the phosphatase activity, so the cheese is still regulated as raw milk cheese with the 60-day aging requirement. However, it does provide for some control of pathogens and yet allows the passage of NSLAB into the cheesemaking process, where it can contribute some additional flavors to the aged cheese.

5.2 Homogenization

Homogenization of milk is typically performed to reduce the size of fat globules to retard or prevent creaming within the milk. Homogenization also results in whiter color, more full-bodied flavor, and better mouthfeel (43). With homogenization, micellar casein is incorporated into the surface coat of the new smaller fat globules so that the fat globules will react differently than native fat globules. Homogenized fat globules will aggregate with the casein and be bound in the casein network during renneting (153). Storry et al. (245) found that gel firmness increased and rate of syneresis decreased with homogenization of milk for cheesemaking.

Homogenization may be used in the production of fluid milk, yogurt, yogurt drinks, ice cream, and some cheeses. Sheep milk has an average fat globule size of 3.99 μm compared to 4.42 μm for cow milk (170). With the smaller fat globules, sheep milk does not form a cream line in fluid milk as does cow milk and typically would not be homogenized (215). In special cases, it may be used to provide increased whiteness and a smoother body to higher-fat fermented milk products. In the manufacture of set-type yogurt, homogenization increases viscosity and reduces serum and fat separation (181). The effect of homogenization of milk for stirred-type yogurt was inconsistent. Homogenization can be used to liquefy or reduce the firmness of the yogurt gel from sheep milk for yogurt drinks (145). Because homogenization tends to increase gel firmness and decrease whey syneresis in renneted milks (245), it typically is not used for semi-soft and hard cheeses. It can be

used to improve the body and texture of reduced-fat cheeses (153, 171). Homogenization is also used in the manufacture of some blue-veined cheeses to reduce the size of fat globules and create a larger surface area on the globules. Then the mold lipase system can more readily react on the fat globules to generate the typical lipolytic flavor of the blue cheeses (178).

5.3 Separation

In some manufactured dairy products, for example, ice cream, butter, yogurt and cheeses, processors need to concentrate fat or reduce fat in the milk used to manufacture those products. In some countries, such as Italy, gravity separation is used to adjust milk composition for manufacture of certain aged cheeses (154). Rauschenberger (215) compared the gravity separation of cow and sheep milk after 48 hours at 4° C (Table 3.24). With smaller fat globules, sheep milk did not form a specific cream line as with cow milk. With cow milk, she recovered approximately 48% of the fat in the cream layer (9.6% of the volume), while Ma and Barbano (154) reported 58% in the recovered upper 8.3% of the separated milk. In the sheep milk, she observed a hazy layer in the upper 25% of the milk, which contained 35.8% of the initial fat. However, gravity separation was not an effective means of producing a cream-like product or a fat-reduced milk from sheep milk.

Several researchers (193, 216, 220) have reported on experimental processes to remove fat and produce a skim milk product from sheep milk. However, none of these studies reported the efficiency of fat removal in the process. Rauschenberger (215) reported on processing conditions necessary to produce sheep skim milk with fat content less than 0.2% (Table 3.25). Centrifugal forces over 1200 × g and cooler temperatures are adequate for effective separation of fat in sheep milk into a heavy cream and skim milk with under 0.2% fat. Fresh sheep milk exhibited slightly better separation than frozen-stored raw sheep milk. Skim milk with less than 0.2% fat is ideal for the production of a quality nonfat dry milk from sheep milk with good shelf life.

5.4 Concentration

The concentration of total solids in sheep milk is ideal for cheesemaking and production of yogurt. In modern enclosed vats and mechanical equipment, milk with solids above 15–16% will tend to have restricted syneresis of whey and higher moistures in the final cheese. The higher retained whey in the cheese will lead to acid and bitter flavors in the final cheese. Sheep milk also contains the proper solids in the milk for production of yogurt without the need for any stabilizers to build the proper body and texture in the final yogurt. The primary products needing some concentration of milk solids are ice cream

Table 3.24. Fat Content of Cream and Skim Milk After Gravity Separation at 4° C for 48 Hours

	Initial Fat	Volume of cream	Volume of skim milk	Fat in cream	Fat in skim milk
	(%)				
Cow milk	3.47	9.6	90.4	17.29	2.00
Sheep milk	5.87	25.0	75.0	8.40	5.03

Reference: (215).

Table 3.25. Centrifugal Separation of Fat from Sheep Milk

Centrifugal force (x–g)	Temperature (° C)	Time (min)	Fat in skim (%)	Fat in cream (%)
1200	30	20	0.36	90.5
1200	20	15	0.12	97.7
1200	10	15	0.14	97.9
1642	30	20	0.49	89.2
1642	20	15	0.22	95.6
1642	10	15	0.20	96.1

Reference: (215).

and dry milk products. Traditionally, milk is concentrated in vacuum evaporators to a final concentration of 30–50% total solids. Evaporation takes place at temperatures around 40° C to minimize heat denaturation of heat sensitive proteins and vitamins (43).

More recently, milk concentration has been performed with membrane filtration procedures. Reverse osmosis (RO) can be used to remove water from sheep skim milk and concentrate milk solids to 24–26% total solids and to 32% total solids with sheep whole milk (262). They recommended concentrating sheep milk during peak production with RO to reduce the freezing and storage costs of milk to be used to produce yogurt in the off-season. The concentrates could be frozen and stored at −20° C for up to 6–8 months without significant development of off-flavors. For seasonal storage of frozen concentrated sheep milk for cheesemaking, Voutsinas et al. (261) recommend the use of ultrafiltration (UF). With UF, protein and fat are retained with the UF membrane and lactose, salts and water are allowed to pass through the membrane into the permeate. In cheesemaking, the protein and fat are recovered in the curd and final cheese while the lactose, salts, and water generally go out in the whey. Accordingly, by concentrating the milk with UF, the cheese yield will not be impacted and there is no need to freeze and store the extra portion of milk that would end up in whey. With UF, Voutsinas et al. (261) were able to concentrate the sheep milk up to 26.5% total solids. The UF concentrates showed good protein stability throughout six months of frozen storage at −20° C. The UF process also tends to concentrate the bacteria in the raw milk, along with the protein and fat. However, bacterial and coliform counts decreased during the frozen storage.

5.5 Drying

Very little information is available in literature pertaining to dried sheep milk. Mills (173) mentions the availability of sheep milk powder for the use in making yogurt. She indicates that both dry whole sheep milk and sheep nonfat dry milk can be produced by spray drying. For nonfat dry milk, the skim milk is pasteurized under minimal pasteurization conditions to avoid denaturation of proteins and then concentrated to a total solids concentration of 45–55%. For dried whole milk, the heat treatment must be increased to inactivate the lipases that would otherwise degrade the milk fat during storage (43). This usually requires temperatures of 80–85° C and is checked for with a negative peroxidase test. The whole milk is then concentrated to 45–55% total solids. The concentrates are then spray dried to produce free flowing powders with moisture contents between 2.5 and 5.0%. Small quantities of sheep milk powders are produced in several European and Asian countries. A typical analysis of one such sheep milk powder is shown in Table 3.26.

6 SHEEP MILK PRODUCTS

6.1 Fluid Milk

Because sheep milk contains about twice the solids of cow and goat milk, the majority of sheep milk is used to produce dairy products, for example, yogurt and cheese. However, Mills (173) reports on the extended use of sheep milk in England for patients with food allergies. Patients unable to digest either cows' or goats' milk had no trouble digesting sheep milk. Sheep milk is a very high-energy milk with a higher content of fat, calcium, phosphorus, and magnesium than cow milk. With smaller fat globules than cow milk, sheep milk does not require homogenization to eliminate creamlines in fluid milk products.

6.2 Fermented Milks

In hot countries with limited refrigeration, fermented milk products with lactic acid tend to suppress any danger from pathogenic organisms that may have been present in the initial milk or may have entered the milk during processing (Mills, 173). Kefir is a cultured sheep milk drink that is fermented with "kefir grains" that contain lactic acid bacteria and

Table 3.26. Typical Analysis of Imported Sheep Nonfat Dry Milk Sample (Source: New Zealand)

Portion of sample	% of total
Moisture	4.6
Protein	47.3
Lactose	40.0
Fat	1.0
Ash	7.1

(Unpublished results).

yeasts (275). During the fermentation, the lactic acid bacteria produce lactic acid while the yeasts produce alcohol and carbon dioxide. Some breakdown of protein also takes place in the yeast metabolism, from which kefir derives its special yeasty aroma (43). Kefir is very popular in Russia and the Balkans and is often referred to as "the champagne of milk" (173). Numerous other fermented milks from various European or Asian countries are also produced from sheep milk (Table 3.27).

6.3 Butter and Ghee

With the high fat content of sheep milk, one would anticipate that butter would be a major product produced from sheep milk. Small quantities of sheep butter are currently being produced in Canada and Europe (91, 173). In Greece, around 4,000 tonnes of sheep butter is produced from whey fat from cheesemaking (173). However, Mills (173) points out that sheep butter has a difficult time competing with cows' milk butter based on price. Sheep milk fat does not contain the levels of carotenoids that cow milk fat does and the white color of the sheep butter is slightly unappealing. Flavor of the butter is entirely dependent on how effective the pasteurization treatment was in eliminating the lipase activity in the cream. Sheep milk fat has a lower iodine number than cow milk fat and is much firmer than cow milk fat (9), thus producing a harder, more brittle butter.

Ghee is a butteroil product produced from unsalted sheep butter and is produced in India and Arab countries. Butter is melted and held, allowing the protein to aggregate. The melted butter is then pumped through a separator, to remove as much moisture as possible, and then through a vacuum vessel to flash off the final residual moisture. Fat content of ghee is between 98.0 to 99.5%. Ghee from sheep milk has a lower iodine value than cow ghee, which indicates a harder fat product (3). Ghee is very susceptible to rancidity development, so it should be packaged in opaque containers and stored in the dark (8).

6.4 Ice Cream

With higher fat and protein in sheep milk, lower-fat ice creams (5% fat) can be produced without concentration of the milk (274). However, more traditional high-fat premium ice creams, which require more than 10% milk solids-not-fat (MSNF), will require additional protein from sheep nonfat dry milk or from concentrated sheep skim milk. O'Kane and Wilbey (194) reported that at higher levels of fat (10%) in ice cream, consumers were able to detect an "atypical" flavor and, in some cases, a "mutton-like" flavor. Wilbey et al. (274) suggest introducing product into the market at lower fat levels to acclimate consumers. Their most preferred product contained 9% fat and 6% protein. Flavorings can also be used to smooth out the fat flavor in sheep milk ice cream.

6.5 Yogurt

Yogurt is the best known and most popular cultured milk product around the world. Consumption of yogurt is highest in countries around the Mediterranean, in Asia, and in Central Europe (43). This is especially true in Greece, where its popularity is due to a firm, smooth texture with special sensory characteristics (134). Many of these areas have a high population of dairy sheep and available milk supply. For good-quality yogurt, milk solids-not-fat need to be in the range of 12 to 16% in the initial milk for fermentation (222). With cow milk, nonfat dry milk or condensed skim milk needs to be added to increase solids or a portion of water needs to be removed from the initial milk by evaporation or membrane separation. With sheep milk, the milk solids are already in the ideal range for yogurt, so milk standardization is not required.

Sheep milk for yogurt production should be pasteurized at 91° C for 30 seconds (138) or 82° C for 30 minutes (271). Milk for yogurt production is heated to high temperatures well above pasteurization to destroy indigenous bacteria and to denature the whey proteins, lactoglobulin and lactalbumin, for smoother body (143). With the smaller fat globules in sheep milk, some processors may not homogenize the milk to minimize fat separation in the yogurt but rather allow a fat layer to form on the top surface of the yogurt. In special cases, homogenization may be used to provide increased whiteness and a smoother body to higher fat yogurts. In the manufacture of set-type yogurt, homogenization increases viscosity and reduces serum and fat separation (181). After cooling to 42–44° C, the milk is inoculated with *Streptococcus thermophilus* and *Lactobacillus delbrueckii* subsp. *bulgaricus* cultures. For

Table 3.27. Fermented Milk Products from Sheep Milk

Product	Country	Description
Arian	Central Asia	Liquid beverage
Arsa	Asia	Milk brandy
Azi	Switzerland	Whey vinegar
Basa	Croatia	Concentrated yogurt
Brano milk	Bulgaria	Thickened fermented milk
Bulgaricus milk	Bulgaria	Nontraditional fermented milk
Chanklich	Middle East	Dried product
Gibneh-Labaneh	Middle East	Dried product
Gioddu	Italy	Beverage
Grushevina	Yugoslavia	Milk paste
Huslanka	Russia	Traditional product
Kashk	Iran	Dried product
Kaymak	Yugoslavia	Pasty, salted
Keshk	Middle East	Dried product
Khoormog	Mongolia	Alcoholic beverage
Kisela Varenika	Bosnia	Soured milk
Kiselo Mleko	Yugoslavia	Traditional product
Kiselo Mljako	Bulgaria	Set yogurt
Kishfa	Iraq	Fermented milk
Klila	Southern Algeria	Dried pellets
Kojurtnak	Kazakhstan	Traditional product
Kurt	Kazakhstan	Semi-dried or freeze-dried
Kurut	Middle East	Dried balls of curd
Kvas	Bulgaria	Summer beverage
Labneh	Middle East	Concentrated yogurt
Leben	Middle East	Yogurt product
Liban	Iraq	Sour milk
Lo	China	Viscous fermented milk
Lyntyca	Poland	Fermented whey beverage
Madeer	Middle East	Like hard, dry cheese
Mast	Iran, Iraq	Yogurt product
Matzoon	Armenia	Yogurt-like product
Oggt	Saudi Arabia	Buttermilk
Oxygala	Roman Empire	Curdlike product
Peskutan	Turkey	Yogurt-like product
Savanyutez	Hungary	Clabbered milk
Skuta	Carpathians	Alcoholic beverage
Sostej	Hungary	Traditional product
Tan	Armenia	Yogurt-like product
Tarag	Mongolia	Clabbered milk
Tarator	Bulgaria	Frozen yogurt w/cucumber
Tarho	Hungary	Yogurt-like product
Torba	Turkey	Concentrated yogurt
Urda	Hungary	Whey cheese
Urgutnik	Bulgaria	Buttermilk
Zhentitsa	Carpathians	Thickened fermented milk
Zincica	Czechoslovakia	Kefir-like beverage

Reference: (146).

set-type yogurt, the inoculated milk mixture is dispensed into cups and allowed to ferment at 44° C until the pH reaches 4.6. The yogurt is then cooled to 4° C and stored at refrigeration temperatures until consumed. Probiotic cultures of *Lactobacillus acidophilus* or *Bifidobacterium* may also be added to the yogurt to improve the nutritional properties of the yogurt product. Kisza et al. (138) reported that yogurt produced with *L. acidophilus* and *S. thermophilus* exhibited significantly better quality than that produced with *L. bulgaricus* and *S. thermophilus.*

In production of stirred yogurt, the treatment of milk is the same as with set yogurt up to the point of cooling after the pH has reached 4.6. At that point, the coagulum is cooled to 15–22° C and gently stirred to provide a smooth pourable consistency (43). Fruit and flavorings are added to the yogurt as it is pumped to the filler. Very little sheep yogurt is produced by the stirred-type yogurt process.

In some countries, consumers prefer yogurt to be slightly sweetened with sugars. Muir et al. (180) recommend that the optimum level of sugar in sheep milk yogurt was 1.2%. As sweetness of the yogurt increased, the perception of sour flavor decreased. Acceptability of yogurts were influenced by both fat content and sugar content. However, they recommended adjusting the level of sugar addition to meet the preferences of each market area.

Sheep yogurt exhibits a stronger structure to the yogurt gel and has less serum separation on storage than cow or goat yogurt (134). Viscosity of the yogurt could be significantly increased and serum separation decreased with homogenization of the milk prior to inoculation (181). Higher solids were also associated with reduced serum separation. Sheep milk yogurt has less acid flavor than a comparable cow milk yogurt because the acid is buffered by the high solids content of the sheep milk (145). Yogurts produced from milk pasteurized at higher temperatures tended to have a decreased rate of acid development and an increased rate of lipolysis (138). Juarez and Ramos (127) reported that yogurt from sheep milk had higher biological value and was easier to digest than cow milk yogurt. This is most likely due to the higher lactase activity in sheep milk that results in the yogurt's having a lower lactose content (133). Dankow et al. (64) also reported that yogurt cultures produced higher levels of acetaldehyde and diacetyl in sheep milk yogurt than in cow milk yogurt.

Because sheep milk production is seasonal, use of frozen milk may be necessary to produce yogurt throughout the year. Seasonal variations in milk composition may also impact the overall quality of the yogurt because the lactobacilli used in yogurt fermentations are sensitive to changes in milk composition (246). Several researchers (11, 262) have reported that good-quality yogurt can be produced from frozen sheep milk. However, various processors have indicated that yogurt produced from frozen sheep milk tends to have a short body and mealy texture (215). Studies at the University of Wisconsin showed that the quality of yogurt from frozen sheep milk was entirely dependent on the quality of the frozen milk (271). Good-quality yogurt can be produced from frozen sheep milk if the milk is frozen and stored at −27° C or less for less than 12 months (271). Milk frozen and stored at −12° C showed a reduction in buffering capacity due to loss of soluble salts or proteins during frozen storage (Table 3.28). Visual evidence of protein destabilization in frozen milk was observed after six months of storage at −12° C. Gel strength was significantly reduced in yogurts made from the milk after six months of frozen storage (Table 3.28). Yogurt produced from milk stored at −27° C for 12 months was comparable to that produced from fresh milk (Table 3.29).

Several researchers (134, 263) recommended concentrating sheep milk during peak production with reverse osmosis (RO) or ultrafiltration (UF) to reduce the freezing and storage costs of milk to be used to produce yogurt in the off-season. Kehagias et al. (134) evaluated the potential production of yogurt from sheep milk that had been concentrated by UF or vacuum evaporation (VE) and frozen at

Table 3.28. Titratable Acidity and Firmness of Yogurt Produced from Sheep Milk Frozen and Stored at −12° C

Time of storage (mo)	Titratable acidity (% lactic acid)	Gel firmness (grams)
0	1.25	125
3	0.99	99
6	0.93	83
9	0.87	59
12	0.90	72

Reference: (273).

Table 3.29. Characteristics of Yogurts Produced from Sheep Milk Frozen and Stored at −12° C and −27° C for 12 Months

Characteristic	Initial milk	Stored at −12° C	Stored at −27° C
Titratable acidity, %	1.25[a]	0.90[b]	1.18[a]
Syneresis, %	75.1[a]	79.7[a]	77.5[a]
Water-holding capacity, %	28.5[a]	25.7[a]	30.4[a]
Firmness, g	125[a]	72[b]	109[a]

[a,b]Means within the same row without a common letter differ ($P < 0.05$

Reference: (273).

−25° C for nine months. The yogurt produced from VE concentrates rated higher in taste preferences than UF samples. However, if lactose or whey were added to the UF samples, the taste problems could be controlled. Voutsinas et al. (263) produced yogurt from sheep milk that was first concentrated with RO and then frozen and stored at −20° C for 6–8 months. These RO yogurts had higher apparent viscosity and curd consistency than yogurts from unfrozen milk. Both RO and control whole milk yogurts had similar syneresis values. RO concentrates of skim milk were inferior to the control because they yielded yogurts with greater syneresis and a slightly grainy texture.

6.6 Cheese

6.6.1 Types of Cheese

Traditionally, production of cheese has been the greatest market for sheep milk throughout the world. Prominent international varieties of cheese produced from sheep milk include Pecorino Romano, Roquefort, Manchego, and Feta. Many of the traditional European sheep milk cheeses are regulated under a Denomination of Origin (DOC) and are protected by the European Union (88). These cheeses are produced in specific regions, with specific breeds of sheep and with certain defined procedures for producing the cheese. Some sheep milk cheeses may be made from raw milk while others are produced from thermalized or pasteurized milk. Table 3.30 lists many of the varieties of cheese produced from sheep milk around the world.

In the United States, sheep milk cheese production was first introduced in Minnesota in the 1980s (40, 243). The economic potential for production of sheep milk cheeses in the United States was again reviewed in 1995 (267). Recommendations were to produce unique value-added cheeses that were not in direct competition with imported sheep milk cheeses from countries with subsidized production. With a limited supply of sheep milk in the United States, recommendations in 1998 were to evaluate the potential for blending of sheep milk with cow milk to produce some unique cheeses that could take advantage of the flavors generated from the sheep milk fat (210, 270). With the 2003 estimated U.S. sheep milk production at 2000 metric tons, most of the sheep milk cheeses currently produced are specialty or artisanal cheeses.

6.6.2 Coagulation of Milk

Sheep milk is higher in fat, protein, and total solids than cow or goat milk. Because cheese curd contains primarily the fat and casein from milk, sheep milk yields significantly more cheese per unit of milk than cow and goat milk (9). All major casein fractions of cow milk are present in sheep milk (5). Casein micelle structure is similar in cow, goat, and sheep milk; however, sheep milk caseins are richer in calcium than cow casein (5). Because casein is the critical component in milk that forms the structure of the curd for cheese, the clotting or coagulation of milk will affect the cheese outcome.

Sheep milk is very sensitive to rennet and, because of its higher β/α_s-casein ratio, coagulation proceeds faster than in cow milk (179). Sheep milk requires less rennet than cow milk to obtain the same coagulation time (129). The rate of curd formation is faster in sheep milk than in cow milk, but the rate of syneresis is slower (179). This difference is due to the higher casein and colloidal calcium content of sheep milk (244). Clotting times are shorter at lower pHs. Bencini (29) reported that renneting time decreased from 17 to seven minutes when the pH of sheep milk was lowered from 6.65

Table 3.30. Listing of Various Cheeses Produced from Sheep Milk

Cheese	Country	Type of Cheese
Abbaye de Belloc	France	High-fat cheese w/ strong flavor like brown sugar
Abertam	Czech Rep.	A hard cheese
Alemtejo	Portugal	Aged cheese made with thistle rennet
Anari	Cyprus	Fresh, soft mild
Anthotiros	Greece	Soft, like Ricotta, from whey
Aragon	Spain	Buttery rind with a salty flavor
Ardi-Gasna	France	Semi-hard w/ yellow/beige rind w/ refined taste
Armavier	Russia	Sour-milk cheese like Hand cheese
Asco	Corsica	Aged raw milk cheese, brine-washed
Azeitao	Portugal	Semi-hard cheese made w/ veg. rennet
Berger Plat	France	White/beige rind with pale blue mold, mild flavor
Beyaz Peymir	Turkey	Semi-hard white, most popular in Turkey
Bitto	Italy	Soft cooked cheese w/ pale creamy color
Brebis du Bersend	France	Semi-hard with natural white or brown rind
Brebis du Lochois	France	Soft cheese with natural white/gray mold
Brebis Frais su Caussedou	France	Soft whey cheese w/ mildly sweet flavor
Brebis Pyrenes	France	Semi-hard w/ a natural dry, hard rind
Bgug-Panir	Armenia	Skimmed milk cheese with herbs
Brindamour	Corsica	Soft, herb-coated
Cabecon	France	Soft raw rindless
Castellano	Spain	Similar to Manchego
Cherkez Peyniri	Turkey	Small wheels of fresh cheese
Le Caussedou	France	Mild, soft cheese with natural blue mold
Cotronese	Italy	Hard Grana, also called Pecorino di Crotone
Elvas	Portugal	Semi-hard, ripened 30–40 days
Eriwani	Caucasus	Brined cheese from fresh milk
Evora	Portugal	Yellow white w/ a dark crust, aged 6–12 months
Feta	Greece	Acid, soft pickled
Fiore Sardo	Sicily	DOC, Italy
Fium'orbu	Corsica	Aged washed-rind
Foggiano	Italy	Made in Apulia, Italy
Fromage de Brebis	France	Soft cheese with a robust flavor
Fromage Corse	France	Soft cheese unripened
Fromage Fermier	France	Soft cheese with a lightly sour flavor, rind
Fromage D'Ossau	France	Semi-hard, natural rind w/ robust flavor
Fromage de Vache	France	Semi-hard w/ rich, complex flavor
Fromagelle	Italy	Small, soft cheese made only in spring or fall
Fromageon Fermier	France	Soft cheese with a mild flavor, natural rind
Galotiri	Greece	Soft w/ a sour brackish taste
Golo	Corsica	Semi-hard to hard washed-rind
Gorbea	Spain	Pressed whitish ivory cheese (smoked)
Graviera	Greece	Semi-hard yellow w/ small holes, 2nd most popular
Grazalema	Spain	Hard pale yellow w/ small eyes, like Manchego
Greuilh	France	Whey cheese that is light and refreshing
Haloumi	Turkey	Semi-soft with mint
Idiazabal	Spain	DOC cheese, semi-hard smoked raw milk cheese
Incanestrato	Sicily	Basketed cheese similar to Pepato w/o pepper
Kajmak	Serbia	Cream cheese that is like Serbian butter

(Continues)

Table 3.30. (Continued)

Cheese	Country	Type of Cheese
Kashar	Turkey	Hard, dk yel rind, second most popular
Kaskavalo	Rumania	Partly skimmed milk with a Provolone type make
Kasseri	Greece	Raw milk bland cheese
Katschkawalj	Serbia	A plastic-curd cheese, Caciocavallo-type
Kefalograviera	Greece	Like a sheep milk Gruyere
Kefalotyri	Greece	Like an extra-aged Kasseri, grating cheese
Kopanuti	Greece	Soft, blue-veined formed in balls size of orange
Ladotiri	Greece	Hard w/ strong flavor
Laruns	France	Semi-hard w/ dry rind and gray, crumbly body
Le Lacandou	France	Soft cheese with a natural rind
Le Niolo	Corsica	Soft, sticky cheese w/ strong odor & taste
Le Vieux Corse	Corsica	Soft doughy cheese stained w/ blue mold
Lescin	Caucasus	Renneted cheese wrapped in leaves & grass ropes
Maile Pener	Crimea	Brined cheese w/ crumbly, open texture
Majocchino	Italy	Similar to Incanestrato
Malvern	England	Raw milk cheese similar to Manchego, less salty
Manchego	Spain	Pasteurized milk cheese, mild, slightly briny, nutty flavor
Manouri	Greece	Like a nutty Ricotta, rich, buttery flavor, from whey
Marches	Italy	A hard, Pecorino cheese
Mesitra	Crimea	Soft cheese made in cooper kettle, eaten fresh
Mihal	Turkey	Hard w/ sharp aroma and taste
Mintzitra	Macedonia	Soft cheese
Mitzithra	Greece	Pot cheese made from whey from Feta, fresh cheese
Moliterno	Italy	Pasta filata similar to Cotronese
Monostorer	Rumania	A washed rind cheese
Mont Cenis	France	A hard, blue-molded cheese, salt wash on surface
Montasio	Italy	Hard straw-colored similar to Asiago
Moularen	France	Soft, washed rind cheese creamy & pleasant
Murazzano	Italy	DOC cheese, slightly garlicy and mushroomy
Myzithra	Greece	Soft like Ricotta
Niolo	Corsica	Strong-flavored, washed-rind similar to Brindamour
Orduna	Spain	Semi-hard, firm yellow w/ small holes
Orgu Peyniri	Turkey	Pasta filata made in the shape of braids
Oropesa	Spain	Hard cheese, dark in color w/ thick rind
Oschtjepek	Slovakia	A plastic-curd similar to Caciocavallo
Ossau-Iraty	France	AOC cheese, Pyrenes style, brown rind, nutty flavor
Ossetin	Caucasus	A cooked and kneaded cheese that is brined.
Ovcji Sir	Slovenia	A cooked cheese put in wooden hoops and dry salted
Ovelheira	Portugal	Hard and salty version of Serra
Pago	Yugoslavia	Made on the island of Pag
Pannarone	Italy	Gorganzola type w/ white mold
Parenica	Hungary	A Caciocavallo-type cheese
Pecorino	Italy	DOC cheese, raw milk Romano, grating cheese
Pecorino Sardo	Sardinia	A Romano-type cheese used for grating
Pecorino Siciliano	Italy	Grating cheese
Pecorino Toscano	Italy	Pasteurized milk cheese, rind, olivey, nutty flavor
Pedroches	Spain	Golden w/ yellow rind, stored in olive oil
Pepato	Sicily	Hard cheese with peppercorns, intense sheep flavor
Perail	France	Soft cheese w/ velvety, rich flavor, natural rind
Puzol	Spain	Same as Queso Fresco Valencianz

Quacheq	Macedonia	Sour whey inoculum, eaten fresh or after curing
Queso Anso-Hecho	Spain	Raw milk cheese similar in flavor to Roncal
Queso de Burgos	Spain	Mild Manchego flavor made from sheep/cow milk
Queso Cassoleta	Spain	Cheese in indented dome shape, served fried
Queso de Serra	Portugal	Creamy and mild white cheese
Queso de Tupi	Spain	Sold in earthenware pots, sheep milk curd with brandy
Rabacal	Portugal	Cylindrical, flat firm cheese, 4–5 in. diam., 1 inch thick
Ragusano	Sicily	Younger, softer elastic sheep cheese like Pepato
Raviggiolo	Italy	Sweet curd put in wicker baskets, similar to Ricotta
Ricotta	Italy	Cooked whey cheese
Ricotta Salata	Italy	Pasteurized, rindless cheese similar to Feta
Robiola Piedmont	Piedmont	Soft, rindless cheese w/ slightly tart, fruity flavor
Romanella	Italy	Very hard white w/ numerous small openings
Roncal	Spain	DOC cheese. hard rinded aged w/ nutty flavor
Roquefort	France	AOC, blue-molded cheese with intense flavor
Salamana	So. Europe	Soft cheese with very pronounced flavor
Saloio	Portugal	Hand cheese w/ slight sourish flavor
San Petrone	France	Soft, sticky dough-like cheese w/ sharp taste
Scanno	Italy	Cheese dipped in iron/acid solution, buttery flavor
Serena	Spain	Hard w/ compact yellow body & mild aroma
Serpa	Portugal	Semi-hard cheese w/ peppery sharp flavor
Serra da Estrella	Portugal	Soft cheese w/ pleasing flavor, thistle coagulant
Sfela	Greece	Semi-hard w/ strong flavor
Sir Iz Mjesine	Yugoslavia	From skim milk, cubed, salted and cured in sheep skin
Sir Mastny	Yugoslavia	Cheese molded in forms
Sir Posny	Yugoslavia	Cheese molded in forms
St. Marcellin	France	Blue mold on outer surface
Teleme	Rumania	Pickled cheese similar to Greek Feta
Texel	Netherlands	Cheese made on the island of Texel
Tibet	Tibet	Hard grating cheese formed in cubes & dried
Tignard	France	Hard blue-veined similar to Gex
Tomar	Portugal	Firm & tangy, crumbly w/ small holes
Tommette de L'Aveyron	France	Soft yellow cheese w/ dry white/gray/red mold
Torta del Casar	Spain	Raw milk cheese w/ buttery, nutty flavor, wheel
Toscanello	Italy	Very hard cheese for grating
Tourmalet	France	Semi-hard w/ pleasantly rustic flavor & aroma
Travnik	Bosnia	Soft cheese salted and cured in kegs
Tricorne de Marans	France	Fresh cheese w/ slightly sweet & sour flavor
Tronchon	Spain	Slightly aged raw cheese w/ mild herby flavor
Tschil	Armenia	Made from sour skim milk, ripened in troughs
Tulurn Peyniri	Turkey	Semi-hard w/ crumbly texture and strong flavor
Tyning	England	Raw milk rinded similar to Pecorino Toscano
Twdr Sir	Serbia	Sharp flavor similar to Brick but less fat
Venaco	Corsica	Aged raw milk cheese, brine-washed
U Rustinu	Corsica	Soft cheese w/ a rind of white and red mold
Vermont Shepherd	USA	Aged Pyrenes-type
Villalon	Spain	Hand cheese in brine 2–3 hr and eaten fresh
Vize	Greece	Hard grating cheese similar to Romano
Xinomizithra	Greece	Whey cheese used in cheese pies
Zamorano	Spain	Similar to Manchego but made from Churra milk

(Information from Web site www.cdr.wisc.edu, World Cheese Exchange).

DOC = Denominazione di origine controllata.

AOC = Appellation d'origine controlee.

to 6.16. Increasing the protein concentration of sheep milk also decreases the renneting time. Curd consistency in sheep milk is largely unaffected by temperature, particularly at lower pHs (29). With the high concentration of soluble calcium in sheep milk, there is no need for addition of calcium chloride to the milk as with cow milk.

Sheep milk has a faster rate of firming than cow milk, regardless of the pH at which clotting takes place (30). Factors impacting the clotting conditions in sheep milk have little impact on the rate of firming of the curd. Bencini (29) reported that increasing the protein concentration of the milk had little effect on the rate of firming of the curd. However, Pellegrini et al. (202) reported that the gel-firming rate was correlated with the casein content of the milk. They also reported that the firming rate of milk with $>$ 500,000 somatic cells/ml was significantly lower than normal sheep milk. The increase in soluble protein and decrease in diffusible calcium might be responsible for those changes.

In Portugal and Italy, a milk coagulant extracted with water from the flowers of cardoons of the genus *Cynara* is used in the manufacture of various sheep milk cheeses (129). In Latin American countries, the wild thistle *C. cardunculus* is also used in coagulating milk for cheesemaking (159). The thistle coagulant is more thermostable. The plant coagulants are slightly more proteolytic on caseins and have a broader specificity than chymosin or rennet (79). The decrease in coagulation rate was more pronounced when the pH of milk was reduced from pH 6.7 to 6.3 compared with reducing the pH of milk from 6.3 to 6.0. Esteves et al. (79) recommended that a lower concentration of plant coagulants should be used in the gelation of milk at low pH, to avoid the possible negative impact of extensive casein proteolysis on the texture and flavor of cheese.

Severe heating of milk can impair its renneting properties, due to the formation of a complex between denatured β-lactoglobulin and κ-casein (63). The complex retards the hydrolysis of κ-casein by rennet and also hinders the aggregation of the renneted micelles. At 85° C, the maximum degree of denaturation was obtained within one to three minutes for sheep milk compared to 10 minutes for cow milk (216). At 80° C, the size of casein micelles increased to about 1.5 times the size of fresh milk micelles. The rennet coagulation time (RCT) was also increased by 1.5 times the RCT of fresh milk. The gel firmness was decreased by 10 to 20%. However, rennetability of sheep milk was much less impaired by severe heat treatment than cow's milk (216).

6.6.3 Handling of Curd

With its high mineral content, the buffering capacity of sheep milk is higher than that of cow milk. This may result in a slightly slower rate of pH change in the milk during fermentation of the milk. When the coagulum is formed, the cutting and handling of the curd will be dependent on the type of cheese being produced. A classification of cheeses made from sheep milk is presented in Table 3.31. When the coagulum is cut, the curd particle begins to shrink, expelling whey that is trapped in the interior of the curd particle. The curd develops a "skin" or a more dense layer of casein micelles due to the loss of fat and whey at the surface (125). The skin prevents further fat loss but does allow further syneresis of whey from the curd. If the curd is cut when slightly firm, the curd does not heal as quickly and is more prone to breakage (125).

When the curd is cut, smaller curd particles will lose more fat and whey, thus leading to a lower moisture cheese. This is the traditional procedure for production of hard cheeses, such as Romano or Manchego. Larger curd pieces will retain more moisture but will be more susceptible to breakage during stirring. Hence, high moisture cheeses are usually made from a coagulum in which the curd is cut to be large and firm (125). After the curd is cut, it is stirred and heated. The starter continues to produce acid, and the combination of stirring, heating, and acid development has a profound effect on syneresis and dissolution of calcium phosphate. These have major implications for the final characteristics of the cheese. The greater the drop in pH after the coagulum is cut, the more moisture will be expelled from the curd. The higher the temperature used to heat the curd after the coagulum is cut, the lower the moisture in the curd (125). As the curd cools, the rate of syneresis also slows, thus more moisture is retained in the curd.

The manner in which the whey and curd are separated can affect the texture of the cheese, as well as influence color and flavor. There are three basic methods by which whey is removed (125). In the manufacture of soft cheese, whey is drained from

Table 3.31. Classification of Cheeses Made from Ewe's Milk

Cheese type	Description
Fresh cheeses	Type of drained yogurt made with the addition of a small quantity of rennet, e.g., Galotiri
Soft cheeses (brined)	Different varieties of Feta cheese, Teleme, Bulgarian white brined
Blue-veined cheese	Roquefort
Semi-hard cheeses	Three categories are produced: 1. Pecorino, Kefalotiri, Ossau-Iraty Pyrenees 2. " Pasta filata", e.g., Kaskaval and Kasseri 3. Manchego
Hard cheeses	Graviera, Halloumi
Whey cheeses	Ricotta, Mizithra, Brocciu, Manouri, Anthotiros

Reference: (129).

the perforations in the cheese molds. In the manufacture of most hard and semi-hard cheese, whey is drained from the vat, with the curd being retained for further processing. In the third process, curd and whey are pumped to a drain table or drain belt where the whey flows through and the curd is held back.

Salt may be added to the curd prior to hooping and pressing. However, the majority of traditional sheep milk cheeses are salted by soaking in a saturated brine long enough to absorb the proper level of salt for the variety of cheese. With the increased firmness of sheep milk curd due to the high solids, casein, and fat, brining time has to be longer because the rate of salt diffusion is lower in the sheep milk curd (129).

6.6.4 Cheese Yields

Because milk costs represent approximately 85% of the cost of producing cheese, it is only fitting that we evaluate cheese yield from sheep milk. Cheese is a product in which the protein and fat of the milk are concentrated, so it is clear that cheese yield is related to casein and fat content of the milk (259).

The majority of the casein and milk fat and more than half of the calcium will be retained in the curd and final cheese. The majority of the whey proteins, lactose, and water are separated out in the form of whey. Because the moisture portion of cheese is actually whey, we do retain small amounts of whey proteins and lactose in the final cheese, proportionate to the moisture content. However, it is obvious that the fat and casein content of the milk will be the key constituents of milk that will contribute the most toward the yield of cheese. Some of the factors that typically impact sheep milk composition and corresponding cheese yield are: breed of sheep, season or lactation, management system, nutrition of the ewe, genetics, milk quality, and milk storage (268).

Because casein is the key component in making up the curd matrix that entraps the fat globules, we look at casein relationships with other milk constituents to forecast the potential cheese quality and cheese yield. The casein/fat (C/F) ratio is critical in controlling the final fat in the dry matter (FDM) of the finished cheese. Minimum FDM specifications are established for many of the cheeses with standards of identity. The casein/total protein (C/TP) ratio will give us some potential information on the amount of intact casein that is present in the milk to give us a good gel structure during curd formation. In most cases, sheep milk would need to be standardized by removing some cream in order to increase the C/F ratio to produce most of the lower fat varieties of cheese (268).

Cheese yields for sheep milk have been reported in the literature by various researchers in the following manner:

1. Gross cheese yield after 1 day, lb/100 lb (22)
2. Adjusted cheese yield to *x*% moisture (206)
3. Quantity of milk (kg) necessary to make 1 kg of full-fat cheese (73, 144)
4. $Y = a + b_f x_f + b_p x_p$ (73)
   $= -0.20 + 0.011$ fat $+ 0.025$ protein

Some typical cheese yields of several varieties of sheep milk cheeses are shown in Table 3.32. These cheese yields will vary based on the previous factors we discussed affecting milk composition, especially fat and casein concentrations. Cheese yields also

may be affected by various processing variables such as (268):

1. Storage of milk
2. Milk standardization
3. Heat treatment of milk
4. Homogenization
5. Type of coagulant
6. Curd firmness at cut
7. Salt addition
8. Moisture loss during ripening

The cheese yields listed in Table 3.32 were measured after the cheese manufacturing process was completed. There was no opportunity for the cheesemaker to predict the potential cheese yield and make adjustments to possibly improve those yields with milk standardization or changing of the make procedure to improve the recovery of milk solids in the final cheese. When using cow milk, cheesemakers have had cheese yield formula for more than 90 years that are used to predict the potential cheese yield, based on milk composition (260). Current research (268) is evaluating the potential cheese yield formulae for application to sheep milk for cheesemaking. With good process control, record-keeping, and consistent cheesemaking operations, the cheesemaker should be able to have uniform composition and cheese yields throughout the season.

6.6.5 Ripening of Cheese

The basic composition and structure of cheese are determined by the cheesemaking process, but it is during ripening that the individuality and unique characteristics of each cheese variety develop. Four, and possibly five, agents are involved in the ripening of cheese: (1) rennet or other coagulants used; (2) indigenous milk enzymes, which are particularly important in raw milk cheeses; (3) starter bacteria and their enzymes, which are released after the cells have died and lysed; (4) enzymes from secondary starters or adjunct bacteria; and (5) non-starter bacteria, that is, organisms that either survive pasteurization or thermalization of the milk or gain access to the pasteurized milk or curd during cheese manufacturing (86). Three primary reactions take place during cheese ripening: glycolysis, proteolysis, and lipolysis. These primary reactions are mainly responsible for the changes in body and texture of the cheese during ripening and are also responsible for the basic flavor of the cheese.

Table 3.32. Reports in Literature on Cheese Yields from Sheep Milk

Cheese	Yield, %	Reference
Manchego	16.7	(126)
Feta	18.1	(126)
Romano	20.2	(126)
Blue	21.9	(126)
Halloumi	18.4	(73)
Manchego type	16.1	(118)

During the cheesemaking process, lactose is converted to lactic acid by the starter bacteria and secondary microflora from the milk. About 98% of the lactose is removed from the cheese in the form of whey but the curd may contain 0.8–1.5% lactose at the end of manufacture (112). The lactose is rapidly metabolized during pressing and brining so that lactose is undetectable by the time the cheese goes into the aging or curing cellars. Cheeses with salt added to curds prior to hooping and pressing may contain some slight residual lactose if the salt concentration is high enough to retard or inhibit the starter bacteria. Curd that is pressed and cooled rapidly will also have a slower rate of lactose fermentation and the potential for residual lactose. Cooler ripening temperatures may slow the growth of starter organisms and allow the growth of undesirable non-starter bacteria that may contribute defects to the cheese (200). Because sheep milk yields double the amount of curd as cow milk, the concentration of starter bacteria in the sheep milk curd may be 50% lower than in the curd of cow milk (76).

Proteolysis is the most complex ripening reaction and the most important for development of flavor and texture. Proteolysis contributes to cheese ripening in at least four ways: (1) a direct contribution to flavor via amino acids and peptides; (2) greater release of sapid compounds during mastication; (3) changes in pH, via the formation of ammonia; and (4) changes in texture arising from breakdown of the protein network, increase in pH, and greater water binding by the newly formed amino and carboxyl groups (86). Generally, α_{s1}-casein is rapidly hydrolyzed during the early stages of ripening, with almost 90% hydrolyzed during the first month (37). Ponce de Leon-Gonzalez et al. (210) reported that

α_{s1}-casein was completely hydrolyzed at 120 days of age. β-casein is hydrolyzed at a slower rate with approximately 50% remaining intact after six months of age (37). Several researchers (117, 187, 210) have reported the same pattern of casein hydrolysis during aging of sheep milk cheeses. Ozer et al. (198) reported that proteolysis developed faster in cheese made from sheep milk than in cheese from bovine milk. Ponce de Leon-Gonzalez et al. (210) observed that α_{s1}-casein hydrolysis was comparable between cow and sheep milk cheeses, but sheep β-casein was hydrolyzed at a significantly lower rate than that from cow milk. Nikolaou et al. (187) observed that both caseins were hydrolyzed more rapidly in cheese made in spring than in summer. Cheeses produced from sheep milk were firmer, more crumbly, less pasty, and more grainy than comparable cheeses produced from cow milk (18, 210). Ordonez et al. (195) indicate that variability in cheese ripening was associated with geographical location, altitude, and climatic conditions.

In most cheeses, relatively little lipolysis occurs during ripening and in some cases is considered undesirable (86). On the other hand, some unique varieties of cheese use rennet paste or microbial lipases to accelerate lipolysis to produce a piquant or lightly rancid flavor, for example, Pecorino Romano (140). Fiore Sardo cheese uses a rennet paste and raw milk bacteria to produce a piquant flavor in that variety of cheese (205). Lipolysis in Serra cheese proceeds slowly with relatively low concentrations of short- and medium-chain free fatty acids (FFA) (155). The rate of lipolysis in cheese produced during the winter was slightly higher than that of cheeses produced in the spring or summer (53). Pasteurized milk cheeses had significantly lower levels of lipolysis than raw milk cheeses (53). The predominant FFA released were oleic, butyric, palmitic, and capric (53, 155). Ha and Lindsay (101) have also identified some branched-chain fatty acids that appear to be responsible for "sheepy" notes in Pecorino Romano cheese. Typically, sheep milk cheeses will have higher amounts of short chain fatty acids than cheeses made from cow milk (97, 210).

6.6.6 Freezing of Curds and Cheese

With the seasonal production of sheep milk, the processor has the challenge of how to ensure a uniform supply of product throughout the year. Because milk production increases sharply in spring, each year there is a surplus of ripened sheep milk cheeses from June to September, causing prices to drop and hindering the marketing and sale of sheep cheeses (248). To even out some of the supply of cheese, several researchers (234, 235, 248) have recommended the freezing of curd or cheese to control the ripening process. Sendra et al. (235) found that with the freezing of curd, there was no difference in moisture loss in the cheeses made from frozen curd. No significant changes in the main components of cheese or in the lipolytic activity were observed. In another study (234), they found that temperature fluctuations during frozen storage of curds did not affect curd composition, proteolysis, lipid stability, and pH. Ripening partially overcame changes in the microstructure observed in the frozen curds.

In fully ripened cheeses that were frozen to control inventory, lactic acid concentration and pH were significantly different in control cheeses and those kept in frozen storage for nine months (248). Proteolysis continued slowly during frozen storage with the result of higher levels of non-protein nitrogen and amino nitrogen at the end of the storage period. They concluded that freezing fully ripened cheeses at $-20°$ C for up to six months was a suitable method of storing cheeses to control inventory throughout the year.

6.7 Whey Products

Reports of sheep whey products in the literature are very limited. Most of the whey from small cheesemakers is either fed back to the ewes as a source of nutrients (173) or spread on agricultural land as a source of plant nutrients (135, 269). Studies at the University of Wisconsin (48, 49, 270) evaluated the potential for production of whey products for food usage. Composition of sheep whey from Manchego cheese production is shown in Table 3.33. Sheep whey had higher protein, fat, and lactose than cow or goat whey. The ash content of sheep whey was lower than that of the other species (48). This was most likely due to a higher retention of colloidal calcium phosphate in the curd with the higher drain pH. The relative proportions of individual whey proteins from the whey of each species are shown in Table 3.34. Sheep whey contained more β-lactoglobulin and less serum albumin and immunoglobulin as a percentage of total whey protein than did cow whey

Table 3.33. Gross Composition of Caprine and Ovine Wheys from the Manufacture of Specialty Cheeses and Bovine Whey from the Manufacture of Cheddar Cheese

Component	Goat Cheddar[1]	Sheep Manchego[2]	Cow Cheddar[3]
	(%, wt/wt)		
Total solids	6.61	7.46	6.70
Water	93.39	92.54	93.30
Fat	0.51	0.82	0.36
Ash	0.61	0.43	0.52
Lactose (by difference)	4.71	5.16	4.50
Total protein (TN-NPN × 6.38)	0.77	1.05	0.60
NPN	0.05	0.08	ND[4]

[1]Means from February, March, April, May, July, September, October, and December.
[2]Means from March, June, and August.
[3]Reference: (266).
[4]Not determined.
Reference: (48).

Table 3.34. Distribution[1] of Whey Proteins in Specialty Cheese Whey from Caprine and Ovine Milks Compared with That in Cheddar Whey from Bovine Milk

Whey protein fraction	Goat Cheddar[2]	Sheep Manchego[3]	Cow Cheddar[4]
Serum albumin	4.0	4.1	6.5
Immunoglobulins	9.7	7.3	13.0
β-Lactoglobulin	58.6	74.0	64.9
α-Lactalbumin	27.0	14.8	15.6

[1]Values reported as mean percentages of total whey protein.
[2]Means from February, March, April, May, July, September, October, and December.
[3]Means from March, June, and August.
[4]Reported values in bovine Cheddar whey. Source: (161).
Reference: (48).

(48). α-Lactalbumin in sheep whey was about the same proportion as in cow whey but less than in goat whey. Proportions of β-lactoglobulin increased during midlactation while α-lactalbumin gradually decreased throughout the lactations. Whey protein concentrates (WPC) produced from sheep whey showed significantly better foam overrun, foam stability, and gel strength than did cow and goat WPCs (49). These characteristics may be due to higher β-lactoglobulin content and lower ash content in the sheep WPC. Ultimately, the potential markets for sheep whey products will depend on the availability of significant quantities of sheep whey for processing and the potential markets for these value-added products (267).

7 MARKETS FOR SHEEP MILK PRODUCTS

7.1 International

Currently, the total production of sheep milk in the world is about 8.2 million metric tons (83). The top 10 sheep-milk-producing countries are shown in Table 3.35. The majority of sheep milk produced is used in production of yogurt and cheeses. Countries such as France, Italy, Greece, and Spain have extensive dairy sheep production areas that supply milk to major commercial sheep-milk-processing plants. These processing plants have modern processing equipment that typically is used in commercial cheese plants processing cow milk. Some of the

Table 3.35. Top Ten Sheep-Milk-Producing Countries in 2000

Rank	Country	1000 Metric tons
1	China	925
2	Italy	850
3	Turkey	785
4	Greece	670
5	Iran	549
6	Syria	475
7	Sudan	465
8	Somalia	430
9	Romania	348
10	Spain	306
Total World Production—2000		8172

Reference: (83).

sheep milk cheeses, such as Roquefort and Manchego, are legally protected under the "denominazione di origine controllata" (DOC) system or the "appellation d'origine controlee" (AOC) system (88). AOC or DOC cheeses are produced in a specific region under a defined process. DOC sheep milk cheeses are identified in Table 3.30. In some countries, sheep milk is blended with cow milk to produce significant quantities of blended milk cheeses (17). Major international varieties of cheese produced from sheep milk are Pecorino Romano, Roquefort, Manchego, and Feta. In developing countries, sheep milk provides critical protein, calcium, and energy food for subsistence and to fight malnutrition (105).

7.2 United States

In the United States, the sheep milk industry is in the early stages of development. The current annual U.S. sheep milk production is estimated to be about 200 metric ton. The majority of the sheep milk is used to produce either yogurt or cheese. Besides the domestic production of sheep milk products, more than 13 million pounds of sheep milk cheeses were imported into the United States during 2001 (114). To avoid competition with imported commodity cheese with subsidies, U.S. processors are concentrating on production of specialty and artisanal cheeses. Many farmstead processors have worked with the American Cheese Society over the last 10 years to develop direct marketing of sheep cheeses and yogurt (105). Seasonal variations in sheep milk production have prompted processors to use some high-quality frozen sheep milk to adjust processing schedules to provide for a uniform supply of products throughout the year. Some processors are also extending the sheep milk supply by blending sheep milk with cow or goat milk to produce additional specialty cheeses with flavor characteristics of sheep milk (210, 270). Outstanding quality of U.S. sheep milk cheeses has been demonstrated by several sheep milk cheeses winning the Best in Show award over cow and goat artisanal cheeses at annual American Cheese Society contests over the past six years. In the 2001 U.S. Cheese Championship Contest, a blended sheep/cow milk cheese won the Best in Show award over all commercial cheeses in the United States (54).

In conclusion, the greatest potential for growth in the sheep milk products market is the production of value-added specialty cheeses and premium yogurt products. Unique properties and flavors of sheep milk can be incorporated into specialty and fermented products that cannot be produced with other sources of milk. With a continued emphasis on production of quality sheep milk, markets for sheep milk products should continue to grow.

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4
Buffalo Milk

4.1 Buffalo Milk Production

Ajit J.Pandya and M. Mohamed H. Khan

1 INTRODUCTION

Buffaloes *(Bubalus bubalis)* are predominant dairy animals in some countries contributing a major share to the world's milk production. The domestic buffalo of Asia is known by various names in different countries, such as Bhains in India, Al-Jamoos in Arab countries, Karabue or Kwai in Thailand, Carabao in the Philippines, and Karabo in Malaysia (73). Probable domestication of buffaloes at a very early date is evident from their appearance on ancient seals in the Indus valley and in Mesopotamia from about the middle of the third millennium B.C. According to the *Encyclopaedia Britannica,* buffaloes were introduced to Italy around 600 A.D., and the name *bubalus* was transferred to it from a North African antelope and then changed to buffalo. Buffaloes and their products are important in the agricultural and rural development of many countries (29). In the last 50 years the buffalo population of Italy has increased from 12,000 heads in 1947 to about 200,000 presently (102). Latin America also is emerging as an important area for buffaloes, with the largest concentration in Brazil. Statistics of buffalo populations indicate about 166 million head (25) worldwide, with India possessing most with 94 million head (Table 4.1), contributing more than 66% to the country's total milk production (Table 4.2). The buffalo is no less important in countries of the near East region such as Egypt, where it plays a vital role in the rural economy (3).

India is home of some of the best breeds of buffaloes in the world. Possession of a dairy buffalo and their numbers in an Indian household indicates the socioeconomic status of the farmer. Rightly dubbed the "living tractor of Asia," the buffalo requires minimal maintenance cost. It is also a walking fertilizer factory, producing about 6,800 kg of dung yearly (19). Buffaloes hold promise for many developing countries with ecological and farming conditions similar to India or Egypt. Buffaloes serve more than one purpose—it is a dual- or triple-purpose (milk, draft, meat) animal in the economy of tropical and subtropical countries. Its service to the people of Asia in draft power for rice paddy cultivation, transport, milk, dairy products, and meat is far greater than that from any other domestic animal.

1.1 Classification of Bovini

Buffaloes belong to the order *Artiodactyla*, suborder *Ruminantia*, family *Bovidae*, tribe Bovini (13). Within *Bovini* three groups are distinguished: *Bovina* (cattle), *Bubalina* (Asian buffalo), and *Syncerina* (African buffalo). Fundamental anatomical differences between African and Asian buffaloes separate *Syncerus* and *Bubalus* into different genera and groups. The African wild buffalo is found in the

Table 4.1. Distribution of Buffaloes (1,000 Head)

Year	1989-1991	1999	2000	2001
World	147969	162067	164446	165724
Africa	2813	3330	3379	3430
Egypt	2813	3330	3379	3430
N C America	7	5	5	5
Trinidad Tobago	7F	5F	5F	5F
South America	1372	1069	1103	1151
Brazil	1371	1068	1103	1150F
Surinam	1	1		1F
Asia (FMR)	143205	157089	159358	160546
Asia	143205	157428	159701	160892
Azerbaidzhan		297	299	302F
Bangladesh	771F	828F	830F	830F
Bhutan	4F	4F	4F	4F
Breunei Darsm	4F	6F	6F	6F
Cambodia	743	654	694	626
China	21412	22677	22599	22769
Georgia		33	35	35F
India	80577	92090	93772	94132
Indonesia	3290	2504	2405	2287
Iran	439	474	460F	460F
Iraq	135F	64F	65F	65F
Kazakhstan		9F	9F	9F
Laos	1066	992	1008	1008F
Malaysia	206	155	155F	155F
Myanmar	2051	2391	2441	2500
Nepal	3020	3471	3526	3624
Pakistan	17377	22000	22700	23300
Philippines	2751	3006	3024	3066
Sri Lanka	917	728	694	690F
Syria	1	3	3	2
Thailand	5152	1912	1900F	1900F
Turkey	428	176	175	170
Vietnam	2861	2956	2897	2950
Europe (FMR)	159	220	241	230
Europe	159	236	257	246
Albania	2			
Bosnia Herzogowina		1F	1F	1F
Bulgaria	24	10	9	9F
Greece	1F	1F	1F	1F
Italy	104	186	201	190
Macedonia		1	1F	1F
Russian FED		16	16F	16F
Yugoslavia SFR	28			
Yugoslavia		21	29	29F
USSR	412			

Source: (25); F = estimate

Table 4.2. Production of Buffalo Milk in the World (1,000 MT)

Year	1989–1991	1999	2000	2001
World	43777	65990	68177	69248
Africa	1261	2018	2030	2051
Egypt	1261	2018	2030F	2051F
Asia (FMR)	42434	63802	65975	67028
Asia	42434	63802	65975	67028
Bangaladesh	22F	22F	22F	22F
Bhutan	3	3	3	3
China	1907F	2600F	2650F	2650F
India	28717	43000	44550	45650
Iran	121	214	226	155F
Iraq	24F	26F	27F	27F
Malaysia	10	7	7	7
Myanmar	93	109	111	114
Nepal	601	744	760	781
Pakistan	10672	16910	17454	17454F
Philippines	5			
Sri Lanka	61	70	68	68F
Syria	1	1	1	1
Turkey	175F	66F	66F	66F
Vietnam	24	30	30	30
Europe (FMR)	82	169	172	170
Europe	82	169	172	170
Bulgaria	19	11	12	12F
Italy	62	158	160F	158F

Source: (25); F = estimate

forest and savannah regions south of the Sahara with two subspecies: *Syncerus caffer caffer* and *Syncerus caffer nanus. S. caffer* is a large, black animal weighing more than 1,000 kg; *S. nanus* is found in West Africa and is smaller and pale in color.

During the Pleistocene period the genus *Bubalus* was distributed in Europe and Southern Asia but when the climate became drier, it was restricted to India, Indochina, and South East Asian Islands. Buffaloes were reintroduced to Europe from the east in its domesticated form. There are three wild buffalo species in Asia called Anoa, Tamarao, and Arni. The Anoa *(Bubalus depressicornis)* is the smallest of recent buffaloes and confined to the Island of Celebes in Indonesia. They live mostly singly or in pairs. They have short horns that point almost backwards. There are two sub-species of Anoa: B. *depressicornis depressicornis* and *B. depressicornis quarlesi. B. depressicornis* is 100 cm in height and dark brown to black in color with small white flecks above the eyelids. Horns are typically 25 cm long. *B. depressicornis quarlesi* is about 63 cm in height and has woolly hair of light-brown color. White marks are present only above the hocks. The horns are triangular in section and only 15–16 cm in length. The Tamarao *(B. mindorensis)* is found only on the island of Mindoro of the Philippines. It is a small animal, 100–120 cm in height, grey-black or dark brown in color with white marks on the head, neck, and legs. Horns are short, strong, and slightly curved. The Arni *(B. arnee)* is distributed in northern India and also in Indochina, found in the reserve forest of Assam, Madhya Pradesh, and Orissa in India and in Nepal. It is about 150–170 cm in height and weighs nearly 1,000 kg with grey-black, dark-grey, or dark-brown colors and very large horns (13).

1.1.1 Domesticated Buffaloes

They are classified into river and swamp buffaloes (43, 87). The river buffaloes are usually black in color with curved or sickle-shaped horns and have

primarily dairy character. Their origin and development was in India, Pakistan, Southwest Asia, and Southeast Europe. Their habitat is river valleys with clean river water. Their normal black color has patches of white hair on the forehead, face, and in the switch of the tail. The river buffalo has been selected to form improved breeds with high milk yield, while the swamp buffalo has not. Their natural habit is the swamp or marshland in Southeast Asia. They have considerable variation in confirmation and color. They are grey at birth and turn slate blue later or dark grey. Swamp buffaloes are primarily work animals in rice-growing areas and are poor in milk yield, varying from 1–4 kg daily, although some animals have produced up to 7 kg. Their gestation period is two weeks longer than that of the river buffaloes (13, 19).

1.2 Distribution of Buffaloes

In Australia, buffaloes were imported to supply meat to the early settlements on Melville Island and Port Essington on the Cobourg peninsula in the extreme north of the Northern Territory (13). They came from Timor, Kisau, and possibly other islands of Indonesia and were of the swamp breed. The imports started in 1824 and ceased in 1849, when the settlements were abandoned and the remaining animals were freed. They quickly became feral and spread to a more suitable area west of the Cobourg peninsula toward Darwin. Here they flourished and, by the 1880s, their population was estimated at 150,000–200,000. It is interesting to note that, when captured young, they become quite tame after two to three weeks in captivity. The feral buffaloes were originally exploited for their hides, which weighed 27–32 kg.

In Southeast Asia, swamp buffaloes were introduced into German New Guinea before 1914 and many went wild between the two wars. There are now feral populations in the extreme east of New Britain and on Selapiu and Duke of York Islands in the Bismarck Archipelago. Small herds under the control of the Mandres plantation are at New Britain, on Alexishafen, and Bogia plantations on the mainland of New Guinea. With few exceptions the buffaloes of Thailand are of the swamp breed. Albinoids are frequent. They are excellent meat producers besides draft animals, but yield little milk. In the Philippines are buffaloes of the swamp breed for work and of the river breed for milk production (62). In Indonesia the swamp buffaloes are used as draft animals but are also milked with low yields. In Malaysia the swamp buffalo known as Kerban has long been domesticated for work in the rice-growing areas but are also used for milk production, and Indian Murrah have been introduced for milk and ghee there and in Sri Lanka/Ceylon and Burma/Myanmar, where the indigenous buffaloes are of the swamp breed and are a small type used for work (101).

In the Caribbean area buffaloes were first brought to Trinidad around 1900 to work as draft animals on sugar plantations (37). The Jafarabadi was the first breed imported, followed by Murrah, Nagpuri, and Surti, and later imports followed between 1924 and 1949. They are still used almost entirely for work and, with the reduction in demand, their numbers are declining. There are no controlled breedings and no testing of milk yield. In general, only aged and injured animals are slaughtered for meat, but recent tests at the University of the West Indies indicate that it would be profitable to fatten young animals (26, 37). A last survey counted about 7,000 buffaloes in Trinidad, a few hundred in Guyana, where they are used for hauling timber, and some in Columbia, Peru, and Surinam.

In Brazil buffaloes of the river type were first imported in 1902, although their origin is not clear (53). They were taken to the island of Marajo at the mouth of the Amazon in Para state. Later imports into Para included swamp buffaloes, known as Carabao, and Indian Murrah and Jafarabadi; Italian breeds came between 1918 and 1921. Swamp buffaloes are found only in the Amazon region and are called Rosilho (roan), although they have a typical dark-grey color (20, 49). River buffaloes are used under extensive range or semi-intensive systems with selective breeding as dairy animals in Para and central Brazil. They are black, sometimes with white marks on head, tail, and lower legs, and are known as Preto buffaloes.

In Africa river buffaloes have at various times been introduced into several countries; however, only a few have survived.

Statistics indicate the importance of buffaloes as dairy animals (Table 4.1), especially in India. The World and Asian buffalo population each increased by 12% by 2001 compared to 1990 (25). The increases in India, Pakistan, China, and Italy were 17%, 34%, 6%, and 83%, respectively. The significance of buffaloes as milk producers is shown in Table 4.2. World and Asia buffalo milk production

increased each by 58% during the time from 1990 to 2001. In India, Pakistan, China, and Italy the increases were 59%, 39%, 64%, and 155%, respectively. Asian buffalo milk production amounted to 97% of the world buffalo milk production. The contributions in milk tonnage from India, Pakistan, China, and Italy have been 66%, 25%, 4%, and 0.2%, respectively.

1.3 Breed Characteristics

1.3.1 Murrah

The Murrah is the most popular breed of domestic Indian buffaloes and is distributed widely (Figures 4.1, 4.2) (38, 43). The home tract of the Murrah spreads through Haryana, Delhi, and Punjab, and true Murrah buffaloes are found in Rohtak, Hissar,

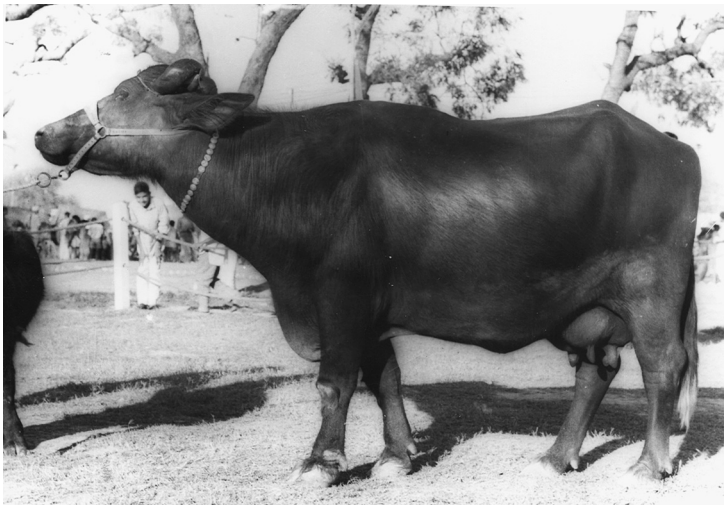

Figure 4.1. Murrah female buffalo.

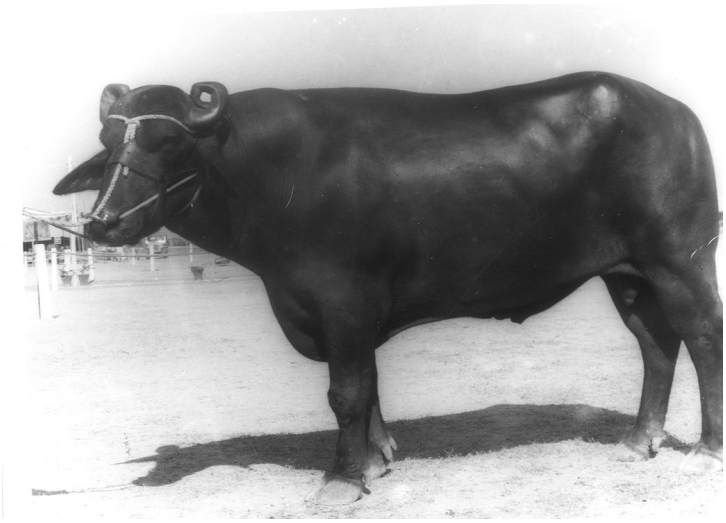

Figure 4.2. Murrah male buffalo, adapted from references 38, 43.

Gurgaon, Karnal, Nabha, Patiala, and parts of Uttar Pradesh west of the river Jamuna. It is a heavy animal with a massive frame and attractively styled horns. The usual color is jet-black with white markings on the face and extremities and variation of fawn grey. Humps are undeveloped as in Taurus cattle. The switch of the tail may be partly or completely white. The udder is well developed, extending from between the hind legs to just behind the naval flap. Teats are long and placed wide, but a great variation in the shape and size of udder and teats exists between individuals. The skin is soft, thin, and flexible with few hairs. Adult male Murrahs may weigh between 450 to 800 kg and females 350 to 700 kg. For registration of Murrah females in the herd book, the minimum milk yield should not be less than 1,360 kg in 300 days (7), but in the herd registry of India, milk yield should be 1,400 kg/300 days of lactation.

1.3.2 Nili-Ravi

Before 1938, Nili and Ravi buffalo breeds were considered varieties of Murrah, but at the first All India Cattle Show held in 1938 (16, 99), the Nili was shown as a separate breed and both breeds were separately described (43). In 1960 the two breeds were described as one Nili-Ravi breed (Figures 4.3, 4.4). It is the main breed in Pakistan. In India it is found in Ferozpore of Punjab. It has a broad, massive forehead and small, tightly coiled horns. It has more coarse hair on the head and face. The udder is large and well developed; the teats are long and placed at equal distance. Milk vessels are long, tortuous, and prominent. The color of the skin is black, but brown animals are also found. White markings on forehead, face, muzzle, legs, and switch are common. Average body weight of an adult male is 600 kg and of the cow 450 kg (39). Milk yield may range from 9 to 18 kg per day, producing about 1,600 kg in a lactation of 250 days.

1.3.3 Mehsana

Mehsana buffaloes are widely distributed in Gujarat and part of Maharashtra. They are one of the main milk sources for various dairies in Gujarat and Maharashtra State. The breed resulted from crossbreeding of the Surti and Murrah breeds and has characteristics of both (Figure 4.5). It is a medium-sized animal weighing 350 to 550 kg. The horns are curved but may vary from sickle shaped to curled. The udder is well developed, and milk yield varies from 1,300 to 1,800 kg in lactations of 300 days. Mehsana are docile and can be reared in stall feeding and grazing. Their skin is thin, color is generally

Figure 4.3. Nilravi female buffalo.

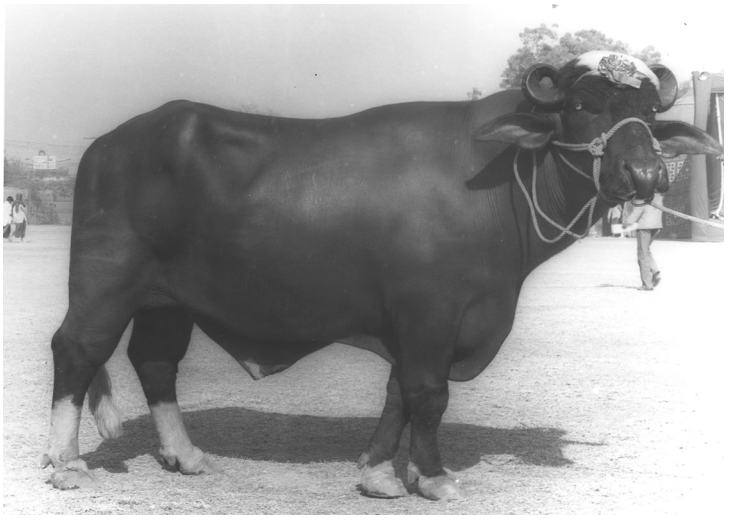

Figure 4.4. Nilravi male buffalo, adapted from references 39, 43.

Figure 4.5. Mehesana female buffalo.

black, and hair is rough but scanty. Females are reputed for regular breeding and persistent milking.

1.3.4 Surti

The home tract of the Surti buffaloes lies between the Sabarmati and Mahi rivers in Gujarat (7, 65, 66). The Surti breed is the main milk producer for the largest cooperative dairy, the Kaira District Co-operative Milk Producers Union Limited. Its number of shareholders, mostly farmers, is about 3 million. Members keep up to five animals in the villages as a part of farming, and women members of the family are generally in charge of milk production.

The Surti buffalo is a well-shaped animal of medium size varying from black to brown *(bhurra)* in color (Figures 4.6, 4.7). Many animals have two white chevrons, one around the jowl from ear to ear and the other on the brisket, like that of the swamp buffaloes. The color of hair below knees and hocks is generally white to brown-grey. Horns are sickle shaped and extended backward parallel to the neck. Average milk yield varies from 1,730 to 1,990 kg in lactations of 10 months.

1.3.5 Zaffarabadi/Jafarabadi

This breed of buffaloes is found in India and Pakistan (43). They are strong, massive animals with a prominently convex forehead, heavy, broad, corru-

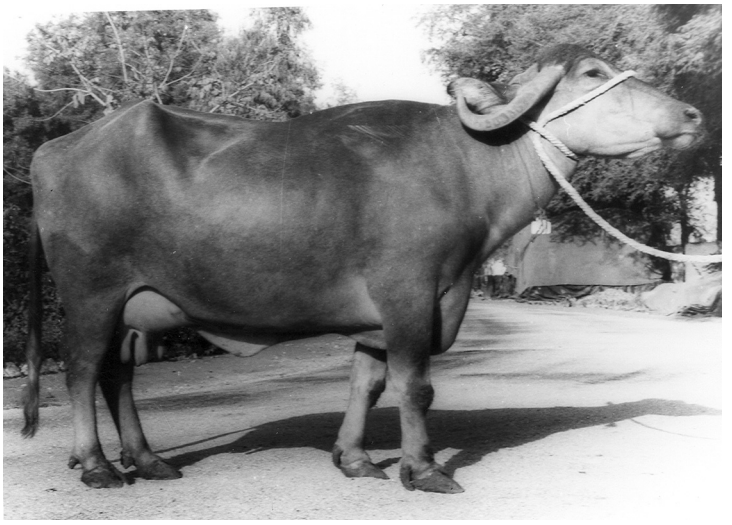

Figure 4.6. Surti female buffalo.

Figure 4.7. Surti male buffalo, adapted from references 7, 65, 66.

gated, and drooping long horns, curved upward at the tip (Figures 4.8, 4.9). Average body weight of adult bulls is 590 kg and of adult females, 454 kg. Body color is usually black but white markings on the face and legs below the knee may also be seen. The females are good yielders and males are famous for pulling heavy loads. Milk yield may range from 1,800 to 2,700 kg per lactation.

1.3.6 Bhadawari

The name "Bhadawari" was derived from the Bhadawari State. The animals are mainly distributed in Uttar Pradesh, Gwalior, and Madhya Pradesh States. They are light- to medium-sized animals with long, compact, flat, corrugated horns of medium thickness. The skin is copper colored with scanty hair.

Figure 4.8. Jaffrabadi female buffalo.

Figure 4.9. Jaffrabadi male buffalo, adapted from reference 43.

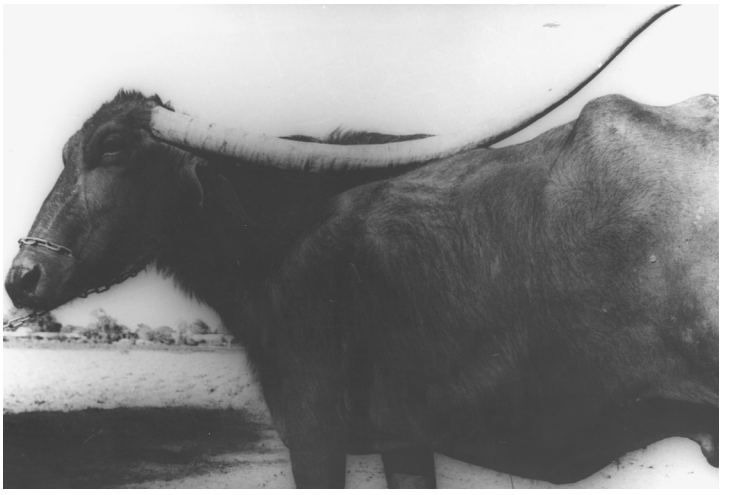

Figure 4.10. Nagapuri female buffalo, adapted from references 43, 77.

White markings on the face are rare. The age at first calving ranges from 30 to 66 months, with milk yield ranging from 470 to 2,070 kg in lactations of 188 to 305 days (92). Butterfat in milk can vary from 8 to 13%.

1.3.7 Nagapuri or Ellichpuri

This breed was first described in 1952 (43), but several strains differing in color have been identified (77). The breed is known for milk and draft in Nagpur and is predominant in Maharashtra. This is a light breed of buffaloes and is well adapted to hilly and jungle areas with tropical climate (Figure 4.10). Horns are very long and heavier in males. Skin and coat color are usually black. Body weight varies from 320 to 400 kg.

1.3.8 Pandharpuri / Dharwari

The breed is found in South Maharashtra, part of Andhra Pradesh and Karnataka. They are medium-sized animals with a long, narrow face and long, flat, and usually twisted thin horns. The breed is hardy and well suited to dry regions (19).

1.3.9 Kalahandi / Peddakimedi

This is a breed in the Eastern hilly part of Andhra Pradesh and Orissa. The color is grey or ash grey. Horns are broad and half curved, running backward. Due to its light color, this breed tolerates sun heat better than the dark-colored buffaloes. The breed is equally suitable for draft purposes on hills to carry loads or in the plains for ploughing the paddy fields, pulling carts and crushing sugarcane. Milk yield is satisfactory. This animal was brought by Peddakimedi people to Orissa and therefore is known as "Peddakimedi" (50).

1.3.10 Mandal / Parlakimedi / Ganjam

These buffaloes are bred in the hilly areas of Orissa and Andhra Pradesh. They are reared in the jungle, usually on natural herbage, and brought down to the plains in large herds for sale. The usual color is brown or grey with yellowish tufts of hair on the knees and fetlocks. The switch of the tail is yellowish white. It possesses an arch-like curved red ring around the chest about 8–9 cm wide. The horns are broad and semicircular, extending backward and inward. Milk yield is satisfactory. They are also good draft animals and the light color is favorable for working in hot sun.

1.3.11 Jerangi

They have been described as distinct from Manda and Kalahandi breeds. They are bred in the Jerangi hills of Orissa, Northern part of Vishakhapatnam,

and West of Ganjam in Andhra Pradesh. This is a small breed whose height does not exceed 114 cm (19). The skin is very thin, horns are conical and small, color is black. They are useful animals for ploughing in water-logged paddy fields. Body and coat color is usually black, but brown and ash grey animals are also found.

1.3.12 Toda

The Toda buffalo is a unique breed confined to the hilly forest areas of Nilgiris (42). The total population is around 3,300. Average herd size is 22 buffaloes. The color of the calf at birth is generally fawn, which changes to ash grey with age. Along the crest of the neck, wither, and back, there is a thick growth of hair like a mane, which gives these buffaloes a bison-like appearance. Adults are ash grey and some are light-cream colored. Horns are crescent shaped. Animals have a dense coat of hair over the whole body. These buffaloes are furious and dangerous, especially to strangers. They live in colonies and fight tigers and other wild animals. They are sacred animals of the Todas, a hill tribe, and are used at the tribe's religious rituals such as for birth, marriage, and death. Females are average milkers and yield between 4 to 9 liters per day. Milk is rich and possesses a specific, well-flavored taste (50).

1.3.13 Assamese / Mongoor

These are medium-sized animals. Horns are small, body is covered with a thick coat of hair, and the color is usually black but the number of albinoids is considerable. Milk yield is low. Further details are not available. These animals breed frequently with their wild counterpart.

1.3.14 Buffaloes of the Near East and Europe

The Asian buffaloes of the river type are distributed in India, Pakistan, Afghanistan, Iran, Iraq, Syria, Turkey, Russia, Azerbaidzhan, Georgia, Egypt, Southeast Europe, Greece, Albania, Yugoslavia, Bulgaria, Romania, Hungary, and Italy (27, 28, 40, 47). The European buffaloes are usually black, dark grey, or dark brown in color. White marks may be found on the head, lower legs, and tail tips. Milk production is of primary importance, followed by meat production from culled animals and surplus young males. Their use as a draft animal has declined considerably.

1.4 Genetics

1.4.1 Chromosomes

Swamp buffaloes of Thailand and West Malaysia have 48 diploid chromosomes, whereas the Murrah breed of the river buffaloes in West Malaysia, Turkey, and Europe have 50, but the wild Tamarao *(Anoa mindorensis)* has 46. Details have been described. Swamp X river crosses have 49. Gene mapping in buffaloes has been slow (53, 69, 70), accounting for about 60% of the genome.

1.4.2 Color

Among river buffaloes, black is the most common color, but unimproved village animals (*desi*) may be grey with white stockings like the swamp breed. Hybrids between black river and grey swamp buffaloes are invariably black, indicating that black is either dominant or epistatic to grey (78). The skin is black but the hair is grey in crosses in Sri Lanka and Taiwan. The swamp buffalo usually has a dark-grey skin with grey-brown hair. The white blaze on the face of river buffaloes is presumably dominant or epistatic. River buffaloes are sometimes brown instead of black, but all breed standards prefer black. Brown is recessive to black, and in spite of negative selection, the frequency of the brown gene is about 30%. The swamp buffalo is sometimes completely white, that is, white hair and pink skin, a condition very rare in river buffaloes. This is not true albinism because, although pigment is lacking from skin and hair, it is still present in the iris, mucosa, horns, and hooves. The frequency of white animals is about 10% in Thailand, varying from 33% in the North to less than 5% in the South. White buffaloes are common in Laos. In Thailand they are said to be less vigorous than the grey and attract lower prices. In China, white is considered unlucky, and white animals are rare. They are unknown in Taiwan. In Thailand, red buffaloes, similar in color to red Shorthorn cattle, have been reported in an area along the sea coast southeast of Bangkok (78) as well as in China; however, they may be white animals with little hair whose skin is reddened by the sun, or grey animals with an abundance of red-brown hair. Genes to explain color inheritance have been suggested for white bbW-, black B-wwR-, grey bbww, grayish-white B-W-, and brown rr. This assumes that w (W) and grey (w) are alleles at one locus and black (B) is at another. It also assumes that white is dominant.

1.4.3 Quantitative Genetics

Heritability (h^2) for age at first calving of buffaloes has been reported at 0.13–0.17 (32), 0.24 (55), 0.27 (93), and 0.77 ± 0.32 (23), but the last figure is exceptionally high. Low heritability estimates indicate that environmental factors rather than genetic factors play an important role in age at first calving (66). A high repeatability (r) of services per conception of 0.32 (72) is in contrast to only 0.01 in other studies (Table 4.3) (93). Heritability of calving interval (Table 4.4) is below 0.15. Repeatability of calving interval varied from 0.05 to 0.20. Gestation length within breeds showed high repeatability of 0.5 (71) with heritability of 0.58. Heritability of peak milk yield in Surti buffaloes was high at 0.78 (Tables 4.5, 4.6) (65), and for milk yield per day of lactation 0.76. Repeatability of milk yield ranged between 0.37–0.55 (Table 4.5). Repeatability and heritability of lactation length varied between 0.16 to 0.27 and 0.06 to 0.27, respectively (Tables 4.7, 4.8) (99). Repeatability and heritability of dry period was generally low (Table 4.9).

1.4.4 Blood Groups and Protein Polymorphisms

There is a close parallel in the J blood group systems of buffaloes and cattle (22, 52, 74, 96, 97). Anti-J of cattle origin reacts with blood samples from buffaloes (45). The pattern in haemoglobins of buffaloes appears to be more complex than in cattle or sheep (46, 76, 100). A number of serum proteins (albumins, transferrins, and esterases) show genetic polymorphisms in several species. In Thai buffaloes three types of transferrins, AA, AD, and DD, were found (52), determined by codominant alleles Tf^A and Tf^D with a frequency of 0.27 and 0.73, respectively. In Bulgarian buffaloes three transferrin types, BB, BC, and CC, were described (57). Polymorphism has also been found in serum albumins of

Table 4.3. Repeatability of Calving Interval (CI) and Service Period (SP) in Buffaloes

Character	r	Number of cows	No. of records	Notes	Reference
CI	0.05	535			(11)
	0.09	340	680	First and second CI	(9)
	0.15	593	1540 pairs	All correlations, first to fourth CI	(4)
	0.20	67	166	Intraclass correlation, first to fourth CI	(92)
SP	0.32	57	244	All correlations, first to sixth SP	(72)
	0.01	107	310	Intraclass correlation, first to sixth SP	(93)

Table 4.4. Heritability of Calving Interval (CI) in Buffaloes

Character	h^2	SE[1]	Method	Reference
CI (first to third)	0.13	(0.35)	Paternal half-sib correlation	(11)
CI	0.00	(0.27)	Paternal half-sib correlation	(24)
CI (first available)	0.08	0.16	Daughter/dam regression	(4)

Table 4.5. Repeatability of Milk Yield in Buffaloes

Character	Lactation	r	Number of cows	No. of lactations	Reference
300-day yield	First to fifth	0.55		752 pairs	(3)
300-day yield	First to sixth, consecutive	0.37	338	376 pairs	(92)
305-day yield	First to third, all pairs	0.50	27		(2)
305-day yield (age corrected)	First to fourth, all pairs	0.39	80	246	(92

Table 4.6. Heritability of Milk Yield in Buffaloes

Character	h^2	SE	Number of daughter/dam pairs	Reference
Total yield, first lactation	0.24	(0.30)	64	(11)
300-day yield, first lactation	0.31			(3)
Total butterfat, 305-day yield	0.06	(0.50)	58	(1)
305-day yield, first lactation	0.26	0.14	255	(10)
Peak yield	0.78	0.16	680	(65)
Milk yield/day	0.76	0.19	507	(98)

Table 4.7. Repeatability of Lactation Length in Buffaloes

r	Number of cows	Number of lactations	Notes	Reference
0.26	345	774	First to fourth lactations correlated in pairs, excluding those under 200 days	(11)
0.16	315	752 pairs		(5)
0.19		1231	All correlations between pairs	(24)
0.25		1210 pairs	Mean of nonconsecutive lactations, first to fourth	(54)
0.24	80	246	Intraclass correlation	(92)
0.27	400	1614	First to fourth lactations	(10)

Table 4.8. Heritability of Lactation Length in Buffaloes

h^2	SE	Notes	Reference
0.11	(0.32)	60 daughter/dam pairs	(11)
0.14	(0.25)	12 sires with 102 daughters	(24)
0.06	0.11	Length of best lactation	(54)
0.27	0.14	255 daughter/dam pairs	(10)
0.24	0.12	67 sires with 618 daughters	(10)
0.11	0.06	1322 Nili-Ravi buffaloes	(99)

Table 4.9. Repeatability and Heritability of Dry Period in Buffaloes

r	h^2	Reference
0.12	0.18	(11)
0.18		(5)
0.12	0.02	(24)
0.68		(92)

Murrah buffaloes (46), controlled by two codominant alleles Al^S and Al^F. Their frequency in Bulgarian buffaloes was 0.46 and 0.54, respectively (57). Three different types of serum amylases (AA, AB, and BB) caused by two codominant alleles Am^A and Am^B have also been reported.

Milk protein polymorphic studies in cattle (58, 84) need to be duplicated in buffaloes because it is now known that genetic variants have significant associations with milk protein contents and exert influences on cheese making properties of milk.

1.5 Reproduction and Milk Production Traits

Being of foremost importance for reproductive efficiency, the average age at first calving in Indian buffaloes is between 41 to 49 months (16, 17, 21, 32, 33, 66), while in a 19-year study of Murrahs, the average age was 55 months (41); in another study, in Pakistan, the range was 32 to 72 months (9); and in Egypt, between 32 and 39 months (36, 47). Probably females are first served only when they have reached

a certain body weight; however, the aim in profitable dairy cattle management is 24 months.

The average calving interval of 20 months for Egyptian buffaloes and an average dry period of eight months (47) is very high, while 14 months and higher were reported for Italian buffaloes (27, 83). Murrah buffaloes in India averaged a calving interval of 14 months after calving between June and November, but 17 months after calving during December to May (33, 75), and other studies with Nili-Ravi, swamp, and Toda buffaloes gave similar values (16, 17, 21, 56).

Gestation length in buffaloes is 30 days longer than in cows (285 days) (77), but swamp buffaloes have 338 days compared to 319 days for river buffaloes (56) and 304 days for Nili-Ravi buffaloes (17).

Average service period of course varies much from farm to farm, with reports of an average of 199 days in India (34). In Murrah buffaloes at different research stations in India, the range was 81–260 days, but much longer in other field studies (16).

The dry period in Murrah buffaloes varied from 99 to 204 days (16, 34) but was longer in other breeds.

Lactation length of Murrah buffaloes at different research stations in India was 294 to 363 days (14, 16, 88) and for Nili-Ravi buffaloes, 321 to 427 days. Season and parity in Murrah buffaloes influenced lactation yield and length by 1704 kg and 266 days, respectively (63).

Peak daily milk yield in Murrah buffaloes averaged 9, 11, 12, 12, and 12 kg for 1st to 5th lactation (6). Mean first lactation milk yield in 305 days was 1,058 kg (88). Better feeding management and selection should improve production (7, 12). Buffaloes with higher age at first calving are supposed to produce more milk than those at younger age (55, 82), but this opinion has long been refuted economically. Swamp buffaloes in China had daily milk yields of 2 to 7 kg with high fat and SNF percentages (49); West Malaysian buffaloes milked 3 kg daily; Indonesian buffaloes, 1 to 2kg; buffaloes in the Philippines had total lactation yields of 488 kg (73); and in Sri Lanka, 360 kg (101).

Approved Indian dairy farms averaged lactation yields of 1,840 kg in 281 days (39, 59). Studies in Dagestan and Azerbaidzhan found lactation milk yields of 750 to 862 kg (48, 87), while Bulgarian buffaloes milked 1,330 kg in 270 to 300 days, Yugoslavian and Romanian buffaloes at similar levels (40, 80), and Italian buffaloes were at 1,507 kg (28). Persistency of milk yield was correlated with lactation yield at 0.29, and the average persistency index in Murrah buffaloes was 86% (61).

1.6 Environmental Physiology

The heat-regulating mechanism is poorer in buffaloes than in cattle due to the less efficient thyroid-adrenal mechanism coupled with the not-so-heavy hair coat. Buffalo calves under one year of age suffer much more than adults from heat. In addition to the ambient temperature, the lactation, pregnancy, and good feeding further increase the heat load in buffaloes. Because the body temperature of buffaloes is lower than that of cows, they have better heat regulation under conditions of shade. Buffaloes prefer to graze in the cool hours of the day (51), and they cool little by sweating. Therefore it is advisable to provide wallowing or water showering, as water sprinklers reduced the rectal temperature of buffaloes by 0.3 to 1.5° C. Wallowing is more effective than housing for buffaloes in reducing body temperature, but artificial wallows become fouled by excreta unless the water is continuously flowing.

Milk yield in buffaloes decreases with high ambient temperature. Splashing water twice daily before milking improved daily milk yield from 0.8 to 1 kg (94). Splashing reduced the body temperature by 0.4° C. Providing wet screens around the shed improved feed consumption and milk yield by 44 and 29%, respectively. Buffaloes have thicker skin than cattle, but the density of hair is only one-tenth of that in cattle, and they have poorly functioning sweat glands.

Conception of Indian buffaloes is about 63% and lower than in cattle (33, 81). The number of inseminations per conception is about 1.6. In Egypt the conception rate was reported to be 36 and 35% in buffaloes and cattle, respectively. In India the conception rate is the highest during the cool season. Significant negative correlations exist between conception rate and air temperature and relative humidity. Buffaloes in India and Pakistan have seasonal patterns of calving, with a peak from August to October. However, there is no evidence that buffaloes are seasonally polyestrous. High environmental temperature shortens the estrus period in buffaloes, and females are sexually inactive during the summer.

Male buffaloes lose libido when unprotected against climatic stress (60). Ambient temperature below 10 and above 35° C, humidity, and air movement influence the quality of buffalo semen. Mating is also nocturnal in a majority of buffaloes. The occurrence of non-motile ejaculations was maximum in summer and winter.

1.7 Nutrition

1.7.1 Dry Matter Intake

Nutritional physiology of buffaloes is similar to that of cattle. However, there are significant differences in feed intake and digestive and metabolic efficiencies between the two species (44). In practice, farm animals are allowed to consume an unlimited amount of food to satisfy their hunger up to satiety, but in normal farm feeding practice most lactating cattle and buffaloes are fed twice or three times a day. The development of the rumen in young calves is affected by age, level and duration of milk feeding, and bulkiness of supplemental calf starter and fodders (17, 35). Growing buffalo calves fed fibrous feeds of low-energy density usually have larger feeding capacity than those reared on high levels of milk feeding or suckling dams for longer periods.

The newborn buffalo calf up to one month of age requires whole milk feeding at 30–35 g dry matter (DM) per kg body weight $W^{0.75}$ (44). Up to three months of age, the requirement increases to 35–45 g per kg $W^{0.75}$. Dry matter intake for three- to six-month-old calves on a high concentrate diet is 75–90 g per kg $W^{0.75}$, while on a high roughage diet the requirement is 65–80 g per kg $W^{0.75}$. The DM intake after six months varies due to palatability, energy, and protein density of feeds, climatic changes, and growth potential of animals. The growing calves need 70–80, 80–90, 90–100, and 100–120 g DM per kg $W^{0.75}$ with average daily weight gain (ADG) less than 400 g, 400–500 g, 500–600 g, and more than 600 g, respectively, up to 150 kg body weight (BW). For the corresponding ADG, the respective intake values may be 80–85, 85–90, 90–95, 95–100 g per kg $W^{0.75}$ for calves between 150 to 300 kg BW.

The average DM requirement for idle adult buffaloes may be 70–80 g per kg $W^{0.75}$ from diets containing about 50% Total Digestible Nutrients (TDN) on a DM basis. An increase of 10–50% in DM intake by pregnant buffaloes may occur with increase in the days after conception, the highest during the terminal quarter of gestation. In India the average daily milk yield of buffaloes is usually 7 to 10 kg. The DM intake of lactating buffaloes is 90–125 g per kg $W^{0.75}$. Dry matter intake during mid-lactation is usually higher, compared to early and late lactation.

1.7.2 Energy Requirements

Mean energy requirements for maintenance has been estimated to be 120, 110, 105 Kcal per kg $W^{0.75}$ for Metabolizable Energy (ME) or 34–35, 31, and 29 g TDN on feeding diets containing about 1.8, 2.0, and 2.25 Mcal ME per kg feed or 50, 55, and 60% TDN on a DM basis, respectively (44). For pregnant buffaloes the demand for additional energy increases gradually from mid-gestation and becomes 30–40% higher than the maintenance requirement during the last quarter of pregnancy. Similarly to cattle, the energy requirement of younger buffaloes during first and second pregnancies is about 20 and 10% higher than the requirement of adult buffaloes. Buffalo milk contains more solids and fat than does cow milk, ranging from 6 to 7% in the milk of Murrah buffaloes but up to 13% in the milk of Bhadawari buffaloes in India. It is rare to find buffalo milk with less than 6% fat. The ME requirement starts at 1,500 Kcal per kg for milk of more than 5% fat content. For each 1% increase in fat content, 160 Kcal is added to the energy requirement. On feeding high-energy feeds (2.5 Mcal or more), the energy requirement is reduced by 8 to 12%. Mean maintenance energy requirements of growing Indian buffaloes is 125, 115, or 108 Kcal ME per kg $W^{0.75}$ on feeding diets containing 50–55, 55–60, and 60–65% TDN/DM, respectively. For every 1 g of ADG, the requirement of ME (Kcal) ranges from 5.3 to 6.8 on low-energy rations, 6.4 to 7.8 on medium-energy, and 7.8 to 9.1 on high-energy rations for calves weighing between 150–200 kg. The corresponding values for calves weighing 200–250 kg are 6.0 to 7.7, 6.7 to 8.3, and 8.1 to 9.6, respectively.

1.7.3 Protein Requirements

The mean Digestible Crude Protein (DCP) requirement is 1.68 g per kg BW for maintenance of buffaloes (13). During pregnancy, additional protein is required for fetal growth up to mid-pregnancy,

which is met by additional feed intake. But thereafter a higher percentage is required in the diet for supporting higher requirements due to faster fetal growth, particularly during the terminal quarter of gestation. Almost double protein requirements for maintenance has been suggested by NRC (1989) (90) for cows, which may be used for buffaloes until specific values are available. The DCP requirements for milk production with fat content of 5, 6, 7, and 8% are 60, 66, 72, and 78 g per kg milk yield. Due to low digestibility of common Indian feedstuffs, the protein requirements are much higher than values for cattle. For buffaloes weighing 100, 200, 300, and 400 kg and gaining 300, 400, and 500 g per day, the requirements for DCP are 166, 190, 214; 229, 254, 278; 285, 309, 334; and 336, 361, 385g, respectively. The mean DCP requirement for growing buffaloes of about 200 kg BW has been derived from the equation:

$$Y = 48.928 + 3.418\,\chi 1 + 0.287\,\chi 2$$

Where Y is DCP intake (g), $\chi 1 = W^{0.75}$ kg, and $\chi 2$ = ADG (g).

1.7.4 Rumen Digestive Physiology

Buffaloes have a larger circumference of muzzle, approximately 40% larger than Holstein cows and 50% greater than most Zebu breeds (68). This makes buffaloes nonbrowsers of shrubs, trees, and forbs, but the large muzzle enables higher rates of intake of forages or crop residues by buffaloes compared to cattle. The first three stomach compartments of buffaloes are the same as in cattle, but the structure and development of the fourth, the abomasum, differs. Average weight of the rumen in buffaloes is greater than for cattle. There is indication that buffaloes have better conversion of forages or crop residues than cattle, and that the rumen of buffaloes becomes functional at an earlier age (91). The length of the small intestine in mature buffaloes is about 10 m less than for Zebu cattle, 17 m less than for Jerseys, and 20 m less than for Holstein cows.

Rumination and the number of rumen movements in adult buffaloes in the morning before feeding, at post-feeding, in the evening, and during eating, drinking, and the resting period differ (13). The pH of ruminal content in buffaloes is generally highly acidic; however, alkaline pH in the morning before feeding and watering, and acidic pH in post-feeding time, is also reported. The rumino-reticulum of buffaloes varies from 40–100 kg depending on adult body size and nature of the diet. It is difficult to empty the rumen even by fasting buffaloes for two to three days. The DM content of rumen ingesta varies from 10 to 15%, and about 83% of the Volatile Fatty Acids (VFA) produced in the rumen are absorbed in the rumen itself. The concentration of VFA in the rumen liquor on feeding crop residues such as wheat straw with concentrate mixtures for adult buffaloes ranges from 80 to 90 mmole/l, and the mean production of acetic, propionic, and butyric acids is about 68, 20, and 10% of total VFA, respectively. Among the *protozoan* species, *Entodinium* was maximum and *Ophryoscolex* could not be detected. Fibrolytic bacteria *Bacterioides amylophilus, Bacteriovibrio fibriosolvens, Clostridium lochheadii,* and amylolytic *Ruminococcus bromi* were readily isolated and more numerous than in cattle. More *Selenomonas ruminantium* were found in buffaloes than cattle when fed a fibrous diet, and greater distribution of cellulolytic and H_2S producers in buffaloes than cattle was also reported.

In feeding experiments it has been observed that buffaloes consumed relatively less than cattle (85). On low-quality roughages, buffaloes have slightly higher digestibility for crude fiber and ether extract, but on high-energy rations the digestibility of DM, organic matter, crude fiber, ether extract, and nitrogen-free extract are similar to cattle (94, 95). Better digestibility in buffaloes than cattle is attributed to slower ruminal outflow rate and lower fasting heat production (68 Kcal per $W^{0.75}$ in buffaloes compared to 82 Kcal in cattle) (44).

Buffaloes have in general higher rumen ammonia nitrogen concentrations than cattle, possibly due to higher activity of microbial deaminases. Potassium and calcium contents were in higher concentration. Blood urea contents in growing buffalo calves were twice that in cattle calves. On low nitrogen diets, buffaloes recycle more urea nitrogen through saliva (85). Feeding trials about nutrient utilization efficiency conducted in India established that DM intake was lower in buffaloes (119 g/ kg $W^{0.75}$) than in cattle (132 g). Mean gross energy efficiency (30 vs. 28%), gross protein efficiency (46 vs. 37%), net energy efficiency (69 vs. 64%), and net protein efficiency (80 vs. 60%) were significantly higher in buffaloes than in cattle. Also, lactating buffaloes consumed significantly less protein and energy than

cattle for the production of 1 kg of 4% fat-corrected milk (15, 35).

1.7.5 Water Intake

The ratio between water and DM intake by buffaloes has been reported between 5.0:1 and 5.5:1 (85, 91), and voluntary water intake decreased with higher levels of green fodder in the ration. Greater feed intake coupled with heat production during lactation stimulates the water intake. Some drinking may be a substitute for eating, and longer time spent on eating and chewing a high-fibrous feed reduces the desire for drinking, which is more true for buffaloes, who thrive on high-fibrous feeds, than for cattle (79).

1.7.6 Environmental Factors

Much information on the effects of environmental factors on voluntary feed intake is available for cattle but not for buffaloes. Increased gut motility under cold exposure leads to increased rate of passage and increased feed intake (18, 51). Provision of shade increases feed intake, body weight, and changes in plasma fatty acid levels in cattle (89). Cooling of the head increased the feed intake in cattle working on treadmills. One way in which cattle adapt to hot conditions is to feed at night when it is cooler. As the proportion of concentrates in the diet is increased, the heat increment of feeding decreases, which can be used to alleviate heat stress.

1.7.7 Photoperiod

In winter, more time is spent on eating during the hours of darkness because the days are too short to allow the animal to meet its requirements (19). During the early part of the night, the inter-meal interval averaged 180 minutes whereas from 24:00–06:00 it was about 300 minutes. Exposing cows to 16 hours of fluorescent lighting per day increased feed intake by 6%, which matched the requirements for an increase in milk yield of 1.4 kg/day.

In conclusion, buffaloes differ from cattle in feeding behavior and morphology of the digestive system. Buffaloes have lower feed intake, slightly better digestibility for nutrients, slower ruminal out-flow rate, and lower fasting heat production than cattle. Buffaloes also have more VFA production, higher rumen ammonia concentration than cattle, better efficiency of utilization of energy and protein, and are efficient converters of fibrous feeds into products.

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4.2 Buffalo Milk Utilization for Dairy Products

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1 INTRODUCTION

This section discusses the composition and physico-chemical properties of buffalo milk, its suitability for manufacture of dairy products, and technologies developed for manufacture of these products. A major portion of the world buffalo milk production comes from the Asian subcontinent of India, and the developed technologies are best suited for the manufacture of dairy products popular there. Owing to basic differences in composition and physico-chemical properties, when technologies developed for buffalo milk are applied to make western-type dairy cow milk products, buffalo milk is often not regarded as a suitable raw material for such western dairy products. A thorough understanding of the properties of buffalo milk is necessary to help resolve problems encountered in the manufacture of dairy products with quality on a par with that from cow milk.

2 COMPOSITION OF BUFFALO MILK

Compositional aspects of buffalo milk have been studied and reviewed by many workers (111, 112, 128, 361). In general, buffalo milk contains higher proportions of all major constituents than cow milk. The majority of compositional studies are on the milk from Murrah buffaloes. However, milk from most buffalo breeds is similar in composition (348) (Tables 4.10, 4.11).

2.1 Lipids

Buffalo milk is nearly twice as rich in fat as cow milk, although the physiology of the animal, stage of lactation, season, feed, breed, time, and sequence of milking are factors affecting the fat content of buffalo milk, as is true for most lactating mammals.

The fat globule in buffalo milk is coarse; 1 ml buffalo milk contains about 2.7 million fat globules, with 60% having a size between 3.5 to 7.5 μ (10). Season of the year, lactation, and stage of milking are main factors influencing fat globule size in buffalo milk. Globules are bigger in colostrum (182). With advanced lactation, the number of fat globules with smaller size (3.5 μ) increase, medium (7.5 μ) size decrease, and large (>7.5 μ) globules show much variation (11). Lactation number also influences size and number of fat globules. Heating of milk leads to increased size but also to a decrease in number of fat globules due to their coalescence. Removal of fat (50–60%) has no appreciable effect on the size of fat globules (274). Neutral lipids are more in the membrane lipids of fat globules than in milk lipids (49, 343) (Table 4.19). The proportion of triglycerides is lower, but that of di- and monoglycerides, cholesterol, and free fatty acids (FFA) is higher in membrane lipids than in milk lipids. Long-chain saturated fatty acids (SAFA) are higher, but short-chain and unsaturated fatty acids (UFA) are lower in membrane lipids of fat globules (49, 297). Creaming ability of buffalo milk has been studied

Table 4.10. Average Composition (%) of Milk from Different Species

Milk constituent	Buffalo	Cow	Sheep	Goat	Human
Fat	7.0	4.3	6.0	4.5	3.5
Protein	4.0	3.4	4.8	3.8	1.9
Lactose	5.1	4.8	5.0	4.7	6.5
Minerals	0.8	0.7	0.5	0.5	0.2
SNF	9.8	9.0	10.3	9.0	7.3
Total solids	16.7	13.3	16.3	13.5	12.1

From references: 302, 361, 398.

Table 4.11. Average Composition (%) and Range of Buffalo Milk from Different Countries

Breed	Water	Fat	Protein	Lactose	Minerals	SNF
Bulgarian	82.6	7.5	4.3	4.8	0.8	9.9
Carabaos	78.5	9.0–10.4	6.0	4.3	0.8	11.2
Caucasian	82.7	7.6	4.0	5.2	0.7	9.8
Chinese	76.8	10.5–12.6	6.0	3.7	0.9	10.6
Egyptian	82.1	6.4–8.0	4.2	4.9	0.8	10.0
Hungarian	83.8	7.2	3.6	4.6	0.8	9.0
Italian	81.9	6.8–7.8	4.3	5.0	0.8	10.2
Murrah (Indian)	82.0–83.1	6.9–9.0	4.1–4.5	5.1	0.8	10.0
Rumanian	81.8	8.2	4.8	4.5	0.8	10.0
Russian	81.0	8.1–8.6	4.8	4.8	0.9	10.5
Sichun	77.6	10.3	5.2	6.1	0.8	12.1

From reference: 303.

(98, 100). Low temperature retarded creaming in buffalo milk in contrast to cow milk. Poor clustering ability of buffalo milk has been ascribed to less agglutinin (223). Optimum temperatures for creaming of buffalo and cow milk were 38° C and 4° C, respectively (89). Although buffalo milk fat contains more total lipids, the proportions of mono-, di- and triglycerides are similar in buffalo and cow milk (288, 289, 290).

Fatty acid composition, however, in buffalo milk fat is different from that of cow milk fat (167, 286, 292, 293) (Table 4.12). Proportions of C4, C16, C17, and C18 fatty acids (FA) are higher, but C6, C8, C10, C12, C14, and C14:1 FA are lower in buffalo than in cow milk fat. The intra-molecular fatty acid distribution is similar to that of other species (105).

Buffalo milk fat has a greater proportion of high melting triglycerides (HMT) than does cow milk fat (9–12% vs. 5–6%) (288). The HMT fraction contains less short-chain and unsaturated fatty acids. High (HMWT), medium (MMWT), and low (LMWT) molecular weight triglycerides in buffalo milk are 42%, 17%, and 41% of total, respectively (23, 24). C18:1 was found more in HMWT, C6:0-C10:0 in MMWT, and C4:0 in LMWT fractions. All three classes are rich in saturated and polyene glycerides but poor in diene glycerides. In contrast to HMWT and MMWT, the major FA of LMWT diene is C18:2. In summer, the proportions of monounsaturated fatty acids (C14:1, C16:1, and C18:1) are higher, but of saturated fatty acids (C4:0, C12:0, C14:0, and C16:0) are lower than in winter milk fat (167). Colostrum and late lactation milk are rich in unsaturated but poor in saturated fatty acids (15, 22, 23). Buffalo milk fat contains more tetraenoic and pentaenoic but less dienoic and trienoic fatty acids than cow milk fat (Table 4.12). Physico-chemical constants of buffalo milk fat are shown in Table 4.13. Buffalo milk fat has a higher melting point (MP), density, specific gravity, and saponification value, but lower refractive index, acid, iodine, Reichert Meissel, and Polenske values than cow milk fat, although they are affected by stage of lactation, season, feed, and thermal oxidation (19, 33, 34, 167, 236). Buffalo milk and ghee contain less free fatty acids than milk and ghee from cows (193, 238, 340, 371).

Cholesterol levels (total and free) in buffalo milk fat appear to be lower than in that of cow milk (275 and 212 mg versus 330 and 280 mg/100 g, respectively). Colostrum and mastitic milk contained more cholesterol than normal milk. Cholesterol content in fore-milk is higher than in strippings; also, it is higher in milk during the spring season. Esterified cholesterol, however, was higher (63.5 mg/100 g) in buffalo than in cow milk fat (64 mg versus 48 mg/100g, respectively) (46, 263).

The phospholipid (PL) content of buffalo milk, butter, and ghee per unit weight of fat is much lower than in cow milk fat (21 mg/100g or 0.3% on milk fat basis) (30, 31, 183, 282) . Colostrum has more PL, which becomes normal in 15 days. The PL contents are maximum in January and minimum in July. The ratio of lecithin : cephalin : sphingomyelin is 48:40:12 in cow milk and 40:48:12 in buffalo milk (310).

Table 4.12. Average Fatty Acid Composition (w/w %) of Buffalo and Cow Milk Fat

Fatty acid	Buffalo milk fat	Cow milk fat
C 4:0 butyric	4.4	3.2
C 6:0 caproic	1.5	2.1
C 8:0 caprylic	0.8	1.2
C 10:0 capric	1.3	2.6
C 10:1 caproleic	Trace	0.3
C 12:0 lauric	1.8	2.8
C 14:0 myristic	10.8	11.9
C 14:1 myristoleic	1.3	2.1
C 15:0 pentadecanoic	1.3	1.2
C 16:0 Br.	0.2	0.3
C 16:0 palmitic	33.1	30.0
C 16:1 palmitoleic	2.0	2.2
C 17:0 margaric	0.6	0.3
C 18:0 Br.	0.2	0.4
C 18:0 stearic	12.0	10.1
C 18:1 oleic	27.2	27.4
C 18:2 linoleic	1.6	1.5
C 18:3 linolenic	0.5	0.6
C 20:4 arachidonic	0.2	0.2
Mono-unsaturated	29.1	34.6
Total unsaturated	31.6	40.7
Total saturated	63.8	57.3
Dienoic		
Conjugated	0.73	0.91
Non-conjugated	0.79	0.86
Total	1.52	1.77
Trienoic		
Conjugated	0.038	0.040
Non-conjugated	0.42	0.49
Total	0.46	0.53
Tetraenoic		
Conjugated	0.0072	0.0053
Non-conjugated	0.17	0.12
Total	0.18	0.13
Pentaenoic		
Conjugated	0.0026	0.0018
Non-conjugated	0.085	0.069
Total	0.087	0.071

From references: 197, 286, 361.

Among minor components, buffalo milkfat contains more squalene (8.3 against 5.9 μg/g) and ubiquinone (6.5 against 5.0 μg/g), but less leutin (3.1 against 4.2 μg/g), lanosterol (82.7 against 93.2 μg/g), ethers (0.8 against 0.9 μg/g), and alkanoles (ethanol, methanol, and butanol) (1.8 against 2.3 μg/g) than cow milk fat (40, 47). The concentration of total carbonyls is 9.8 μg/g fat in buffalo milk (41), and keto-glycerides are also present (106). Buffalo milk has less unsaponifiable matter than cow milk (392–398 against 416–450 mg/100 ml) (45, 47), which is higher in spring than in summer or winter milk. Detailed fatty acid composition of buffalo milk fat has been published (190, 289, 336), including

Table 4.13. Physico-chemical Constants (Range) of Buffalo and Cow Milk Fat

Constants	Buffalo milk fat	Cow milk fat
Softening point, ° C	34.3–36.3	33.5–35.9
Melting point, °C	33.4–46.4	31.5–35.2
Acid value, μm	0.17–0.352	0.25–0.27
Refractive Index	1.4515–1.4533	1.4498–1.4530
BR Reading	41.00–43.50	41.05–42.40
Saponification value	218.23–236.10	221.0–238.0
Iodine value	27.00–33.90	27.70–37.32
Reichert-Meissl value	27.83–35.50	24.6–29.7
Polenske value	0.7–1.6	1.3–1.8
Density, g/ml	0.905–0.917	0.888–0.911
Grain size, mm	0.20–0.41	0.098–0.190
Amino acids, % of SNF	40–56	
Essential: nonessential amino acids	0.6:1	
	Buffalo milk	Cow milk
Acidity, % lactic acid	0.13	0.15
Buffer value at pH 5.1	0.0417	0.0359
Curd tension, g	32–85	28–54
Density at 20° C	1.0310	1.0287
Electrical conductivity, mmhos	6.69 ± 0.223	6.615 ± 0.271
Fat globules size, nm	3.5–7.5+	3.85
Fat globules, millions per mm^3	3.2	2.96
Fluorescence under UV light	Greenish yellow	Pale bluish
Freezing point, ° C	−0.552 to −0.558	−0.522 to −0.530
Heat capacity, Cal / g /° C at 20° C	0.852 ± 0.017	0.933–0.954
Oxidation reduction potential, Eh	+0.31 V	+0.258 V
pH at 20° C	6.74	6.60
Phosphatase activity (units/100)	28	82
Refractive index	1.3448	1.3338
Surface tension	55.4 (49.51–50.70)	55.9
Thermal conductivity, Kcal / h m ° C	0.5689 ± 0.00734	0.460
Thermal expansion	4.106×10^{-4}	—
Viscosity, centipoise	2.04	1.86

From reference: 65, 234.

the influence of season, dietary conditions, preservation by LP treatment, stage, and number of lactations (Table 4.14).

2.2 Proteins

The protein content of buffalo milk is higher than in cow milk, 3.8–4.3% (26, 109, 275, 331) (Table 4.15), with 80% of total proteins being caseins and whey proteins being higher in clostrum.

Almost all casein of buffalo milk is present in the micellar form (90–95% in cow milk) (108, 317, 318, 319). The size of the micelle in buffalo milk ranges from 80–250 nm with the majority being 110–160 nm compared to 70–110 nm in cow milk (331). The voluminosity of the buffalo casein micelle is 2.7–3.7 ml/g in the temperature range of 25–37° C (376). Solvation of the casein micelle as calculated from voluminosity is 2.6–2.9 g water/g casein. This is much lower than the solvation of cow milk casein. Opacity of the buffalo casein micelle is greater than that of the cow casein micelle (321). Amino acid composition of whole, alpha-s-, beta-, and kappa-casein from buffalo milk is given in Table 4.15 (108). Buffalo casein contains lower proportions of sialic acid (2.0mg/g casein), hexose (2.5mg), and

Table 4.14. Factors Influencing Different Parameters of Lipid Profile of Buffalo Milk Fat

Factor	Fat globule size	Fat content	Fatty acid makeup	Phospholipid content	Sterol content
Breed of animal		303			
Stage of lactation	269	26	23	145	129
Lactation number		275	193		194
Season	397	120	286	30	48
Feed		244	298		28
Time of milking		182			
Portions of milking	182	419		182	203
Disease of udder		203	194		203

Sources are reference numbers inside table columns.

Table 4.15. Distribution of Nitrogen in Different Fractions of Buffalo and Cow Milk

	Buffalo milk			Cow milk		
Nitrogen fraction	Nitrogen mg/100 g	% of total N	% of total protein	Nitrogen mg/100 g	% of total N	% of total protein
Total nitrogen	600.3	100	-	573.3	100	-
Protein nitrogen	573.7	94.2	100	542.3	94.6	100
Casein nitrogen	460.7	75.6	80.3	437.0	76.2	80.6
alpha-lactalbumin	48.3	7.9	8.4	39.0	6.8	7.2
beta-lactoglobulin	37.0	6.1	6.4	36.3	6.4	6.7
Proteose-peptone	31.0	5.1	5.5	29.7	5.2	5.5
Non-protein	35.0	5.7	-	31.0	5.4	-

From reference: 361.

hexosamine (1.8mg), but higher proportions of Ca (322), while heating of milk reduces sialic acid, hexose, and hexosamine contents (320). Buffalo casein has 24 Ca binding sites/molecule, and its calcium-binding capacity is 11.1 g Ca atoms/105 g casein (283).

Electrophoretic separation of casein components showed 44, 53, and 3% for buffalo alpha-s-, beta-, and kappa-casein vs. 55, 39, and 6% for the cow milk casein fractions (113, 159, 328). All three fractions of buffalo milk casein have slower mobility than cow milk casein. The proportions of alpha-s-1-, alpha-s-2-, beta-, and kappa-caseins were 40, 6–9, 35, and 12%, respectively (422). The alpha-s-1-casein is a single peptide without an S-S bridge. The molecular weight is 33,500 dalton (328). The N and P contents of buffalo alpha-s-1-casein are about 15 and 0.1%, respectively. Amino acid composition of buffalo and cow alpha-s-1-casein is similar (Table 4.16) (8). No genetic polymorphisms have been published for buffalo alpha-s-1-casein. Buffalo alpha-s-2-casein has 2 subfractions with 10 and 11 P residues, while in cow milk there are 4 subfractions with 10-13 P residues (353). The molecular weight is 33,500 dalton (328). Like alpha-s-1-casein, the alpha-s-2- also has no genetic polymorphs. The molecular weight of beta-casein is 27,400 dalton. The possibility of genetic polymorphisms of beta-casein in buffalo milk has not been confirmed. Buffalo milk contains more proteose peptone (PP) (330.5 mg/100 ml) than cow milk (240.5 mg/100 ml). Buffalo kappa-casein is heterogeneous with 8 subfractions, which are similar in P but different in carbohydrate contents. Two genetic variants have been reported but not confirmed (8). Amino acid composition of buffalo kappa-casein is comparable

Table 4.16. Average Amino Acid Composition (g/100g) of Whole, alpha-s-, beta-, and kappa-caseins from Buffalo and Cow Milk

	Whole casein		alpha-s-casein		beta-casein		kappa-casein	
Amino acid	Buffalo	Cow	Buffalo	Cow	Buffalo	Cow	Buffalo	Cow
Aspartic acid	6.9	7.1	8.0	8.0	4.4	4.9	8.0	7.3
Tyrosine	5.8	6.3	6.9	7.8	2.8	3.2	7.8	7.4
Serine	6.1	6.3	5.2	6.6	6.4	6.8	5.9	6.1
Glumatic acid	22.7	22.4	21.4	24.5	21.8	23.2	20.6	17.4
Proline	11.9	11.3	7.6	8.5	15.9	16.0	10.9	8.8
Glycine	1.8	2.7	2.7	2.9	1.5	2.4	0.5	1.3
Alanine	3.0	3.0	3.0	3.2	1.7	1.7	6.0	5.4
Half cystine	0.3	0.3	0.2	0.0	0.0	0.1	0.9	1.4
*Valine	7.1	7.2	4.9	5.0	8.0	10.2	7.4	5.1
*Methionine	2.7	2.8	2.2	3.1	3.3	3.4	1.2	1.0
*Isoleucine	6.0	6.1	5.8	6.4	5.1	5.5	7.7	6.1
*Leucine	10.1	9.2	8.8	8.1	12.2	11.6	5.6	6.1
*Threonine	4.4	4.9	2.8	2.8	3.4	5.1	9.5	6.6
*Phenylalanine	5.4	5.0	4.9	4.4	5.9	5.8	3.3	4.1
*Lysine	7.2	8.2	8.0	9.5	6.7	6.5	5.6	5.76
*Histidine	2.9	3.1	2.5	3.4	2.7	3.1	2.2	1.7
*Arginine	3.0	4.1	3.2	3.9	1.8	3.4	3.8	4.0
*Tryptophan	1.4	1.2	2.2	2.0	0.5	0.6	1.4	1.0

* Essential amino acids in human nutrition.
From references: 8, 108.

to that of cow milk, but poorer in sialic acid (Table 4.16).

The proportions of whey proteins in buffalo milk are similar to those in cow milk, and the amino acid composition of buffalo beta-lactoglobulin (LG) is identical to that of cow milk (209) except that it does not exhibit genetic polymorphisms (333). The molecular weight of buffalo LG is 38,500 dalton. Buffalo and cow alpha-lactalbumin (LA) have the same crystalline form and similar nitrogen content. The molecular weight of buffalo LA is 16,200 dalton, and no genetic polymorphisms have been observed (201). Buffalo LA has one major and three minor fractions, but all are active in modifying the activity of glactosyl transferase in the synthesis of lactose (361). The concentrations of immunoglobulins (Ig) are very high in buffalo colostrum (185, 186), and four classes have been identified (IgGa, IgA_1, IgA_2, and IgM). Lactoferrin content of buffalo milk is 0.320 mg/ml and much higher than in cow milk (0.05 mg/ml) (406). Its content in buffalo colostrum is still higher (0.75 mg/ml). The molecular weight is 73,700–74,000 dalton.

2.3 Minerals

Buffalo milk has more minerals than cow milk (323, 356, 357, 358, 359, 360) (Table 4.17), but breed, season, time of milking, stage of lactation, and health of udder influence their concentrations. The amount of total divalent cations (Ca + Mg) is 1.5 times higher in buffalo milk (200 mg vs. 132 mg/100ml cow milk), and still higher in the colloidal phase of buffalo milk (150 mg vs. 78 mg/100ml cow milk. The dissolved Ca and P increase progressively with the advancement of lactation (420). The concentration of trace minerals in buffalo milk is given in Table 4.17 (255).

2.4 Other Constituents

The concentration of free amino acids, creatine, and taurine is higher in buffalo milk (5.1, 246 mg, and 5.9 moles/100 ml vs. 4.0, 167 mg, and 4.1 moles/100ml cow milk) (70, 412), while orotic acid is low (19.6 μg/100ml vs. 52.6 μg/100ml cow milk) (257). Urea has been reported to be much lower in buffalo

Table 4.17. Average Concentration and Range [ ] of Mineral Constituents in Buffalo and Cow Milk

Mineral		Buffalo milk	Cow milk
Calcium, mg/100 ml	Total	183 [163–224]	114
	Dissolved	40 (22)	39 (34)
Magnesium, mg/100 ml	Total	18 [16–30]	11
	Dissolved	8 (46)	8 (70)
Sodium, mg/100 ml	Total	44 [45–57]	50
	Dissolved	42 (95)	47 (94)
Potassium, mg/100 ml	Total	107 [102–148]	148
	Dissolved	101 (95)	143 (98)
Phosphorus, mg/100 ml	Total	82 [89–137]	85
	Dissolved	26 (31)	38 (45)
Citric acid, mg/100 ml	Total	159 [158–218]	166
	Dissolved	115 (84)	152 (96)
Chloride, mg/100 ml	Total	58 [57–106]	106
	Dissolved	57 (99)	106 (100)
Ca/P	Total	1.71	1.04
	Dissolved	1.11	0.84
Ca + Mg/P + Citrate	Total	1.52	0.94
	Dissolved	0.82	0.66
	Buffalo milk, range in ppm		
Copper	0.07–2.6		
Iron	0.4–13		
Boron	0.5–1.4		
Zinc	3.2–7.3		
Sulphur	157–314		
Iodine	8.6–19.4		
Cobalt	0.7–1.6		
Manganese, μg/100 ml	38.2–65.8		
Fluoride	0.4–18.5		

Value in parentheses is the percentage of total in the dissolved phase.
From references: 69, 197, 361.

milk (17–22 mg/100ml) than in cow milk (37–40 mg/100ml) (44, 284). The content of uric acid is the same (0.26 mg/100ml) in buffalo and cow milk, while the concentration of ammonia in buffalo milk (0.7mg/100ml) is lower than in cow milk (1.6mg/100ml).

2.5 Vitamins

The vitamin A content in buffalo milk is generally higher (about 340 IU/kg) than in cow milk (230 IU/kg) (222). However, due to the absence of carotenoids and high fat content, its total vitamin A potency per unit weight of fat is lower than in cow milk fat (326). The feeding of cotton seed to buffaloes leads to an increase in vitamin A content in its milk fat (236). Heating of milk causes a decrease in its vitamin A content (84). Buffalo milk fat contains less tocopherol (25.9 μg/g) than cow milk (34.8 μg/g) (221), but because of the higher fat content, buffalo milk contains more (334.21 μg/kg vs. 312.2 μg/kg cow milk). The ascorbic acid content of buffalo milk is about 23–30 mg/kg (370). The concentrations of B vitamins in buffalo milk are: thiamin, 0.5; riboflavin, 1.0; nicotinic acid, 2.6; biotin, 26.8; folic acid, 0.1; pantothenic acid, 1.5; pyridoxine, 3.8; vitamin B_{12}, 3.4; and p-aminobenzoic acid, 26.8 μg/ml (242).

2.6 Pigments

Butter fat from stored buffalo milk or cream develops a greenish-yellow color (196), but the color is absent in butter fat prepared from sterilized milk or cream. The color development in raw milk reaches its maximum in two hours. The presence of two noncarotenoid pigments, dominant green and minor blue with absorption maxima at 660 and 380 nm, respectively, has been established (66). The greenish-yellow pigment was identified as biliverdin and is bound to casein (306). During souring it is detached from casein and undergoes rapid reduction to a fat-soluble yellow pigment, bilirubin, with an absorption maximum at 450 nm (407). In milk, the pigment is masked by its attachment to protein. The pigment is not synthesized by microorganisms, but blood biliverdin is the precursor for biliverdin in milk (305, 306).

2.7 Enzymes

Some 20 enzymes have been isolated, purified, and identified in buffalo milk. Alkaline phosphatase (AP) has significance in milk pasteurization, but its activity in buffalo milk is about two-thirds of that in cow milk (345) and is found more in cream. Optimum pH is 9.5 and its activity is increased by Ca, Mg, and Mn. Lipase activity is less in buffalo milk but increases with the progress in lactation. Homogenization increases its activity (325). Optimum temperature is 37° C and optimum pH 8.4–9.0. The enzyme is distributed in skim milk and cream. Xanthine oxidase activity in buffalo milk is similar to that in cow milk (330), with variations due to season, storage time and temperature, homogenization, and heating. The enzyme has a molecular weight of 310,000 dalton and a Km value of 142.86. The optimum temperature is 60° C and pH 8.5 with an absorption maximum at 280 nm. Protease activity of buffalo milk is slightly higher than in cow milk, with optimum pH 8.0 and temperature 37° C (345). Lysozyme content of buffalo milk (15.2 μg/100 ml) is lower than in cow milk (18.0 μg/100 ml) (191), while ribonuclease is higher (130). Lactose synthetase in buffalo milk was studied by Mahajan et al. (199, 200).

2.8 Factors Influencing Composition of Buffalo Milk

As is cow milk, the composition of buffalo milk is influenced by many factors. There are about nine recognized breeds of buffaloes. All of them vary in milk yield and composition (352). Buffaloes with a dry period of 50 days or shorter produced less milk in the following lactation. Gross composition of buffalo milk changes with stage of lactation (Table 4.18) (329), with protein and fat contents increasing, but lactose decreasing in advancing lactation. SNF yield increased from first (0.494 kg/day) to fifth lactation (0.702 kg/day) (195). Milk lipids change with advancing stage of lactation. Large size fat globules increase in percentage, volatile acids are reduced, free fatty acids increase (about 10%), medium-size fatty acids decrease (7%), long-chain fatty acids increase (5%), and unsaturated fatty acids increase (335) (Table 4.19). Monoglycerides, phospholipids, and free fatty acids in buffalo milk fat decrease with lactation number, but the concentration of cholesterol increases because of deterioration of the epithelial cells of the udder. Protein contents rise with stage of lactation. The levels of kappa-casein, beta-casein, LG, and LA increase after parturition; the levels of gamma-casein and Ig are high at parturition and decrease rapidly thereafter. The percentage of LG and LA within total whey proteins diminishes towards the end of lactation, while serum albumin and minor proteins increase (153).

Stage of lactation has significant effects on Cu, Fe, and K contents of buffalo milk. Soluble Ca decreases gradually, while soluble Mg, Na, and Cl increase (26), with Cl from 55 mg/100g in the third month to 83 mg/100g at the end of lactation. Milk composition of Murrah buffaloes changes with season and on different farms (211, 229) (Table 4.18). Monsoon season had the highest and winter the lowest fat and protein percentages in one study of buffalo milk (252), while fat, TS, and SNF contents were maximum during summer and minimum in late autumn in another study (83). As to reasons for seasonal variation in milk composition, research showed that for each 10° decline in temperature the fat percentage increases by about 0.2%. Buffaloes calving in winter had best performance in milk yield and lactation length (229) (Table 4.18). High melting glycerides, short-chain fatty acids, fat globule size, protein fractions, and vitamins also change seasonally in buffalo milk, with cholesterol content being higher in summer, possibly because of lack of green fodder.

Milking affects the composition of buffalo milk, including the milker person, time of milking, letdown time, temperament of the animal, interval

Table 4.18. Effect of Stage of Lactation and Season on Buffalo Milk Composition (g/100 ml Milk)

Stage of lactation	Months post-partum								
	1	2	3	4	5	6	7	8	9
Protein	4.2	3.2	4.2	4.6	4.3	4.8	4.6	4.5	4.5
Fat	6.1	6.2	6.9	6.5	8.9	8.9	8.6	9.5	9.6
Lactose	3.6	5.7	5.5	5.9	4.5	5.9	5.3	5.0	4.8
SNF	7.2	7.4	8.2	8.9	8.1	8.4	9.0	8.5	9.2
TS	13.2	13.6	15.1	15.4	17.0	17.3	17.9	17.0	18.8
	[←——— Rising phase ———→]				[←——— Declining phase ———→]				

Season	Milk yield, kg/day		Fat %		Lactose %	
	Pregnant	Non-pregnant	Pregnant	Non-pregnant	Pregnant	Non-pregnant
Winter (December–February)	9.31	9.65	6.7	6.6	3.6	3.6
Spring (March–April)	8.64	8.32	7.3	7.3	5.1	5.0
Hot, dry summer (May–June)	5.75	6.81	7.5	7.5	5.5	5.6
Hot, humid summer (July–August)	4.10	6.31	8.4	8.4	5.1	5.2

Season of calving	Number of samples	Fat %	Protein %	Total solids %
November to February	511	7.1 ± 0.08	4.2 ± 0.03	17.2 ± 0.10
March to June	88	7.5 ± 0.13	4.4 ± 0.04	17.6 ± 0.015
July to October	1063	7.1 ± 0.08	4.3 ± 0.0.3	17.2 ± 0.09
Overall for all samples	1662	7.2 ± 0.08	4.3 ± 0.03	17.3 ± 0.09

From references: 211, 229, 252, 329.

Table 4.19. Composition of Buffalo Fat Globule Membrane and Skim Milk at Different Lactation Stages

Days after calving	Lactation stage					
	Early	Mid	Late	Early	Mid	Late
Days	(94)	(195)	(290)	(94)	(195)	(290)
Components	Fat globule membrane			Skim milk		
Total neutral lipids	76.1 ± 1.7	74.9 ± 2.4	78.1 ± 0.4	74.3 ± 0.4	68.5 ± 2.1	72.2 ± 0.9
Triglycerol	51.7	47.7	47.7	50.0	50.1	51.3
Diglycerol	7.2	9.2	9.0	8.5	2.9	4.9
Monoglycerol	2.6	4.4	4.0	2.4	2.1	1.9
Cholesterol	5.3	4.9	7.2	4.8	5.4	6.4
FFA	6.6	4.6	6.5	6.0	6.6	5.6
Cholesterol esters	2.6	4.1	3.1	2.8	2.1	2.3
Total phospholipids (PL)	19.6	17.8	18.0	24.1	26.2	24.1
Phosphotidyl inositol	2.4	1.3	2.5	2.4	1.3	3.1
Phosphotidyl inositol serine	3.1	2.7	2.4	3.3	4.2	3.5
Sphingomyelin	3.5	3.4	3.0	4.2	5.8	4.3
Phosphotidyl choline	4.4	4.3	4.9	5.3	6.3	5.6
Phosphotidyl ethanolamine	5.5	5.8	6.1	6.9	7.8	6.8
Cholesterol/PL Ratio	0.40	0.50	0.56	0.32	0.25	0.36

From references: 49, 297, 343.

Table 4.20. Effect of Milking Behavior on Composition of Buffalo Milk

Milking behavior	Letdown time (min)	Milking time (min)	Flow rate (kg/min)	Fat %	SNF %	TS %	Milk yield (kg/day)
1	1.85	4.44	0.87	7.07	8.78	15.96	8.31
2	1.92	4.07	0.81	7.79	8.76	16.63	6.47
3	2.0	4.38	0.86	7.21	8.76	15.94	7.84
4	2.15	4.62	0.79	7.10	8.78	16.0	6.88
5	1.88	4.18	0.82	7.08	8.86	15.87	7.10

From reference: 276.

between milkings, and portion of milking (276) (Table 4.20). Variation in fat percentage is generally greater than that of the other milk constituents (59). Buffalo milk drawn first from the udder is low in fat (4%) compared to the last strippings (15–16%), and the last milk has larger fat globules (4.5 nm vs. 4.3 nm).

Feeding also affects fat contents most. Urea feeding to Surti buffaloes changed the iodine value of milk fat (250). Agro-industrial byproduct feeding can influence buffalo milk composition (387). Silage feeding increased the concentration of C14, C16, and C18 fatty acids in buffalo milk fat, and concentrate feeding raised the C18:1 and C18:2 fatty acid contents. The desaturation system in the mammary gland converts stearic (C18) to oleic acid (C18:1). Buffaloes fed cottonseed oil showed a marked increase in oleic acid and vitamin A contents of the milk fat (236). Replacement of 20–30% protein of the feeding ration by urea increased the folic acid content significantly.

Clinical and sub-clinical mastitis affects the pH, viscosity, specific gravity, clotting time, and gross composition of buffalo milk (134, 135). Casein content decreases in abnormal milk, including relatively higher concentration of alpha-s-casein and kappa-casein and lower concentration of β-casein (294). With the changes in composition also come changes in processing buffalo milk into products, which are important to be understood.

2.9 Physico-chemical Properties

Table 4.13 gives average values for various physico-chemical properties of buffalo and cow milk. Acidity varied from 0.05% to 0.20% in 464 samples of buffalo milk (80), and colostrum had the highest acidity. In fresh milk, lactic acid accounted for 25% of total acidity. Titratable acidity gradually increased with advancing lactation. Acidity was correlated with fat and SNF percentage in buffalo milk but not in cow milk (147, 301). The pH of buffalo milk in a four-year study ranged from 6.57 to 6.84 and was not influenced by month, lactation number, or season of calving, but correlated with SNF and lactose contents (215). The maximum buffering index (number of equivalents of acid or alkali required to change the pH of 1 liter of milk by unity) was 0.0417 at pH 4.9–5.1 for buffalo milk and 0.0359 at pH 5.1–5.2 for cow milk (300, 301).

Curd tension (CT) in buffalo milk (32–85 g) is nearly 1.5 times that of cow milk (28–54 g) and increases at the end of lactation (304), but heat treatment from pasteurization decreases it by 10–28%, boiling by 58%, sterilization by 87%, homogenization by 24–73%, and addition of sodium citrate or sodium hexa-meta-phosphate by up to 97% (389). Buffalo milk with 6.4% fat and 10.2% SNF had mean density of 1.034 g/ml at its freezing point (314) with little difference between cow and buffalo milk, but separation of cream (removing fat) increased the density of buffalo milk. Electrical conductivity (EC) of buffalo and cow milk has been reported to be 6.69 and 6.62 mmhos, respectively, with a significant relationship to the Cl content of milk (272). The average fat globule in buffalo milk is larger (< 1.5 to $> 10\mu$ with 60% fat globules in the 3.5 to 7.5 μ range) than in cow milk. One ml of buffalo milk contains 2,700,000 fat globules (274).

The freezing point (FP) of buffalo milk is in the range of -0.552 to $-0.558°$ C (148), but boiling and souring decrease the FP, and vacuum treatment, cold storage, and the addition of water increase the FP. Heat capacity (HC) of buffalo milk is 0.852 Cal/g/° C at 30° C and is lower than in cow milk (342). Oxidation reduction potential (Eh) of buffalo

milk ranges from +0.129 to +0.469 volt with an average of +0.310 volt at 30° C (157) and is higher than that of cow milk (+0.258 volt). The Eh of Egyptian buffalo milk is higher (range +0.47 to +0.60, average +0.539 volt). Bacterial contamination of milk, pasteurization, boiling, and sterilization affect Eh values (149). The refractive index (RI) of buffalo milk (at 40° C) varies from 1.3462 to 1.3534 compared to cow milk, which is 1.3449 to 1.3480, with proteins and lactose contributing most (295, 296). Surface tension (ST) of buffalo milk at 20° C is 45–55 dynes/cm vs. an average of 56 for cow milk (55), but it changes with fat level and storage (413). Thermal conductivity (TC) of whole buffalo milk varies from 0.5487 to 0.5937 (average 0.5689 K Ca\h m°C) at 42° C (341) and is not influenced by fat and SNF contents, but increases with an increase in temperature. Thermal expansion (TE) of buffalo milk (7% fat) was 1.3 and 6% when heated from 4 to 40° C, and up to 95° C, respectively, and higher than in cow milk (342).

Average viscosity in centipoise (CP) of buffalo milk is 1.773 and 1.661 at 30° C, 1.563 at 27° C, 2.245 at 20° C, and 2.45 at 15° C (79), with a negative correlation between viscosity and temperature, and positive correlation with fat, SNF, and TS contents (56). Relative viscosity increases by about 15% due to HTST pasteurization, 30% due to LTLT pasteurization, 56% by two-stage homogenization, and 86% in single-stage homogenization of pasteurized milk (39, 262), while phosphate, citrate, lactose, and lipids cause a significant increase in viscosity (421). Ethanol stability (ES) of buffalo milk, measured as concentration of ethyl alcohol in aqueous solution that would coagulate the milk, ranged from 60–72% against 70–80% for cow milk (399). The ES was not correlated to fat, SNF, or protein contents, nor to acidity or pH of milk, but was mainly due to higher soluble Ca, casein, P, and Cl contents. Heating of buffalo milk to $> 80°$ C increases the ES. Heat stability (HS) may be equal between buffalo and cow milk (233, 361), but change in pH due to natural souring or the addition of acid or alkali causes a considerable change in HS. Colostrum and mastitic milk were very unstable (377, 390). Buffalo concentrated milk is much less stable compared to cow concentrated milk.

Rennet stability of buffalo milk (25.6 min) is lower (28.2 ± 0.54 min) than for cow milk (268). The addition of sodium citrate or removal of calcium causes an increase, while the addition of calcium chloride causes a decrease in the time of coagulation. Salt balance (SB) in terms of molar ratios of total cations and anions were 0.8305 and 0.5004, respectively, for buffalo and cow milk (323). Lowering the pH of buffalo milk significantly increased the concentration of Ca, Mg, and P in the soluble phase (176).

3 MICROBIOLOGICAL QUALITY OF RAW BUFFALO MILK

Total viable bacterial counts of buffalo raw milk in the Cairo area ranged from 10^3 to 10^8/ml in summer (146), while lower counts of 69, 54, and 149 $\times$ 10^3/ml were reported in samples collected in winter, summer, and monsoon seasons, respectively, from southern India (202), but 0.1–32 and 0.03–0.13 $\times$ 10^6/ml in winter and summer, respectively, from northern India (116). Counts for milk samples from farms, villages, and from machine milking varied widely at 10^6/ml (103). Average proteolytic counts in raw buffalo milk collected in winter, summer, and monsoon seasons were 19, 12, and 27 $\times$ 10^3/ml, of acid producers 5, 9 and 19 $\times$ 10^3/ml, of psychrotrophic organisms 6, 4, and 12 $\times$ 10^3/ml, and of lipolytic counts 150–2,500 and 710–12,000 $\times$ 10^3/ml in machine- and hand-milked samples, respectively.

Mesophilic spore-forming bacterial counts of 4, 13 and 7 $\times$ 10^3/ml were found in summer, monsoon, and winter seasons, respectively, in southern India (202). Thermophilic spore-forming counts of 27/ml in raw milk and 47/ml in pasteurized buffalo milk were reported from western India (245), identifying *Bacillus licheniformis, B. cereus, B. subtilis, B. pumilus, B. coagulans, B. firmus, B. macerans, B. stearothermophilus,* and *B. circulans.* Egyptian buffalo milk samples showed average aerobic spore-forming bacterial counts of 42 $\times$ 10^2/ml in summer and 380/ml in winter (178, 351, 352). The predominant species were *B. subtilis* (42%), *B. megaterian* (35%), *B. circulans* (5%), *B. cereus* (5%), and psychrotrophic types (3%), *B. pumilus, B. badius,* and *B.firmus,* but *B. megaterian* dominated heat-treated buffalo milk. Anaerobic spore-forming bacteria from raw milk were *Clostridium perfringens, Cl. Butyricum,* and *Cl. Sporogenes,* with *Cl. Perfringens* isolates comprising 100 non-hemolytic and 8 hemolytic strains, which were pathogenic (220). Mean total

clostridial counts of 74/100 ml and spore counts of 26/100 ml have been reported in Indian buffalo milk (372). Under Egyptian conditions the mean growth rates of total bacteria, coliforms, and spore formers were 0.71, 0.80, and 0.70 generations/hour, respectively (141). Incidence of enterococci in raw buffalo milk sold in cities was 2,490/ml (68, 138) with *Streptococcus faecalis* subsp. *liquefaciens* being isolated.

4 BUFFALO MILK AS A RAW MATERIAL FOR THE MANUFACTURE OF PRODUCTS

In India, buffalo milk is considered a superior-quality raw material for processing as well as for the manufacture of a large number of dairy products, both western and traditional or indigenous. All products that can be made from cow milk can be made also from buffalo milk; however, there are some inherent differences in the compositional and physico-chemical properties that need to be recognized for best commercial exploitation by producers, processors, and consumers. Dairy processors in private or organized sectors pay a premium price for buffalo milk. Technologies have been developed to solve problems encountered in making products from buffalo milk (65, 323). Buffalo milk, because of its higher fat, SNF, and TS contents, yields relatively more cream, butter, cheese, condensed milk, and other dairy products. The higher fat content has helped in extending the milk supply in cities by toning (toned milk has its fat content reduced to 3% by adding skim milk or reconstituted skim milk, while maintaining the SNF content of milk at the original level of 8.5%). The higher TS content also provides more calories per unit weight (about 100 calories/100g for buffalo milk vs. 70 calories/100g for cow milk). The higher proportion of beta-casein makes buffalo milk nutritionally more human friendly. Cream separation and churning of butter is facilitated by the larger-size fat globules and higher proportion of solid fat in buffalo milk.

The emulsifying capacity of buffalo milk fat is better due to a higher proportion (50%) of butyric-acid–containing triglycerides compared to only 37% in cow milk. The texture of ghee is better due to bigger grain size, which may be due to a higher proportion (9–12%) of high melting triglycerides compared to only about 5% in cow milk fat. Buffalo ghee is also less prone to hydrolytic rancidity. Buffalo milk contains less total and free cholesterol (275 and 212 mg/100g fat) compared to cow milk (330 and 280 mg/100g fat, respectively) and more tocopherol (334 μg/kg for buffalo vs. 312 μg/kg for cow milk) (48). Buffalo milk can be preserved naturally for longer time periods due to high peroxidase activity. Buffalo milk contains more Ca, Ca/P ratio, P, taurine, and lactoferrin and less Na, K, and urea than cow milk, which makes it better nutritionally for infants. Traditional dairy products such as *dahi* (fermented), *khoa* (desicated), and *paneer* (acid-coagulated) made from buffalo milk are superior in body and firmer in texture due to the higher TS, protein, and fat contents.

The ratio of fat : protein : lactose : ash is different in buffalo milk compared to cow milk. This can affect processing and may need to be standardized to maximize yield. The higher proportion of solid fat makes buffalo butter harder and less spreadable. The hydrolysis of fat is slower in buffalo milk, which affects ripening of cheeses. Buffalo milk casein micelles are larger and contain less kappa-casein, which makes the primary phase of rennet action slower, while the secondary phase is faster due to more Ca. Buffalo milk curd looses moisture quickly; as a result, the cheeses are hard and dry. Slower proteolysis leads to more time in development of cheese flavor, body, and texture (323).

Raw buffalo milk inhibits bacterial growth more than cow milk. Its lactoferrin content is in higher concentration in buffalo than in cow milk and chelates iron, thereby exerting antimicrobial activity, which has been demonstrated against coliforms, *Bacillus stearothermophilus, Klebsiella,* and *Staphylococcus aureus* (32, 406). The frequency of occurrence of most pathogenic bacteria in raw market milk from buffaloes was lower than that in cow milk (116).

5 MARKET MILK AND RELATED PRODUCTS

In India, buffalo milk is popular because of its thick cream layer (*malai*), which thickens further upon boiling and storage. The high viscosity of buffalo milk exerts an added influence on the consumer's preference. It is known to impart a distinct whitening effect to tea and coffee because of the greater quantity of casein and whey proteins. Boiling of buffalo milk causes the release of more sulfhydryl

compounds, which contribute to the popular nutty, cooked flavor as a drink. Full-cream buffalo milk is sold at a premium price because of its flavor and its ability to produce good-quality products. Consumers and dairy plant processors prefer buffalo milk because of its high fat and SNF contents. In the early stages of dairy development in India, processing plants were generally located in areas where buffaloes predominated. Dairy plants purchase milk on the basis of fat and SNF contents, and more money is paid for buffalo milk to the milk producers (65).

The chemical superiority of buffalo milk over that of other species makes it preferable for processing as fluid milk and in the manufacture of a variety of fermented milks, yogurt, fat-rich products, frozen desserts, evaporated milk, milk powder, cheese, and other dairy products, although there is considerable scope for enhancing the microbiological quality of raw buffalo milk obtained from rural areas by the organized sector because of limited refrigeration facilities (206). Preservation of raw buffalo milk by the Lactoperoxidase Thiocyanate Hydrogen Peroxide System (LP) under field conditions has been successfully demonstrated in many countries, such as Pakistan, Sudan, Kenya, Sri Lanka, Bangladesh, and India. The concentration of the enzyme lactoperoxidase in buffalo milk has been found to range from 0.173 to 0.200 units/ml, and that of SCN at 1–10 ppm during various seasons of the year (189). The LP system was strongly bacteriostatic for mesophilic and thermophilic spores in buffalo milk, and the effect on the psychrotrophic population was distinctly bactericidal (18). The LP system enables the extension of "shelf life" for transport of milk from rural areas to distant processing centers even under tropical conditions. The oxidative stability of lipids in ghee and paneer made from buffalo milk preserved by the LP system was found to be similar to that from fresh untreated buffalo milk (189); however, the rate of acid development was slower in fermented milk products. The setting time was delayed by 1.5 hours for yogurt, and the manufacturing time of Mozzarella cheese was delayed by two hours, although the quality of both fermented products compared well with that of untreated milk.

The emergence of the LP system for preservation of raw buffalo milk has been a major advance for progress in restructuring rural milk collection systems in developing countries. LP preserved milk has been pasteurized and used for fermented milk products, acidophilus milk, and concentrated milk. Sensory evaluation using 9-point Hedonic scales showed desirable acidity development and good acceptability by consumers (264). Use of hydrogen peroxide for milk preservation produced 89–92% reduction in coliform count at 38° C after 30 and 60 seconds, and at 52° C it caused 99.9% reduction in coliforms (177). The addition of H_2O_2 to buffalo or cow milk improved the keeping quality of milk by destroying or inactivating great numbers of bacteria (93), while milk samples without the addition of H_2O_2 did not usually keep sweet for six hours at room temperature. Bronopol (0.02%) used as a preservative in India did not affect the analysis of milk for cell contents and protein but affected fat to some extent (20). Treated raw buffalo milk was preserved for 10 days compared to 16 days for cow milk, and a good-quality dahi/yogurt was prepared .

Recombining milk, or "toning," is practiced by many processing plants in India to augment the shortage of milk supply. According to the Prevention of Food Adulteration Rules (267), toned milk in India must contain not less than 3% fat and 8.5% SNF. Buffalo milk with an average of 6.5% fat will give about double its quantity in toned milk, when calculated amounts of skim milk powder (SMP) and water are added to adjust the SNF content. Otherwise, the basic ingredients used in recombining are SMP and butter or butter oil. The organoleptic properties of recombined milk are affected by the heat treatment of milk at drying to powder. A cooked flavor is found in milk heated sufficiently to denature whey proteins, as free sulphhydryl compounds are released. Low-heat powder is preferred in recombining if cooked flavor is to be avoided. Another problem in recombining arises from the use of stored butter oil, often leading to off-flavor in the market milk. The addition of 50 parts of fresh buffalo milk to 50 parts of recombined milk together with 0.2% sucrose, 0.25ppm diacetyl, and 0.03% sodium citrate improved the flavor scores of recombined milk (160).

Heat treatment of buffalo milk can lead to denaturation of milk proteins (122). Pasteurization had no significant effect on gel filtration and electrophoretic properties of casein and whey proteins. Boiling of buffalo milk at 100° C for three minutes or superheating at 115° C for 90 seconds resulted in complete change of β-lactoglobulin as evident from electrophoresis. Casein also, because of molecular

degradation, showed a new peak on starch gel electrophoresis with a few trailing bands. Heating buffalo milk to different temperatures for control of microbiological quality increased denaturation of whey proteins from 54% at 72° C to 60% at 90° C (334), while the initial SPC of 3.1–5.8 million/ml was reduced to 47,000/ml at 72° C and to 1,500/ml at 90° C, and coliforms were not found in the milk heated above 75° C.

Ultra High Temperature (UHT) processing of buffalo milk started in the 1980s (16, 17). A very high sterilizing effect at 140° and 145° C with 9.6 seconds holding time was achieved for B. subtilis and B. stearothermophilus spores, respectively. Bactofugation can be effectively linked with UHT processing of buffalo milk, permitting a saving of 51 × 104 kcal/day of thermal energy for a plant processing 50,000 liters milk/day (373). Lactulose content can serve as an indicator of thermal efficacy in UHT processing. Oxidative and hydrolytic deterioration of fat in UHT-processed buffalo milk has been a cause of limiting shelflife to 3–4 weeks under field conditions in India, while sedimentation in containers was not a serious problem (365). Urbanization and increased awareness of health and nutrition has helped the dairy industry in India to introduce different kinds of milk with composition as wanted by consumers. Sterilized flavored milk was available under various brand names in different cities. Examples are "ENERGEE," by a dairy in Mumbai, and "KOOL," recently introduced by the AMUL company. UHT-processed buffalo milk has been introduced successfully in several tropical countries, but considerable scope exists for improving the quality of raw milk intended for UHT processing.

6 FAT-RICH DAIRY PRODUCTS

6.1 Cream

Research findings related to fat and fat-rich dairy products from buffalo milk have been reviewed by Pandya et al. (234). According to the Prevention of Food Adulteration laws (267) in India and the Bureau of Indian Standards, cream, excluding sterilized cream, means the product of cow or buffalo milk or a combination thereof, which contains not less than 25% milk fat. Buffalo milk with its higher fat percentage and larger fat globules can give a cream of 56% fat and 5.3% SNF compared to 50% fat and 3.1% SNF for cow milk (155). Creaming rates of buffalo and cow milk are different. Creaming in buffalo milk is slower, and a higher temperature than that used for cow milk is beneficial (127). The slow creaming of buffalo milk has been attributed to lack of the homogenization-sensitive component of the agglutinin complex in buffalo milk.

6.2 Butter

White unsalted butter is an intermediate product in ghee making and table butter (salted). Because of the high fat content and larger-size fat globule, the buffalo milk cream churns more readily than does cow milk cream. Buffalo cream containing 30–38% fat and pasteurized at 90–95° C was most suitable for butter making, with an optimum churning and working temperature of 14–17 and 15–16° C, respectively, for a 99.5% fat recovery (12). Standardizing buffalo cream to 35% fat, neutralizing to 0.1% lactic acid if cream is sour, and addition of "breakwater" during churning to minimize fat losses in buttermilk have been recommended (77). Due to larger fat globules, the churning of buffalo cream was accomplished in 10 minutes for 35% fat cream and in five minutes for 55% fat cream, compared to 17 and 12 minutes, respectively, for cow cream having 35 and 55% fat (156).

Rheological properties of buffalo butter include terms of consistency, hardness, elasticity, plasticity, viscosity, cohesiveness, adhesiveness, spreadability, structure, and texture. Various factors influence the consistency of butter: composition of milk fat; treatment given to cream, for example, pasteurization temperature, ripening, heating, cooling, and aging; method of butter manufacture; degree of mechanical working given to butter; post-manufacturing conditions of butter; composition of butter; presence of fractionated fat/vegetable oils and surface active agents in butter; and air content of butter, which have been studied in buffalo butter by several researchers (1, 14, 78, 144, 187, 219, 241). Buffalo butter is 1.9 times harder than cow butter because of its refractive index, higher yield stress ranging between 917–1,637 dynes/cm^2, viscosity between 285–16,38 poise at 13 ° C, and penetration value between 6.3–11 mm at 18° C, compared to respective values for cow butter at 559–2,015 dynes/cm^2, 182–565 poise, and 7.1–11.6 mm (219, 239). Different approaches, such as: thermal treatment to cream; ripening of cream; salt-

ing of butter; addition of low melting butter fraction; and addition of vegetable oil to improve the spreadability of butter, have been proposed (240). A good spreadable butter shall have penetration value of 8–17 mm, extruder thrust of 0.5–1.2 kg, and minimum of 0.7% oiling-off. Butter made by the continuous method showed higher oiling-off than conventionally made butter.

Preservation of butter by the addition of ascorbic acid (0.2%) to delay rancidity and oxidized flavor development has been suggested (90). Winter buffalo butter had increased rate of acid development compared to summer butter (154). Decreasing the cream pH from 7 to 6 increased the rate of acid development in buffalo butter but not in cow butter. Storage temperature of −10 and −20° C for salted and unsalted buffalo sweet cream butter, respectively, has been recommended for up to three months (9). Addition of 4% salt to inhibit lipolysis in butter prepared from ripened buffalo cream has been proposed for 30 to 90 days' storage at 5° C (150), but added salt at 1.1–2.8% stored butter at 0° C for three months (349).

6.3 Ghee (Clarified Butter Fat)

Among all fat-rich dairy products from buffalo milk, ghee occupies a prominent position (235) (Tables 4.21–4.23). About 28% of the milk produced in India is utilized for ghee manufacture. Factors affecting the composition, flavor, and textural properties of ghee have been discussed (285). The Indian Dairy Association organized a ghee conference in 1980 and 2002. Chemically, ghee is nothing but 99.5% milk fat. It is a complex lipid of glycerides, free fatty acids, phospholipids, sterols, sterol esters, fat soluble vitamins, tocopherol, carbonyls, hydrocarbons, carotenoids, small amounts of charred casein, and traces of minerals such as calcium, phosphorous, iron, and copper.

For the manufacture of ghee, many methods are available, but 90% of Indian ghee is made by the traditional method (231). Increased awareness about energy management has led to the development of energy-efficient and continuous methods of ghee manufacture, which include using an oil separator or scraped surface heat exchangers (4, 230). Use of microwaves for ghee making resulted in higher vitamin A and E contents and appreciably lower levels of cholesterol (212). The different methods of ghee manufacture are: (1) desi or traditional; (2) creamery-butter; (3) direct cream; (4) pre-stratification; and (5) continuous.

The traditional method uses simple technology, inexpensive equipment, and a small scale of operation,

Table 4.21. Constituents of Ghee

Major constituent	Triglycerides (Neutral fat)
Unsaponifiable matter (soluble in fat)	• Vitamin A, β- carotene, Xanthophylls, Lycopene, α- tocopherol, • Sterols: Vitamin D, Cholesterol and cholesterol esters, 7-Dehydrocholesterol, Ergosterol, Lanosterol • Vitamin K • Hydrocarbons: Squalene
Trace constituents	Normally present but in widely variable amounts, sometimes adventatious: • Diglycerides, Monoglycerides • Phospholipids, Proteins, Lactose (in various combinations among themselves, and with fat, to give fat-soluble compound) • Free acids: Water soluble, such as formic, acetic, propionic, and lactic; fatty acids such as butyric, caproic, oleic, and so on • Fat breakdown products such as fat hydroperoxides, free aldehydes and ketones, lactones, and so on • Bound aldehyde • Moisture • Dissolved gases • Minerals such as calcium, magnesium, copper, iron, and so on

From reference: 298.

Table 4.22. Concentration of Major and Minor Constituents of Ghee

Component	Cow ghee	Buffalo ghee
Triglycerides		
Short chain (%)	37.6	45.3
Long chain (%)	62.4	54.7
Trisaturated (%)	39.0	40.7
High melting (%)	4.9	8.7
Partial glycerides		
Diglycerides (%)	4.3	4.5
Monoglycerides (%)	0.7	0.6
Phospholipids		
Total cholesterol (mg %)	330.0	275.0
Lanosterol (mg %)	9.32	8.27
Lutein (μg/g)	4.2	3.1
Squalene (μg/g)	59.2	62.4
Carotene (μg/g)	7.2	0.0
Vitamin A (μg/g)	9.2	9.5
Vitamin E (μg/g)	30.5	26.4
Ubiquinone (μg/g)	5.0	6.5

From reference: 344.

Table 4.23. Fatty Acid Composition of Cow and Buffalo Ghee (Molar %)

Fatty acid		Western cow	Indian cow	Buffalo
Saturated				
Butyric	C4	9.6	8.8	11.4
Caproic	C6	3.5	3.5	3.1
Caprylic	C8	1.8	2.2	1.0
Capric	C10	3.1	3.0	1.6
Lauric	C12	3.6	3.8	2.6
Myristic	C14	9.5	9.9	10.6
Palmitic	C16	23.4	26.1	30.3
Stearic	C18	9.2	9.1	10.5
Higher saturated	C20–26	0.8	1.0	0.7
Unsaturated				
Lower unsaturated	C10–14:1	1.8	1.8	1.0
Hexadecenoic	C16:1	3.6	2.8	3.6
Oleic	C18:1	26.2	24.7	21.6
Unsaturated polyethenoic	C18–22:2+	3.9	3.5	2.0
Values for some fat constants				
Reichert Meissl value		30	27	32
Polenske value		2.5	1.8	1.6
Iodine value		36	35	30

From reference: 235.

and it makes superior organoleptic quality. The principles entail: (1) fermentation of the primary raw material, that is, milk; (2) a mechanical process to gather milk fat in concentrated form; and (3) heating the fat concentrate at a specified range of temperatures to remove moisture and induce interaction of milk fat with the fermented residues of milk SNF. The characteristic aroma, flavor, and taste of ghee depend on the first and third steps. Owing to basic lack of control in the techniques, ghee produced by the traditional method may vary in quality attributes. To prepare 1 kg of ghee, one has to start with 15–20 kg milk, which makes the process unsuitable for large-scale industrial applications (Table 4.24).

Ghee making by the creamery butter method is the usual industrial practice. In this process, the milk is first heated to around 40° C and separated through a centrifugal cream separator. The cream is pasteurized, cooled, aged, and converted into butter. To improve the flavor of the final product, the cream is sometimes ripened using lactose fermenting starter cultures, and churning is then carried out in the usual manner. Butter is then heat clarified at temperatures ranging from 110 to 140° C, and residues are removed by filtration or through a clarifier. This processing method has the advantage of reduction in bulk volume to be handled, high fat recovery, good flavor, economy of operation, and the possibility of employing pre-stratification (76, 298) (Table 4.25).

The direct cream method suggests that ghee is obtained by directly heat clarifying the cream in a two-step procedure. The method includes dilution of cream to the original volume of milk with water and re-separating the same; washing the cream with ordinary or acidified water; use of cream with high fat percentage; and ripening of cream. The flavor of this ghee is mild and milky.

When butterfat is heated to around 80° C and left undisturbed, it leads to the formation of distinct layers. The lowest layer has highest specific gravity and is made up of the serum portion of butter. The other layer is largely fat, and curd particles form an intermediate stratum. Based on these facts, the pre-stratification method was developed. Apart from shortening the period of clarification with savings in energy, the yield of ghee also increases by about 8%.

Table 4.24. Improvements in Traditional Method of Ghee Making

Steps	Recommendations
Milk	Use clean, freshly strained milk.
	Boil once for 10 min or until 5% volume reduction and cool quickly.
Fermentation	Use mixed starter of right type.
	Use 2–2.5% in winter and 1% in summer.
	Sour up to 12–15 hr in winter and 8–10 hr in summer.
Curd	Do not accumulate beyond one day.
Churning	Perform in gear-driven wooden beater fixed on a vessel with a draining device at the bottom.
	Cary out churning in cold. Add cold water if desired, but do not exceed the volume of the curd taken.
	After butter granules are formed, drain buttermilk, add cold water, and gently churn again to wash butter.
Butter	Do not store before melting. If doing so is unavoidable, float in 1% salt solution in an enamel or porcelain vessel.
Clarification	Heat to 80° C and hold for 30 min.
	Remove lowermost water layer.
	Clarify upper layers of curd and fat by heating in an enamel, glass, or stainless steel vessel.
	When cracking due to water removal stops, heat for a few minutes without burning.
Ghee	Store in an earthenware, porcelain, or enamel jar filled to the top; store in a cool place.
	Withdraw small quantities for use into a smaller container.

From reference: 231.

Table 4.25. Comparison of Different Ghee Making Processes

Particulars	Indigenous process	Cream butter process	Direct cream process	Pre-stratification process	Continuous process
% Fat recov. (maximum)	88–90	88–92	92	93	93
Aroma	Strong, nutty.	Pleasantly rich.	Mild, milky.	—	Mild
Flavor	Acid.	Normal.	Rather flat.	—	Flat
Texture	Packed. Coarse grain.	Slushy fine grain (cow). Packed fine grain (buffalo).	Mostly liquid with slight granulation.	Fine grains.	Greasy
Aroma retention on storage	Taken as 100.	140	233	—	—
Flavor retention on storage	Taken as 100.	150	160	—	—
Nr. stages involved	3	2	2	3	3
Clarification using heat	Easy, economical. Pre-stratification possible.	Easy, economical. Pre-stratification possible.	Difficult, slow. Pre-stratification not possible.	Easy and economical.	Easy and economical.
Essential equipment	Butter churn.	Cream separator and butter churn.	Cream separator.	Cream separator and butter churn.	Scraped surface heat exchanger
By-product produced	Buttermilk, ghee residue.	Skim milk, buttermilk, ghee residue.	Skim milk, ghee residue.	Skim milk, buttermilk, ghee residue.	Skim milk, buttermilk, ghee residue.
Acceptability	Small scale.	Large scale.	Large scale.	Large scale.	Very large scale.
Domestic advantages	Full traditional characteristics, clarification by stratification technique; economical, easy; cheap, butter churn required; useful consumable by-products.	High fat yield; clarification by pre-stratification; easy and economical.	Maximum fat yield, very high keeping quality; rapid process.	Reduced energy requirement.	

Industrial advantages	Same as domestic advantages	Same as domestic advantages By-products can be further usefully processed.	Same as domestic advantages By-products can be further usefully processed. Phase reversal can be incorporated, thereby reducing subsequent clarification ecoprocess.	Same as domestic advantages	Cleaning-in-place (CIP) possible. Very rapid Economical. Efficient. Simple. Hygienic, robust design. By-products can be used fruitfully
Domestic Disadvantages	Poor yield of fat. Low keeping quality.	Sensory quality. Medium keeping quality. Expensive cream separator needed.	Sensory quality. Expensive cream separator required. Slow clarification.	—	Expensive; installation costs are high Cannot be used on small scale.
Industrial Disadvantages	All the above. Slow, three-stage process. Requires careful control. Large-scale production not possible.	The first two; process requires careful control.	Sensory quality	Preciseness required in removing bottom layer of serum.	In addition to above, careful control is required.

From references: 76, 298.

Dairy plants have adopted and modified the traditional batch process for commercial continuous production, which involves centrifugal separation of moisture followed by final dehydration under vacuum (Table 4.25). Alternatively, a scraped surface falling film heat exchanger along with a melting vat and mechanical clarifier has been developed for continuous ghee making. Salient features of continuous process ghee making are: (1) very high heat transfer coefficient and hence compact design; (2) better control over quality of product; (3) only small hold-up of raw material in the plant at any time and hence no chances of the whole batch's getting spoiled; (4) no spillage loss; (5) simple, robust, and hygienic design; (6) minimum strain on the operator; (7) can be cleaned in place; (8) high degree of automation possible; (9) no surface fouling and hence heat transfer coefficient can be maintained throughout the run of the system; (10) easy capacity control; (11) no foaming problem; (12) cream can be handled conveniently; and (13) economic operation.

Requirements for a high-grade ghee are that it should have a natural, sweet, pleasant odor, an agreeable taste, and be free of rancidity and objectionable flavors. A pleasant nutty, slightly cooked, and caramelized aroma is generally prized. A good texture requires large and uniform grains with very little liquid fat, and a greasy texture is objectionable. When ghee is melted, it should be clear, transparent, and free of sediment or foreign coloring matter. The color should be bright yellow for cow ghee and white, with or without a yellowish or greenish tinge, for buffalo ghee (the intensity of color depends on the method of preparation). The chemistry of ghee flavors is complex. More than 100 flavor compounds including FFA, carbonyls, lactones, and reducing sustances have been identified (416). Carbonyls and lactones play a major role. Fatty acids C6–C12, although present in low concentration (0.4–1.0 mg/g) and accounting only for 5–10% of total fatty acids, contribute significantly to ghee flavor. The average FFA level of cow ghee is higher than in buffalo ghee. Of flavoring compounds in ghee, about 50% are carbonyls (415). Not the absolute quantity but a definite blend of carbonyls in quantitative and qualitative terms is important for characteristic ghee flavor. As with carbonyls, a definite proportion of lactones and a balanced ratio are responsible for the normal, pleasing flavor. The average concentration of flavor components in ghee was found to be in μg/g: FFA, 53.6; carbonyls, 4.3; and lactones, 30.3 (107).

The development of flavors comes from the metabolic activity of starter bacteria on various milk, cream, and butter constituents such as lactose, citrates, and glucose that lead to enhancement of flavor compound production such as carbonyls and free fatty acids. These compounds are incorporated into the final product upon moisture removal during the clarification process. The incorporation is facilitated by the acidity in the ripened cream and butter, which at low pH can increase the intensity of the chemical reactions. Ghee that is hard, greasy, or has a waxy texture is not liked by consumers (166, 232). Factors influencing grain formation in ghee are: (1) species of the animal; (2) feed; (3) season; (4) fatty acid composition; (5) free fatty acids content; (6) method of manufacture; (7) temperature of clarification; (8) initial melting temperature; (9) seeding; (10) rate of cooling; (11) agitation; (12) storage temperature; (13) storage time; (14) pan design; (15) humidity; and (16) shape of the container.

The basic objective of preparing ghee is to preserve the most costly ingredient of milk, that is, milk fat (279). Various methods and additives for the preservation of ghee have been used successfully, including natural antioxidants such as Mango seeds, Sorghum grain powder, *"Tulsi"* (*Ocimum sanctum Linn., Krishna* variety) leaves, and onion skin water extracts (311, 323. 338).

6.4 Sterilized Cream

Methods for manufacture of sterilized cream from buffalo milk have been developed (38, 251). The cream is standardized to 20 or 22% fat, preheated to 85° C, 0.2% Na_3PO_4 or trisodium citrate is added, and homogenized at 65–67 C and 175 and 35 kg/cm^2 pressure; this is followed by canning, sterilization in a rotary sterilizer at 110 or 114–115 or 120° C for 14–15 minutes, and immediate cooling. The product stored at room temperature had a shelf life of six months.

6.5 Cultured Cream

A procedure for cultured buffalo cream with 15% fat has been developed without the addition of stabilizers or rennet using *S. lactis* as the culture. Mint-

flavored cream was preferred over cumin or garlic flavor by consumers (132).

6.6 Butteroil

Effects of heat on flavor and physico-chemical characteristics of milk fat, including the lactone profile of butteroil prepared from milk of different species including buffalo, have been studied (25, 366).

6.7 Fractionated Fat

Heating of milk fat to a particular temperature followed by holding for a specific period at a given range of temperatures is known as fractionation. Fractionation is used to obtain milk fat fractions to meet specific end-use requirements. Buffalo milk fat was fractionated by heating unsalted butter at 60° C and holding at 30° C for 24 hours to give four fractions (IV, III, II, and I), the first three being solid at 30, 25, and 18° C, respectively, and the last being liquid at 18° C (21, 378) (Table 4.26). Iodine value showed a reverse order. There was no significant species difference in melting points, but iodine values were consistently higher in cow than in buffalo milk fat.

6.8 Cream Powder

Cream powder means a dried milk product containing higher fat content than whole milk powder. It usually contains 40 to 70% fat, 22 to 57% SNF, less than 2% moisture, and about 1% stabilizers and emulsifiers. The topic is covered in section 7, "Concentrated and Dried Milk Products" (323).

6.9 Butter Powder

Butter powder is a dairy product in powder form having the same fat content as butter, that is, about 80%. It has been developed by Prasad and Gupta (265) by dehydrating buffalo cream or an emulsion of milk fat with or without addition of nonfat milk solids or other food ingredients.

6.10 Butter Spreads

Rheological properties of dairy spreads prepared from buffalo cream butter and different levels of sunflower or safflower oil have been studied (188). A low-fat butter spread using byproducts such as condensed skim milk and condensed sweet cream buttermilk (CSCBM) as SNF source and buffalo milk fat as fat source was superior to a low-fat butter spread without CSCBM and with 15% SNF and 45% fat (414).

6.11 Malai

Malai means a product rich in butterfat prepared by boiling and cooling cow or buffalo milk or their combination (233). It shall contain not less than 25% fat. This is usually made by simmering a large quantity (about 10 kg) of milk in a shallow pan on a nonsmoky brisk fire until a thick layer of milk fat and denatured protein is formed on the top surface. This is removed with a flat ladle and put aside for cooling. The process is repeated twice or thrice when most of the fat has been removed. The product is smooth and white in appearance and tastes like clotted cream. The yield of malai is about 20–25% of milk. Malai is sold and consumed without any

Table 4.26. Glyceride Composition of Different Fractions of Buffalo (BM) and Cow (CM) Milk Fat

							%	
Fraction	% Yield		% Triglycerides		% Diglycerides		Monoglycerides	
	BM	CM	BM	CM	BM	CM	BM	CM
IV	42.9	10.7	95.3	94.1	3.3	4.1	1.4	1.8
III	40.4	28.7	96.1	96.0	3.4	3.2	0.6	0.8
II	11.4	34.9	95.1	96.0	3.8	3.3	0.7	0.7
I	5.3	25.7	95.2	94.1	3.7	4.1	1.1	1.0
Whole fat			95.8	95.8	3.6	3.9	0.6	0.8

From references: 22, 378.

addition of sugar; however, with sugar it is a traditional favorite delicacy in villages for people of all ages.

6.12 Makkhan (Desi/Cooking Butter)

This is a product obtained from cow or buffalo milk or their combination or cream or curd obtained from cow or buffalo milk or their combination without the addition of preservatives including common salt, coloring matter, or flavoring agents and is free of other animal fat, wax, mineral oils, vegetable oils, and fats (233). It shall contain not less than 76% milk fat by weight. Normally, makkhan is prepared at household level by churning a convenient quantity of curd in an earthen or metal pot with a desi churner *(mathani)*. The composition of makkhan is variable and may contain 10–40% moisture, 60–65% fat, and portions of curd (about 4%) and acidity.

7 CONCENTRATED AND DRIED MILK PRODUCTS

7.1 Concentrated and Dried Milk

Buffalo milk is preferred for the manufacture of a large number of dairy products because of its high TS and fat content, but not for the manufacture of condensed and dry milk products. The major problems encountered in the manufacture of condensed milk from buffalo milk are viscosity, lactose crystallization, age thickening, discoloration in sweetened condensed milk, and coagulation during sterilization in the case of evaporated milk (38, 380). The answers to these problems lie in choosing the right temperature/time combination of preheating/forewarming of milk, the use of the right level and type of stabilizer, the best condition of added sugar (in case of sweetened condensed milk), and lactose crystallization under controlled conditions of temperature and agitation (121).

The problem of fat separation can be lessened by reducing the fat content of buffalo milk before homogenization to 3% (115). Standardization levels of different fat and SNF contents have been proposed and patented (258, 261, 270, 271, 315), along with treatment with sodium cation exchangers to replace one-third of calcium ions with sodium ions.

Preheating or forewarming apart from reducing the microbial load causes two other effects: a significant increase in the effectiveness of evaporators; and the stabilizing proteins, making the evaporated milk more resistant to the sterilization heat (50). Preheating of milk at temperatures of 115–118 or 120° C without holding for better stability of the concentrate has been suggested (37, 259, 260). Homogenization of full cream milk before or after concentration reduces heat stability. There is an increased adsorption of milk proteins on disrupted fat globules leading to formation of centers of high protein concentration favorable to coagulation (258). Separation of fat is a problem in unhomogenized milk, which can be solved by homogenization at low pressures at 65° C. Two-stage homogenization at 84.3 kg/cm^2 pressure in the first stage and 42.1 kg/cm^2 pressure in the second stage after concentration gave minimum fat separation and destabilization (315). Homogenization of 35% TS concentrate at a pressure of 175 kg/cm^2 in the first stage and 35.1 kg/cm^2 pressure in the second stage gave minimum destabilization effects (261).

Additives have an important role in maintaining the critical equilibrium between the natural anions and cations of milk, which determines its maximum heat stability. The addition of salts has a direct effect on the stability of the casein micelles, and an indirect effect by facilitating the denaturation of whey proteins and their interactions with casein under the effect of minerals in milk especially Ca, Mg, phosphates, and citrates, representing a system in equilibrium in which a change in concentration in the soluble phase produces changes in the colloidal phase. Consequently, the addition of stabilizing agents modifies the mineral composition of the serum of milk (50). Various combinations of stabilizers and additives at different concentrations to milk or concentrated milk prior to sterilization have been tried. Replacement of 25% of calcium ions with sodium and potassium ions increased heat stability of condensed milk and concentrates containing up to 31% TS for successful sterilization (29). Addition of a solution of citrate ions at the rate of 0.025% under iso-pH condition before preheating gave best results (315). Replacement of 9–22% of calcium with sodium increased the shelf life of evaporated milk to more than eight months (270). Other successful additives were acid casein, Na_2HPO_4, trisodium citrate, and kappa-carageenan, 2-deoxyribose (118, 355, 390). After all pretreatments, the milk is condensed under vacuum and filled into tins/cans (usually 200 g capacity). The cans are then sterilized using commercial sterilization time/temperature combinations (usually 121.1° C at 1.05 kg/cm^2 for 7.5–16 min-

utes) (315). After sterilization, the product is cooled to room temperature as quickly as possible and stored at room temperature.

Sweetened condensed milk is manufactured from buffalo milk following a standardized procedure (380): (1) adjusting milk to a fat:SNF ratio of 1:2.4; (2) addition of 0.02–0.03% trisodium citrate; (3) flash heating of milk to 115–116° C; (4) mass crystallization after condensing by seeding with finely ground lactose and holding at 28–29° C for three hours; and (5) adjusting the composition of the final product to 75–76% TS and 43.5–44% sugar. The product can be stored for a year at 5–8° C, or 34 weeks at room temperature, and for 25 weeks at 37° C.

Dried milks from buffalo milk may have defects of poor solubility, liberation of free fat, and fat oxidation. To meet the requirements of physico-chemical and functional properties, certain modifications in the processing parameters have been suggested. Skim milk powder and whole milk powder from buffalo milk have bigger size particles and more clustering of casein micelles (152). High preheating temperature (95° C) of milk and packaging of powder in nitrogen gas beneficially influenced the quality of milk powder. Nearly instant buffalo skim milk powder was manufactured by the single-pass method using 50% TS concentrate with an atomizer speed of 7,000 rpm, with air temperature between 180–200° C for inlet air and 95° C for outlet air (312). Addition of antioxidants such as butylated hydroxy anisol (BHA) at the rate of 0.01% has been proposed as a simpler and less expensive means than the inert gas packing for short-term storage of whole milk powder (82). Spray-dried buffalo whole milk powder containing nordehydroguratic and citric acids (at 0.05% by weight of fat) kept well for six months at 20° C (142). Addition of Tween 60 accelerated the deterioration of powdered milk fat. Vacuum roller drying yielded powder with good solubility, smaller mean particle size, lower free-fat content, higher bulk density, and better dispensability and sinkability but brownish color compared with atmospheric roller drying (327). Dried whole milk powder prepared from buffalo milk by concentrating it to 42–45% TS in a triple-effect evaporator, spray drying it in an integrated fluidized bed dryer with inlet/outlet air temperature of 180° C/75° C, cooling to 30° C, packed in 25kg HDPE bags (80 g thickness), and enclosed in hessan-kraft paper can be stored at room temperature for up to eight months depending upon initial moisture content (308).

7.2 Infant Milk Foods

With the advancement of technology it is now feasible to prepare infant milk foods from buffalo milk, which reasonably well correspond to that of human milk with respect to compositional and bio-chemical characteristics. Scope exists for further developments to simulate the bio-immune attributes of human milk and provide protection to infants against enteric infections. Heating of buffalo milk and addition of phosphates or citrates lowered the curd tension of infant milk foods and made them more digestible for infants (57, 58). A method of roller-dried infant milk food from buffalo milk includes standardization to 2.5% fat, pasteurization at 85° C, addition of vitamins and cane sugar, and homogenization at 70.3 kg/cm^2. The final product contains 23% protein, 55% carbohydrates, 14% fat, 4.6% ash, 2.4% moisture, 1.1% calcium, phosphate, and added vitamins, which on reconstitution should give a beverage of 1.8% fat and 2.5% protein. Spray-dried whey protein isolate was utilized for the adjustment of the whey protein: casein ratio in modified infant formula (205). Investigations have been carried out for the development of manufacturing technology of infant formula according to compositional standards proposed by WHO/FAO Code Alimentarius Commission (165, 227). One of several methods for the preparation of "humanized" buffalo milk involves the removal of alpha-casein by trypsin digestion, enrichment of milk fat with polyunsaturated fatty acids (PUFA) from vegetable oil, addition of lactose, iron, and vitamins, and removal of calcium by electro dialysis (110, 181, 364, 396). Low-lactose infant food, either from calcium co-precipitates or sodium caseinate from buffalo skim milk with unsalted buffalo butter and ground cane sugar, was organoleptically acceptable (133, 254). It contained 24% protein, 25% fat, 4.5% ash, and 40% carbohydrates including 2% lactose, and it had a solubility index of 4.8 ml and a protein efficiency ratio of 2.7. A lactose hydrolyzed infant formula from buffalo milk contains viable cells of *Bifidobacterium bifidum* (1.2×10^5 cfu/g of formula) to improve the intestinal microflora of infants (227, 253). A formula for preterm infants has also been developed (299).

7.3 Other Dehydrated and Formulated Products

Many new dehydrated and formulated products of commercial importance have been developed using

buffalo milk, such as dried ice cream mix, dried cream, butter powder, malted milk powder, *dahi* powder, *shrikhand* powder, *khoa* powder, tea and coffee complete, mango milk powder, chocolate milk powder, and instant *gulabjamun* mix (280, 281).

A dried ice cream is made from a standardized liquid mix (12% fat, 11% SNF, 15% sugar, and 0.3% stabilizer), and after being homogenized (175 and 50 kg/cm^2), pasteurized (77.2° C for 30 minutes), spray dried to have 4% moisture in the final product, and packed in polyethylene bags, it can be stored for two months (374). Another ice cream powder procedure uses cream, skim milk, and condensed skim milk from buffalo milk with stabilizers and emulsifiers such as pregelatinized potato starch, Tween 80, and sodium alginate at different proportions (36). The ice cream mix contained 37% TS (17% fat, 14% SNF, 5% sugar and 0.4–0.7% additives), was homogenized at 176 kg/cm^2 and 35 kg/cm^2, heated to 68° C for 30 minutes, and held for 16 hours at 5–10° C before spray drying, using inlet and outlet temperatures of 160° C and 73° C, respectively, with an atomizer speed of 16,500 rpm. The powder obtained was dry blended with refined sugar in the ratio of 100:40. The finished product contained 1.8–2.0% moisture, 25% SNF, 31% fat, and 41% sugar.

Buffalo cream powder has been produced by standardization of the fat:SNF ratio, use of stabilizers, and adjustment of the homogenization pressure and spray drying conditions (346). Free-flowing butter powder containing 80% fat has also been manufactured from buffalo milk (265). The product was made from ripened cream and skim milk powder by spray drying at 170–180° C inlet and 80–85° C outlet temperatures, and was very acceptable. To reconstitute, 19 parts water at room temperature were added to 81 parts of powder.

Dahi powder has been made by standardizing buffalo milk to about 3.5% fat, concentrating it to 30% TS, adding starter culture and setting, draining a part of the whey, breaking the curd, homogenizing, and spray drying. Uniform quality *dahi* could be obtained by reconstituting one part *dahi* powder with three parts lukewarm water and cooling for about one hour at refrigeration temperature (65).

Shrikhand powder was prepared by spray drying buffalo milk *shrikhand* or buffalo milk (158, 198). The manufacturing steps involve preparation of curd, drainage of whey using muslin cloth to obtain *chakka* containing 60–65% moisture, addition of sugar at the rate of 18kg/100kg *chakka,* homogenization of the slurry at 100 kg/cm^2 at room temperature, adjustment of TS to 35%, and final spray drying, using inlet and outlet temperatures of 180–200° C and 80° C, respectively. Packed in nitrogen gas, the product quality remained unaffected for 30 days of storage at 30° C. Another process was developed by De and Patel (75). Skim milk *shrikhand* powder reconstituted with ripened cream was close to freshly prepared *shrikhand*.

Dried cheese spread has also been manufactured from cheddar cheese blends (5–6 months age), cream or butter, and emulsifiers (184). The blend was heated to 60° C, homogenized, and spray dried. The gas-packed product had a shelf life of 10 months at 30° C.

Khoa powder making involves preparation of *khoa* from homogenized buffalo milk, conversion to a 16–18% TS slurry, addition of sodium citrate (0.5% by wt. of *khoa* solids), micro-pulverization at 60° C, roller drying, and gas packing (243). The product can be stored for 105 days at room temperature and was acceptable for *peda* and *gulabjamun* preparation (280, 281).

Chhana, the base material for many Indian sweets and delicacies, is a product that needs considerable skill in making (391). *Chhana* powder can be reconstituted with water for the preparation of *Sandesh*, but for *Rasogolla* making it needs more work. *Chhana* powder is manufactured by spray drying to an approximate composition of 3.5% moisture, 42% fat, 46% protein, 4.5% lactose, and 4.5% ash.

A ready-to-constitute "Tea Complete" powder has also been prepared, involving: (1) extraction of tea with boiling water; (2) mixing the tea extract and sugar with standardized concentrated buffalo milk; and (3) preheating the mixture to 60° C and spray drying at 180–185° C inlet and 98–100° C outlet air temperatures. The final product contained 13% fat, 31% SNF, 39% sugar, and 14% tea solids and can be stored at ambient temperatures for one month in poly-coated pouches, but more than six months in nitrogen packing (162). Fifteen grams of powder was reconstituted with warm water to produce a cup of 140 ml tea.

Similarly, "Coffee Complete" was manufactured from full cream buffalo milk (379). The product contained about 7.5% instant coffee and can be reconstituted for a hot coffee drink by adding six times water. The product can be stored for 1½ years at 5–8° C temperature.

Manufactured mango powder has 14% fat, 40% milk SNF, 27% sugar, 18% mango solids, and 1% stabilizer (347) and involves homogenization and pasteurization of a mixture containing concentrated skim milk, cream, and sugar and spray drying. Storage life of the powder packed in nitrogen and stored at room temperature was more than one year. Chocolate milk powder has also been made using buffalo milk (3).

8 BUFFALO MILK CHEESES

Cheese making is more craft than science and is a means of conserving milk solids. Well-known cheese varieties of the world evolved and developed in Europe have conventionally been produced mainly from cow milk. However, buffalo milk is now being utilized for making a variety of cheeses. In Italy, fresh and Pasta Filata cheeses, especially Mozzarella and Borelli cheeses, are traditionally prepared from buffalo milk. In Balkan countries, several types of white brined and pickled cheeses are prepared from buffalo milk. Beli-sir-u-kriskama (Serbia), Bjalo salamureno sirene (Bulgaria), Brinza (Israel), Domiati (Egypt), Feta (Greece), Lori, Imeretinskii, Limanskii, and Osetinskii (Russia), Telemea (Romania), and Queso Blanco (South and Central America) are well-known cheeses produced also from buffalo milk. In countries where buffalo milk predominates, several cheese varieties, which were earlier made from cow milk, are now manufactured from buffalo milk. An emerging global market for buffalo milk cheeses has given a new dimension to the buffalo milk industry (323) (Table 4.32).

8.1 Cheddar Cheese

Cheddar cheese is important in India, and its manufacture from buffalo milk has been reviewed (249, 401). Unlike cow milk, buffalo milk is regarded as a poor raw material for the manufacture of hard varieties of cheese such as Cheddar, owing to quantitative and qualitative differences. The use of techniques standardized for cow milk does not yield typical Cheddar cheese. Difficulties are: (1) slow development of acidity; (2) higher curd tension; (3) shorter renneting period; (4) low moisture retention in cheese; (5) hard, dry, crumbly, corky body and texture; (6) slow flavor development; (7) higher fat losses in whey; and (8) slower proteolysis (180) (Table 4.27).

However, procedural improvements have resulted in Cheddar cheese made from buffalo milk that is comparable to that from cow milk (63, 164, 392) (Tables 4.28–4.31). Average composition of 123–129-days-old Cheddar was 31% moisture, 43% fat,

Table 4.27. Problems Associated with Buffalo Milk for Cheddar Cheese Making

Parameter	Effect	Probable reason
Acid development	Slow	High buffering capacity (60, 69)
Curd tension	High	High Casein and Ca content and large size casein micelle
Rennet action		
Overall	Fast	Higher amount of Ca (114, 197, 273)
Primary	Slow	Difference in size of casein micelle, less kappa-casein on micelle (108, 131)
Secondary	Fast	Higher amount of Ca (114, 197, 273)
Fat losses in whey	More	Larger size fat globules
Moisture retention in curd and cheese	Low, higher evaporative loss in ripening	Larger size and lower voluminosity of casein micelles (376), higher amount of minerals (64, 217)
Body and texture	Hard, dry, short, crumbly	Larger size casein micelles (108, 316, 319), higher mineral makeup of casein micelles, low moisture
Flavor development	Slow	Low moisture, slow proteolysis (111), slow lipolysis (92, 121, 286, 287)

From references in ( ).

Table 4.28. Measures to Improve Acid Development in Buffalo Milk Cheddar Cheese

Approach	Suggestion
Adjustment of casein : fat ratio	Similar to cow milk (35, 97, 170, 224)
Heating of milk	Higher than normal (13, 170)
Rate of starter addition	1.5–2.5% (51, 52, 400)
Ripening of milk	Until acidity of milk reaches 0.21–0.22% lactic acid (97, 121)

Table 4.29. Measures to Improve Moisture Retention in Buffalo Milk Cheddar Cheese

Approach	Suggestion
Admixing of cow milk	19% TS level (226)
Admixing of sweet cream buttermilk	25% of casein replacement (168)
Additives	
Sodium citrate	0.1 M (94)
Pectin	0.1% (170)
H_2O_2 catalase treatment	0.06% and 0.008% (74)
H_2O_2 with sorbic acid	0.10–0.2%; 0.10/0.15% (95)
Homogenization	Slight to 25 kg/cm2 pressure (225, 392)
Heat treatment of milk	70° C, 30 min
Lactose hydrolysis of milk	60–70% hydrolysis (170, 172, 394)
Use of fungal rennet	(404)
Scalding of curd	31° C/30 min; 38.7° C/60 min; 36° C/60 min (400)
Half whey salting	1.5–2.0% of whey drained (63, 266)
Cheddaring	Early and high piling (400)

Table 4.30. Measures to Improve Body and Texture of Buffalo Milk Cheddar Cheese

Approach	Suggestion
Admixing of cow skim milk	50:50 (417)
Admixing of cow or goat milk	Up to 50% (307, 368)
H_2O_2 catalase treatment	0.06% and 0.008% (74)
Milk homogenization	Slight to 25 kg/cm^2 pressure (225, 392)
Lactose hydrolysis of milk	60–70% hydrolysis (170, 172, 394)
Half whey salting	1.5–2.0% of whey drained (63, 266)
Addition of protease and lipase-rich extract of *L. casei*	50 ml each with 2% salt (170, 307, 410)
Addition of live cells of *L. casei*	0.2% (367)

22% protein, and 22% NPN of total N (173). The procedure of Czulak (63) yields Cheddar cheese maturing faster with less bitterness incidence and slow flavor development during ripening, which was progressing rapidly on conversion into processed cheese. Different types of rennets produced no significant change in total nitrogen and nitrogen fractions except lower concentrations of amino acids after 150 days of ripening (207, 208). Lower levels of free ammonia, H_2S, and flavor contents were found in buffalo milk Cheddar cheese than in that from cow milk (174, 175).

Higher heat treatment of buffalo milk resulted in improved Cheddar flavor with an appreciable increase in free fatty acids (13). Mucor rennet gave higher moisture retention, greater proteolysis, higher

Table 4.31. Measures Suggested to Accelerate Ripening of Buffalo Milk Cheddar Cheese

Approach	Suggestion
Adjustment of casein : fat ratio	0.65–0.70 (35, 97, 170, 224)
Pre-salted milk	1.0%
Lactose hydrolysis of milk	60–70% hydrolysis (170, 172, 394)
Heating of milk	Higher, 74° C for 30 min (170)
Milk homogenization	Slight to 25 kg/cm^2 pressure (225, 392)
Str. Liquefaciens as starter adjunct	(71)
Use of fungal rennet	(400, 404)
Half whey salting	1.5–2.0% of whey drained (63, 266)
Washing of curd	Water—30% of curd at 37° C (121, 217, 291)
Curd slurry and cells of *L. casei*.	2.0% and 0.2% (367)
Addition of cheese slurry in curd	10% (392, 395)
Lipase and protease extract in curd	0.001% and 0.01% (171)
Temperature of ripening	12–13° C (405) and 15° C (42, 163)

release of total volatile fatty acids, and better organoleptic qualities than calf rennet (403, 405). Type of milk or starter culture did not affect total nitrogen content during ripening, but soluble nitrogen and almost complete degradation of alpha-s-1-casein occurred within nine months, while most of beta-casein persisted throughout 12 months of ripening (381, 382, 383). Another study noted less decrease in total glycerides and triglycerides, lower soluble nitrogen, low active -SH groups, low activity of lipases and proteinases, and release of FFA at six months of ripening in buffalo milk Cheddar cheese as compared with cow milk Cheddar cheese (409). Maximum proteinase activity in cow milk Cheddar cheese was 1.5 times greater. Lower moisture content and rate of proteolysis are mainly responsible for low sensory scores of buffalo milk Cheddar cheese (418). Ripening at 13° C increased lipolytic and proteolytic activities, but not enough to produce typical flavor. Buffalo milk cheese gave acceptable flavor by eight months, but calcium lactate crystals dominated the surface (411). Prolonging aging up to nine months led to development of unclean flavor with weak body and greasy texture. Higher acidity proved beneficial to a certain extent (247, 248). Cheeses made with 0.20% whey-draining acidity showed maximum proteolytic and lipolytic changes. When skim milk was substituted up to 25% by sweet cream buttermilk for its equivalent casein content, faster proteolysis, lipolysis, and good organoleptic quality of buffalo milk Cheddar cheese were found (168).

Total bacterial counts at 120 days were low in cheese samples inoculated with gram-negative lipolytic bacteria, whereas the counts were much higher in samples inoculated with gram-positive cocci (362). Out of 105 lactobacillus species isolated, one strain of *Lactobacillus casei* possessed high proteolytic activity in cow and buffalo milk, and its use in starters for Cheddar cheese manufacture was suggested (72). Micrococcal counts increased in the first month and gradually declined during ripening. Proteolytic bacteria were present in buffalo milk cheese only after one month of ripening and not in 12-month–ripened cheese (382).

Rheologically, during ripening Meito rennet cheese had lower values for viscosity and hardness at different stages compared to calf rennet cheese (388, 389). Milk acidity at setting and whey acidity at draining changed the quality of buffalo milk Cheddar cheese in hardness and brittleness values. Cohesiveness decreased only in cheeses made with different whey-draining acidities, whereas springiness, gumminess, and chewiness were not affected (246).

8.2 Mozzarella Cheese

Mozzarella is a well-known variety of Italian cheese with popularity worldwide (62). The term "Mozzarella di bufala" in Italy has legal protection as a product made strictly from buffalo milk (62, 204). Mozzarella is popular as a pizza topping in the United States and Europe. Along with classic Mozzarella, many different forms such as *bocconcini*

Table 4.32. Information on Some Cheese Varieties from Buffalo Milk

Cheese	Information provided	Reference
Brick	Standardized procedure	(332)
Brinza, or Bryndza	Conditions of pickling	(324)
	Yield and quality	(423)
Cashcaval	Manufacturing procedure	(313)
Cottage	Manufacturing procedure	(237)
Cream	Standardized procedure	(369)
Domiati	Storage studies	(99)
	Accelerated procedure for manufacture	(86)
	Use of salt tolerant lactic bacteria and ripening in sealed polyethylene pouches	(88)
	Quality of cheese from raw milk	(88)
	Lactose hydrolysis of cheese milk	(140)
	Use of sour cream buttermilk	(102)
	Structure of cheese	(210)
	Use of pasteurized milk and	(139)
	ripening behavior of cheese	(138)
	Starter microorganisms	(5)
	Rennet addition	(85)
	Level of salt addition	(117)
	Time for ladling the curd	(91)
	Addition of vegetables	(7)
	Addition of Capsicum tincture	(350)
Emmenthal	Standarized procedure	(192)
Karish or Kariesh	Procedure for making	(6)
	Composition and nutrition	(2)
Mish	Procedure for making	(337)
Ras	Use of chymosin and pepsin	(101)
	Direct acidification method	(136)
	Accelerated ripening with enzymes	(96)
	and trace elements	(67)
	Curd slurries	(143)
	Inactive dry yeast and yeast autolyzate	(137, 424)
	Addition of amino acids	(95)
	Composition of cheese	(87, 27)
Requeson	Manufacturing procedure	(53)
Ricotta	Manufacturing procedure	(256)
	Composition	(213)
Stracchino	Microbiological quality and ripening	(214)
Surti	Manufacturing procedure	(309)
	Standardized method for large scale production.	(43)
Valle Grana	Procedure	(54)

(titbits), *ovoline* (egg-like), *plaits, nodini* (small knots), and *ciliegine* (small cherries) are also prepared. Manufacture of buffalo milk Mozzarella cheese has been standardized employing two different approaches. The conventional approach, or "starter culture method," involves fermentation of milk by starter cultures, rennet coagulation, separation of curd, stretching, and brining of the product. The other procedure, referred to as "direct acidification technique," involves addition of acids instead of starter culture before renneting.

During the starter culture method, buffalo milk is standardized to a casein : fat ratio of 0.7 : 1, pasteurized (72° C/no holding), inoculated with 2% starter

culture of *Streptococcus thermophilus* and *Lactobacillus bulgaricus* (1:1), and incubated at 37° C for 40–45 minutes until an acidity of 0.01 to 0.02% lactic acid develops; rennet is added at 37° C; milk is allowed to set for about 30–45 minutes, the curd is cut and then cooked with the whey at 40° C for about two hours and 30 minutes until an acidity of about 0.4% lactic acid is reached; after draining of the whey, 2.5–3.0% sodium chloride is added and the curd is immersed in boiling water for 4–5 minutes; the curd is then plasticized manually or mechanically at 85–90° C and shaped into balls or rectangular blocks; the product is immersed in pasteurized cold water at 4–5° C for two hours and finally packaged in polyethylene bags or other suitable packages and stored at 5–8° C (402). The starter culture method for production of buffalo milk Mozzarella cheese includes microbial rennet (Meito) and dipping in brine until it attains a salt content of about 1.75% (119).

The direct acidification technique produces good-quality Mozzarella cheese from buffalo milk (354). In this process, instead of starter culture an addition of 1.6–3.5 ml HCl or 2–4 ml acetic acid per liter of buffalo milk gives the desired pH at 6–8°C, 0.9–1.0g calf rennet or 0.4–0.5g meito rennet per 100 liters of milk is added, and the temperature is raised to 35° C; the set curd is cut, stirred for about 20 minutes in whey at 35° C, and then dipped into whey for 30 minutes, which improves the melting and stretching properties of the cheese; the whey is drained off; 3.0% common salt is added and the curd is plasticized at about 90° C; it is then shaped into blocks, immersed in water at 4–5° C for two hours, and packaged. The method has also been modified to use lactic acid to a pH of 5.0 at 20° C and cooked at 37° C for 30 minutes to obtain an acceptable-quality buffalo Mozzarella with superior meltability and lower fat leakage than Mozzarella made by the conventional process (402).

To reduce fat and protein losses in the traditional Mozzarella manufacturing process, ultrafiltration of milk has been used in a modified procedure (218) involving ultrafiltration of skim milk to about 10% protein, fermentation of the retentate with lactic starter (at 1–1.5%), followed by diafiltration. When a pH of about 5.8 is obtained, further concentration of milk is done by ultrafiltration to attain a TS level of about 40–45%. Cream is added to the mixture. "Pre-Mozzarella" is cooled to 4° C for 10–12 hours to permit the resolubilization of phosphocalcic salts and the raising of the pH from 5.4 to 5.8. Lactic starter of *Streptococcus thermophilus* and *Lactobacillus bulgaricus* (1.5%) and rennet (0.1%) are added, the milk is incubated until the pH of the milk reaches 5.2, the curd is plasticized in a water bath at 60° C for five minutes, and this is followed by brining and packaging in the usual manner. The stretchability of the product is comparable to the traditional method, but the melting characteristics were slightly inferior. Mozzarella has also been prepared from concentrated (1.4 to 2 times) retentate by direct acidification with 10% glacial acetic acid. The moisture content of the product was relatively lower, but excellent melting and stretching characteristics were observed (104).

Mozzarella was also manufactured from vacuum preconcentrated buffalo milk (339). The process includes concentrated milk with about 32% TS, for which the casein:fat ratio was adjusted to 0.7 : 1 and the concentrated milk is fermented by adding 2.5% *Streptococcus salivarius* var. *thermophilus* starter, coagulating at 37° C with 1.75g rennet/100 kg concentrated milk; the curd is cooked at 42° C, drained at an acidity of 0.75% lactic acid, plasticized in water at 100° C for a minute, and moulded. Homogenization of the concentrated milk enhanced the cheese yield but impaired the stretchability of the curd.

During the plasticization of curd and drainage of whey, heavy losses of milk solids occur in Mozzarella manufacture, which have been addressed with a number of procedural changes in temperature, time, and acidity of whey (160, 161) and have resulted in a whiter, smoother cheese with a more piquant, acidic flavor but with less desirable texture. Buffalo milk Mozzarella cheese manufactured from pasteurized milk had more keeping quality and better organoleptic properties than that made from raw buffalo milk. Cheese produced from milk with 6% fat had higher protein and total solids but reduced fat recovery. Despite lower viscosity and higher elasticity and meltability, Mozzarella from high-fat milk exhibited excessive fat leakage on baking. Cheese prepared from milk with 3% fat had poor textural qualities, but fat leakage was less. Such a product was preferred over high-fat Mozzarella (384). Mozzarella cheese from 4.0% fat milk was suitable for pizza making. The lower fat levels did not have any significant effect on stretchability of cheese. Good-quality Mozzarella cheese was obtained from different combinations of milk fat and pH. Milk

with 2.0% fat renneted at pH 5.6 produced an acceptable product; milk with 3.0% fat renneted at pH 5.2 also yielded a satisfactory product. In general, milk with higher fat levels acidified to a lower pH and resulted in improved yields and superior meltability and stretchability (354).

The casein : fat ratio of milk has been correlated with Mozzarella cheese quality and yield. As the casein:fat ratio in milk was increased from 0.5 to 0.9, cheese yields decreased from 16.2 to 13.8 kg/100kg buffalo milk (384, 385). Melting, stretchability, and fat leakage properties of Mozzarella were also influenced by the casein:fat ratios. Cheese made from milk with a low casein:fat ratio exhibited superior melting but had more fat leakage. Rheological characteristics of the cheese were also affected by the casein:fat ratio in milk. Mozzarella made from milk at a casein:fat ratio of 0.5 showed less hardness, cohesiveness, springiness, chewiness, and gumminess than the cheeses made from milk with higher casein:fat ratios. Cheese made from milk with a casein:fat ratio of 0.7 had the highest total sensory score, while the score was lowest for cheese made from milk with a 0.9 casein : fat ratio (386).

Different starter cultures produce buffalo milk Mozzarella cheese with different sensory scores (61), but culture composition and incubation conditions have been standardized (228). The type of acid can make a difference; cheese made with acetic acid gave comparatively higher melting and stretch quality than hydrochloric acid. Mozzarella prepared with microbial rennets such as Meito (from *Rhizomucor pusillus*) and Modilase (from *Rhizomucor mieheior*), or by using traditional calf rennet, shows different texture, melting, and stretching qualities (119). Greater acidity of whey at draining increases rheological characteristics, hardness, cohesiveness, gumminess, and chewiness of Mozzarella cheese. Maximum springiness was obtained, when whey acidity was 0.4% lactic acid, but meltability and fat leakage decreased, while sensory scores were higher at 0.5% lactic acid (386).

Mozzarella made by the traditional fermentation process has a unique flavor. About 85 volatile flavoring compounds have been identified in buffalo milk Mozzarella cheese (216). Ketones made up about half of the total volatile components. Alcohols (20%), aldehydes (10%), esters (1%), lactones (2.3%), sulphur compounds (0.1%), aromatic hydrocarbons (3.4%), and nitrogen compounds (11%) were the other important flavoring compounds. A new compound, belonging to the ketone group, with an aroma of smoked cheese, was also detected. The aldehydes and ketones, together with 1-octen-3-ol, linalol, geraniol, indole, 4-methylphenol, and furfural, apparently influenced the flavor of Mozzarella cheese significantly.

Stretchability of Mozzarella cheese is influenced by the level of fat in the milk, with low-fat milk (3% fat) producing a coarse and hard cheese and high-fat milk (5% fat) resulting in a soft product with excessive fat leakage on a pizza. It has been suggested that Mozzarella prepared from a 4% fat milk and using a culture of *Streptococcus thermophilus* and *Lactobacillus bulgaricus* in a 1 : 1 ratio produces cheese with the right flavor, textural, and rheological qualities for pizza topping (119). Raw buffalo milk produced a harder, more gummy and chewy Mozzarella than did preheated milk to 70° C (393).

8.3 Gouda Cheese

Gouda is an important semi-hard variety cheese from cow milk, originating from The Netherlands. By modifying the process, an acceptable-quality Gouda cheese can be prepared from buffalo milk (123, 278), wherein buffalo milk is standardized to a casein:fat ratio of 0.65, pasteurized at 63° C for about 30 minutes, and rapidly cooled to 36° C; then, about 15 g potassium nitrate is added per 100 liter of milk, annatto color is added at 75 ml per 100 liter of milk, starter culture is added at the rate of 1.25, milk is renneted with about 2.8 g calf rennet per 100 liter of milk, curd is set in about a half hour and cut into cubes of 15 mm. It is then cooked at 36° C for 25–30 minutes, about 10% of the whey is drained, equal volumes of water at 60–70° C are added so that temperature of the curd reaches nearly 42° C, cooling is continued for another 30 minutes, and all whey is drained. The curd is hooped and then pressed at 0.6 psi for about three hours with curd temperature maintained at 37–38° C; the cheese block is brined in a 21% salt solution for three days at 15° C and at a pH of 5.5–5.7. After brining, the cheese blocks are dried for 7–10 days with periodical application of dry salt on the surface; after about 15 days, the cheese blocks are paraffined and ripened in cheese chambers at 15–16° C and 85–90% relative humidity for about a month. Technology for manufacture of Gouda cheese from local Carabao buffalo milk was

developed in the Philippines (73). Added enzymes to enhance cheese ripening resulted in a product with superior flavor, body, texture, and color (277). Addition of the enzyme increased pH, soluble protein, and free fatty acid contents of the cheese. However, increased levels of added enzyme resulted in excessive proteolysis with flavor and textural defects. Addition of about 15% goat milk to buffalo milk considerably improved Gouda cheese quality. The mixed-milk product exhibited rapid ripening and a superior body and texture. There was a marked improvement in the flavor of the cheese.

8.4 Buffalo Milk Swiss Cheese

Swiss cheeses are characterized by the presence of shiny eyes, a slightly woody texture, sweet fragrance, and hazelnut-like flavor. These cheeses are popular due to their mild flavor when compared to Cheddar cheese. Swiss cheese was prepared from buffalo milk after the process was modified (408). A standardized procedure for making a good-quality Swiss cheese from buffalo and cow milk mixed in a 60:40 ratio has been published (179).

8.5 Cheese Spreads from Buffalo Milk Cheeses

Cheese spreads are gaining popularity due to their mild flavor and ease of use. Spreads have been successfully prepared from buffalo milk Cheddar cheese (81). A process was standardized for the manufacture of spreads from buffalo milk cheese by evaluating blends of emulsifying salts. The influence of using different forms of buttermilk solids or plain buttermilk, concentrated buttermilk, concentrated fermented buttermilk, or buttermilk chakka in processed cheese spread making has been evaluated (124, 125, 126).

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4.3 Traditional Indian Dairy Products

Ajit J.Pandya and M. Mohamed H. Khan

1 INTRODUCTION

The need for preservation of milk for extended periods of time at tropical temperatures has resulted in the diversion of surplus liquid milk into preparation of a large number of traditional dairy products. The art of preparing sweets from surplus milk was developed centuries ago by Vedic Indians. Milk and milk products formed the principle ingredient of foods, which are popular and consumed in India since ancient times due to their social, economic, religious, medicinal, and cultural significance (13). Most of these products are made on a small scale using age-old techniques. In spite of large variations in compositional, physicochemical, sensory, and microbiological quality, the traditional milk products offer several technological and social benefits such as employment, income generation, and improvement of the dietary status of the people. Except for the manufacture of *Chhana*, for which cow milk is preferred, buffalo milk is preferably used for making most of the traditional Indian dairy products (1).

Early Buddhist and Jain works mention sweets prepared from insipissated milk (heated and concentrated) (12), used by rich people at the end of their meals, and by travelers when it was difficult to get foods. In the Mauryan period, sweets were prepared from concentrated milk with the addition of honey or sugar. In the post-Gupta period, milk was half evaporated and then drunk, or after reduction to one-third of the original quantity, it became a regular dish. When one-sixth of the original quantity remained, it was used for preparing sweets, and when only one-eighth remained, it was called *Sarkara* (powder) (4, 29).

It is most profitable to salvage milk as fluid milk, yet in India only about 40% of the 81 million tons of milk annually produced are used as fluid milk. The remaining milk is converted into a variety of tasty, traditional products. Their characteristics are widely scattered production units on a small scale, large variation in the quality of raw materials, lack of scientific understanding and literature, absence of standards and standardized procedures, lack of equipment, labor-intensive procedures, and wide variation in the quality of the finished products (21, 22). Simple technology, low investment, low cost of production, high profit margins, established markets, simple infrastructure, and low operational overheads are a few reasons for large production volumes of these products (28). The potential of these products has received attention by dairy technologists in recent years for the characterization of quality attributes, standardization of manufacturing techniques, enhancement of shelf-life, and development of continuous commercial manufacturing methods, which has resulted in international acceptance and export (14, 15, 42, 52) (Tables 4.33, 4.34).

2 KHOA

Khoa (*Khava, Mava, Palgoa*) is one of the most important traditional Indian dairy products, prepared by partial dehydration of milk through heating under controlled conditions (22). Buffalo milk is preferred over cow milk because it gives greater yield and more desirable body and texture. Khoa forms an important base for preparation of indigenous milk sweets such as *Burfi, Peda,* and *Gulabjamun* throughout India. During the process of Khoa production, the heat coagulation of milk proteins, especially the whey proteins, gives it a characteristic cooked flavor. Vigorous stirring exerts an appreciable homogenizing action. Water is dispersed as fine droplets. The color of Khoa depends on the type of milk used, being whitish from buffalo milk and yellowish from cow milk with a slight tinge of brown at times. Khoa should have no less than 20% fat and may be made also from goat or sheep milk.

There are different types of Khoa (17). *Pindi* Khoa is characteristically a circular ball with smooth, homogeneous body and texture, free from burnt particles and browning effects, with characteristic cooked flavor and free of objectionable odor and sour taste. *Danedar* Khoa has granular texture and uneven body. The size of the grains depends upon the amount of coagulant added and the quality

Table 4.33. Classification of Traditional Indian Dairy Products

Class	Product	End use
Heat-desiccated products	*Kheer*	Direct consumption as sweet dish
	Dudhpak	Direct consumption as sweet dish
	Basundi	Direct consumption as sweet dish
	Rabri	Direct consumption as sweet dish
	Khoa	As base for many sweets such as *Peda, Burfi, Gulabjamun,* etc.
Heat-and acid-coagulated products	*Chhana*	As base for many sweets such as *Sandesh, Rasogolla, Chumchum,* etc.
	Paneer	In vegetable curries, *pakoras, paratha,* sweets, etc.
Fermented products	*Dahi*	Direct consumption; also as base material for *Chakka* and *Makkhan*
	Chhash	Direct consumption as refreshing beverage
	Lassi	Direct consumption as refreshing beverage
	Misti Dahi	Direct consumption as sweet dish
	Chakka	As base material for *Shrikhand*
	Shrikhand	Direct consumption as sweet dish
	Shrikhand wadi	Direct consumption as sweet dish
Fat rich products	*Makkhan*	For smearing *chapattis*, also as base for ghee making
	Ghee	Conserving surplus fat and for smearing *chapattis*
Frozen products	*Kulfi*	Direct consumption as frozen sweet

Adapted from (52).

Table 4.34. Manufacturing Principles of Traditional Indian Dairy Products

Principle of manufacture	Indian product	Western product
Partial dehydration (in open pan) with addition of sugar and sometimes rice	*Kheer*	Condensed milk
Partial dehydration with addition of sugar	*Rabri*	Clotted cream
As above, and freezing	*Kulfi*	Ice cream
Open pan desiccation	*Khoa*	Evaporated milk
Open pan desiccation with sugar	*Basundi*	Sweetened condensed milk
Fermentation	*Dahi*	Yogurt, curd
Fermentation and draining of whey	*Chakka*	Quarg
As above, with addition of sugar	*Shrikhand*	Sweetened curd
Rennet coagulation and whey draining	*Paneer*	Soft cheese
Heat and acid coagulation	*Chhana, Paneer*	Lactic-coagulated green curd
Heat clarification of cream, butter	Ghee	Samna, butter oil

Source: (28).

of milk used. Citric acid when added should not exceed 0.1%. This type of Khoa is used as a base for preparation of *Kalakand* cake and pastries, and for *Dhap Khoa*, also called *Kaccha Mava*, which has a loose and sticky body. It contains less than 60% total solids and has a higher moisture content than do Pindi and Danedar Khoa. Dhap is preferred for preparation of *Gulabjamun* because it forms uniform balls with desired rheological qualities after being fryed and soaked in sugar syrup (Table 4.35). Quality of milk must be fresh and free of objectionable odors because it influences the quality of Khoa (Table 4.36).

The ancient method of making Khoa is a batch process and consists of boiling off water from the milk in an open pan with continuous stirring until a

Table 4.35. Specifications for Khoa Products

Characteristics	*Pindi*	*Danedar*	*Dhap*
Total solids, % by mass, minimum	65	60	55
Fat, % by mass, (on dry basis), minimum	37	37	37
Total ash, % by mass, (on dry basis), maximum	6	6	6
Titratable acidity (as lactic acid), % by mass, maximum	0.8	0.9	0.6
Coliform count / g, maximum	90	90	90
Yeast and mould count / g, maximum	50	50	50

Source: Bureau of Indian Standards, 1980:4883.

Table 4.36. Quality of Khoa As Influenced by Different Parameters

Parameter	Effect on Khoa quality
Buffalo milk	Light-greenish color; soft, loose body; smooth, granular structure; rich, nutty flavor and somewhat sweet taste
Cow milk	Pale-yellow color; moist surface; sticky body; sandy texture; rich, nutty flavor and slightly salty taste
Goat milk	Yellow color; slightly hard body; smooth texture; pronounced salty taste
Reconstituted milk	Pale-yellow color; moist surface; uniform texture; soft, smooth body; cooked smell; slightly salty taste
Acidic milk	Coarse texture; sour smell; sour/bitter taste
Dilution with water	No effect on quality but reduced yield and browning discoloration
Starch added milk	Hardens the body and results in pasty and sticky texture of Khoa
Neutralized milk	Texture is improved but not the flavor
Colostrum milk	Deep color and pasty texture
Raw vs. pasteurized milk	No marked difference in quality
Concentrated milk (31 % TS)	Normal color and flavor, smooth texture
Homogenized milk	Less fat leakage; less browning; soft; reduced patting tendency; improved color; and less free fat on the pat
Lactose-hydrolyzed milk	Resistance to mold attack; sweet taste; soft body; uniform texture; and brown color
RO milk homogenized Khoa	Appreciable flavor, body, and texture of Khoa; less greenish tinge; less free fat; if raw milk is used, then rancid flavor
Continuous Khoa making machine	Coarse texture and soft body
Roller-dried Khoa	Less flavor than Khoa that is made employing traditional method
RO concentrated	Typical in flavor and texture, higher free fat and moisture

Compiled from various sources

semi-solid mass of dough-like pasty consistency is attained. About two liters of milk per operation is convenient to handle in a heavy bottom iron pan over a brisk, nonsmoky fire. Average yield from cow and buffalo milk is 18% and 22%, respectively. Standardization of buffalo milk to 5% fat is suggested for satisfactory Khoa quality. Khoa may also be made from roller-dried skim milk powder and white butter (19). Khoa making in an open pan at atmospheric pressure is energy expensive, requiring 455 kcal of energy per kg milk. Technology for use of vacuum to concentrate milk for Khoa production has been developed (9), and facilities are now available in many commercial dairy plants. With a multiple-effect evaporator, cow and buffalo milk can be concentrated to 31 and 40% total solids (TS), respectively, and this preconcentration of milk consumes less energy (209 kcal/kg milk). Energy consumption in RO concentration is estimated to be 90 kcal/kg of milk for batch process and 25 kcal/kg for

the continuous process (27). Khoa made from roller-dried whole milk has usually satisfactory quality, but spray-dried powder reconstituted to 65% TS yields products that are lacking the characteristic nutty flavor. Reconstitution to less than 40% TS is necessary to prolong heating time for the unmasking of the sulfhydryl groups, to increase the intensity of cooked flavor, and to release free fat to avoid stickiness. Adjusting processing variables of the roller-dried processing such as steam pressure, roller speed, degree of concentration of milk, flow rate, and distance between rollers and scrapper blades are also effective (5). A new system of inclined scraped surface heat exchanger (ISSHE) feeds the milk concentrate to the ISSHE at the desired flow rate by adjusting the capacity of a screw pump (39). The inclination of the ISSHE permits formation of a pool of boiling milk critical for formation of Khoa. Fresh, concentrated milk enters the pool of boiling concentrated milk, while an equivalent mass continues leaving the pool as semisolid mass. Scrapers repeat removing coagulated particles from the heat transfer surface and mixing it back into the pool of heated milk. The coagulated particles absorb milk, resulting into agglomeration and formation of characteristic Khoa texture. The inclination of the scraper provides interface between metal, milk, and air, which enhances the heat coagulation of proteins. The use of ISSHE provides continuous operation, uniform quality of the product, minimum operational losses, flexibility to change Khoa characteristics, possibility for automation, in-place cleaning, optimum utilization of service, less manpower requirements, little hold-up of raw milk in the plant at any time, no chance of whole milk's getting spoiled, quick start-up, and most important, no environmental contamination because of the totally enclosed system (10, 11, 43). Table 4.37 gives average values for yield and composition of Khoa.

Several factors affect quality of Khoa: boiling temperature during desiccation, length of desiccation, stirring speed, lump formation until it reaches a pasty consistency, and then lowered temperature to 80–88° C. Continued heating at high temperature at later stages results in undesirably coarse texture, besides burnt flavor and brownish appearance. Heating at temperature lower than the optimum is more time consuming and produces sandy texture, browning, and flat flavor. Milk should be stirred at a medium to high speed (95–100 and 156–160 circular stirring per minute) for desirable texture. Stirring at low speed results in undesirable texture and flavor (29).

The heating and stirring of milk causes evaporation of water, reduction of volume, change in appearance, concentration of TS, increase in viscosity, decreased intermolecular distance of milk components, increased interaction, and destabilization of the native structure of milk and is necessary to provide keeping quality of product (17). The remaining water is dispersed throughout the body of Khoa in the form of fine droplets, saturated with lactose and partly attached to proteins. Rich, nutty, slightly cooked flavor and sweetish taste are characteristic attributes of Khoa, due to short-chain ketones and saturated aldehydes. Pentene-2-one is the major flavoring component along with small amounts of octanone, nonanone, acetaldehyde, propionaldehyde, and benzaldehyde. Development of cooked flavor is attributed to active sulfhydryl (-SH) groups and release of H_2S. Various sources of -SH groups in milk are β-lactoglobulin, serum albumin, fat globule membrane proteins, κ-casein, and proteose-peptone, and cystine is the principal site of -SH groups in these milk proteins. Shelf life of Khoa is affected by the quality of the raw milk, sanitary conditions during manufacture, post-production contamination, moisture content, type of packaging material, method of packaging, temperature of storage, and additives/preservatives added (25)

2.1 Related Heat-Desiccated Products

Kheer/Payasam/Payas is an Indian dessert prepared by partial dehydration of whole milk along with cooking of rice (27). Sugar and other additives such as coconut, pistachio, cashew nut, almonds, and saffron are also added at the completion of the cooking

Table 4.37. Average Yield and Composition of Khoa

Parameter (%)	Cow milk Khoa	Buffalo milk Khoa
Yield	17–19	21–23
Moisture	25.6	19.2
Fat	25.7	37.1
Protein	19.2	17.8
Lactose	25.5	22.1
Ash	3.8	3.6
Iron, ppm	103	101

process. Kheer is characterized by its sweet, nutty flavor and is very popular, especially at festivals. Other cereals and seeds can also be part of Kheer, which on average contains 67% moisture, 33% TS, 9% lactose, 1.4% ash, and 9% added sugar. The yield is around 50% of the milk and is mainly dependent on the amount of rice, semolina, and sugar added. Shelf life is one to two days at room temperature and six to seven days at refrigeration. In traditional processing of Kheer, the whole milk is boiled and previously soaked rice (2.5–5% by volume of milk) is added; boiling is continued until rice is properly cooked and gelatinized. To this sugar is added about 7% by volume of the initial milk; this is heated and then cooled and garnished with chopped nuts and cardamom (4, 20).

Another product, *Basundi*, contained in market samples about 8–12% fat, 6–8% protein, 15–20% lactose, 15–20% sucrose, 1.3–1.6% ash, and 40–45% TS with an acidity—0.36%, pH 6.6, Sp. gravity 1.12, and viscosity 75.24 m.Pa.s. The color is light brown, body and texture are smooth with minute flakes, flavor is pleasant; when slightly cooked, it has a rich, nutty taste (31, 32).

Rabri is a heat-desiccated and sweetened whole-milk product containing several layers of clotted cream. Rabri is very popular in the northern regions of India. In the making of Rabri, the milk is slowly evaporated (without being stirred) at simmering temperature (85–90° C) in a *Karahi* pan over an open fire. Pieces of skin that form on the surface of the milk are continuously broken up and moved to the side of the Karahi (about one-tenth of the original milk), followed by concentration of the milk threefold, with the addition of sugar at 6% of the milk. Then, layers of clotted cream are immersed in the mixture, and the finished product is obtained by heating the whole mass for another short period. Many people feel that Rabri is a product of a pre-Khoa stage. Rabri has a plastic consistency and a light caramel color and flavor. The yield of Rabri is 30% of the milk, and it can be stored for two days at ambient temperature and 7–12 days with refrigeration. A well-made Rabri contains around 51% TS, 11% lactose, 16% fat, 10% protein, 12% sucrose, 1.9% ash, and 0.31% acidity (lactic acid) (23).

2.2 Khoa-Based Sweets

Peda/Penda/Pera/Pendha is a very popular dairy sweet throughout India. It is prepared from cow or buffalo milk. It is similar to *Burfi* but has a harder texture and better keeping quality. There are numerous varieties of Peda and the method of manufacture varies by regions. Pedas are mostly consumed as religious prasad as well as a mark of jubilation. In Uttar Pradesh state, Pedas are made small, are round in shape, and have a burnt-chocolate flavor and long keeping quality. In Gujarat state and the western part of India, Pedas are white in color and are made from buffalo milk (56). Traditionally Peda is prepared by heating Khoa in a thick bottom pan with the addition of sugar (30% of Khoa) until the moisture is removed to 10–15%, followed by partial cooling, addition of flavoring and coloring, and forming the dough into flat circular pieces of about 4 cm diameter and 1 cm thickness, weighing about 10–20 g. Because the cost of sugar is less compared to Khoa, many Peda manufacturers use more sugar to earn more profit, and it has more shelf life. Peda can also be prepared from dried Khoa, sugar, and water in the proportion of 2:1:1 by weight (40) (Table 4.38).

Manufacture of Peda is also done by organized dairies. One dairy in Gujarat uses specially made oil-fired burners and shallow iron pans to prepare Peda on a large scale. Fresh buffalo milk (5 liters in a batch) with 6% fat, 9% SNF is heated with continuous agitation, followed by the addition of 450 g sugar (when milk comes to a first boil). Heat desiccation is continued until the desired consistency (75–85% TS) is reached. While hot, the paste is transferred to a tray, cardamom and saffron are added, and it is then manually formed into Peda (about 20 g), allowed to cool and dry for 16 hours at room temperature and packed in cardboard containers. Another dairy plant uses ISSHE to make Khoa, which is heated the next day to remove further moisture (about 6–8%) and mixed with sugar, *kesar, cocoa powder,* and cardamom. The kneaded mass is held for 16–20 hours at room temperatures, and Pedas are prepared with a *Rheon* encrusting machine.

Burfi is another popular Khoa-based sweet prepared by heating mixtures of Khoa and sugar into a homogeneous consistency, followed by cooling and cutting into small cubes. It is prepared from cow or buffalo milk, is highly nutritious, and contains considerable amounts of milk solids. Several varieties of Burfi are sold in the market under different names: Mawa Burfi, Fruit Burfi, Chocolate Burfi, Rawa Burfi, and Coconut Burfi. In all types of Burfi, however Khoa and sugar is used in different proportions. Other ingredients such as coconut, *pista*,

Table 4.38. Chemical Composition of Peda Prepared by Different Manufacturers

Constituent	*Sugam* Peda	*Gopal* Peda	Market Peda
Moisture %	—	13.5	6.5–10
TS %	80 min	—	—
Fat %	13–15 min	20	3.3–17.9
Protein %	—	19.5	6.3–11.8
Lactose %	—	16.3	7.3–11.7
Carbohydrate/sugar %	26–27 max	31.8	52.1–60.5
Ash %	—	—	1.4–3.4
Cocoa powder %	5 min	—	—
Coliform / g	Absent	—	—
SPC / g	3000 max	—	—
Yeast and mold / g	Absent	—	—
Acidity as % LA	—	0.18	—

min = minimum; max = maximum; - = no data

fruits, and *rawa* are incorporated into the product to impart a special taste to it. In some parts of India, *Chhana* is also used as an ingredient for partial replacement of Khoa (Table 4.39).

Manufacturing stages of Burfi include desiccation of milk into Khoa, incorporation of sugar in crystalline form or as syrup, and an admixture of other ingredients to get the desired body and texture (soft, semi-hard, and hard). While still hot, the product is poured into molds. After cooling, the mass is cut into pieces of required size and shape and packaged. Buffalo milk with 6% fat or cow milk with 4.5% fat is utilized (45). If 0.15% sorbic acid is applied, Burfi can be stored up to 90 days.

Kalakand is made from *Danedar*, or granular Khoa. It is light caramel in color, with a firm body. To make Kalakand, some citric acid is added to Khoa during heating to permit formation of grains when the semi-solid stage is reached. Sugar is added and stirred in. Flavorings and nuts can also be added. After five minutes the mixture is transferred to a tray greased with ghee for cooling and setting.

Gulabjamun is prepared by deep frying Khoa balls with wheat flour in vegetable oil or ghee and soaking them in sugar syrup. It is round and cylindrical in shape, dark brown in color, and has a firm body and smooth texture. It is served warm as a dessert and is known as Ledigene in the Eastern states of India. In industrial Gulabjamun making (1), Khoa (70% TS) is mixed with flour (19–22%) and other ingredients to make a dough to be fed to a portioning machine. Each portion weighing 8 g is transferred by a belt conveyor to a ball forming machine. The balls are transferred by conveyor to a frying machine at 140° C temperature. Fried balls are transferred to a sugar syrup soaking tank. They swell and weigh 17 g each. They are put into cups, and fresh sugar syrup is added for storage under refrigeration. In traditional Khoa making, 300 g are mixed with 35 g wheat flour and 3 g baking soda. The mixture is kneaded into dough, rolled into small balls, and deep fried in ghee until the balls are golden brown. The balls are put into a 60% sugar solution and allowed to soak until served. Gulabjamun contains (on dry basis) 10% fat, 32% sugar, 6% protein, and 14% other solids (24, 30, 37, 53).

Kalajamun / Kalajam is similar to Gulabjamun but darker. It can be prepared from Chhana or Khoa

Table 4.39. Composition of Burfi

Constituents	Percentage	Constituents	Percentage
Moisture	4.7–31.4	Fat	8.8–27
Protein	1.4–20.5	Lactose	5.6–21.5
Carbohydrates	24.8–59.7	Ash	1.5–5.2

by mixing it with small amounts of wheat flour (5–6%) and baking powder (0.5%); it is then kneaded into smooth balls and deep fried in ghee until almost black. Frying at high heat gives a black color to the crust but the inside remains white. The balls are then soaked in 60% sugar syrup for few hours.

3 CHHANA

Chhana is a coagulated milk product obtained by direct acidification of milk in hot condition used for a variety of sweets. It is estimated that about 4% of the total milk produced in India is converted into Chhana. In the batch method about 2–4 liters milk are used. Legally, Chhana is produced from cow or buffalo milk with citric acid or lactic acid precipitation or sour milk. Cow milk (49) or a mixture with buffalo milk (26, 51) is preferred because it produces a more desirable texture, especially for *Rasogolla*. Chhana should not contain more than 70% moisture and not less than 50% fat on a dry-matter basis. Milk fat levels of less than 4% result in hard and rubbery texture, but levels higher than 5% cause greasiness in Chhana and the sweets made from it. Chhana should not have any signs of seepage of fat or water, but the surface should not be dry. No extraneous color shall be added. It shall have a pleasant, curdy flavor that is slightly acidic. Materials used for packaging shall not impart any off-flavor (18). Presence of colostrum in milk affects the texture of Chhana mostly negatively. Initial milk acidity due to any reason produces undesirable sour smell and bitter taste in Chhana that renders it unsuitable for making sweets. Pretreatment by neutralizing with $NaHCO_3$, sodium citrate, or disodium phosphate stabilizers has been partially successful in removing the undesirable flavor, and such Chhana can be utilized for making dry sweets such as *Sandesh*. Adulteration with starch results in a gelatinous mass on coagulation, which is unfit for sweets preparation (41).

In the traditional method of Chhana manufacture, milk is usually heated in a large iron *Karahi* to the boiling point. The coagulant usually is aged acidic Chhana whey added on top of the milk until coagulation takes place and the Chhana collects in lumps. The contents are emptied over a piece of coarse cloth and may be pressed with weighted boards. Ultrafiltration can also be used for Chhana making (50). The pH or acidity of coagulation is governed by the amount of acid added, which determines to a great extent the body and texture of Chhana. At pH 5.6, the coagulation of milk is incomplete and Chhana is soggy; at pH 5.5–5.3, the Chhana is soft and smooth. Decreasing the pH to 5.2 reduces moisture content of Chhana and increases hardness. Lower temperature and more time for coagulation increase the moisture content and softness of Chhana, and vice versa. Citric acid coagulant produces pastiness in texture, which makes Chhana more suitable for *Sandesh* preparation. Lactic acid coagulants or aged sour Chhana whey produce granularity in the texture, which makes the Chhana more suitable for *Rasogolla.* Calcium lactate as a coagulant gives higher yields (24–25%) compared with citric acid (17–18%), which is attributed to better retention of moisture and higher recovery of milk solids. Color, body, texture, flavor, and taste also are different (Tables 4.40–4.44).

Chhana manufacture by the continuous method involves standardized milk pumped from the holding tank at a rate of 250 liters/hour, heated to a temperature of 96–98° C in tubular heat exchangers with steam at a pressure of 2–5 kg/cm^2. Milk is brought in contact with preheated and filtered sour whey in a mixing chamber and then circulated through 8 m–long holding tubes for effective, complete coagulation. The product is directed to the mechanical strainer for drainage. Chhana should have a moisture content of 55–60%. The drained whey is transferred to another tank, where it is held overnight for lactic acid fermentation to be used on

Table 4.40. PFA Requirements for Chhana

Requirements	Skim milk *Chhana*	Whole milk *Chhana*
Moisture (% by mass, max)	60	65
Milk fat (% by mass, on dry basis)	5 (max)	50 (min)
Protein (% by mass, on dry basis, min)	30	25
Ash (% by mass, on dry basis, max)	5	5

Table 4.41. Factors Influencing Yield, Composition, Sensory Characteristics, and Keeping Quality of Chhana

Factor	Yield	Composition	Sensory characteristics	Keeping quality
Type of milk: Cow/Buffalo	Y	Y	Y	Y
Quality of milk				
-colostrum	Y	Y	Y	Y
-late lactation	Y	Y	Y	Y
-developed acidity	N	may	Y	Y
-mastitic	Y	Y	Y	Y
Composition of milk	Y	Y	Y	N
Standardization of milk	Y	Y	Y	Y
Heat treatment to milk	Y	Y	N	Y
Homogenization of milk	Y	Y	Y	Y
Type of coagulant	Y	Y	Y	Y
Strength of coagulant	Y	Y	may	may
Temperature of coagulation	Y	Y	Y	Y
Coagulation pH	Y	Y	Y	Y
Treatment of coagulation	Y	Y	Y	Y
Packaging	N	N	N	Y
Treatment to Chhana	N	N	Y	Y
Moisture content of Chhana	Y	Y	Y	Y
Storage temperature	N	N	Y	Y
Hygienic conditions in manufacture	N	N	Y	Y
Method of manufacture	Y	Y	Y	Y

Y = yes; N = no

Table 4.42. Average Yield and Composition of Chhana

Parameter (%)	Cow milk	Buffalo milk
Yield	16.4	22.5
Moisture	53.4 (50.3–55.3)	51.6 (48.9–53.3)
Fat	24.8	29.0
Protein	14.4	14.4
Lactose	2.1	2.4
Ash	2.05	1.98

subsequent days (3). The coagulation of milk in Chhana making is due to the combined chemical and physical changes in the precipitation of the casein micelles brought about by the action of acids aided by high temperature and including the loss of part of calcium and phosphate from the micelles.

Chhana sold in the market at present is not packaged satisfactorily. On overnight transportation, bamboo baskets with leaf lining may be used, while for short trips no packaging is done. Modern packaging materials can profitably include plastic products. Wrapping of Chhana with wax paper, plastic, or aluminum foil can extend the shelf life. During storage, some dehydration takes place depending on temperature and spoilage; growth of molds increases with higher temperatures, as do undesirable flavors and tastes. Wholesomeness of the market product depends upon the length of storage and temperature. Average store life of cow and buffalo milk at 38–40° C, 22–26° C, and 4–10° C is two, three, and 12 days, respectively. Shelf life of Chhana at room temperature (37° C) is two days but 12 days at 7° C. Although sterility is not officially required for Chhana, the product is practically sterile at the time of making, but contamination can occur during packing and storage (7).

4 RASOGOLLA

Rasogolla (*Rosogola, Rasgolla, Rasgulla*) was first invented in 1868 at Calcutta (West Bengal) in a place known as Bag Bazaar by a sweets confection-

Table 4.43. Composition and Partitioning of Milk Solids in Chhana and Whey

	Composition of whey (%)		Partitioning of TS in Channa and whey			
Constituent	Cow	Buffalo	Cow		Buffalo	
Yield	84.4	76.4	Chhana	Whey	Chhana	Whey
Water	93.6	91.8				
Total solids	6.4	8.2	58	42	65	35
Fat	0.5	1.6	90	10	85	15
SNF	5.9	6.6	42	58	48	52
Proteins	0.4	0.4	89	11	91	9
Lactose	5.1	5.8	7	93	12	88
Ash	0.4	0.4	48	52	60	40

Table 4.44. Defects in Chhana and Their Causes

Type of defect	Reason(s)
Flavor defects:	
Smoky	Smoky fire used for boiling and simmering of milk.
Sour	Excessive acidity of coagulant acid/sour whey used.
Rancid	Fat hydrolysis due to lipase action in Chhana during storage at room temperature or above.
Stale	Excessively long period of storage at low temperature (below 5–10° C).
Body and texture defects:	
Hard body	Inadequate fat content in milk used; inadequate moisture content in Chhana due to faulty method of manufacture.
Coarse texture	Excessive acidity in milk used; inadequacy of fat content in milk used; too high or too low temperature of coagulation.
Color and appearance:	
Dry surface	Excessively low fat content in milk used.
Surface skin	Surface of Chhana exposed to atmospheric air.
Visible dirt/ foreign matter	Incorrect or no straining of milk; condition of vessel used for milk coagulation/boiling; dirty surroundings during handling of Chhana and transport of unpacked Chhana.
Moldy surface	Long storage of Chhana, especially in humid atmosphere, and excessive moisture content in Chhana.

Source: (15).

er, Shri Nobinchandra Das. Since then, Calcutta has been the main center of Rasogolla production. Various types are sold in the market: ordinary, sponge, canned, and diabetic. Each type differs from the other in taste, body and texture, method of preparation, and packaging. Canned Rasogolla is made for sale to different places and exported, while ordinary, sponge, and diabetic types are prepared for local sale. The latter has, instead of sugar, alcoholic sugars such as sorbitol. Sponge Rasogolla differs from the ordinary in taste, body, and texture. Sponge Rasogolla is fluffier in texture than ordinary Rasogolla and becomes small in volume when it is chewed. Product standards are given in Table 4.45.

Preparation of Rasogolla by the traditional method comprises preparation of Chhana and then Rasogolla. In preparation of Chhana balls, additives such as wheat flour, baking soda, or *samunder jhaag*, as well as color and flavor, are mixed, ground in a meat grinder, and then kneaded by hand into a soft, smooth dough, which is cut into small pieces of about 10 g, made into round balls, and dropped into boiling sugar syrup. Usually 20–30 minutes of total heating are required for complete cooking depending

Table 4.45. Specifications for Rasogolla and Syrup

Parameter	Requirement
Moisture (% by weight, max)	55.0
Fat (% by weight, min)	5.0
Sucrose (% by weight, max)	45.0
Proteins (% by weight, min)	5.0
Acidity of syrup, ml 0.1N NaOH required to neutralize 100 ml syrup, max	6.0
Concentration of syrup (max)	55° Brix
Bacterial count / g, max	500
Coliform count / g, max	Nil

Source: Bureau of Indian Standards.

on the size of the Chhana balls. At the end, Rasogolla absorbs sugar syrup and swells to about three times its original size. Rasogolla can also be prepared by the pressure cooker method (6). Generally, 13–15 balls are taken in each batch, and about 15–20 minutes are required at 1 kg/cm^2 pressure. Rasogolla in syrup are stored at 4–6° C. A method of making Rasogolla from buffalo milk has also been published (51). Buffalo milk is brought to a boil, cooled to 70° C, and coagulated with 0.5% lactic acid until whey pH is around 5.7. Contents are cooled and coagulum is transferred to a muslin cloth to drain until it ceases to drip. Chhana is kneaded with *suji, maida,* and *samunder jhaag* to obtain desired texture; it is then portioned into balls, which are cooked in boiling 80% sugar syrup for about 30 minutes, and after cooking, the Rasogolla are dipped in 40% sugar syrup and kept under refrigeration.

Cow milk is preferred for Rasogolla preparation, while buffalo milk leads to the production of hard, brittle, chewy, coarse Rasogolla, which is not liked (8). It is also possible to make satisfactory Rasogolla from goat milk. Standardization of cow milk to 4% fat and 8.6% SNF helps to make good-quality Rasogolla, while standardization of buffalo milk to 5% fat is useful. Goat milk with 4% fat is best for Rasogolla preparation. Coagulation of cow milk at 80° C is optimum, while for buffalo milk the recommended temperature is 70° C. The pH of coagulation for cow milk is 5.4, but for buffalo milk pH 5.7 is optimum. Immediate straining is recommended for making Rasogolla from cow milk, whereas a delayed straining method is recommended for buffalo milk, because this will improve softness and smoothness of Chhana for good-quality Rasogolla. *Maida* may be added as a binding material, while incorporation of baking powder is to bring about proper swelling of balls in sugar syrup during cooking. Strength of cooking sugar syrup is important in controlling texture because if concentration of sugar syrup is not proper, balls may crack, flatten, or burst, thereby losing the desirable characteristics of the final product. In the preparation of Rasogolla, the strength of cooking sugar syrup varies from 30–80% between plants, but 50–60 % makes best results.

Chhanna murki is a sweet in the shape of cubes coated with sugar. It has a firm body and texture. It is popular in Northern and Eastern India. A similar sweet is *Chhana Pulao*, in which Chhana is shaped into rice-like grains and colored golden. To prepare Chhana murki, Chhana is kneaded and cut into small cubes of about 1 cm, which are cooked in boiling sugar syrup until firm. Cubes are then coated with sugar and sometimes flavored and colored. *Chumchum Chhana* is prepared from Chhana dough, rolled into balls, and cooked in boiling 50% sugar syrup in a manner similar to that of making Rasogolla. Balls are removed from the syrup and cut in half, a layer of Khoa is sandwiched in between, and the surface is coated with sugar or Koa. *Kheer mohan* is another sweet from Chhana and is preferred for its texture and taste. In making it, Chhana is kneaded with 1–4% wheat flour into a smooth dough and then rolled into balls that are flattened and processed like Rasogolla. After being cooked, these balls are dipped in concentrated milk and covdered with grated Khoa. *Pantooa/Pantua* is similar to Gulabjamun (27). It also uses Chhana, baking powder, and wheat flour. The dough is rolled into balls, which are deep fried in ghee and, after removal, are soaked in 60% sugar syrup before being served. To make *Rasmalai*, first Chhana is processed the same as for Rasogolla and then the flat balls are dipped in concentrated milk.

5 SANDESH

Sandesh is a popular Chhana-based sweet of Eastern India and Bangladesh. It is classified into three main varieties: Low Moisture/Hard Grade or *Kara Pak*; Medium Moisture/Soft Grade or Naram Pak; and High Moisture or *Kachha Gola*. Soft grade is the best selling variety in India. There are wide differences in the chemical composition, microbiological

qualities, and sensory characteristics of market samples due to variation in the quality of milk and methods of preparation. A method of manufacturing Sandesh from buffalo milk has been standardized (48).

6 PANEER

Paneer is an important indigenous dairy product and traditionally a variety of pressed Channa. It is a soft, uncured variety of cheese like Cottage and Queso Blanco, and is manufactured using heat and direct acid coagulation, as in many countries of Central and South America. Paneer consists of casein, part of denatured whey proteins, almost all fat, colloidal salts, and soluble milk solids, hence preserving valuable milk solids during the flush season (44). Paneer is made from cow or buffalo milk by precipitation with sour milk, lactic acid, or citric acid. It shall not contain more than 70% moisture and the milk fat content should not be less than 50% on dry matter basis, but skim-milk Paneer is also produced (Table 4.46, 4.47).

Good-quality Paneer shall have a pleasant odor, mildly acidic flavor, and spongy body. Before coagulation, the milk shall be boiled for complete destruction of pathogenic bacteria. Coagulants are lactic acid, citric acid and their sodium, potassium salts or sour whey, which was heated to render it microbiologically safe. Sorbic acid and its sodium, potassium salts or propionic acid and its sodium and potassium salts or other permitted preservatives may be added up to 2000 mg/kg of product. No extraneous coloring shall be added. The technology of Paneer preparation is simple. The only difference between Paneer and Chhana preparation is that after coagulation, sufficient pressure is employed in the case of Paneer to drain off the whey, and Paneer is used either in raw form or in cooking, while Chhana has a variety of uses including as a base in the manufacture of varieties of sweets. Buffalo milk is preferred for Paneer making because it gives a hard body from more calcium and total solids. Paneer from cow milk is too soft and fragile.

Table 4.46. Specifications for Paneer

Parameter	Content
Moisture (% by mass, max)	60
Milk fat (% by mass, on dry basis, min)	50
Titratable acidity (as lactic acid, % by mass, max)	0.5
Bacterial count/g, max	5×10^5
Coliform count/g, max	90
Yeast and mold count/g, max	250

Source: Bureau of Indian Standards.

Table 4.47. Influence of Different Treatments on Shelf-Life of Paneer

Treatment	Shelf-life in days at 7° C
Plain water dipping	10
Chlorinated water (35 ppm)	10
Buffered water (pH 7.5)	Faster deterioration in 8 days
Acidified water (ph 5.5)	6
Brine solution (5 %)	22
Acidified brine (5.5 pH)	20
K-sorbate (2%)	10
Delvocid solution (0.5%)	8
H_2O_2 (2%)	22
Delvocid + H_2O_2	32

Adapted from (46, 47).

Recovery of total solids from skim milk is 47%, but from buffalo milk it is 68%. Yield of Paneer increases with higher milk-fat contents. The flavor score of Paneer increases with higher heat treatment of milk. Paneer prepared from milk heated at low temperature has very weak body and is unsuitable for frying. The best texture is obtained in Paneer from milk heated to 90° C . The improvement in flavor at higher temperature could be due to the heat-induced changes in a number of flavorful sulfur compounds, which are responsible for cooked flavor. The improvement in texture could be due to more intense heat induced protein-protein interactions. The increase in yield may be due to complex formations between whey proteins and caseins (46). For coagulation, generally 1% citric acid solution is used, but 2% citric acid is needed for cow milk. Inorganic acids such as HCl or phosphoric acid could be used in Paneer making; however, they are not legal. Yield and hardness increase directly with the coagulation temperature while solids losses in whey decrease. Low temperature (60° C) gives flat flavor. Hardness of Paneer in terms of penetration value ranges from 183 to 114 in direct relation with

decreased pH from 5.4 to 5.1. Maximum flavor, texture, and appearance scores are obtained in coagulation at pH 5.35. Additives such as Na-citrate, ammonium carbonate, and carboxymethyl cellulose (CMC) may influence quality of Paneer. CMC interferes with the melting and results in a bitter taste. Certain hydrocolloids such as Na-alginate, iota-carageenan, and pre-gelatinized potato starch are also tried for improving the moisture-holding capacity of Paneer.

Generally, Paneer is packed in polyethylene bags. Spoilage usually starts from the surface as aerobic conditions stimulate growth of bacteria. Hence, the main approach is to exclude air completely (47). Parchment paper results in formation of rind, and Paneer can be stored for 18 days. Rind formation provides a tough surface, which can be parafined to further improve keeping quality. Blocks tightly wrapped with heat-shrunk film can keep well for 16 days. It is suggested that Paneer should be vacuum packed.

7 DAHI

Dahi, or curd, is a fermented milk product similar to but not exactly the same as yogurt. Dahi is made from pasteurized or boiled cow or buffalo milk by souring naturally or with lactic acid or bacterial cultures. Dahia may contain added sugar. Skim milk Dahi is also made. For sweet Dahi from whole-milk cultures, mainly *Streptococcus lactis*, *Streptococcus diacetylactis* and *Streptococcus cremoris* may be used singly or in combination with or without *Leuconostoc* species. For sour Dahi the same cultures as for sweet Dahi along with *Lactobacillus bulgaricus* or *Str. thermophillus* or both are used. More details are covered in the section on Shrikhand that follows. Dahi is prepared on a small or large scale. In small-scale production at home, milk is boiled, cooled to room temperature, inoculated with previous-day Dahi, and allowed to set over night for next-day consumption. For Dahi production on a large scale by organized dairies, the milk is preheated, filtered, standardized, again preheated, homogenized, pasteurized, cooled, inoculated with cultures, filled into cups, incubated until the desired acidity is reached, cooled, and stored (Tables 4.48, 4.49).

There is a wide variation in the quality of Dahi (28). The color may be yellowish for cow and white for buffalo milk with a mild, pleasant smell and clean, acidic taste, and the body is free of gas holes and whey pockets. In India, Dahi is part of the daily diet in most housholds. It is consumed as such or with sugar added, or converted into different *Raita* by adding grated cucumbers, pieces of banana, apples, or other fruit as well as salt, sugar, powdered mustard seeds, cumin seeds, and so on. Dahi is also churned into *Desi* butter to obtain ghee, and it can be made into *Chakka* and *Shrikhand* (16). Sweetened Dahi is prepared in Eastern India into *Misti/Lal Dahi* or *Payodhi*. It has a brown color, a cooked and caramelized flavor, and a firm body. It is added with 6–18% sugar to milk before boiling or at the time of setting. The heat treatment causes the milk to turn to a brown color.

8 SHRIKHAND

It is an indigenous sweet made by mixing *Chakka* (similar to Quarg) with other ingredients such as sugar and condiments (Table 4.41) (33). Cream may be added to make Shrikhand from skim milk Chakka. Its consistency should be very smooth without syrup pockets and free of fat separation and uneven color. It should contain not less than 7% fat and 9% protein (34, 54, 55, 57). The traditional method of Shrikhand manufacture involves preparation of Dahi by culturing milk with natural starter or curd from a previous batch made with lactic fermentation, and implies the gradual increase in lactic

Table 4.48. Requirements for Fermented Milk Products

Characteristics	Sweet Dahi	Sour Dahi
Acidity (as lactic acid, % by weight, max)	0.7	1.0
Yeast and mold count/gm, max	100	100
Coliform count/gm, max	10	10
Phosphatase test	Negative	Negative

Source: Bureau of Indian Standards, 1973:7035.

Table 4.49. Composition of Whole-Milk Dahi

Constituent	Contents, %
Fat	5–8
Protein	3.2–3.4
Lactose	4.6–5.2
Ash	0.7–0.72
Lactic acid	0.5–1.1
Water	85–88

acidity as a result of lactose metabolism by starter bacteria in milk. Formation of acid curd is a prerequisite in the manufacture of many dairy products such as cottage cheese, yogurt, Dahi, and Shrikhand. The type of lactic acid curd differs by their eventual use in products. Acidity of curd set for American Cottage Cheese usually does not exceed 0.48 to 0.6% LA, whereas curd for yogurt usually has 0.8% LA; for Dahi and Shrikhand, the traditional practice is to use boiled milk and to achieve acidity of 1% LA and above. Curd from buffalo milk is firmer than that from cow milk because it contains more fat. As a result, the curd acquires some mellowness, which is offset by high calcium, larger micellar size of casein, and more β-casein in buffalo than in cow milk; also, a higher rate of syneresis is observed in buffalo milk Tables 4.50–4.53).

The use of whole milk for Dahi making yields a smooth body but higher fat losses in the whey, up to 0.4% fat in the whey. So, it is preferred to use skim milk, which also causes less moisture retention in the curd. Heating of the milk at 90° C for 10 seconds increases the yield of *Chakka* by 5% compared to 70° C, which is attributed to the precipitation of heat denatured whey proteins, α-lactalbumin and β-lactoglobulin. Traditionally, small amounts of the previous day's whey or curd are used as a source of lactic culture for setting the curd. However, this method is not suitable for industrial requirements because of considerable risk of uncontrolled fermentation. The use of contaminant-free lactic culture in a desired state of activity is an essential prerequisite for good fermented milk products, which also require the presence of both acid and flavor-producing microorganisms in the starter culture. The pH attained, the extent of gas formed, and the proteolytic activity influence the quality of curd formed, and the relative production of diacetyl and other aromatic compounds determine flavor characteristics.

Starter cultures exhibit varying rates of lactic acid production. Most Streptococci can produce acid up to 1%, while Lactobacilli exceed this level. *Lb. bulgaricus* and *Lb. acidophilus* are typical examples of fast and high acid-producing organisms. The rate of acid production increases in mixed strains of *Streptococcus thermophillus* and *Lactobacillus bulgaricus* compared to their individual activity. *Lactobacillus bulgaricus* is inhibited in milk containing more than 20% TS. The traditional method of using previous days' culture for setting fresh Shrikhand curd results in about 1% lactic acidity within 12–16 hours at an incubation temperature of 25 to 30° C.

Syneresis of curd, the expulsion of whey from curd, is essential for a desirable texture of Shrikhand. The expulsion of whey is a function of the moisture-binding capacity of casein and is influenced by the composition of milk, heat treatment,

Table 4.50. PFA and BIS Specifications for Shrikhand

Characteristics / constituent	PFA requirements	BIS requirements
TS, % by mass, min	58	58
Milk fat, (on dry basis), % by mass, min	8.5	8.5
Milk proteins (on dry basis), % by mass, min	8.5	10.5
Titratable acidity (as lactic acid), % by mass, max	1.4	2.5
Total ash (on dry basis), % by mass, max	Not in PFA	1.4
Sugar (sucrose) (on dry basis), % by mass, max	72.5	72.5
Total ash (on dry basis), % by mass, max	0.9	0.9
Coliform count/g, max	Not in PFA	10
Yeast and mold count/g, max	Not in PFA	50

BIS = Bureau of Indian Standards
PFA = Pure Food Allowance

Table 4.51. BIS and PFA Specifications for Chakka

Characteristics	Skim-milk Chakka		Whole-milk Chakka	
	BIS	PFA	BIS	PFA
TS, % by mass, min	20	20	30	30
Milk fat, (on dry basis), % by mass	5 (max)	5 (max)	33 (min)	33 (min)
Milk protein (on dry basis), % by mass, min	60	60	37	37
Titratable acidity (as lactic acid), % by mass, max	2.5	2.5	2.5	2.5
Total ash (on dry basis), % by mass, max	5.0	5.0	3.5	3.5
Coliform count/g, max	10		10	
Yeast and mold count/g, max	20		20	

Table 4.52. Composition of Dahi, Chakka, and Shrikhand

Constituent	Dahi	Chakka	Shrikhand
TS %	9–10	22–23	57–60
Fat %	Trace	Trace	5–6
Protein %	3.7–3.9	13.5–14.0	6.5–7.0
Sucrose %	—	—	40–43
Ash %	0.72	0.95–1.08	0.49–0.55
Reducing sugar %	4.5–4.7	3.0–3.2	1.6–1.7
Titratable acidity	0.9–0.95	2.1–2.22	1.05–1.10
pH	4.4–4.6	4.4–4.6	4.4–4.6

Adapted from (33).

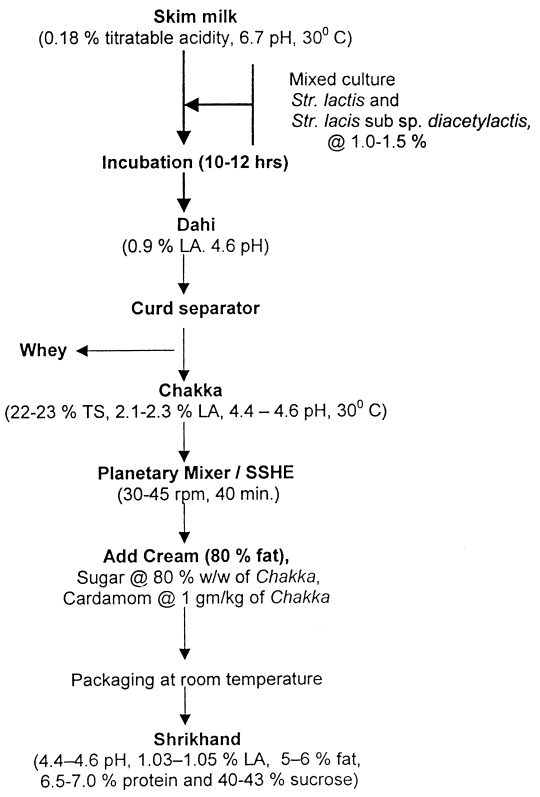
Table 4.53. Average Composition of Market Samples of Shrikhand

Constituents	Mechanized process	Organized dairies	Small-sector manufacturers
Moisture, %	41.4	40.4	36.4
Fat, %	5.5	6.0	5.4
Milk fat, %, in dry matter	—	10.1	8.4
Protein, %	7.4	6.4	6.2
Milk protein, % in dry matter	12-68	10.8	9.7
Sucrose, %	41-63	45.1	49.4
Sucrose, % in dry matter	70–88	75.6	77.5
Reducing sugar	3–74	1.66	2.59
Ash, %	0.41	0.46	0.34
Ash, % in dry matter	0.69	0.77	0.54

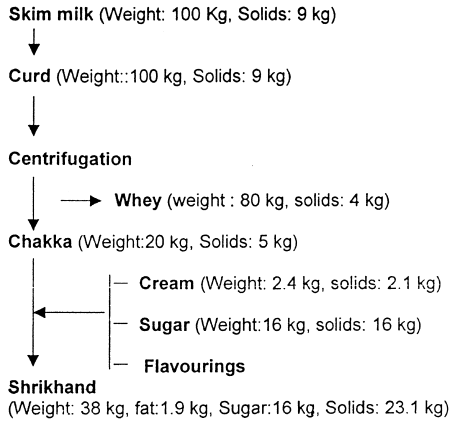
Source: (55).

level of calcium ions, and pH of the coagulation. In traditional Shrikhand making, the milk is placed in muslin cloth bags and left for the whey to drain for about 8–10 hours. Chakka is the traditional product obtained after whey drainage from Dahi obtained by lactic acid fermentation of milk. Recently the use of centrifuges to remove whey has also been practiced. Chakka is made from skim or whole milk from cows or buffaloes, or from reconstituted skim milk combined with standardized milk. The color is yellowish from cow and white from buffalo milk and should have a pleasant yogurt-like flavor.

The industrial method of Shrikhand manufacture is shown:



Mass balance in Shirkhand manufacture:



Due to a high sugar content, Shrikhand has higher keeping quality than Dahi/yogurt but depends on initial microflora of yeasts and bacteria (58). During storage study at 37° C, SPC, spores, lipolytic, and proteolytic counts decreased, while yeast and molds increased. Only staphylococci count increased during storage at 10° C for 45 days, while all other types decreased. The keeping quality of Shrikhand at 10° C was 42 days but only 2–3 days at 30° C. Off-flavors developed by 40 days at 10° C. By the addition of potassium sorbate at 0.05%, the storage stability can be enhanced by 25%. Heat treatment by thermization can extend the shelf life of Shrikhand (35, 36, 37, 38).

9 EPILOGUE

An attempt has been made to bring together information on various production and processing aspects of traditional buffalo milk products and to achieve wider appreciation for them beyond the borders of India. Although buffaloes thrive mostly on low-quality roughages, their milk is rich in composition and hence an economical raw material for making dairy products. Certain unique characteristics of buffalo milk compared to cow milk give it potential superiority and may explain its popularity in many countries besides India.

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5
Mare Milk

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1 INTRODUCTION

In 1915, there were more than 21.4 million horses in the United States; then, a gradual decline in numbers occurred as the horse was replaced by tractor, truck, jeep, and automobile (10). Horses in the United States have been used for working, racing, games, and as show animals, not as dairy animals. Similarly in Western Europe, the most important product of equine breeding is the foal, whereby studies on mare milk have been concerned mainly with the growth and health of the newborn horse (44).

On the other hand, horses have been traditionally used as dairy animals in central Asia, Mongolia, and the former Soviet Union, where mare milk has been one of the most important food sources for the human populations in these regions. The milk has mainly been used for the manufacture of a lactic alcoholic beverage, named Koumiss, and cheese (45, 48, 51). It is estimated that 30 million people throughout the world drink horse milk more or less regularly (16). Currently, Koumiss is manufactured at an industrial level in those counties (68).

The composition of mare milk is significantly different from that of bovine milk (8, 37, 44, 45). Mare milk is similar to human milk, with particular reference to its low nitrogen content, its low casein-to-whey protein ratio, and its high content of lactose (4). Furthermore, certain characteristics including high polyunsaturated fatty acids and a low cholesterol content appear to support the interest in increasingly using mare milk for human consumption (26).

Interest has been increased in the use of mare milk for human nutrition in the past several years, especially in France and Germany (17, 44, 75). Recently in Italy, mare milk has been considered as a possible substitute for cow milk as formula for allergic children (6, 11). Mare milk also has been used for the treatment of certain human pathologies such as hepatitis, chronic ulcer, and tuberculosis (49, 64). This premise of therapeutic value and hypoallergenicity of mare milk to humans is probably based on the fact that horse milk composition is often considered to be close to that of human milk (16).

2 PRODUCTION AND ANIMAL MANAGEMENT OF DAIRY HORSES

2.1 Distribution of Dairy Horses in the World

Horses are distributed throughout the world, while the majority of dairy horse herds is found in Euroasia, especially Russia, Mongolia, and northern China. Dairy horses are located in Inner Mongolia in north China and its periphery, Kazakhstan, Kirghizia, Tadzhikistan, and Uzbekistan as well as some parts of Russia near Siberia (16, 74). They are also found in Tibet and Xinjiang, and Eastern Europe (Belarus, Ukraine) as well as central Europe, especially Hungary, Austria, and Germany (16, 75).

2.2 Breeds of Dairy Horses

Different breeds of dairy horses are used for mare milk production in the world. Several native Kazakh breeds, weighing 500–600 kg, are found for milk production in the former USSR and Mongolia. Among them, jade Kazakh and draft Kazakh produce more milk than do saddle Kazakh, owing to better adaptation ability to environments (16). In Kazakhstan, Kushum horse breeds are used as producers of meat or milk. Draft horses from Russia and Lithuania, weighing 650–700 kg, are employed not only for military use but also for dairy purpose (16). Lokai horses in Tadzhikistan and Novo-Kirghiz horses in Kirghizia are traditionally used for riding and now also for milk production. In Mongolia, a number of crossed breeds are being used to produce milk (16, 74). Haflinger, as the most important dairy breed with an adult weight of 500 kg, is famous for its milk production capacity in European countries. Actually, any horse breed can be developed into a milking herd if milking is accepted by mares.

2.3 Horse Feeding and Nutrition Management

2.3.1 Nursing the Newborn Foal

Although some dairy horse–producing regions may entirely depend on natural pasturing and hays without much supplementary feeds, better nutritional management would be highly desirable for greater-quality milk production. It would be very important for the foal to receive a good nutrition for bone development and growth while still suckling the mother. A majority of normal foals will nurse within one to two hours after foaling. The most vigorous foals will nurse within 30 to 45 minutes (10). The first milk, colostrum, is very important for the newborn foal because it contains antibodies that provide immunity for the foals. For approximately the first 36 hours after birth, the foal's intestinal tract is permeable to these antibodies, so they can be readily absorbed into the body.

Because mare milk is deficient in iron, copper, and some other nutrients, the young foal soon needs a source of these minerals plus other nutrients for maximum growth and development (10). Because the peak milk production usually occurs at two to three months after foaling, the milk becomes a smaller percentage of the foal's total ration intake as it grows older.

Crude protein in milk dropped from 19.1% shortly after birth to 3.8% at 12 hours later, and to 2.2% at two months later (70). Other milk nutrients including fat, calcium, phosphorus, sodium, potassium, and others also decline as the lactation period advances. This is the basis for a good creep feeding program, which is recommended (10).

2.3.2 Creep Feeding

At about 10 to 15 days of age, the foal will start to nibble on the feed given to its mother. However, what the foal takes from its mother's feed often will result in a nutritionally imbalanced diet. Due to this possibility, it is recommended that foals be provided with a well-balanced creep feed within two to three weeks after foaling. The creep feed plus the milk that foals receive from nursing their mother would provide a well-balanced ration (10).

The foal should be provided with clean and fresh creep feed so that no moldy and sour feed is consumed. If the mother provides a good amount of milk and the foals are on excellent pasture, it would be difficult to get them started consuming a creep feed. In such conditions, it may be necessary to get them started by letting them nibble some feed from a person's hand (10). Because the preparation and formulation of a high quality creep ration is difficult for most horse owners, it would be best to use a good commercial creep feed that is adequately fortified with protein, vitamins, minerals, and other nutrients required for the growth of the young foal.

A foal should be consuming at least one-half pound (0.227 kg) of creep feed/day per 100 pounds (45.4 kg) of body weight at five to six weeks of age (10). The creep feed would help avoid setbacks, which can occur when the foal is weaned from its mother. An example of creep ration for nursing foals is shown in Table 5.1. Additional salt and minerals may also be recommended in case the foal needs more than the ration shown in Table 5.1. Vitamin supplementation for a creep ration, or rations for growing foals and lactating horses, are very important for the adequate growth and milking. Table 5.2 shows vitamin premix for horse rations, assuming that the concentrate feed makes up one-half of the total feed intake of the horse. The remainder of the feed is from milk (in case of foal) or forage (hay

Table 5.1. Sample Creep Ration for Nursing Foals

Feed Ingredient	Percentage in ration[a]
Oats groats, rolled	15.0
Oats (heavy oats), rolled or flaked	20.0
Corn barley, milo, or a combination of them, rolled or flaked	35.75
Soybean meal	15.0
Dried skimmilk	5.0
Blackstrap molasses	5.0
Dicalcium phosphate (or other calcium and phosphorus source)	2.0
Limestone, ground	0.75
Vitamin supplement[b]	0.5
Salt, trace mineralized[c]	1.0

[a]The levels of feeds in the ration can be adjusted to provide 18% protein, 0.90% calcium, and 0.8% phosphorus.
[b]See the composition of vitamin premix in Table 5.2.
[c]See the composition of salt and trace mineral levels in Table 5.3.
Adapted from Cunha (10).

Table 5.2. Vitamin Premix for Horse Rations

Vitamin	Level in 1 lb (454 g) of premix with carrier
A	400,000 (IU)
D	40,000 (IU)
E	800 (IU)
K	200 (mg)
Thiamin	240 (mg)
Riboflavin	400 (mg)
Niacin	1.2 (g)
Pyridoxine	120 (mg)
Pantothenic acid	480 (mg)
Choline	6.0 (g)
Vitamin B12	1.2 (mg)
Folacin	120 (mg)
Carrier (includes all vitamins in it)	1.0 lb[a]

[a]Other vitamins could be included if so desired at the following levels in the above 1 lb (454 g) premix: vitamin C, 5 g; and PABA, 2 g. If myoinositol is used, it can be added at a level of 0.1 to 0.3% of the ration.
Adapted from Cunha (10)

and/or pasture). The levels of vitamin premix can be adjusted depending on the percentage of concentrates in the ration by decreasing or increasing the amount added. Some of the vitamins included in this premix may be omitted if the rations used are not for racing or performance horses (10).

The recommended supplementation of trace mineralized salt for horses is shown in Table 5.3. The horses most likely consume less than 1% salt in the total feed intake from concentrates, pasture, and/or hay (10). The total creep ration should contain 0.90% calcium and 0.6% phosphorus. The trace mineralized salt should contain iodine, iron, copper, cobalt, manganese, zinc, and selenium for adequate supply of the minerals (Table 5.3).

2.3.3 Feeding the Growing Horse

The period between weaning and about one year of age is one of the most critical times in the life of a

Table 5.3. Recommended Trace Mineralized Salt for Horses

	Level of mineral element added to		Equivalent in ppm of total ration if salt is % of the total feed intake[c]	
Trace mineral	High level[a] salt (%)	Regular level[b] salt (%)	High level salt (ppm)	Regular level salt (ppm)
Iodine	0.018	0.009	1.8	0.9
Iron	1.000	0.500	100.0	50.0
Copper	0.100	0.050	10.0	5.0
Cobalt	0.010	0.005	1.0	0.5
Manganese	0.400	0.200	40.0	20.0
Zinc	1.000	0.500	100.0	50.0
Selenium	0.001	0.001	0.1	0.1

[a]High level of trace minerals for racing and performance that requires a high level of nutrition.

[b]A regular level of trace minerals for horses used for pleasure riding and not demanding activities.

[c]This assumes that the trace mineralized salt will be fed at a 1% level in the concentrate feed and that it will also be self-fed in a mineral box.

Adapted from Cunha (10).

growing horse. It is necessary for weaning foals to be fed a high-quality, palatable ration. This condition makes them better prepared for the adjustment from consuming their mother's milk to a regime that is no longer dependent on milk as a part of the ration. Foals fed on a creep feed and used to concentrates will have little shock at the time of weaning.

Table 5.4 depicts a sample ration that can be fed to weanling foals. Oats are an excellent source of feed for young, growing horses. For a source of energy, corn, milo, or barley is formulated, and soybean meal is considered to be the best plant protein supplement for the rations of young and growing horses.

Horse weanlings grow rapidly and develop considerable bone and muscle, whereby they must be fed a well-balanced diet in adequate quantity. Using the 1979 NRC Committee on Nutrient Requirements of the Horse, Hintz et al. (25) showed information on the weight and rate of gain made by growing horses at various ages (Table 5.5). The tabulated data reveal that horses of heavier mature weights gain faster than those of lighter mature weights.

Table 5.4. Sample Ration for Weaning Foals

Feed	Percentage in ration[c]
Oats (heavy oats) rolled or flaked	25.0
Corn, barley, or a combination of them, rolled or flaked	30.8
Milo (or corn or barley)	15.0
Soybean meal	15.0
Dehydrated alfalfa meal (20% protein)	5.0
Blackstrap molasses	5.0
Vitamin supplement[a]	0.7
Dicalcium phosphate (or other calcium and phosphorus source)	2.0
Limestone, ground	0.5
Salt, trace mineralized[b]	1.0

[a]Vitamin premix in Table 5.2.

[b]Salt and trace mineral mix in Table 5.3.

[c]These levels should be adjusted to provide 18% protein, 0.85% calcium, and 0.75% phosphorus. This ration would be fed with hay and/or pasture that had at least 12% protein.

Adapted from Cunha (10).

Table 5.5. Daily Gain by Growing Horses[a]

		Weight of growing horse (lb) mature weight of horse (lb)			Daily gain of growing horse (lb) for mature weight of horse (lb)		
	Age (months)	880	1100	1320	880	1100	1320
Nursing foal	3	275	341	374	2.20	2.64	3.08
Weanling	6	407	506	583	1.43	1.76	1.87
Yearling	12	583	715	847	0.88	1.21	1.32
Long yearling	18	726	880	1045	0.55	0.77	0.77
Two-year-old	24	803	990	1188	0.22	0.33	0.44

[a]All numbers are in pounds: 880, 1100, and 1320 lbs in metric system are 400, 500, and 600 kg, respectively.
Data from Hintz *et al*. (25).

2.3.4 Feeding Regimen of the Lactating Horse

With some exception of heavy exercise or work, no other function of a horse has greater nutritional demands than lactation. After parturition, the nutrient requirements of mares increase by at least 75%, mostly due to the physical demand of milk production (21). Because of a very inefficient process of the conversion of the mare's digested nutrients into milk, the nutrient requirements for milk production are particularly high. The conversion of digestible energy to milk energy is known as only 60% efficient. Because of this inefficiency, the mare should be fed a ration that contains at least 13% crude protein in order to ensure proper milk production. This requirement can be met by feeding the milking mare a 14% crude protein grain supplement, a mineral and salt supplement, and high-quality roughage, containing approximately 12% crude protein (21).

If the nutrient needs of lactating mares are not met, their milk production, body weight, and condition will be affected. This is evidenced by the reduced milk production when dietary protein levels are inadequate. Furthermore, deficiency in dietary energy levels will cause weight loss in the lactating mare due to the depletion of body energy for milk production (21).

The lactating mare cannot consume enough good-quality grass hay or grass forage to meet her protein, vitamin, and mineral requirements. Nevertheless, if free-choice alfalfa or plenty of lush, green legume pasture is provided, the mare is usually able to take enough roughage (approximately 2.5 to 3.0 lbs/100 lbs body weight, or 1.1 to 1.4 kg/45 kg body weight) to meet her protein, calcium, and vitamin A needs (21). Most commercially marketed feeds for the lactating mare not only meet the protein and energy needs of the mare but also provide adequate amounts of calcium, phosphorus, and vitamins.

2.3.5 Changes in Mare Milk Composition by Dietary Modification

High-concentrate diets for mares decrease milk protein content, which is in contrast to what happens in the cow. This may be partially attributable to a dilution effect resulting from a higher milk yield (16). A low-protein diet for the milking horse will result in reduced protein content in her milk due to the deficiency of amino acids in the diet.

Lactose content of milk throughout the lactation is usually stable and independent of diet, due to its contribution to milk osmotic pressure (16, 59). It was, however, reported that lactose content was lower in hay-fed mares than concentrate-fed mares, suggesting a negative effect of the roughage diet on precursors of lactose such as glucose and propionate (16).

It is known that a high concentrate diet with low roughage decreases the milk fat content in cows, goats, as well as in mares (59), which is attributed to the decrease in de novo synthesis of precursors such as acetate and butyrate (16, 59). Linolenic acid content was highest when mares were fed on pasture during summer months where grasses are rich in linolenic acid and total fatty acids. Lipid fortification with maize oil rich in oleic and linoleic acids increased these fatty acids in milk (16). Supplementation of fish oil, which is rich in C20 and C22

fatty acids, led to a very limited incorporation of eicosapentaenoic and docosahexaenoic acids in milk, suggesting a very low transfer from the diet to milk, as in the cow (16).

3 MILK PRODUCTION OF DAIRY HORSE

3.1 Secretion and Production of Mare Milk

The release of milk from the alveoli and intralobular ducts is normally inhibited until parturition. The high levels of estrogen and progesterone during pregnancy stimulate the release of prolactin, which stimulates milk secretion from the anterior pituitary gland (69). There is, however, a feedback mechanism through which high estrogen and progesterone levels also inhibit the action of prolactin on the mammary glands. During pregnancy, some milk synthesis occurs, and when estrogen and progesterone levels drop just after parturition, milk secretion is significantly increased by prolactin (21, 69).

As the lactogenesis progresses by activated mammary secretory cells, the collection ducts and teats fill with milk, and the gland becomes swollen and firm. Retention of milk prior to parturition distends the alveoli and depresses milk production. However, the release of oxytocin from the neurohypophysis during parturition by uterine smooth muscle contraction as well as suckling by the newborn (Figure 5.1) causes contractions of the muscle-like myoepithelial cells within the alveoli and intralobular sinus (21). This chain reaction causes milk ejection (milk let-down), which results in diminishing pressure within the alveoli, and milk secretion is stimulated. This is the reason that frequent suckling or hand milking can enhance milk production.

When the foal suckles, stimulation of the nerve endings within the mare's teats triggers the release of special hormones from the hypothalamus that, in turn, maintain lactation (21, 69). Mares have peak milk production from one to three months after parturition, and then this milk production gradually decreases until soon after weaning. The quantity of milk production varies among individual horses, depending on breed type, nutrition, environment, health, and management conditions (21). Horses are hand milked in many places, including in Mongolia, as shown in Figure 5.2. A heavy draft mare produces about 40 lbs (18 kg) of milk per day during peak lactation, whereas a light horse mare produces about 33 lbs (15 kg) per day and a pony mare produces about 27 lbs (12 kg) per day (21).

It was reported that a mare of average milking ability and weighing 1,100 lbs (499 kg) can produce approximately 300 lbs (136 kg) of milk during five months' lactation (21). Light horses produce about 3

Figure 5.1. Lactating mare and its nursing newborn foal. Adapted from Evans and Torbeck (21).

Figure 5.2. Horse milking in Mongolia. Photo by Heping Zhang.

percent of their body weight per day in milk during the first 12 weeks of lactation, and 2 percent per day during the later stages of lactation. In contrast, pony mares produce 4 percent of their body weight in milk per day during early lactation and about 3 percent per day after the first 12 weeks (21).

3.2 Quality of Mare Milk

The first milk, colostrum, after the foal's birth, has antibodies that are required for protection of the newborn against diseases. The antibodies in mother's colostrum are immunoglobulins, with the main antibody being immunoglobulin G. If the foal gets 500 mL of colostrums, the foal will be protected, although there is a limited time to do so. When collecting colostrum, it is necessary to analyze for IgG concentration and neonatal isoerythrolysis antibodies. On the farm, a colostrometer (modified hydrometer) can be used to measure the specific gravity, which indicates the IgG concentration. Specific gravity in mare's colostrum should be greater than 1.06, where an ideal concentration of IgG is 50 g/L. It is preferable to collect colostrum from mares less than 15 years of age. Mares 4–10 years old are likely the most suitable candidates for colostrum collection.

The bacteriological quality of mature horse milk is higher than that of cow milk, and its somatic cell counts are low (16). Mastitis is not likely to be a limiting factor for mare milk production, because the mare has a small-sized udder, which would limit the exposure of the teats to infection.

Mare milk has a high level of unsaturated fatty acids, but it is much less sensitive to oxidation due to the existence of natural antioxidants in the milk. However, lipolysis may occur, so that it would be necessary to preserve the milk by freezing, lyophilization, or spray drying if the milk is not fermented or consumed immediately (16).

4 COMPOSITION OF MARE MILK

4.1 Gross Composition

It is known that gross composition of milk varies considerably between species, as mammary secretion is physiologically and structurally correlated to the nutritional requirements of the newborns of each specific species (44). Table 5.6 shows the comparison of the gross composition of mare, human, and cow milks, where some significant differences exist between the three species.

The lactose content of mare milk is similar to that of human milk, which is higher than that of cow milk. However, both mare and human milk have significantly lower levels of protein and minerals than does cow milk (Table 5.6). The energy content of mare milk is significantly lower than both human and cow milks (12, 29, 64). Fat accounts for only 25% of the energy in horse milk, as compared to 50% for human or cow milk. The energy value of mare milk ranges between 2.0 and 2.5 MJ/kg, which is lower than that of humans and other farm animals (16).

The total solids content and their changes associated with stage of lactation for mares of the four breeds are shown in Table 5.7. The total solids content of colostrum immediately after foaling ranged from 14.6 to 29.4%. Dry-matter content decreased quickly following two days after foaling. Due to the high variation, breed differences in dry matter were not significant (Table 5.7) (8). Its content decreased sharply during the first two to five days, and remained at 10.4 % from eight days of lactation.

Because cow milk contains clearly higher levels of salts than do mare and human milk, it is less suitable as a replacement for human milk. Mare and human milk are quite similar in milk sugar levels, including galactose, which is a constituent of the myelinic sheath of the central nervous system cells (44). Researchers (39) indicated that the structural complexity of the minor carbohydrate fractions of human milk makes a functional comparison with cow and mare milks difficult, and this premise has been little studied in mare milk (71). Considering the aforementioned gross composition, mare milk would be, on the whole, a more suitable nourishment for human infants compared to cow milk (45, 66).

4.2 Lipid Composition

Mare milk has very low levels of fat compared to those of human and cow milks (Tables 5.6 and 5.8).

Table 5.6. Gross Composition of Mare Milk in Comparison to Human and Cow Milk

	Mare		Human		Cow	
Fat (g kg^{-1})	12.1	(5–20)	36.4	(35–40)	36.1	(35–39)
Crude protein (g kg^{-1})	21.4	(15–28)	14.2	(9–17)	32.5	(31–38)
Lactose (g kg^{-1})	63.7	(58–70)	67.0	(63–70)	48.8	(44–49)
Ash (g kg^{-1})	4.2	(3–5)	2.2	(2–3)	7.6	(7–8)
Gross energy (kcal kg^{-1})	480	(390–550)	677	(650–700)	674	(650–712)

Mean value, and between brackets, range values in literature.
Data from references 1, 29, 44, and 64.
Adapted from Malacarne et al. (44).

Table 5.7. Changes in Total Solids Contents of Colostrum and Normal Mare Milk (g/100 g Milk)

Breed	No. of sample	Days of postpartum 0–0.5		2–5		8–45	
		$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD
Haflinger	4	24.45	± 4.34	12.87	± 1.49	10.61	± 2.12
Breton	6	24.65	± 6.38	11.93	± 2.05	10.39	± 1.24
Boulonnais	3	25.42	± 4.12	12.15	± 2.22	10.37	± 1.73
Hungarian Droughut	16	26.28	± 3.16	12.78	± 1.64	10.40	± 1.57

Adapted from Csapo et al., (8).
$\overline{X}$: Mean; SD: Standard deviation.

Table 5.8. Lipid Composition of Mare Milk in Comparison to Human and Cow Milk (Mean Value)

	Mare	Human	Cow
Fat (g kg^{-1})	12.1	36.4	36.1
Triglycerides (%)	81.1[a]	98.0	97.0
Phospholipids (%)	5.0	1.3	1.5
Unsaponifiable (%)	4.5[b]	0.7	1.5
Free fatty acids (%)	9.4	Trace	Trace

References for mare, human and cow milk are 57, 31, and 1, respectively.

[a]Mono- and di-glycerides 1.8%.

[b]Non-identified fractions 0.3%.

Adapted from Malacarne et al. (44).

Fat content in colostrum immediately after foaling averaged 2.9%, while that of transition and normal milks averaged 2.1% and 1.2%, respectively (8). There were no clear differences in fat content between colostrum and normal mare milk.

Milk lipids are dispersed as emulsified globules, and fat globule size of mare milk is about 2–3 μm (33, 44). Fat globules are coated with three layers: an internal protein layer, an intermediate layer consisting of a phospholipid membrane, and the external layer consisting of high-molecular-weight glycoproteins (44). Solaroli et al. (64) reported that there is a branched oligosaccharide structure on the surface of these glycoproteins in mare milk, which is similar to that of the fat globules in human milk.

Average diameter of fat globules for human and cow milks are 4 and 3–5 μm, respectively (72). Researchers (30, 35) reported that the external membrane of human milk fat globules is coated with an array of glycoprotein filaments, similar to mare milk, which may enhance digestion by binding lipases. Cow milk-fat globules are coated with a thin, protective film, with external layers constituted of proteins and phospholipids (31).

4.2.1 Triglycerides

Cow and human milk fats are almost totally made of triacylglycerols, while horse milk contains less than 80% triacylglycerols and the rest of mare milk fat is mainly composed of free fatty acids and phospholipids (Table 5.8); the respective amounts of these fractions remain to be seen (12, 16, 30, 44). Variation in the number of carbon atoms in di- and triglycerides is a characteristic of different species' milk fat (55). Pagliarini et al. (52) postulated that the distribution follows a typical unimodal pattern (maximum at 50–52 carbon atoms) in mare and human milk fat, while in cow milk it follows a bimodal pattern (first maximum ranging from 34 to 40 carbon atoms and the second from 42 to 54).

In mare milk, palmitic acid (C16:0) is preferentially associated at the sn-2 position (55), whereas it is equally located in 1 and 2 positions in cow milk. From a nutritional point of view, the structure of triglyceride is a primary factor affecting the action of lipase enzyme for fat absorption (44). In human milk, C16:0 is preferably located in the sn-2 position, so that the assimilation of this fatty acid in children is favored (40, 73).

4.2.2 Fatty Acids

The fatty acid composition of feedstuffs has a greater influence on the fatty acid composition of milk fat in horses than in ruminants (8), indicating that microbial action in the rumen can result in a greater modification of dietary fats than would occur in the body metabolism of the horse. Compared to human and cow milk, mare milk fat has especially lower levels of stearic and oleic acids and is higher in palmitoleic, linoleic, and linolenic acids (Table 5.9) (8, 14, 15, 27, 38, 64). Fatty acids of mare milk are easily absorbed in the human small intestine and often referred as dietary fatty acids due to no occurrence of the preliminary hydrogenation that is taking place in ruminants.

Comparison of the fatty acid composition of colostrum with that of normal mare milk showed that the fat of colostrum contains less octanoic, decanoic, dodecanoic, myristic, palmitic, and palmitoleic acids than normal milk. On the other hand, normal mare milk has less stearic, linoleic, and linolenic acids than colostrum (Table 5.9). No significant differences in fatty acid contents were found among different breeds of horses (8).

Csapo et al. (8) compared the fatty acid composition of mare milk fat on day 45 of lactation with that of cow milk and found that mare milk fat contained 2.1 times as much dodecanoic acid, 3.1 times as much decanoic acid, 4.9 times as much linoleic acid, 9.6 times as much octanoic acid, and 224 times as much linolenic acid as cow milk fat (Table 5.9). On the other hand, mare milk fat contained only 0.62

Table 5.9. Fatty Acid Composition of the Lipids in Colostrum and Normal Milk of Mares and Cows (Relative Percentage of the Fatty Acid Methylesters)

	Days postpartum							
	Mare						Cow	
	0–0.5		2–5		8–45		5–270	
Fatty acids	$\overline{X}$	S.D.	$\overline{X}$	S.D.	$\overline{X}$	S.D.	$\overline{X}$	S.D.
Octanoic	1.39	0.18	2.56	0.94	2.79	0.91	0.29	0.022
Decnoic	5.41	0.47	8.59	2.89	8.05	2.25	2.61	0.219
Dodecanoic	7.90	1.57	9.89	3.19	8.97	2.10	4.35	0.362
Myristic	6.30	0.26	9.67	1.89	8.72	1.97	14.00	0.998
Palmitic	21.32	1.58	25.63	2.99	23.28	3.58	44.06	2.10
Palmitoleic	2.80	1.97	5.07	1.14	3.96	1.52	2.08	1.009
Stearic	2.36	0.53	1.63	0.51	1.55	0.79	7.94	1.001
Oleic	17.12	0.21	13.77	5.38	13.72	2.58	17.25	1.533
Oleic(ω6)	0.78	0.29	0.74	0.21	0.69	0.24	*	
Linoleic	0.78	0.83	6.40	0.90	7.53	1.47	1.72	0.198
γ-Linolenic(ω6)	0.75	0.13	0.51	0.03	0.61	0.19	*	
Linolenic	24.11	2.57	15.53	1.99	20.12	4.12	0.09	0.02

*Not determined.

Adapted from Csapo et al. (8).

times as much myristic acid, 0.53 times palmitic acid, and 0.2 times stearic acid as cow milk fat. The mare milk fat has higher unsaturated or short-chain fatty acids, which is more desirable as a dietary constituent than cow milk fat. Because of these large differences in the fatty acid composition between the two species, the authors suggested that the presence of cow milk in a blend of milks from the two species can be detected.

As does human milk, mare milk has a lower proportion of saturated fatty acids with a low and high number of carbon atoms (C4:0, C6:0; C16:0; C18:0) compared to cow milk (44). On the whole, the percentage of unsaturated fatty acids in mare and human milks is similar and higher than that in cow milk (44). Free fatty acids are found in mare milk in considerable amounts, whereas only traces are present in human and cow milk (57).

4.2.3 Polyunsaturated Fatty Acids

Mare milk has particularly high levels of polyunsaturated fatty acids (PUFA) such as linoleic acid and especially linolenic acid, when compared with other species milk (12, 44). Svahn et al. (67) expounded that linoleic acid (C18:2) of the ω-6 group, and α-linolenic acid (C18:3) of the ω-3 group, are considered essential fatty acids, because animal organisms cannot synthesize these compounds. The high linolenic acid content observed with forage-based diets is a characteristic of horse milk, while monogastric species do not eat forages, which are the main dietary source of linolenic acid (16).

Marconi and Panfili (45) reported that the PUFA contents ($C_{18:2}$ and $C_{18:3}$) of raw and powdered mare milk samples (19–25%) were much higher than those in cow milk (2–4%) (Table 5.10). These values of fatty acids in mare milk powder are similar to the results reported by other authors for raw mare milk (8, 15, 52). The variations in fatty acid composition of mare milk may be attributable to a greater influence of feedstuffs in horses than in ruminants (8).

In light of monounsaturated fatty acids (MUFA), mare milk has similar levels to those of cow milk, except a higher C16:1 content (5–8%) than cow milk (2–3%) (45). Marconi and Panfili (45) also found that the ratios between unsaturated and saturated and between PUFA and MUFA were markedly higher in mare milk powder than in cow milk powder (Table 5.10). A mathematical function (C8:0 × C10:0 × C12:0 × C18:2 × C18:3)/C14:0 × C18:0) was identified using this peculiarity of fatty acid composition in mare milk, which led to detect the possible adulteration of mare milk with cow milk (8).

Table 5.10. Fatty Acid Composition of Mare and Cow Milk (Percentage Total Fatty Acids)

	Mare milk			Cow milk	
Fatty acid	Raw[a]	Powder[b]	Vitaminized Powder[b]	Pasteurized	Powder[b]
C4:0	trace	trace	trace	3.30	3.0 ± 0.31
C6:0	trace	trace	trace	2.00	1.5 ± 0.23
C8:0	3.1 ± 0.10	2.5 ± 0.24	1.82 ± 0.06	1.20	1.32 ± 0.06
C10:0	7.8 ± 0.52	5.5 ± 0.29	4.9 ± 0.31	2.50	3.49 ± 0.01
C10:1	1.4 ± 0.12	1.17 ± 0.09	1.27 ± 0.04	trace	trace
C12:0	8.6 ± 0.64	6.2 ± 0.38	6.7 ± 0.35	2.90	3.5 ± 0.30
C14:0	8.1 ± 0.35	6.8 ± 0.46	7.8 ± 0.32	11.0	12.7 ± 0.33
C16:0	19.5 ± 0.52	21.5 ± 0.76	20.6 ± 0.60	28.0	33.8 ± 0.91
C16:1	5.8 ± 0.16	5.2 ± 0.63	7.8 ± 0.19	2.90	1.8 ± 0.13
C18:0	1.16 ± 0.04	0.9 ± 0.19	0.60 ± 0.03	12.0	8.5 ± 0.52
C18:1	20.5 ± 0.69	26 ± 1.2	21.0 ± 0.55	27.0	25.4 ± 0.19
C18:2	10.3± 0.18	18 ± 1.0	11.6 ± 0.26	2.10	1.11 ± 0.01
C18:3	8.4 ± 0.40	3.4 ± 0.11	13.1 ± 0.43	1.80	0.72 ± 0.03
SFA[c]	48.2	43.2	42.3	62.9	67.6
MUFA[d]	27.8	33.3	30.1	29.9	27.2
PUFA[e]	18.8	22.0	24.8	3.9	1.8
TUFA[f]: SFA ratio	1.0	1.3	1.3	0.5	0.4
PUFA:MUFA ratio	0.7	0.7	0.8	0.1	0.1

[a]Mean values ± standard deviations of one sample analyzed in triplicate.

[b]Mean values ± standard deviations of one composite sample (prepared mixing three different lots or brands for mare and cow milk samples, respectively) analyzed in triplicate.

[c]SFA = Saturated Fatty Acids.

[d]MUFA = Monounsaturated Fatty Acids.

[e]PUFA = Polyunsaturated Fatty Acids.

[f]TUFA = Total Unsaturated Fatty Acids.

Adapted from Marconi and Panfili (45).

PUFA are precursors of long-chain polyunsaturated fatty acids (LC-PUFA), which are indispensable structural components of all cellular membranes (44). In addition, some LC-PUFA are known as precursors of eicosanoids, which have biological activity to modulate various cellular and tissue processes (35). Mare milk and its Koumiss have high levels of LC-PUFA, where the special properties of LC-PUFA may be accounted for the curative substances for hepatitis, chronic ulcer, and tuberculosis (64).

4.2.4 Conjugated Linoleic Acids

Conjugated linoleic acids (CLA) refer to a class of positional and geometric isomers of linoleic acid. They have been known as antioxidative and anticarcinogenic agents in recent years (56). Milk fat is an important source of potential anticarcinogens from the naturally occurring CLA group (44). Mare milk has negligible levels of CLA (mean value 0.09% of total fatty acids). CLA content of human milk has been reported as 0.2 to 1.1%, while that of cow milk ranges from 0.2 to 2.4% (30).

It has been shown that the percentage of fatty acids with less than 16 carbon in horse milk has 15–35% variability (16). The *trans* monounsaturated fatty acids and conjugated linoleic acids are not present in significant quantities in mare milk, even though *trans*-octadecenoic acid has been found at a level of 1% of fatty acids in colostrum. These fatty acids are specific to ruminant milks, due to ruminal hydrogenation (16).

4.2.5 Phospholipids

As shown in Table 5.8, mare milk has the highest levels of phospholipids, when compared to human and cow milk (57). The phospholipid composition of

mare milk is different from human and cow milk (31, 33). When compared to human milk, phospholipids of mare milk are relatively high in phosphatidyl ethanolamine (31% vs. 20%) and phosphatidyl serine (16% vs. 8%), and less rich in phosphatidyl choline (19% vs. 28%) and phosphatidyl inositol (trace vs. 5%), and the sphingomyelin proportion is similar (34% mare vs. 39% human) (31, 44).

Phospholipids are complex lipid compounds constituted mainly by polyunsaturated fatty acids, and they are present in all living cells as structural components of the lipoprotein layers of the cell membrane, particularly in neural cells (1).

4.2.6 Sterols

Compared to cow and human milk, mare milk appears to have a greater proportion of the unsaponifiable fraction (Table 5.8) (57). Among three species, human milk has the lowest level of unsaponifiable fat (Table 5.8), and mare milk is significantly higher in this fat fraction than cow milk. The sterol fraction in mare, human, and cow milk is composed partially of cholesterol, approximately 0.3–0.4% of the lipid content in all milks (31, 52).

4.3 Protein Composition

4.3.1 Major Protein Components

The major components of mare milk are quite similar to those of human milk, as shown in Table 5.11 (44). Both species' milks contain comparable levels of whey protein *in toto* and NPN content. Mare milk has about 10% non-protein nitrogen ranging from 8–15%, twice that of cow milk and half that found in human milk (16). The non-casein nitrogen is higher in mare milk with regards to both whey protein and non-protein nitrogen fractions (45).

In contrast, cow milk has a higher casein content than do mare and human milks, with the former being defined as *caseineux* milk in French (1, 8, 44, 52, 64). Proteins of mare milk are made of 40–60% caseins, close to the proportion in human milk (40%) and much less than in the milk of other species dairy breeds (16). The free amino acid fraction of mare milk is especially rich in serine and glutamic acid (16).

The whey protein fraction represents approximately 40% in mare milk, slightly more than 50% in human milk, and less than in cow milk (Table 5.11). The characteristic composition of cow milk major protein resembles other ruminant milks such as goat and sheep, while it is quite different from mare milk because cow milk is characterized by an acid-enzymatic, mixed coagulation (44). This characteristic of richness in whey protein in mare milk makes it more favorable to human nutrition compared to cow milk, due to its relatively greater supply of essential amino acids (22, 44).

4.3.2 Caseins

Caseins of mare milk are mainly composed of equal amounts of β-casein and α_s-casein (Table 5.12) (50), which have been characterized (19). On the other hand, Doreau and Martin-Rosset (16) reported that mare milk caseins contain β-casein and γ-casein,

Table 5.11. Main Nitrogen Fractions of Mare Milk in Comparison to Human and Cow Milk

	Mare		Human		Cow	
Crude protein (g kg^{-1})	21.4	(15–28)	14.2	(9–17)	32.5	(31–38)
True whey protein (g kg^{-1})	8.3	(7.4–9.1)	7.6	(6.8–8.3)	5.7	(5.5–7.0)
Casein (g kg^{-1})	10.7	(9.4–12.0)	3.7	(3.2–4.2)	25.1	(24.6–28.0)
NPN × 6.38 (g kg^{-1})	2.4	(1.7–3.5)	2.9	(2.6–3.2)	1.7	(1.0–1.9)
% of Total Protein						
True whey protein (%)	38.79		53.52		17.54	
Casein (%)	50.00		26.06		77.23	
NPN x 6.38 (%)	11.21		20.42		5.23	

Mean value and, between brackets, range values reported in literature.
References for human and cow milks are 1, 3, and 15; and those for mare milk are 9, 46, and 52, respectively.
Adapted from Malacarne et al. (44).

Table 5.12. Casein Distribution of Mare Milk in Comparison to Human and Cow Milk

	Mare		Human		Cow	
Casein (g kg^{-1})	10.7		3.7		25.1	
% of total casein						
α_s-casein (%)	46.65	(40.2–59.0)	11.75	(11.1–12.5)	48.46[a]	(48.3–48.5)
β-casein (%)	45.64	(40.1–51.4)	64.75	(62.5–66.7)	35.77	(35.8–37.9)
κ-casein (%)	(7.71)[b]		23.50	(22.2–25.0)	12.69[c]	(12.7–13.8)
Micelles size (nm)	255		64		182	

Mean value and, between brackets, range values reported in literature.
References cited include 3, 44, and 50.
[a]38.46 α_{s1}-casein and 10.00 α_{s2}-casein.
[b]κ-casein and other fractions not characterized.
[c]100% was reached with γ-casein fraction (3.08%).
Adapted from Malacarne et al. (44).

which represent 50% and less than 10% of total caseins, respectively, while it contains αs1- and α_{s2}-caseins as 40% of total caseins, and a small quantity of k-casein. The same authors also showed the recent identification of six fractions of β-casein in mare milk, which differ by the prominence of a phosphate group. Mare milk caseins contain lower levels of proline and glutamic acid, and higher aspartic acid than bovine milk counterparts (16).

Egito et al. (18) demonstrated that mare milk has several biochemical properties similar to that of bovine and human k-casein, including the presence of carbohydrate moieties and susceptibility to hydrolysis by chymosin (group II). They also noted that k-casein in mare milk was proportionally lower than in cow and human milks. Mare milk has the largest casein micelles among the three species, as shown in Table 5.12. Goat milk also has significantly greater micellular diameter than cow milk. Cow and mare milk micelles have a sponge structure, while human milk has a reticular, fairly regular, and very loose structure due to numerous canals and caverns (28).

Cow milk has significantly higher α_{s1}-casein content than do mare and human milk. The cow casein fraction is responsible for firmer cheese curd formation as well as for the certain degree of the onset of allergic reactions in children (47). Compared to bovine milk, mare milk is relatively richer in β-casein, and thereby able to supply children with abundant amounts of casomorphins (7). Mare and human milk as well as goat milk form a finer, softer curd, which is physiologically more suitable for infant nutrition and gives better digestibility compared to cow milk counterparts (32, 54, 64).

4.3.3 Whey Proteins

The whey proteins of mare milk after the colostral stage contain 2–19% serum albumin, 25–50% α-lactalbumin, 28–60% β-lactoglobulin, and 4–21% immunoglobulin (16). As shown in Table 5.13, the pattern of mare milk whey has a distinctive concentration and distribution of proteins and enzymes in the lacteal secretion, differing from those of bovine and human counterparts (41, 52, 64).

Both mare and bovine milks contain significant amounts of β-lactoglobulin, while human milk is devoid of this whey protein (Table 5.13). It has been shown that β-lactoglobulin is a major protein responsible for the onset of allergic reaction that affects a significant percentage of infants nourished with formula milks other than mother's milk (5, 6, 24).

Compared to other dairy species, mare milk is rich in lysozyme and lactoferrin (16). Although Doreau and Martin-Rosset (16) stated that lactoferrin content of mare milk is particularly high (0.2–2 g/kg milk), which is 10 times higher than in cow milk and slightly lower than in human milk. Table 5.13 (44) shows a different pattern, where human milk has significantly higher content (three times) than mare and cow milk. Lysozyme content in mare milk is significantly higher than in human and cow milk (Table 5.13), while Doreau and Martin-Rosset (16) reported that the level in mare milk (0.8 g/kg) is similar to that in human milk and much higher than in cow milk. The antimicrobial property of mare milk may be attributable to the higher levels of lysozyme and immunoglobulins in the milk (64). Cow milk is

Table 5.13. Whey Protein Distribution[a] of Mare Milk in Comparison to Human and Cow Milk

	Mare		Human		Cow	
True whey protein (g kg^{-1})	8.3		7.6		5.7	
% of total whey protein						
β-lactoglobulin (%)	30.75	(25.3–36.3)	Absent		20.10	(18.4–0.1)
α-lactalbumin (%)	28.55	(27.5–29.7)	42.37	(30.3–45.4)	53.59	(52.9–53.6)
Immunoglobulins (%)	19.77	(18.7–20.9)	18.15	(15.1–19.7)	11.73	(10.1–11.7)
Serum albumin (%)	4.45	(4.4–4.5)	7.56	(4.5–9.1)	6.20	(5.5–76.7)
Lactoferrin (%)	9.89		30.26		8.38	
Lysozyme (%)	6.59		1.66		Trace	

Mean value, and range values in parenthesis that are reported in literature.
References for human and cow milks are 3, 41, and 64, respectively; and for human milk reference is 41 only.
[a]Proteose-peptone fraction was not reported in the considered references.
Adapted from Malacarne et al. (44).

deficient in these antimicrobial factors, where immunoglobulins act as the primary defense against microbes, although they are rich in colostrums (64).

4.3.4 Amino Acid Composition

The amino acid profiles of raw, powdered, and vitamin-fortified mare milk, and pasteurized and powdered cow milk, are shown in Table 5.14. Compared to cow milk counterparts, powdered mare milk had significantly higher levels of arginine, half cystine, and aspartic acid (45). These amino acid values of raw and powdered mare milks are in agreement of those reported by Doreau et al. (13). Glutamic and aspartic acids are the largest fractions of the free amino acids existing in mare milk (Table 5.14).

The powdered mare milk had lower lysine content than those values reported by other researchers for raw and freeze-dried mare milk (9, 66). The low lysine content in the powdered product may be accounted for the loss of the amino acid during the drying process and storage, with moisture and temperature changes through the formation of ϵ-lactulosyl-lysine (Amadori compound), produced in the early stage of the Maillard reaction (45). Marconi and Panfili (45) confirmed this phenomenon by the high furosine content through molecular markers of the thermal and storage processes (20, 58), which can be obtained by acid hydrolysis of ϵ-lactulosyl-lysine of powdered samples. The lysine loss in mare milk powders, especially in the vitamin-fortified powdered milk, could be mainly due to storage conditions. Moisture content greater than 6% and the air temperature would favor the Maillard reaction (45, 58).

4.4 Vitamins

Vitamin contents of mare colostrum and normal milk (Table 5.15) revealed that colostrum contained 2.6, 1.7, 1.4, and 1.5 times higher vitamin A, D_3, C, and K_3 contents, respectively, compared to the milk from 8–45 days of lactation. Vitamin C content was also higher in colostrum than in normal milk, and mare milk had higher vitamin C than did cow milk (8). Other vitamins in normal mare milk were comparable to cow milk.

The vitamin contents of mare milks reported by Souci et al. (65) were lower than those reported by Csapo et al. (8), as shown in Table 5.14. The vitamin fortified mare milk powder sample has an exceptionally high level of α-, γ-, and δ- tocopherols. They were added in order to improve shelf-life as well as the nutritional quality of the product (43). Moreover, the powdered mare milk samples had a higher amount of *cis/trans* retinol ratio than in raw mare milk due to the isomerization of *trans* retinol during thermal treatment (53).

4.5 Minerals

The mineral composition of mare milk during 3–196 days of lactation is shown in Table 5.16 (46). Significant variations are observed. The milk produced from 3–15 days of lactation clearly showed more ash (0.601 g), Ca (135.5 mg), P (87.5 mg), and

Table 5.14. Amino Acid Profile of Mare and Cow Milk (g/16 g N)

	Mare milk			Cow milk	
Amino acid[a]	Raw	Powder[b]	Vitaminized Powder[b]	Pasteurized[b]	Powder[b]
Threonine	4.13	4.2 ± 0.18	3.86 ± 0.07	4.0 ± 0.18	4.4 ± 0.31
Half Cystine	1.55	1.55 ± 0.02	1.53 ± 0.06	0.76 ± 0.03	0.66 ± 0.02
Valine	5.60	5.2 ± 0.35	5.7 ± 0.31	6.1 ± 0.18	6.0 ± 0.33
Methionine	2.53	2.0 ± 0.11	2.40 ± 0.04	2.66 ± 0.09	2.56 ± 0.09
Isoleucine	4.62	4.5 ± 0.28	4.6 ± 0.35	5.1 ± 0.15	5.0 ± 0.23
Leucine	8.61	8.6 ± 0.30	9.00 ± 0.02	9.0 ± 0.20	9.6 ± 0.14
Tyrosine	4.53	5.0 ± 0.24	5.1 ± 0.30	4.5 ± 0.23	4.70 ± 0.04
Phenylalanine	4.13	4.87 ± 0.07	5.0 ± 0.19	4.6 ± 0.21	4.91 ± 0.08
Lysine	7.06	6.2 ± 0.13	5.1 ± 0.18	7.6 ± 0.39	7.2 ± 0.22
Aspartic acid	8.26	8.35 ± 0.02	8.5 ± 0.25	7.4 ± 0.21	6.9 ± 0.10
Serine	5.60	5.43 ± 0.06	5.6 ± 0.16	5.1 ± 0.22	5.0 ± 0.39
Glutamic acid	18.2	17.7 ± 0.25	17.6 ± 0.43	18.9 ± 0.75	18.3 ± 0.64
Proline	7.46	7.7 ± 0.59	7.9 ± 0.23	9.1 ± 0.40	8.9 ± 0.27
Glycine	1.95	1.61 ± 0.04	1.67 ± 0.04	1.75 ± 0.04	1.79 ± 0.02
Alanine	3.15	3.39 ± 0.08	3.4 ± 0.11	3.1 ± 0.12	3.3 ± 0.11
Histidine	2.49	2.50 ± 0.02	2.3 ± 0.13	2.3 ± 0.17	2.59 ± 0.07
Arginine	5.20	5.68 ± 0.09	5.8 ± 0.12	3.1 ± 0.15	3.14 ± 0.01
Chemical score	> 1.00	> 1.00	0.88	> 1.00	> 1.00

[a]The sum of amino acids was standardized at 95% protein in order to allow a correct comparison between data.

[b]Mean values ± standard deviations of one composite sample (prepared mixing three different lots or brands for mare and cow milk samples, respectively) analyzed in triplicate.

Adapted from Marconi and Panfili (45).

Mg (10 mg) than in the following phases of the lactation cycle. The ratio of Ca to P was 1.55 in mare milk at the beginning of the lactation. The value of the Ca:P ratio is near 1.7 and slightly increased throughout lactation.

Comparing to the first two weeks postpartum, the milk produced during the second month of lactation contained 25% less Ca and 30% less P. The milk of the fourth month contained 45% less Ca and 49% less P. The milk taken at drying-off was the poorest both in Ca (68.5 mg) and in P (35.7 mg). The variations due to the lactation stage observed (46) are in accordance with those found by other authors for saddle breeds (63, 60, 70), as well as for other horse breeds (9).

Table 5.15. Vitamin Content of Colostrum and Normal Milk of Mare and Cow (mg/kg)

	Postpartum days		
	Mare		Cow
Vitamin	0–0.5	8–45	5–270
A	0.88	0.34	0.352
D_3	0.0054	0.0032	0.0029
E	1.342	1.128	1.135
K_3	0.043	0.029	0.032
C	23.8	17.2	15.32

Adapted from Csapo et al. (8).

5 MANUFACTURE AND UTILIZATION OF MARE MILK PRODUCTS

Mare milk and its products have been produced and utilized in the regions where traditional horse breeding for dairy production has been practiced. Because horse milk has some compositional similarities to human milk and possesses several therapeutic values, it has recently entered the markets of western European countries (16, 75).

Among the horse milk products, koumiss is the most widely consumed traditional mare milk product. Commercial mare milk cheese may not exist

Table 5.16. Change in Mineral Composition of Mare Milk for Different Stages of Lactation (g or mg/100 g Milk)

Minerals			Lactation period (d) and (drying-off)					
			3–15	16–30	31–60	61–90	91–120	(166–196)
Ash	G	$\overline{X}$	0.601	0.495	0.450	0.410	0.342	0.370
		SD	0.020	0.017	0.014	0.017	0.015	0.024
Ca	mg	$\overline{X}$	135.5	121.1	101.7	92.9	74.8	68.5
		SD	5.4	5.1	3.9	5.4	4.2	1.0
P	mg	$\overline{X}$	87.5	68.5	60.9	54.6	44.6	35.7
		SD	5.1	2.4	2.0	1.2	2.4	2.0
Mg	mg	$\overline{X}$	10.0	8.7	7.2	6.4	5.4	4.0
		SD	0.8	0.4	0.5	0.4	0.2	0.4
Ca : P	—-	$\overline{X}$	1.55	1.77	1.67	1.70	1.68	1.92
		SD	0.09	0.05	0.05	0.08	0.15	0.11

Data adapted from Martuzzi et. al. (46).

due to the lack of its coagulation properties. Powdered horse milk products have been commercially produced and marketed in retail outlets such as health food stores in certain developed countries. A few other forms of dairy horse products may be available or utilized including for a certain cosmetic purpose (74, 75).

5.1 Koumiss

5.1.1 Product Characteristics of Koumiss

Koumiss is a fermented alcohol-containing beverage made from mare milk. Koumiss is widely consumed as a popular drink by different product names in Russia and western Asia, Mongolia, and Northern China (Table 5.17). It is especially preferred by elderly people from tradition or for its therapeutic uses (16). Koumiss usually contains 0.6–3% alcohol, averaging 2%, and it is slightly gaseous. Its end products of fermentation have lactate and ethanol, due to a consortium of bacteria and yeast added to the milk (16).

Sweet koumiss contains 0.6–0.8% acidity as lactic acid and 0.7–1.0% ethanol. Strong koumiss contains 1–1.2% acidity and 1.8–2.3% ethanol with pH values 4.2–4.7. The processing of koumiss has major problems in process control related to unpleasant taste due either to the proliferation of yeast or an excess of acidification. In Russia and Germany, the name "kumys" is often used especially for a product that is produced from cow milk, using the same fermentation process (16). The manufacturing technology of koumiss is similar to kefir except that mare milk is used for koumiss. Generally, koumiss contains more alcohol than does kefir, while fer-

Table 5.17. Koumiss Products Made in Different Countries

Product name	Country	Alcohol content
Airag, Arrag, Chige	Mongolia	3%
Araka	USSR	NA
Busa	Turkmenistan, USSR, China	7%
Fuli	Finland	NA
Kjaeldermelk	Norway	0.5%
Ma tung	China	NA
Puma	Finland	NA
Shubat	USSR	NA

Adapted from Zhang and Yang (74).
NA = not available.

Figure 5.3. Koumiss fermentation in urn. Photo by Heping Zhang.

menting flora in kefir is more variable than in koumiss. Proper adjustment of fermentation is believed to be the key factor for producing high-quality koumiss (74). An example of koumiss fermentation in urn is shown in Figure 5.3.

5.1.2 Microbiology of Koumiss

The composition of microflora in original koumiss is very variable. The dominating microorganisms consist mainly of lactic acid bacteria and yeast. The microbial composition of koumiss differs from one production site to the other. Among yeast species, different genera of *Saccharomyces, Torula, Torulopsis,* and *Candida* are found. Studying Koumiss microflora, Khrisanfova (34) found that yeasts in the product consisted of three main types: lactose fermenting (*Saccharomyces lactis*), lactose non-fermenting (*S.cartilaginosus*), and carbohydrate non-fermenting yeasts (*Mycoderma*). Koroleva (36) indicated that lactose-fermenting yeast included *Kluyeromyces maxianus* subsp. *marxianus* and *Candida kefyr.*

Lactic bacteria of Koumiss mainly belong to *Lactobacillus* and *Lactococcus* species. The main microorganisms responsible for lactic acid development are generally thermophilic lactobacilli such as *L. delbrueckii subsp bulgaricus.* However, a recent investigation on the composition of koumiss microflora, sampled separately from homemade koumiss in Mongolia in Inner Mongolia of China, showed that different lactobacilli species might be involved in fermentation (74). Many different strains of the isolates from the seven samples of homemade koumiss were identified (Table 5.18) (74).

During 1940–1960, after the introduction of pasteurization of mare milk, starter composed of pure cultures of lactobacilli such as *L. delbrueckii* subsp. *bulgaricus* and yeasts was used for koumiss manufacture. Those yeasts in koumiss related to the species *S. lactis* were best capable of producing alcohol (2–3.5%). Both species of *Saccharomyces* were able to produce antibiotic substances. Skorodumova (62) isolated yeasts of *S. lactis* that exhibited high antibiotic activity against *Mycobacterium tuberculosis* and other harmful microorganisms. Species of *L. kefir* can also be found, and these strains grow best at higher temperatures than those normally used in koumiss manufacture. The use of a mixed starter culture consisting of *Saccharomyces lactis, L. delbrueckii* subsp. *Bulgaricus,* and *L. kefir* were recommended (34)

The antibiotic activity of yeasts became stronger when they grew together with lactic bacteria.

Table 5.18. Lactobacilli Strains Isolated from Homemade Koumiss Products from Inner Mongolia of China and Mongolia

Samples	Lactobacilli strains identified	Original place
10-3702	*Lactobacillus acidophilus, Lactobacillus delbrueckii* subsp. *Bulgaricus*	XiMen, Inner Mongolia, China
7-3702	*Lactobacillus casei, Lactobacillus curvatus, Lactobacillus acidophilus*	XiMen, Inner Mongolia, China
1M	*Lactobacillus kefiranofaciens, Lactobacillus acidophilus, Lactobacillus sake*	Ulan Bator, Mongolia
2M	*Lactobacillus acidophilus, Lactobacillus acetolerans*	Ulan Bator, Mongolia
M_1	*Lactobacillus acidophilus, Lactobacillus agilis, Lactobacillus coryniformis* subsp. *coryniformis, Lactobacillus casei, Lactobacillus curvatus*	Ulan Bator, Mongolia
M_2	*Lactobacillus delbrueckii* subsp. *bulgaricus, Lactobacillus agilis*	Ulan Bator, Mongolia
M_3	*Lactobacillus zeae, Lactobacillus agilis*	Ulan Bator, Mongolia

Adapted from Zhang and Yang (74).

Banikova and Lapshina (2) developed a starter for industrially manufactured koumiss from cow milk. This starter consists of yeasts belonging to the species *S. lactis*, which is active against *Mycobacterium tuberculosis*, and of lactose-fermenting *L. delbrueckii* subsp. *bulgaricus* and *L. acidophilus*. The lactobacilli were introduced into the starter to increase antibiotic activity of the koumiss.

Shigaeva and Ospanova (61) developed two types of koumiss starters, selecting strains for their ability to produce aroma, acid, and alcohol as well as to grow together. The best combination was composed of *S. lactis* 273, *L. delbrueckii* subsp. *bulgaricus* 168, *S. lactis SK* or *S.lactis* 1-27, *L. delbrueckii subsp. Bulgaricus* b-3, *Acetobacter aceti* B-3, and *L. delbrueckii* subsp. *lactis* 17. The presence of acetic acid bacteria in koumiss starter enhances the typical aroma of koumiss made from pasteurized mare milk.

5.1.3 Preparation of Koumiss Starter

Starter for koumiss is prepared under conditions that provide for equal growth of all microorganisms. The starter is prepared by mixing 10–15 ml of pure cultures of *L. delbrueckii* subsp. *bulgaricus, L. acidophilus* and yeasts obtained by rinsing 2–3 tubes with 300 ml of pasteurized milk cooled to 30° C. The milk is first incubated at 30° C for 7–10 hours and subsequently at room temperature for a further 3–6 hours to stimulate the growth of yeasts. For the preparation of the intermediate starter, the milk is inoculated with 10–20% of the above starter and fermented at 30° C for 3–8 hours and then at room temperature for another 3–6 hours. This starter is used for preparation of bulk starter by adding 10–20% of the starter to skim milk, which has been pasteurized at 85–90° C for 10 to 30 min. After the acidity of milk reaches at 85–90° T, the starter is agitated and then held for 3–4 hours to promote the growth of the yeasts. During this period the starter is stirred at least 10 times each for 5 min. Acidity of the finished starter should be in the range of 110–140°T (74).

Lactic acid starter culture of *Lactococcus lactis* subsp. *lactics*, producing lactic acid, and *Lactobacillus delbrueckii* subsp. *bulgaricus*, producing lactic acid and acetaldehyde, are major contributors to the flavor of koumiss. The yeast *Candida kefir* and *Torulopsis* species produce ethanol and carbon dioxide. Koumiss processing generally lasts 4–6 hr. After milk seeding, processing includes sequences of mixing and aging, sometimes milk addition in the course of the process, to reach the expected degree of acidity and alcohol level.

5.1.4 Processing Technology of Koumiss

The general manufacturing procedure for the production of koumiss products is described in the following steps (74):

1. First, two starter cultures need to be prepared, one containing thermophilic lactic acid bacte-

ria, incubated at 35–37° C for 6–7 hr, and the other containing lactose-fermenting yeasts, incubated at 28–30° C for 15–18 hr.
2. For the second stage of production, the two mother starter cultures are mixed with a small quantity of mare milk, and incubation is continued at 26–29° C. Fresh milk is added at regular intervals until the starter is ready after 3–4 days.
3. Third, starter is then added at about 30% to fresh milk. Fermentation is carried out at 26–29° C for 2 hr with stirring to allow air to penetrate for yeast growing. Fermented mare milk is to settle and then is packed in bottles and sealed.
4. Fermentation is continued in bottles at 18–20° C for 2–3 hr and then cooled to 4–6° C until consumption. Depending on fermentation time, sweet koumiss can be made for one day or strong koumiss for three days. The koumiss containing high levels of alcohol can be distilled into a liquor-like beverage.
5. The final koumiss products should contain: 10–13% of total solids; protein, 2.0–2.5%; fat, 1.0–1.3%; carbohydrate (lactose), 4.5–5.5%; ash, 0.4–0.7%; energy, 37–40 kcal per 100 mL; and average 2% alcohol.

5.2 Powdered Mare Milk Products

West European countries, especially Germany, France, and Italy, have recently begun selling mare milk powder products in chemist's and health food stores (45, 75). These products can be directly ingested or rehydrated in water before consumption. The vitamin-fortified, powdered mare milk was also produced and marketed. The powdered mare milk products retained some peculiar characteristics of raw mare milk such as high whey protein and polyunsaturated fatty acid (C18:2; C18:3) contents and low casein content (45).

5.3 Frozen and Lyophilized Horse Milk

In developed western European countries, horse milk is also sold as frozen milk and capsules of lyophilized milk for people who seek health food or specialized organic foods (16, 75). Lyophilized mare milk, packaged in 100-gram powder bags, is distributed in the developed countries of Western Europe. This is equal to approximately 1 liter of fresh mare milk. Frozen mare milk is sold in packages of 2 deciliters. Neither frozen nor freeze-dried milk has had any kind of preservatives added (74). Some minor volumes of frozen or lyophilized colostrum are distributed to feed orphan foals, or to newborn foals that refuse to suck mother's colostrum, or where the mother's colostrum is deficient in quality and quantity (16).

5.4 Other Horse Milk Products

In Europe, mare milk is also used for cosmetology (16, 75). A range of cosmetic products are manufactured using horse milk, where creams containing about 10% mare milk, soaps and moisturizers have been commercialized (16, 75). Although these products are commercially marketed, they remain marginal products due to the lack of demonstrated specificity of mare milk compared to cow milk which is less expensive (16).

In Norway, mare milk, together with ethereal oils, also is employed as natural ingredients to produce Gyda's Shampoo for sensitive skin and scalp (74). In Germany, a freeze-dried form of fermented mare milk (granulate Kumylac), Kumylac lotion, and bath and shower gel also have been marketed (75).

5.5 Utilization and Beneficial Effects of Mare Milk Products

Mare milk has been widely utilized to replace human milk in many regions in the past (16, 66). The mare milk protein is particularly rich in whey protein, polyunsaturated fatty acids, and vitamin C (52). For the same reasons, mare milk is highly sensitive to preservation and/or processes.

5.5.1 Low Allergenic Property of Mare Milk

Cow milk allergy is a common problem in infancy and early childhood (23, 54). It has been reported that most children with a cow milk allergy can tolerate mare milk. The protein profile of mare milk has some similarities to human milk, and the high lactose content of mare milk makes it pleasant to consume.

Subjects of 25 children with severe IgE-mediated cow milk allergy showed strong positive skin tests to cow milk, while only two of the 25 had positive skin

test responses to mare milk (42, 74). These data strongly suggest that mare milk, with appropriate modifications, can be used as a good substitute of cow milk in children with severe IgE-mediated cow milk allergy. Moreover, horse milk digestibility, measured *in vitro* or in rats, is higher than cow milk and similar to human milk, probably because whey protein is more digestible than casein. Horse milk is also evacuated more rapidly from the stomach than cows' milk (42).

5.5.2 Therapeutic Values of Mare Milk

Although horse milk and its products have been well known to be beneficial for human health for centuries in Russia and West Asia, much literature is based on empirical evidence from the past rather than scientific experimentations (16, 75). It is reported in Mongolian medicine that mare milk is, as with camel milk, more efficient than cow milk for treating chronic hepatitis and peptic ulcer. Horse milk also has antacid properties. These therapeutic effects may be attributed to the higher content of phospholipids, and vitamin A contributes to healing (16, 74).

Use of horse milk to treat the suffering of patients from tuberculosis has been practiced for a long time in Russia and Mongolia (74). It has been reported that drinking mare milk increases the number of erythrocytes and lymphocytes, and restores a normal erythrocyte sedimentation rate. These beneficial effects were confirmed by the long experience of Russian sanatoria, which dispensed lasting treatments (16).

Some other diseases and symptoms including anemia, nephritis, diarrhea, and gastritis, and other digestive diseases are also treated with mare milk and koumiss, especially for postoperative care (16). Koumiss is believed to have better therapeutic effects than raw horse milk, because the fermented product has some added ingredients during manufacture, and some microbial metabolic by-products such as peptides, bactericidal substances, synthesized vitamins, and presence of fatty acids of the n-3 series, which could stimulate immune system and promote antibacterial activities (16, 74).

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6
Camel Milk

El-Sayed I. El-Agamy

1 INTRODUCTION

Camels support the survival of millions of people in arid and semi-arid areas of the world. They possess remarkable abilities to exploit very limited resources because they are extremely well suited for life under harsh conditions of hot climates where water is frequently scarce. Also, they provide milk almost all year around in quantities much greater than other animals living under the same conditions. The camel is also used as a pack animal to carry up to 600 kg on its back, and is valued as a riding and draft animal. Furthermore, it provides meat, fine hair, and hide. In spite of these economic and ecological advantages of camels, little attention has been directed to them.

The *Camelidae* originated in North America millions of years ago (188). Camels migrated from America in the late Tertiary period and evolved in other parts of the world. The camel family *Camelidae* belongs to the order *Artiodactyla* (even-toed ungulates) and suborder *Tylopoda* (pad-footed). The old-world camels belong to the genus of Camelus with two species: *Camelus dromedaries* (one-humped camel) and *Camelus bactrianus* (two-humped camel). The new world camels belong to the genus *Lama* with three species: *L. guanicoe* (the guanaco), *L. peruana* (the llama), and *L. pacos* (the alpaca) and to the genus *Vicugna* with only one species, the Vicuña (243). The camelids, which inhabit the areas of South America, have adapted to the specific environments of cold atmosphere and relative lack of oxygen. Although these animals are renown for their wool quality, they are bred not only for their wool but also for meat, and are used as beasts of burden (29). On the other hand, the Dromedary (*Camelus dromedarius*) inhabits the hot, arid areas in Africa, Asia, and the Middle East. The name "Dromedary" is derived from the Greek *dromeus*, or "runner." The Dromedary is slim, long-legged, and short-haired, and its habitats are the warm, arid, and semi-arid areas (210). The two-humped camel (*Camelus bactrianus*) inhabits and is adapted to cold and arid regions such as the frozen deserts of Mongolia, China, and the Commonwealth of Independent States (the former Soviet Union). This animal is slightly smaller than the Dromedary and is stockier, more short-legged, has two distinctive humps, and its wool is of good quality (Figure 6.1a). The name "Bactrianus" refers to the area "Baktriana" in North Afghanistan where this type of camel is thought to have originated (44). Cross-breeding between Dromedary and Bactrian has been achieved. The crossing of a Dromedary female with a Bactrian male results in a one-humped hybrid, which is found in Iran and Turkey. The hybrid is stronger than the parents and used as pack animal. However, crossing a Bactrian female with a Dromedary male results in a hybrid with unattractive appearance and that is less robust (100). The Arabian camel was probably domesticated in the region of today's Yemen and Oman about 3,000 to 4,000 years ago and was then introduced into North and East Africa, Persia, and India (202). This chapter is more concerned with the one-humped Dromedary camel.

Figure 6.1a. A herd of Bactrian camel (two-humped camel). Photo by the author; Almaty, Kazakhstan.

Figure 6.1b. Suckling of a Dromedary female camel (one-humped camel) by her calf before milking. Photo by the author; Egypt.

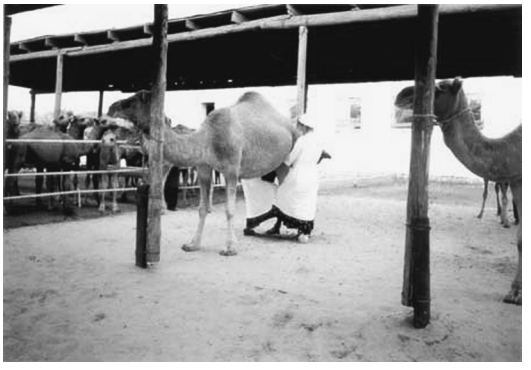

Figure 6.1c. Hand milking of a Dromedary female camel. Photo by the author.

2 CAMEL ADAPTATIONS

The ability of camelids, especially Dromedary, to adapt to arid conditions is unique among large herbivores. The most significant feature of this adaptation is the economic use of water in their metabolism. Camels are completely different from other domestic animals in their attempt to maintain steady body temperature with the rise of air temperature. Cattle, sheep, and goats expend energy and lose precious liquid, while in camels the body temperature fluctuates almost 6° C from early morning to late afternoon (201). These fluctuations are important in water balance. As the body temperature rises during the hot day, water, otherwise used to keep the temperature down, remains unexpended. The excess heat is stored in the body and is dissipated to the cool environment at night without use of water. Meanwhile, an elevated body temperature reduces the heat flow from the hot environment to the body and therefore reduces the amount of water needed to prevent further temperature rise. Sweat that is formed evaporates directly from the skin rather than from the tip of the hair as in other animals. The latent heat of vaporization is therefore drawn from the skin rather than from the atmosphere. The water, which is not utilized for cooling, is therefore available for milk production (233).

Camels have the lowest water turnover of all domestic animals. This enables them to continue eating, even when deprived of water for up to 54 days (108). As camels continue eating fodder, which contains relatively large quantities of fluid, their lactation is unaffected by the heat and lack of drinking water (140, 236). Also in times of water scarcity, urea and water are reabsorbed from the kidneys (71), while salt is excreted in a highly concentrated urine (235). Urea is re-utilized to provide microbial protein, which eventually is transformed to urea in normal body metabolism and recirculated as urea (233). The recirculation of water and nitrogen enables the camel to survive for about two months (108), and in the cool months enables camels to obtain all water requirements from forage.

3 CAMEL POPULATIONS AND DISTRIBUTIONS

According to FAO statistics, there are about 19 million camels in the world, of which 15 million are found in Africa and four million in Asia (Table 6.1). About 79% of the world's camel population is found in Africa, and all are one-humped. Camel populations are more concentrated in North East Africa, in Somalia, Sudan, Ethiopia, and Kenya, than in the West or North regions. In Asia, camel populations are greater in India, Pakistan, Saudi Arabia, Mongolia, China, Afghanistan, United Arab Emirate, Yemen, and Iran. In these regions, one-humped or two-humped camels or both are present. Fewer numbers of camels are found in regions of several other countries in Asia, including Russia. Generally, it is noticed that the numbers of camels increased during the last decade, especially in Africa, with 14.2 million head in 1989 and 15.1 million in 2001.

Table 6.1. World Camel Populations (74)

Country	Population (1000 head)
Africa	**15,124**
(a) North Africa	***699***
Algeria	240
Tunisia	231
Egypt	120
Libya	72
Morocco	36
(b) North East Africa	***11,445***
Somalia	6,200
Sudan	3,200
Ethiopia	1,070
Kenya	830
Eritrea	75
Djibouti	70
(c) West Africa	***2,961***
Mauritania	1,230
Chad	725
Mali	467
Niger	415
West Sahara	106
Nigeria	18
Asia	**4,198**
India	1,030
Pakistan	800
Saudi Arabia	400
Mongolia	360
China	326
Afghanistan	290
United Arab Emirates	200
Yemen	190
Iran	145
Other countries	457
Europe	**12**
Russia	12

4 MILK YIELD AND LACTATION

The camel, as with the cow, has a four-quartered udder. There are four teats, which can be well formed like cows' teats but usually are not as long or as thick, resembling more the teats of heifers (233).

Camels are mostly milked by hand (Figures 6.1b and 6.1c), however, machine milking is also used in some countries on a small scale, as in Kazakhstan, Russia, India, Saudi Arabia, Mauritania, and Egypt. It was noticed that the milk yield of camels milked by machine was higher than that of hand-milked camels (168). It is well known that milk yield is affected by several factors, such as forage quantity and quality, watering frequency, climate, breeding age, parity, milking frequency, calf nursing, presence of the calf, milking method (hand or machine milking), health, reproductive status, and individual merit.

Available data on camel milk yields are highly varied among regions (Table 6.2). This is mainly due to the effect of one or more of some of the above factors. In addition, under pastoral conditions, there is no consistent milking frequency, and the calves still suckle throughout the lactation, making estimates highly speculative. The importance of the presence of the calf on milk letdown is well understood by camel herdsmen, and in most circumstances the calves are always present to initiate milk letdown before the camels are milked. Camels whose calves survived past weaning had mean daily yields 65% higher than camels whose calves died before weaning. Mean lactational yields were 2.9 times higher (209). In Egypt, the nomadic people believe that if the calf dies, the camel will stop lactating and not accept any other calf to suckle her. It is common practice for herdsmen to let the calf suckle its mother to initiate milk letdown, because without this suckling the camel cannot be milked well (personal observation). The calf depends more or less on its mother's milk because of problems in the availability of drinking water (236).

Table 6.2. Milk Yields of Camels

Country	Daily yield (kg)	Milk yield (kg) (305 days)	Lactation period (months)	Reference
Dromedary				
Africa				
Egypt	4	1,068–1,373	9	(68)
Ethiopia	5–13	1,525–3,965	12–18	(138)
Libya	8.3–10	2,532–3,050	9–16	(92)
Sudan	5–10	1,525–3,050	10–12	(67)
Tunisia	4	1,220	12	(28)
E. Africa	3.5–4.5	1,068–1,220	9–18	(38)
Algeria	4	1,220	9–18	(91)
Kenya	2.7–5.3	986–1,945	12–13	(88, 105, 209)
Somalia	3–9	915–2,745	9–18	(105, 190)
Asia				
India	4.5–18	1,655–5,551	10–18	(133, 183)
Pakistan	8–20	2,440–10,675	12–35	(139)
China	7.5	2,285	16–17	(72)
Bactrian				
China	1.7–5	514–1,525	14–18	(44, 192, 238, 244)
Mongolia	1–2	477	16	(43)

Frequency of milking has a considerable effect on camel milk production. In Egypt, the milk yield was increased by 10–12% when milking occurred 3–4 times instead of twice per day (205). It was found that over a period of one month, camels that were milked four times per day gave 6–7.5 liters compared with 5.5–6.5 liters per day for those milked twice a day (73). More important, neither the heat of summer (140) nor the lack of drinking water (236) depressed milk yields.

The literature is full of conflicting data on milk yield of camels. Total yields of 13,560 kg per animal per lactation have been recorded (239). In Northern Kenya, yields of up to 50 liters a day have been reported (87), as well as peak milk yields of 20–40 liters a day (134, 139). In Tunisia, a daily milk yield of 2–4 kg was recorded for 14 camels over a lactation period of 8 months (167).

The milk production potential of four Saudi camel breeds was recorded during three consecutive lactations, and daily milk yields were 6.8, 8.1, 8.9, and 9.3 kg/head/day, with the maximum daily yields of two breeds at 14 and 18.3 kg/head (117). Several studies claimed that the milk yield of camels was higher than that of dairy cattle kept at the same arid conditions (117). In Kenya, camels yielded more than four times as much milk as cattle in the Samburu and Rendile areas (213). When camels and cattle were kept at the same hot conditions, only 1–2 liters per cow were produced versus 4 liters per camel (219). In another comparative study (140), camels, cows, and buffaloes were maintained under an intensive management system. The daily average milk yield was 19, 11, and 7 kg for camels, cows, and buffaloes, respectively. The total yield over a period of 305 days was 5,696, 3,385, and 2,065 kg for camels, cows, and buffaloes, respectively. The study showed also that when milk yields of cows, buffaloes, and camels were compared in Punjab villages, the daily yields were 4, 5, and 19 kg, respectively, under the harsh conditions of the arid region. This reflects the potential of camels as dairy animals.

The lactation curve of camels is different from that of other lactating mammals, because in cattle, the milk yield is low at the beginning of lactation and gradually increases until a plateau is reached before declining. However, in camels, it is high in the first seven months and then declines rapidly. This is probably due to poor management as well as milking practices (130). Different data on milk yields of Dromedary and Bactrian camels from different countries are shown in Table 6.2. For an accurate comparison, milk yields were calculated for a lactation period of 305 days. As shown, the milk

yield of Bactrian camels is low compared with that of the Dromedary.

The effect of milk yield on the chemical composition of Dromedary milk was studied (247). It was found that protein content was significantly lower in high-yielding camels than in the milk of low-yielding ones. However, there was no clear difference in contents of milk fat, lactose, and water between low- and high-yielding camels. The effects of bovine somatotropin (BST) on yield and composition of milk in dromedaries were also studied (246). Somatotropin increased milk production, but neither fat nor protein contents in milk at the time of maximum response were affected, although during the first week after injection of BST, a decrease in protein and increase in fat was recorded.

5 MILK COMPOSITION

5.1 Colostrum

It is well known that the milk of various mammals is adapted to their suckling young's requirements. For all mammals, colostrum is considered a vital food for the newborn, especially in the first days after birth, due to its high content of transfer immunity factors, that is, immunoglobulins in addition to its nutritive value.

Camel colostrum is not yellowish to reddish in color as that of cattle, but yellowish white (170). It has a lower viscosity than that of cattle and its color is bright or dark yellowish (50, 52, 53, 184, 237). In different regions of Egypt, Bedouins do not give colostrum to camel calves, because they believe that colostrum is harmful (personal observation). The same behavior was reported from Kenya (193).

Data on the chemical composition of camel colostrum are limited and varied from author to author. Table 6.3 shows the gross composition of camel colostrum of Dromedaries and Bactrians. Variations are mainly due to sample analysis and sampling time, that is, some colostrum samples are taken and analyzed within a few hours (50), after one day (52), or through the first week (6). In addition to that, other factors as breeding, health status, and so on are affecting the composition of colostrum.

Overall, camel colostrum contains high levels of total solids including total proteins, which are particularly high in whey proteins, that transfer immunity (immunoglobulins). It also has high contents of ash and chlorides, but low levels of lactose. These characteristics are similar to those of bovine colostrum (231). However, in most reports camel colostrum had very low fat contents, contrary to bovine milk, with high fat contents (231). Some differences between colostrum composition of Dromedary and Bactrian camels are also noted, with Bactrian colostrum being higher in contents of lactose, protein, and ash than that of Dromedaries.

The distribution of different nitrogenous constituents of Dromedary colostrum has been studied (50). No other data are available in the literature on this subject. As shown in Table 6.4, casein, whey protein, and non-protein nitrogen represent 34, 57, and 9% of total nitrogen, respectively. These ratios are quite different from those of bovine colostrum (155). Generally, non-protein nitrogen is higher in camel colostrum than in that of cows, goats, and human colostrum (50, 59). The mineral content of camel colostrum is given in Table 6.5. The only complete data showed that the mineral contents decreased with progressing lactation (237).

5.2 Normal Milk

5.2.1 Color and Taste

Dromedary milk has a very white color and can be foamy (50), similar to Bactrian milk (116). The taste of camel milk is usually sweet when camels are fed green fodder, but sometimes it is salty due to feeding on certain shrubs and herbs in the arid regions (50, 52, 116).

5.2.2 Physicochemical Properties

The physicochemical characteristics of camel milk from different countries are given in Table 6.6. It is clear that the data markedly vary from region to region. This is again mainly due to several factors such as the analyzed samples of individuals or bulk, the analytical procedure used, lactation period, animal breeding, feeding regimen, and so on. Means of all constituents were calculated from the available data (Table 6.6) for Dromedary and Bactrian milk, and compared with those of other species (Table 6.7). The total solids content is higher in normal Bactrian than in Dromedary milk. The effect of lacking drinking water on the composition of Dromedary milk was studied (237). It was found that water

Table 6.3. Physicochemical Characteristics of Camel Colostrum

Country	pH	Specific gravity	Titratable acidity %	Total solids %	Fat %	Solids non-fat %	Lactose %	Protein %	Casein %	Whey protein %	Whey protein: casein	Ash %	Chloride %	Reference
Dromedary														
Egypt (a)	6.70	1.043	0.153	15.28	0.40	14.88	2.65	11.23	5.17	6.06	1.17	1.00	0.22	(50)
Egypt (b)	6.65	1.050	0.165	21.19	3.30	17.89	4.47	11.72	4.39	7.33	1.67	1.70	0.19	(52)
Kenya	-	—	-	-	4.50	-	4.41	11.42	—	—	—	—	—	(130)
India	—	—	0.26	25.08	0.45	24.63	4.25	17.78	—	—	—	2.60	—	(170)
Saudi Arabia	—	—	-	20.50	0.20	20.30	2.70	13.00	—	—	—	1.00	—	(6)
Bactrian														
China	—	—	—	25.07	0.35	24.72	4.51	18.93	-	-	-	1.13	—	(244)
Kazakhstan	—	—	—	30.40	0.20	30.20	7.20	19.40	—	—	—	3.80	—	(204)

(a) Analysis of colostrum sample within 3 hours post-partum.
(b) Analysis of colostrum sample within 24 hours post-partum.

Table 6.4. Distribution of Nitrogenous Constituents in Dromedary Colostrum (52)

Nitrogenous constituents	Range (mg/100 ml)	Mean ± SE	% of total N
Total N	1,801–2,602	2,022 ± 194	—
Non-protein N	169–210	185 ±011	9
Casein N	497–912	0688 ± 131	34
Whey protein N	932–1,293	1,149 ± 120	57
Albumin N	287–485	396 ±065	20
Globulin N	486–903	0633 ± 123	31
Proteose peptone N	54–182	120 ±042	6

Table 6.5. Mineral Content of Camel Colostrum

Na	K	P	Ca	Mg	Zn	Fe	Time of analysis after parturition	Reference
			mg / L					
437	1,654	1,008	1,465	174	18	1.9	7 days	(96)
—	—	1,480	1,802	190	—	—	3 hours	(50)
—	—	2,550	1,560	450	—	—	0 hour	
—	—	1,650	1,810	320	—	—	24 hours	(237)
—	—	1,790	1,790	180	—	—	48 hours	

content of milk changes greatly, although the diet remained unchanged throughout the year. Water content of milk was 86% when drinking water was freely accessible, but when drinking was restricted, the water content of milk increased to 91%. This may explain why water and total solids contents of camel milk in different data varied. On the other hand, this explains also the superb adaptation of camels to the desert environment in order to supply her calf with milk of sufficient nutritional value and water content.

Values of specific gravity, fat, protein, lactose, and ash are higher in Bactrian than Dromedary milk. No data on pH values of Bactrian milk are available yet. In comparison to other species, camel milk has the lowest pH value and mares' milk the highest. The titratable acidity (as percent lactic acid) of camel milk is lower than that of cow's, buffalo's, sheep's, and goat's, but higher than that of human's, ass', and mares' milk. The specific gravity of camel milk is near that of cow and goat milk. Total solids content of Dromedary milk is similar to that of cow milk, while it is higher in Bactrian milk and above all other species except buffaloes and sheep. Fat and protein contents of Dromedary milk are similar to cow milk, but higher in Bactrian milk.

The casein contents of Dromedary and cow milk are similar, while whey protein fractions are higher in Dromedary milk. Bactrian milk has also higher contents of casein and whey protein compared to milks of other species, except sheep milk. The ratio of whey protein to casein in Dromedary and Bactrian milk is higher than in cow, buffalo, sheep, and goat, but lower than in human, ass and mare's milk proteins. This may explain why the coagulum of camel milk is softer than that of cow and buffalo milk (50). The state of fat, that is, its diameter, and the ratio of fat to casein can affect the smoothness of the formed curd. Obviously, the ratio of fat to casein is higher in camel than in cow milk.

Lactose content is similar in Dromedary and cow milk, but it is higher in Bactrian milk. The ash contents in Dromedary or Bactrian milk are similar to those of cow, buffalo, and goat, but lower than in sheep milk. The available data on chloride contents of camel milk show that the level is higher than in milks of other species. This may be due to the effect of feeding as well as the types of fodders grazed by camels (234).

The freezing point of Dromedary milk is between −0.57° C and −0.61° C (228). It is lower than that

Table 6.6. Physicochemical Parameters of Dromedary and Bactrian Milk*

Country	Water %	Total solids %	Fat	Milk solids non-fat %	Protein %	Casein %	Whey protein %	Lactose %	Ash %	pH	Specific gravity	Acidity %	Chloride %	References
Dromedary														
Egypt	87.8	12.2	3.75	8.56	3.13	2.43	0.95	4.50	0.80	6.53	1.03	0.16	0.19	(50, 68, 76, 104, 188)
Libya	87.0	13.0	3.30	9.70	3.30	—	—	5.60	0.80	—	—	—	—	(95)
Saudi Arabia	87.7	12.3	3.49	8.87	3.26	1.90	0.90	4.78	0.83	6.50	—	0.13	—	(5, 6, 159, 198)
Kenya	87.7	12.3	4.33	8.62	3.20	2.64	—	4.34	0.82	—	—	—	—	(82, 130, 230)
Somalia	86.9	13.1	4.60	8.50	3.00	—	—	4.90	0.60	6.50	1.03	—	—	(161)
Ethiopia	85.6	14.4	5.50	8.90	4.50	—	—	3.40	0.90	—	—	—	—	(138)
India	90.2	9.80	3.20	6.60	2.70	—	—	4.20	0.60	6.50	1.03	0.17	—	(40)
Tunisia	87.9	12.1	3.76	8.37	3.43	2.88	—	—	0.81	6.53	1.03	0.16	0.20	(125)
Pakistan	87.1	12.9	5.22	7.71	2.68	—	—	4.30	0.73	6.60	—	0.14	—	(245)
Bactrian														
Former USSR	85.3	14.7	5.16	9.53	3.87	2.80	0.93	5.13	0.71	—	1.03	—	—	(136, 137)
China	84.6	15.4	5.52	9.86	3.98	—	—	4.92	0.94	—	1.04	—	—	(192, 244)
Mongolia	84.5	15.5	5.40	10.10	4.40	—	—	4.80	0.90	—	—	—	—	(116)
Kazakhstan	84.5	15.5	5.17	10.37	4.45	3.22	1.10	4.82	0.68	—	1.03	—	—	(203)

*Values given are means calculated from different sources.

Table 6.7. Physicochemical Parameters of Camel Milk as Compared with Milk of Different Species

	Species, mean values								
Constituents	Dromedary	Bactrian	Cow	Buffalo	Sheep	Goat	Human	Ass	Mare
Water %	87.59	84.81	87.78	83.81	82.95	87.30	88.66	90.79	89.74
Total solids %	12.41	15.19	12.25	16.19	17.05	12.12	11.34	9.16	10.16
Fat	3.96	5.32	3.60	6.75	5.95	4.15	2.80	0.95	1.01
Milk solids non-fat %	8.45	9.87	8.65	9.44	11.10	7.97	8.54	8.21	9.15
Protein %	3.22	4.09	3.24	4.18	5.25	3.02	1.97	1.86	2.31
Fat:Casein	1.65	1.77	1.43	2.09	1.47	1.79	3.94	1.51	1.04
Casein %	2.4	3.01	2.51	3.22	4.06	2.32	0.71	0.63	0.97
Whey protein %	0.93	1.02	0.73	0.96	1.19	0.70	1.26	1.23	1.34
Whey protein: Casein	0.36	0.34	0.24	0.27	0.29	0.28	1.77	1.94	1.38
Lactose %	4.56	4.95	4.65	4.45	4.91	4.21	6.30	5.95	6.40
Ash %	0.79	0.81	0.76	0.81	0.94	0.74	0.27	0.40	0.44
pH	6.55	—	6.68	6.70	6.79	6.70	6.90	6.85	7.01
Titratable acidity %	0.15	—	0.18	0.18	0.19	0.17	0.06	0.08	0.10
Specific gravity	1.029	1.033	1.032	1.035	1.037	1.031	1.029	1.026	1.028
Chloride %	0.142	—	0.117	0.120	0.108	0.116	0.035	0.032	0.028
Energy (KCal/L)	665	920	701	1035	1043	721	619	430	480

Dromedary and Bactrian values were calculated from data in Table 6.6; other species values from reference (65).

of cow milk (−0.51 to −0.56° C). Higher salt or lactose contents in camel milk may contribute to this result (50). The viscosity of Egyptian camel milk was estimated at 2.2 cPas (107), 2.35 cPas (50), which is higher than for cows (1.7 cPas), goats (2.12 cPas), but less than for sheep (2.48 cPas), and similar to that of buffaloes (2.2 cPas) (156). The electrical conductivity of 50 samples of camel milk ranged between $34–58 \times 10^{-4}$ with a mean value of $46 - 10^{-4}$ mhos (50). Camel milk has a high alcohol stability number (32.3) (50) versus 20.8, 10.3, 12.5, and 14.1 for cow, buffalo, goat, and sheep milk, respectively (156).

Whole camel milk has a maximum buffer index between 0.060 and 0.062 at pH 5.2, while the minimum ranged between 0.011 and 0.012 at pH 7.7 to 7.9 (50). The corresponding values for cow, buffalo, sheep, and goat milks were 0.034, 0.043, 0.049, and 0.042 at pH 5.2 for their maximum buffer indices, respectively. However, their minimum buffer indices were 0.006 (pH 8.40), 0.007 (pH 8.65), 0.007 (pH 8.45), and 0.006 (pH 8.50), respectively (156). Other studies revealed that camel skim milk has a maximum buffering capacity at pH 4.95 versus at pH 5.65 for cow skim milk (12). The differences in buffer capacity of camel milk and that of other species reflect the compositional variations in constituents involved in the buffering system such as proteins and salts.

5.2.3 Nitrogen Distribution of Camel Milk Constituents

Data from different sources reveal that casein N, whey protein N, and non-protein N ranged from 61–76%, 17–29%, and 5.8–10.6%, respectively. This indicates that normal camel milk has slightly higher contents of whey proteins and non-protein N (5, 18, 50, 65, 84, 159, 160). Changes in nitrogenous constituents of normal camel milk throughout lactation of nine months were studied (50) (Table 6.8). Total nitrogen decreased sharply with progressing lactation. Casein nitrogen decreased in the pre-lactation period, then increased in mid-lactation and decreased until the end of lactation. Whey protein nitrogen decreased and non-protein N increased with lactation progress.

Table 6.8. Changes in Nitrogenous Constituents of Camel Milk During Lactation (50)

Lactation period	Total N, mg N/100 ml	Non-protein N, % of total N	Casein N, % of total N	Whey protein N, % of total N
Early lactation (1^{st}–3^{rd} month)	574	11	65	24
Mid-lactation (4^{th}–6^{th} month)	526	13.1	73.8	16.9
Late-lactation (7^{th}–9^{th} month)	444	14	66.7	13.9

5.2.4 Milk Salts

It is well known that salts play an important role in the physical state and stabilization of milk proteins. These salts are calcium, magnesium, phosphate, and citrate. The ratio between cations (Ca^{2+}, Mg^{2+}) and anions (P^{3-}, cit^{3-}) is known as the salt balance, which is affected by stage of lactation, feeding, and health status of the udder. Data from several sources on minerals of camel milk are shown in Table 6.9. The concentrations of all major minerals such as Ca, Mg, P, Na, and K in camel milk seem to be similar to those of cow milk. On the other hand, it was found that the concentration of citrate in camel milk (128 mg/100ml) (167) is lower than in cow milk (160 mg/100ml) (230). The low level of citrate in camel milk may be an excellent advantage in the medicinal properties of camel milk, because lactoferrin activity, one of the antimicrobial factors in milk, is enhanced with low levels of citrate (see section 6.1).

The levels of minor minerals, such as iron, zinc, copper, and manganese, in camel milk were reported as 0.–3.7 mg/L, 2.8–4.4 mg/L, 0.11–1.5 mg/L, and 0.2–1.9 mg/L, respectively (12, 18, 23, 50, 95, 96, 122, 145); while in cow milk, the corresponding values are 0.3–0.8 mg/L, 3.5–5.5 mg/L, 0.1–0.2 mg/L, and 0.04–0.20 mg/L, respectively (198). From a nutritional point of view, data in Table 6.9 reveal that the ratio of Ca:P is 1.5 for camel milk versus 1.29 and 2.1 for cow and human milk, respectively. This ratio is important, because if the cow milk-based formulae used for feeding infants contain high levels of phosphate, this may lead to hyperphosphatemia and low serum calcium (128).

5.2.5 Milk Vitamins

In the literature, very limited data on vitamins of camel milk are available. Of these, the concentrations of water-soluble vitamins are given in Table 6.10, compared with those of cow and human milk. Vitamins of B_1, B_2, folic acid, and pantothenic acid are low in camel milk, while contents of B_6 and B_{12} are similar to those in cow but higher than in human milk. Camel milk is richer in niacin and vitamin C than cow milk. The high level of vitamin C in camel milk has been reported in several studies (50, 61, 81, 84, 139, 141). This property is present in Dromedary and Bactrian milk. In comparison to the content of vitamin C in milk of other species (Figure 6.2), it was found that camel milk contained 52mg/L vs. 27, 22, 29, 16, 35, 49, and 61mg/L for cow, buffalo, sheep, goat, human, ass, and mare's milk, respectively (61).

5.2.6 Nutritive Value of Camel Milk

Amino acid composition of camel milk proteins compared with that of milk of other species is shown in Table 6.11. Glutamic acid is the major amino acid in camel milk, similar to other species. Lysine is present at low level in camel milk. Overall, the amino acid composition of camel milk proteins appears to be similar to that of cow, buffalo, sheep, and goat milk. The ratios of essential to non-essential amino acids are quite close in milks of all species, being 0.93, 1.00, 1.06, 1.02, 0.95, 0.99, 1.03, and 1.07 for camel, cow, buffalo, goat, sheep, ass, mare, and human milk, respectively (61).

All reported data reveal that camel milk proteins have the satisfactory quality balance of essential amino acids for human diets, or exceeding the FAO/WHO/UNU requirements (75) for amino acids.

It has been documented that several amino acid differences exist between human and cow milk, which can present problems in feeding cow milk-based formulae to certain infants. Human milk has a high cystine:methionine ratio and some taurine (217). Cow milk has a lower cystine : methionine ratio and essentially no taurine. The human infant's liver and brain have only low levels of cystathionase,

Table 6.9. Mineral Content of Camel Milk (mg/L)

Ca	Mg	Ca:Mg	P	Ca:P	Na	K	Na:K	References
1,275	80	7.08	974	1.31	—	—	—	(184)
1,965	209	9.40	626	3.14	—	—	—	(7)
1,330	100	13.30	1,080	1.23	—	—	—	(237)
1,676	175	9.58	1,368	1.23	—	—	—	(50)
1,320	160	8.25	580	2.28	360	600	0.60	(95)
1,160	80	14.50	710	1.63	360	620	0.58	(107)
1,149	135	8.51	840	1.37	588	1,726	0.34	(5)
1,060	120	8.83	630	1.68	690	1,560	0.44	(159)
1,570	80	19.63	1,040	1.51	—	—	—	(82)
1,462	108	13.54	784	1.86	902	2,110	0.43	(23)
760	40	19.00	490	1.55	390	1,610	0.24	(145)
1,160	123	9.43	874	1.33	677	1,437	0.47	(160)
1,182	74	15.97	1,480	0.80	581	1,704	0.34	(96)
1,040	110	9.45	740	1.41	520	1,640	0.32	(65)
(760–1,965)	**(40–209)**	**(7.08–19.63)**	**(490–1,480)**	**(0.80–2.28)**	**(360–902)**	**(600–2,110)**	**(0.24–0.60)**	Range
1,294	**121**	**11.89**	**873**	**1.50**	**563**	**1,445**	**0.42**	Average
1,230	120	9.23	950	1.29	580	1,410	0.33	Cow milk (36)
290	40	7.3	140	2.1	130	580	0.22	Human milk (119)

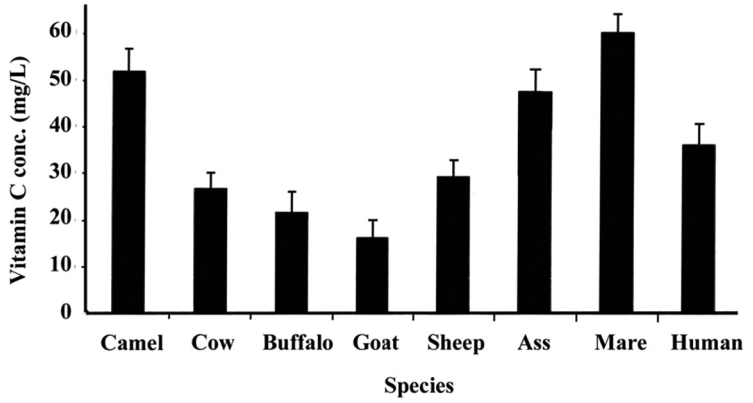

Figure 6.2. Vitamin C concentration in milk of different species. Bars indicate standard error of the mean (61).

Table 6.10. Water-Soluble Vitamins (mg/kg) in Camel, Cow, and Human Milk

Vitamin	Camel (81,138,198)	Cow (36)	Human (119,178)
Thiamin (B_1)	0.33–0.60	0.28–0.90	0.14–0.16
Riboflavin (B_2)	0.42–0.80	1.2–2.0	0.36
Vitamin B_6	0.52	0.40–0.63	0.11
Vitamin B_{12}	0.002	0.002–0.007	0.0005
Niacin	4–6	0.5–0.8	1.47–1.78
Pantothenic acid	0.88	2.6–4.9	1.84–2.23
Folacin	0.004	0.01–0.10	0.052
Ascorbic acid	24–52	3–23	35–43

the enzyme that converts methionine to cystine (the fetus and pre-term infant are completely lacking this enzyme). Cystine is important for central nervous system development (217). Taurine is made from cystine and is needed for brain and retinal development, and function of bile salts (11, 89, 217). Data in Table 6.11 show that the ratio of cystine:methionine is lower in camel milk (0.38) than in cow (0.5) and human (0.6) milk due to the high content of methionine in camel milk proteins.

Another amino acid problem in human milk compared to cow milk or its formulae are the concentrations of phenylalanine and tyrosine, because infants have a limited ability to metabolize these amino acids, which can build up and cause phenylalanine ketonuria (PKU babies) (119). Human milk has low levels of both phenylalanine and tyrosine. Data in Table 6.11 show the low content in human milk of phenylalanine and tyrosine. Their levels in cow and camel milk seem to be similar. The ratios of phenylalanine:tyrosine are 0.7, 2.7, and 2.5 for human, cow, and camel milk, respectively.

Data in Table 6.12 show that camel milk is similar to cow milk in many constituents compared to human milk. Camel milk has a calorific value of 665 Kcal/liter versus 701 Kcal/liter for cow milk. Camel milk is high in vitamin C and niacin, as well as in Ca, P, Mg, Na, K, Zn, and Mn, being similar to cow milk, but richer in Cu and Fe. Camel milk also contains higher levels of carnitin (Vitamin BT) (410 nmol/L) than cow milk (235–290 nmol/L) (10).

Human consumption potential from camel milk compared with recommended dietary allowances is presented in Table 6.13. Camel milk can meet at least as well or better significant portions of daily nutrient needs of humans, especially the essential amino acids. Because human requirements in the heat of arid lands are based less on calories and

Table 6.11. Amino Acid Composition of Camel Milk Proteins Compared with Other Species (g/100 g Protein)*

	Camel	Cow	Human	Ass	Mare	Buffalo	Sheep	Goat
Essential								
Arginine	4.03	3.65	3.3	5.2	6.7	3.3	3.6	3.4
Histidine	2.70	3.25	2.8	2.0	3.0	2.5	3.8	2.2
Isoleucine	5.10	4.90	3.7	4.0	3.1	6.1	4.9	5.9
Leucine	9.70	9.30	9.5	10.7	9.9	9.9	9.9	9.6
Lysine	7.20	8.10	10.1	8.7	7.4	8.0	8.2	8.6
Methionine	3.15	2.45	1.7	1.6	1.9	2.3	2.5	2.7
Pheylalanine	5.00	4.20	3.9	4.3	4.2	4.0	3.8	4.1
Threonine	5.73	7.25	8.3	5.7	7.4	8.2	8.4	7.9
Tryptophan	1.20	1.40	0.5	—	—	—	—	—
Valine	6.65	7.60	8.2	7.8	9.5	7.3	7.5	6.0
Nonessential								
Alanine	3.00	3.95	4.2	4.4	3.5	4.1	3.5	5.6
Aspartic	6.98	7.00	6.7	5.1	5.2	5.9	6.4	6.4
Cystine	1.20	0.90	1.0	1.3	1.1	2.1	1.5	1.7
Glycine	1.50	2.45	2.1	1.9	1.5	1.5	1.7	2.1
Glutamic	21.7	18.6	16.8	16.3	17.2	16.5	16.5	16.8
Proline	12.0	9.85	10.6	12.9	11.0	10.1	10.8	9.8
Serine	5.20	6.15	4.1	5.2	5.2	4.7	4.5	4.1
Tyrosine	4.55	4.60	2.9	2.9	2.7	3.0	2.7	2.9

*Values for camels and cows are means calculated from different sources (65, 159, 186, 198, 244); for the other species, sources are 61, 64.

Table 6.12. Relative Composition of Camel and Cow Milk in Relation to Human Milk Set at 100% (36,50,64,65,159)

Constituents	Camel	Cow	Constituents	Camel	Cow
Total solids	109	108	***Vitamins (continued)***		
Fat	141	129	Pantothenic acid	40	168
Protein	163	164	Vitamin B6	473	455
Casein	338	354	Folacin	80	100
Whey proteins	74	58	Vitamin B12	400	1000
Lactose	72	74	Vitamin A	54	48
Ash	**293**	**281**	Vitamin E	13	26
Minerals			Energy (Kcal)	107	113
Ca	446	424	Cholesterol	—	100
Mg	303	300	***Essential amino acids***		
P	624	679	Arginine	127	111
K	249	243	Histidine	99	107
Na	433	446	Lysine	70	82
Zn	98	140	Threonine	67	87
Fe	380	100	Valine	78	93
Cu	390	75	Phenylalanine	122	108
Vitamins			Methionine	178	144
Vitamin C	149	77	Leucine	100	98
Thiamin	322	421	Isoleucine	126	132
Riboflavin	169	888	Tryptophan	240	280
Niacin	260	37			

Table 6.13. Camel Milk Intake Compared with Recommended Dietary Allowances (RDA) for Humans (176,178)

	1 cup (245 g) camel milk intake contains	RDA	
		Man	Woman
Energy (Kcal)	163	2,300	2,200
Protein (g)	7.9	63.0	50.0
Thiamine (mg)	0.114	1.2	1.0
Riboflavin (mg)	0.150	1.4	1.2
Niacin (mg)	1.127	15.0	13
Vitamin B_6 (mg)	0.127	2.0	1.6
Vitamin B_{12} (μg)	0.490	2.0	2.0
Folate (μg)	0.980	200.0	180.0
Vitamin C (mg)	9.0	60.0	60.0
Vitamin A (μg)	37.0	1000.0	800.0
Vitamin E (mg)	0.130	10.0	8.0
Calcium (mg)	317.0	800.0	800.0
Phosphorous (mg)	214.0	800.0	800.0
Magnesium (mg)	30.0	350.0	280.0
Potassium (mg)	354.0	—	—
Iron (mg)	0.466	10.0	10.0
Zinc (mg)	1.1	15.0	12.0

more on protein and especially liquid, relatively small amounts of camel milk can supply human needs. For minerals, the minimum daily requirements of calcium or phosphorus (800 mg) are easily met by 2.5 and 4 cups for Ca and P, respectively.

5.2.7 Milk Proteins

5.2.7.1 Caseins The protein fraction of cow milk consists of about 80% caseins (CN). Four different genetic products are designated as alpha-s_1, alpha-s_2, beta-, and kappa-caseins, which together form micellar structures of 20 nm to 500 nm by non-covalent aggregation (218). Casein is a phosphoprotein, which precipitates in raw milk upon acidification to pH 4.6 at 20°C. The casein micelle determines the colloidal stability of the polydisperse system in milk. The dimension and the composition of the casein micelle is of great importance for the coagulation process. Coagulation time varies with the micelle size and reaches an optimum with small and medium size micelles, which have higher kappa-casein contents than the larger micelles (49, 187). Smaller micelles also give firmer curd than larger micelles at the same casein concentration (99). Published data on the state of the casein micelle structure in camel milk are scarce. Different techniques were applied, and results are somewhat contradictory, but all show that the casein micelle in camel milk is different from that in cow milk.

One study used electron microscopy after solidifying milk with agar. The casein micelle ranged in size from 25 to more than 400 nm. No clear identification of smaller micelles was shown (98). Freeze-fractured samples of camel milk were examined by electron microscopy (82). The distribution of casein micelles was significantly broader than that of cow and human milk with a greater number of large particles. The particles in the lowest size class with diameters smaller than 40 nm comprised about 80% of the total number of particles, but represented only 4–8% of the mass or volume of the casein. The volume distribution curve of casein micelles in camel milk is broad and shows a maximum between 260 and 300 nm versus 100–140 nm for cow milk casein. In another study (50), the diameter of camel casein micelles was estimated at 956 Angstrom (Å) (905–1031Å) vs. 823Å, 801Å, 716Å, and 662Å for buffalo, goat, sheep, and cow milk casein. This indi-

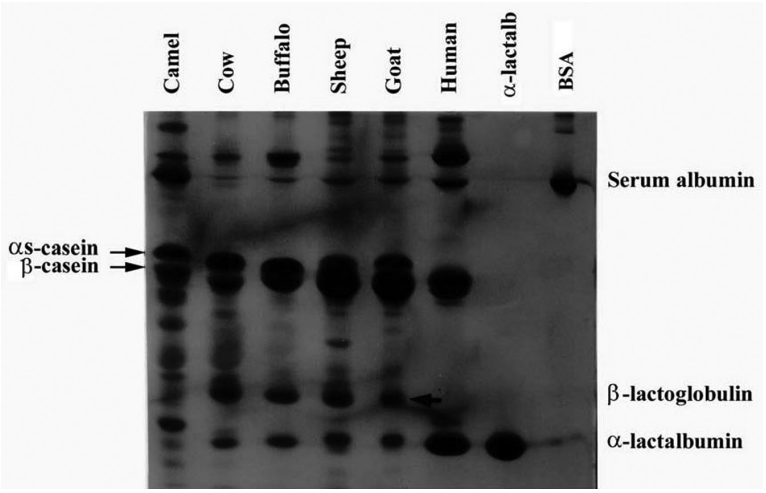

Figure 6.3. SDS-PAGE (10%T) of milk proteins from different species (65).

cates that casein micelles of camel milk are bigger in diameter than those of other species.

5.2.7.2 Casein Fractionation Whole camel milk proteins were separated on polyacrylamide gel electrophoresis (Figure 6.3) and compared with those of cow, buffalo, sheep, goat, and human milk. Camel milk casein fractions are slower in migration than those of other species. Consequently their molecular weights are higher, but whey proteins have the same migration behavior. In addition, the beta-lactoglobulin band is absent from camel milk proteins. This was confirmed by a molecular study (128). Camel milk proteins have several minor peptides, being lower in molecular weights compared with milk of other species. These peptides may play an important role in the therapeutic value of camel milk (50, 54, 64).

Acid casein was prepared from camel milk by HCl precipitation at pH 4.6, separated on polyacrylamide gel electrophoresis using alkaline native-PAGE (Figure 6.4), and compared with that of other species. Two major fractions, a slower one and a minor fraction, faster in migration than from cow

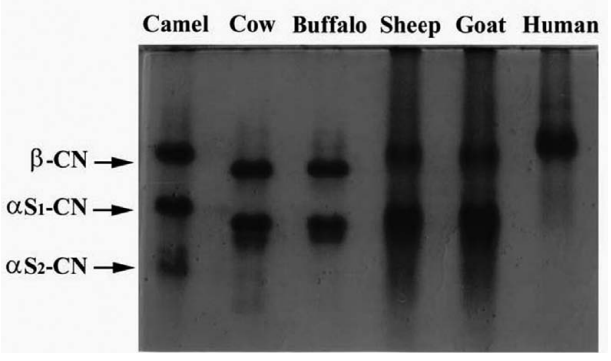

Figure 6.4. Alkaline native-PAGE (12.5%T) of acid camel milk casein and that of other species. Anode is toward bottom of photo (64).

and buffalo milk caseins were identified. The major fractions belong to beta-CN and alpha-s_1-CN, respectively. The third, faster fraction was suggested to be alpha-s_2-CN. Molecular weights of alpha-s_1-CN and beta-CN were estimated at 33 and 29.5 kDa, respectively (64). Camel milk casein was also fractionated on ion exchange chromatography and fractions were identified by polyacrylamide gel electrophoresis (144). Four casein fractions were identified as alpha-s_1-, alpha-s_2-, beta- and kappa-CN. Their corresponding molecular weights were 31, 25, and 27 kDa for alpha-s_1, alpha-s_2 and beta-CN, respectively. The study showed also that alpha-s_1 and beta-CN were dominant, whereas alpha-s_2-CN appeared as a diffuse band on the gel, and the kappa-CN band was absent from the gel, although it was isolated by ion exchange and identified by amino acid sequence as homologous to cow milk kappa-CN. Furthermore, alpha-s_1- and beta-CN of camel milk were phosphorylated to about the same extent as in cow milk, while alpha-s_2-CN was more heavily phosphorylated than that of cow milk casein (200).

The amino acid compositions of camel milk caseins are given in Table 6.14. Data reveal that there are close similarities in the amino acid compositions between camel and cow milk casein fractions. Recently (128), camel milk acid-casein was fractionated on reversed-phase HPLC chromatography. Four fractions were well identified as alpha-s_1-, alpha-s_2-, beta-, and kappa-CN. Full-length clones corresponding to the four caseins were sequenced. The molecular weights, number of residues in the sequences and *p*Is of purified casein fractions were estimated (Table 6.15). It was found that the ratio of beta-CN to kappa-CN is lower in camel milk casein than in cow milk. This low ratio affects some of the processing characteristics of camel milk casein micelles in heat treatment and enzymatic coagulation. The same study revealed that the pH values of isoelectric points (*p*I) of camel and bovine milk caseins were similar, although camel milk caseins were less phosphorylated than cow milk caseins.

Camel alpha-s_1-CN and beta-CN, similarly to bovine caseins, were devoid of cysteine residues, and alpha-s_2-CN and kappa-CN contained only two cysteines. The proline content in camel caseins was slightly higher than in cow caseins, with 9.2% in alpha-s_1-, 4.5% in alpha-s_2-, 17.1% in beta-, and

Table 6.14. Amino Acid Composition of Camel Milk Casein Fractions (144)

	Casein fraction (%)							
	alpha-s_1-CN		alpha-s_2-CN		beta-CN		kappa-CN	
Amino acids	Camel	Cow	Camel	Cow	Camel	Cow	Camel	Cow
Alanine	3.0	4.5	2.9	3.9	2.9	2.4	4.8	8.3
Arginine*	4.9	3.0	1.8	2.9	1.9	1.9	2.7	3.0
Aspartic acid	9.1	7.5	6.5	8.7	3.8	4.3	6.2	7.1
Cysteine	0.0	0.0	1.0	1.0	0.0	0.0	0.6	1.2
Glutamic acid	20.9	19.6	21.8	19.3	19.5	18.7	17.7	16.0
Glycine	2.3	4.5	1.9	1.0	1.2	2.4	2.2	1.2
Histidine*	2.3	2.5	2.7	1.4	1.8	2.4	1.9	1.8
Isoleucine*	6.2	5.5	5.3	5.3	5.7	4.8	6.9	7.1
Leucine*	8.0	8.5	5.1	6.3	10.8	10.5	7.2	4.7
Lysine*	7.3	8.0	16.6	11.6	5.9	5.3	5.6	5.3
Methionine*	1.7	2.5	1.6	1.9	2.9	2.9	1.5	1.2
Phenylalanine*	2.7	4.0	5.1	2.9	3.8	4.3	3.6	2.4
Proline	8.4	8.5	5.1	4.8	18.3	16.7	14.4	11.8
Serine	8.0	8.0	6.7	8.2	6.1	7.7	6.3	7.7
Threonine*	4.9	2.5	8.0	7.2	5.0	4.3	7.1	8.9
Tyrosine	4.6	5.0	5.7	5.8	2.5	1.9	3.6	5.3
Tryptophan*	1.0	1.0	2.2	1.0	0.0	0.5	0.7	0.6
Valine*	4.8	5.5	6.1	6.8	8.0	9.1	7.1	6.5

*Essential amino acids.

Table 6.15. Physicochemical Characteristics of Camel and Cow Milk Caseins (47,128)

Species	Casein fraction (CN)	Molecular mass (kDa)	pI	Relative amount in total casein	Amino acid residues
Camel	alpha-s1-CN A	24.755	4.41	22.0%	207
	alpha-s_1-CN B	24.668	4.40	—	—
Cow	alpha-s_1-CN B	22.975	4.26	38.0%	199
Camel	alpha-s_2-CN	21.993	4.58	9.5%	178
Cow	alpha-s_2-CN A	24.348	4.78	10.0%	207
Camel	beta-CN	24.900	4.66	65.0%	217
Cow	beta-CN A_2	23.583	4.49	39.0%	209
Camel	kappa-CN	22.294-22.987	4.11	3.5%	162
Cow	kappa-CN	18.974	3.97	13.0%	169

CN A, CN B, CN A_2 = casein genetic polymorphs.

13.6% in kappa-CN, compared to 8.5%, 4.8%, 16.7%, and 11.8% in cow caseins, respectively. This higher proline content in camel caseins may lead to destabilization of secondary structures in a more pronounced manner than it does in cow milk caseins (128).

Limited pronounced structural differences were found between camel and cow milk caseins, when sequence comparisons were made. Although alpha-s_1-CN of camel and cow milk had a low percentage similarity in primary structure, similarities in the secondary structure (a series of alpha-helical regions followed by a C-terminus with little defined secondary structure) predominated. In camel milk alpha-s_1-CN, hydrophilicity of the N-terminal end was slightly more pronounced. Similarly to cow milk, camel alpha-s_2-CN was the most hydrophilic among the four caseins and had a high potential for secondary structures, mainly alpha-helices. The two cysteine residues also occurred at about position 40 (128). For the camel milk kappa-CN secondary structure, it was found that it is similar to that of cow milk kappa-CN, with an N-terminal alpha-helix containing one cysteine followed by beta-pleated sheets and a second cysteine. Both cysteine residues are at the positions similar to those in bovine milk kappa-CN.

It is well known that in bovine kappa-CN, the site of cleavage by chymosin is at Phe^{105}-Met^{106}, leaving a macropeptide of 6.707 kDa, 64 amino acids in length with an pI of the unmodified peptide at pH 3.87, and the amino acid sequence from His^{98} to Lys^{112} is involved in binding and cleavage of bovine kappa-CN by chymosin (227). In camel milk kappa-CN, the site of cleavage by chymosin was found to be at Phe^{97}-Ile^{98} (Figure 6.5), leaving a macropeptide of 6.774 kDa, 65 amino acids in len gth with an pI of the unmodified peptide at pH 4.13 (128). As shown in Figure 6.5, all protein residues are conserved in camel milk kappa-CN, and the bovine residue Leu103 was replaced by Pro^{95}. This additional proline residue is suggested to help the stabilization of the conformation of kappa-CN in the active site cleft of camel chymosin, different to the conformation of cow milk kappa-CN in the cleft of

Camel :

$$Arg^{90} - Pro - Arg - Pro - Arg - Pro - Ser - \mathbf{Phe^{97} - Ile^{98}} - Ala - Ile - Pro - Pro - Lys - Lys^{104}$$

Cow :

$$His^{98} - Pro - His - Pro - His - Leu - Ser - \mathbf{Phe^{105} - Met^{106}} - Ala - Ile - Pro - Pro - Lys - Lys^{112}$$

Figure 6.5. Sequence comparison of the chymosin–sensitive region of camel and cow milk K-CN (128).

bovine chymosin. Moreover, histidine residues in the sequence His^{98} to His^{102} of cow milk kappa-CN are replaced by more basic arginine residues in camel milk kappa-CN (Figure 6.5). This leads to the camel milk kappa-CN backbone not in need to be bound as tightly to chymosin as it was shown for cow milk kappa-CN (175).

5.2.7.3 Whey Proteins It is well known that the major whey proteins of bovine milk are beta-lactoglobulin, with 55% of total whey protein, alpha-lactalbumin, with 20.25%, and blood serum albumin, with 6.6% (199). Other minor whey proteins, such as immunoglobulins and proteose peptones, are also well characterized (30, 93). Camel milk whey proteins were isolated and identified by chromatographic, electrophoretic, and immunochemical analyses (20, 21, 22, 37, 64, 77, 128). Camel milk whey proteins were fractionated on polyacrylamide gel electrophoresis using alkaline native-PAGE technique and compared with those of other species (Figure 6.6) (64). Electrophoretic patterns of camel milk whey proteins showed different electrophoretic behavior than those of other species. Camel milk alpha-lactalbumin is slower, but serum albumin is faster in migration than those of milk proteins of all examined species. Furthermore, no distinguishable band in camel milk belonging to beta-lactoglobulin was detected on the gel. This is similar to human milk. The molecular weights of camel milk whey proteins were estimated using SDS-PAGE (Figure 6.7) as 67, 15, and 13.2 kDa for serum albumin, alpha-lactalbumin A, and alpha-lactalbumin B, respectively. For cow milk proteins, the molecular weights were 66.2 kDa for serum albumin and 14.4 kDa for alpha-lactalbumin (64). Therefore it may be easy to detect an admixture of camel milk with cow, buffalo, sheep, or goat milk using such technique (57).

Camel whey proteins were separated by gel chromatography on sephadex G100(37). Two different alpha-lactalbumins (A and B) were isolated and characterized. Although they have equal MW (14 kDa), their *p*Is, amino acid composition, and N-terminal sequence are different. In another study (20), camel whey proteins were separated by gel chromatography on sephadex G-25 followed by HPLC analysis. Amino acid and primary structure analyses revealed the presence of whey proteins homologous to bovine alpha-lactalbumin. The isolated camel milk alpha-lactalbumin had 14.6 kDa MW and 123 amino acid residues.

Two different unknown proteins were isolated from camel whey, having MW of 14 and 15 kDa as well as 117 and 112 amino acid residues. The protein of 14 kDa is rich in cysteine/half-cystine, while that of 15 kDa has no cysteine. No obvious structural similarities were noted between these proteins and other known milk proteins (19, 21, 22). Recently, acid whey prepared from camel milk was separated by HPLC analysis. Three peaks were iden-

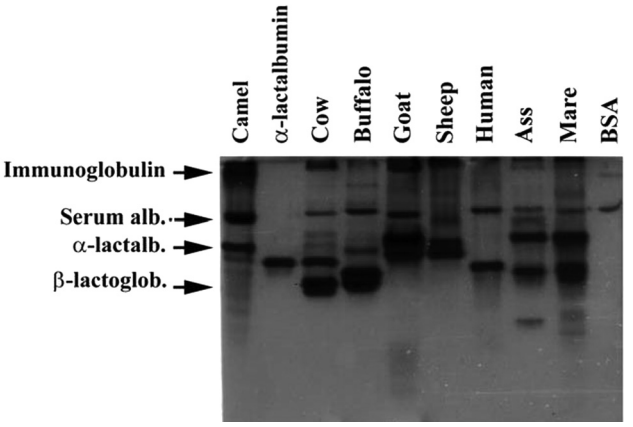

Figure 6.6. Polyacrylamide gel electrophoresis (alkaline native-PAGE), 12.5%T of camel milk whey proteins compared with those of other species. Anode is toward bottom of photo (64).

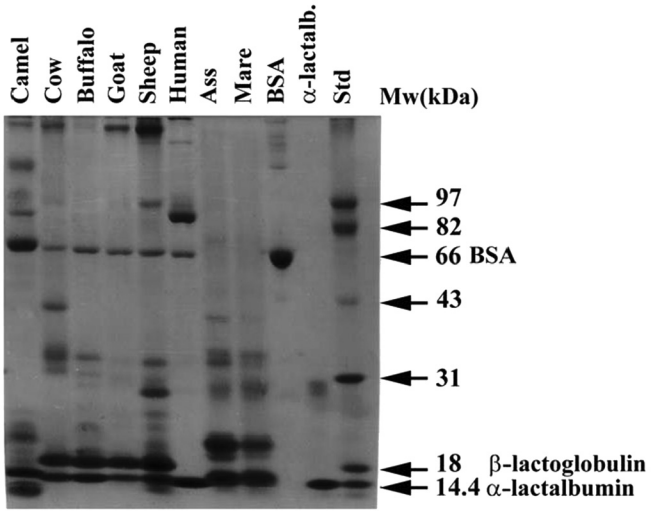

Figure 6.7. SDS-PAGE (7.5–15%T, gradient gel) of camel milk whey proteins compared with those of other species. Std: Standard protein marker. Anode is toward bottom of photo (64).

tified by N-terminal sequencing as whey acidic protein, alpha-lactalbumin, and lactophorin (128). Their ratios were 86.6, 11.5, and 1.9% for alpha-lactalbumin, lactophorin, and whey acidic protein, respectively.

SDS-PAGE analyses of fractionated proteins showed that blood serum albumin and other proteins co-eluted with alpha-lactalbumin as minor fractions. Table 6.16 summarizes the physicochemical characteristics of purified camel whey proteins compared with those of cow milk. Camel milk lactophorin is a major protein in camel whey, whereas bovine lactophorin is a minor protein in whey. Camel milk lactophorin was not isolated from proteose peptone component3 (PP3), as it is in bovine milk protein. Moreover, bovine PP3 consisted of several proteins of which lactophorin was just the main fraction. The primary structures of camel and bovine lactophorin are highly similar. The percent sequence similarity of camel lactophorin to bovine and caprine lactophorin is much higher than to that of rat and murine whey (128). Lactophorin is present in higher amounts in camel milk compared to bovine milk, and this could be of high potential benefit in milk processing because lactophorin is an inhibitor of lipase (93).

It was found that camel milk whey has an acidic protein (12.5kDa), possessing a potential protease inhibitor (21). Depending on these findings, it is suggested that the higher level of natural preserving agents may bring about a longer storage or shelf life of raw camel milk as compared with other raw milk (50, 77). In addition, camel milk whey has other proteins with different anti-microbial actions such as immunoglobulins, lysozyme, lactoferrin, and lactoperoxidase. Their structure, characteristics and inhibition effects are discussed in section 6.1.

6 MILK PROTEIN ALLERGY

Human milk is a perfect food for a human newborn. However, some babies, when fed infant formula, which is mainly based on cow milk or soybean ingredients, suffer from allergy. This allergy results from an abnormal immunological response to one or more of cow milk and even soybean proteins. All fractions of casein as well as beta-lactoglobulin are the most common allergens (220). Because of the seriousness of this phenomenon, which can lead to anaphylactic shock and sometimes death (146), many studies were done to reduce the allergenicity of cow milk proteins (102, 154, 220), or to find a

Table 6.16. Physicochemical Characteristics of Camel and Cow Milk Whey Proteins (41,47,111,128)

Species	Casein fraction	Molecular mass (kDa)	pI	Amino acid residues	Concentration in milk (mg/L)	Similarity to corresponding cow milk proteins
Camel	alpha-lactalbumin	14.430	4.87	123	>5000	88.5%
Cow	alpha-lactalbumin	14.186	4.65	123	600–1700	
Camel	Lactophorin A	15.442	5.10	137	954	83.6%
Cow	Lactophorin	15.304	6.03	135	300	
Camel	Whey acidic protein	12.564	4.70	117	157	—
Cow	beta-lactoglobulin B	18.281	4.66	162	<4000	

substitute such as goat milk (101), ass milk (114), mare milk, and camel milk (64).

In Egypt, camel milk is used by nomads, after dilution with water, to feed their infants (50). Similar behavior is found in China (244) and Mongolia (116). This traditional feeding regimen may be explained by: (a) camel milk is free of beta-lactoglobulin (128) as is human milk; (b) the ratio of whey protein to casein in camel milk is high, which results in soft curd and therefore easier digestibility (50).

The immunological relationship between human milk proteins and their counterparts in camel, cow, buffalo, goat, sheep, ass, and mare milk was studied (64). It was revealed that an immunological relationship exists between human, ass, and mare milk caseins, while it was weak with goat and camel milk, and no immunological relationship was found between human, cow, and buffalo milk caseins (Figure 6.8). When antiserum to human milk whey proteins was applied in immuno-diffusion analysis (Figure 6.8), two precipitin lines were detected

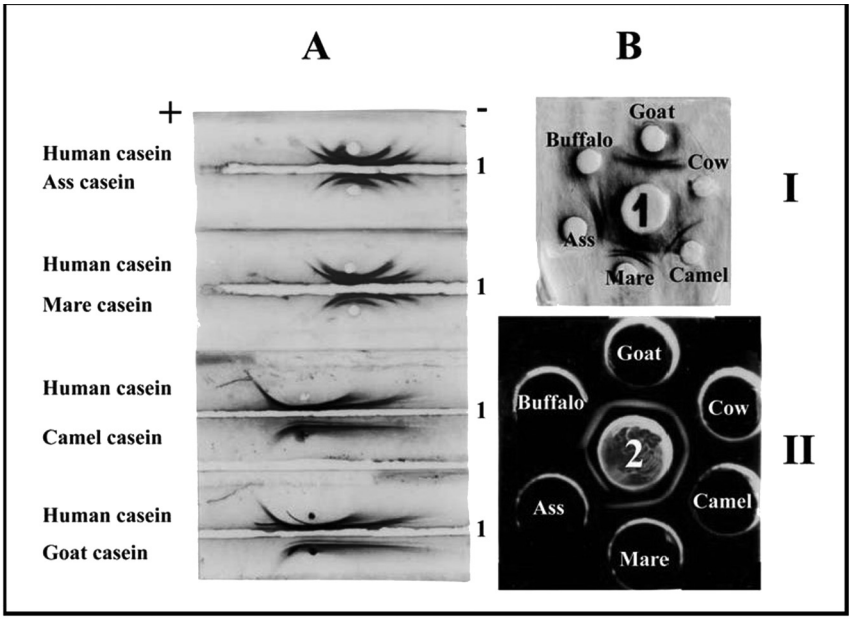

Figure 6.8. Immunoelectrophoretic analysis of human, ass, mare, camel, and goat caseins (A). Immunodiffusion analysis of caseins (BI) and whey proteins (BII) of different species. 1: Rabbit antihuman whole casein; 2: Rabbit antihuman whole whey protein (64).

between human and ass milk proteins versus only one precipitin line with proteins of other species. It indicates that the antigenic similarities are stronger between ass and human milk whey proteins than to that of milk of other species.

6.1 Immune System in Camel Milk

Milk does not only contain nutrient components. As do other biological secretions such as saliva, tears, bronchial, nasal, and pancreatic fluid, it also contains minor protective proteins. These are specific proteins, that is, antibodies or immunoglobulins and non-specific proteins, which include complements, lysozyme, lactoferrin, lactoperoxidase system, xanthine oxidase, and leucocytes. All these proteins form what is known as immune system in milk (185). The concentration of protective proteins varies according to species, and it responds to the special needs of the newborn. Human milk is rich in lysozyme and lactoferrin, while in bovine milk, lactoperoxidase and xanthine oxidase are the main protective proteins (185).

Immunoglobulins are known as specific protective antibodies, which are found in human or animal body fluids or blood serum due to the immune response resulting from exposure to a certain antigen such as virus, bacteria, and so on. They are polypeptide chains with high molecular weights. Immunoglobulins are classified into five classes as immunoglobulin G (IgG), immunoglobulin M (IgM), immunoglobulin A (IgA), immunoglobulin D (IgD), and immunoglobulin E (IgE).

The immunoglobulin molecule is composed of four polypeptide chains, two light chains (lambda or kappa) and two heavy chains (alpha, gamma, mu, delta or epsilon). The type of heavy chain determines the immunoglobulin isotype, IgA (alpha), IgG (gamma), IgM (mu), IgD (delta) and IgE (epsilon). Immunoglobulin classes differ in amino acid composition and sequence as well as molecular weight. IgA is dominant in blood serum, while seretory IgA (SIgA) is dominant in milk (33). Table 6.17 shows immunoglobulin classes and subclasses of different species. Three classes, IgG, IgA, and IgM, are recognized in camel milk (51). IgG class is found to have three different subclasses, IgG_1, IgG_2, and IgG_3 (51, 104). The molecular weights of heavy and light chains of camel immunoglobulins are shown in Table 6.18. Camel immunoglobulins have molecular weights different from those of cow, buffalo, and human milk. Camel milk IgG subclasses were purified

Table 6.17. Immunoglobulin Classes and Subclasses in Milk of Camels and Other Species

Species	Classes and subclasses				
Camel[a]	IgG_1, IgG_2, IgG_3	IgA	IgM		
Cow[b]	IgG_1, IgG_2	IgA	IgM		
Buffalo[c]	IgG_1, IgG_2	IgA	IgM		
Sheep[b]	IgG_1, IgG_2	IgA	IgM		
Goat[b]	IgG_1, IgG_2	IgA	IgM		
Mare[b]	IgG_a, IgG_b, IgG_c, IgG_T	IgA	IgM		
Human[b]	IgG_1, IgG_2, IgG_3, IgG_4	IgA_1, IgA_2	IgM_1,IgM_2	IgD	IgE

References: [a] (51), [b] (190), [c] (60).

Table 6.18. Molecular Weights (kDa) of Immunoglobulins of Different Species

Immunoglobulins	Camel[a]		Cow[b]		Buffalo[c]		Human[d]	
	H	L	H	L	H	L	H	L
IgG (whole molecule)	60	29	55	26	56	28	50	25
IgM	80	27	75	22.5	66	33	73.8	25.2
IgA	55.5	22.5	61	24	58	30	59.5	25.6
*FSC	78		74		68		79	

H and L: Heavy and Light chains.

*FSC: Free secretory component.

References: (a) (51), (b) (30), (c) (60), (d) (190).

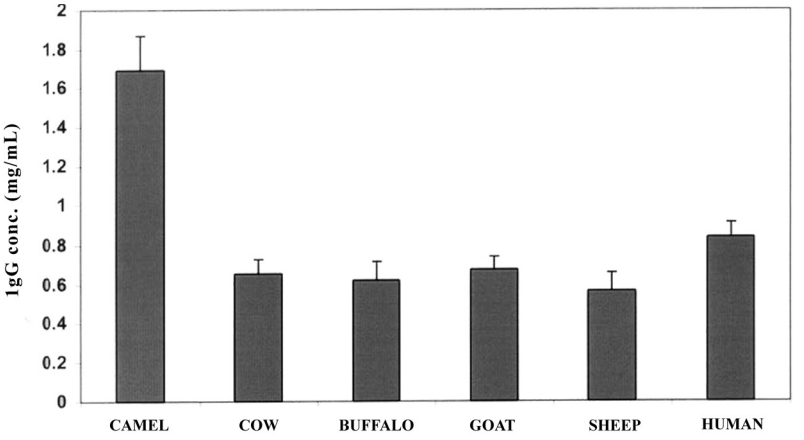

Figure 6.9. Immunoglobulin G concentration in milk of different species. Bars indicate standard error of the mean (61).

and their molecular weights determined (104) as 50, 46, and 43 kDa for IgG_1, IgG_2, and IgG_3 heavy chain, respectively. The reactivity of camel blood serum or milk IgG to protein A (51, 104) or protein G (104) was recognized. Secretory IgA and IgM have no affinity to protein A (51). The concentration of immunoglobulins in milk varies depending on some factors as stage of lactation, health status of animal, and species. Total content of IgG in milk of different species is shown in Figure 6.9. Camel milk contains the highest level of IgG (1.64 mg/ml) verssus 0.67, 0.63, 0.70, 0.55, and 0.86 for cow, buffalo, goat, sheep, and human milk, respectively (61).

The concentrations of IgG subclasses in camel colostrum and normal milk were determined (53). The concentrations of IgG_1 and IgG_2 were high on the first day and declined on following days (Table 6.19). Meanwhile, IgG_1 represented 91.6% of total IgG on day 1, whereas IgG_2 represented only 8.4%. The high level of IgG_1 indicated the dominance of this type of immunglobulin in camel colostrum, similar to bovine colostrum (30, 142).

6.2 Non-Specific Protective Proteins—Lysozyme (EC 3.2.1.17)

Lysozyme cleaves beta (1-4)-glycosidic bonds between N-acetylmuramic acid and N-acetyl-D-glucosamine residues in peptidoglycan, the constituent of bacterial cell walls. There are two types of lyso-

Table 6.19. Average Concentration of Immunoglobulin Subclasses in Camel Colostrum and Normal Milk (53)

	IgG_1 (mg/ml)		IgG_2 (mg/ml)	
Days postpartum	Range	Mean	Range	Mean
1	(25.56–84.25)	53.80	(1.81–6.02)	4.94
2	(18.66–70.91)	36.67	(1.33–5.02)	3.68
3	(13.06–40.12)	23.69	(0.92–2.84)	1.83
4	(6.99–27.24)	14.23	(0.49–1.93)	0.95
5	(4.76–17.35)	08.55	(0.34–1.23)	0.62
6	(4.29–12.04)	07.15	(0.30–0.85)	0.49
7	(4.11–10.07)	06.02	(0.29–0.71)	0.40
14	(1.01–2.29)	01.35	(0.07–0.16)	0.11

Table 6.20. Molecular Weights of Lysozyme from Different Sources

Source	Molecular weight (kDa)
Camel milk	14.4[a], 15.0[b]
Cow milk	18.0[c]
Human milk	15.0[d]
Mare milk	14.4[e]
Goat milk	15.0[f]
Lysozyme "c"	15.0[g]
Lysozyme "g"	20.5[g]

References: [(a)] (63), [(b)] (45), [(c)] (48), [(d)] (172), [(e)] (118), [(f)] (123), [(g)] (14).

zymes: those found in hen egg whites and known as chick-type c-lysozyme, and those found in goose egg whites or goose-type g- lysozyme (14). Lysozymes c and g differ in their amino acids sequence and molecular weights. Lysozyme g is heat labile and contains half as much cystine and tryptophan residues as lysozyme c (14, 42). Lysozyme is found in secretions of milk, tears, nasal secretions, urine, and so on. Lysozyme in human, goat, mare, and camel milk is considered type c lysozyme. However, it is unclear whether bovine milk lysozyme is a type c or g lysozyme. Lysozyme was purified from camel milk (45, 63). Molecular weights of lysozyme from different sources are shown in Table 6.20.

Immunological studies (63) on camel milk lysozyme showed, that there is no antigenic similarity between camel and bovine milk lysozyme, suggesting different structures. The concentration of lysozyme in mammalian milks varies from 13 μg/100ml in buffalo milk (66) to 79μg/100ml in mare's milk (118). Camel milk contained 228, 288 and 500 μg lysozyme/100ml (17, 45, 66). In cows' milk the corresponding values were reported as 7 (225), 13 (142), and 37μg/100ml (63). The variations in the reported values are mainly due to the effect of lactation stage.

A comparative study of lysozyme concentration in milk of different species is shown in Figure 6.10. Camel milk has a considerably higher concentration of lysozyme than cow, buffalo, sheep, and goat milks, while lower than in human, ass, and mare's milk (61). The equivalent concentration of lysozyme in camel milk represents 11, 18, 10 and 8 times that of cow, buffalo, sheep and goat's milk, respectively. Lysozyme concentrations in milk vary according to factors such as lactation period and health status of the animal. It increases in pre-colostrum, colostrums, and during udder infection (31, 174). Table 6.21 shows the changes in lysozyme contents in daily samples of camel and cow colostrum, and normal milk. In camel and cow milk, colostrum contained higher concentrations of lyszoyme than normal

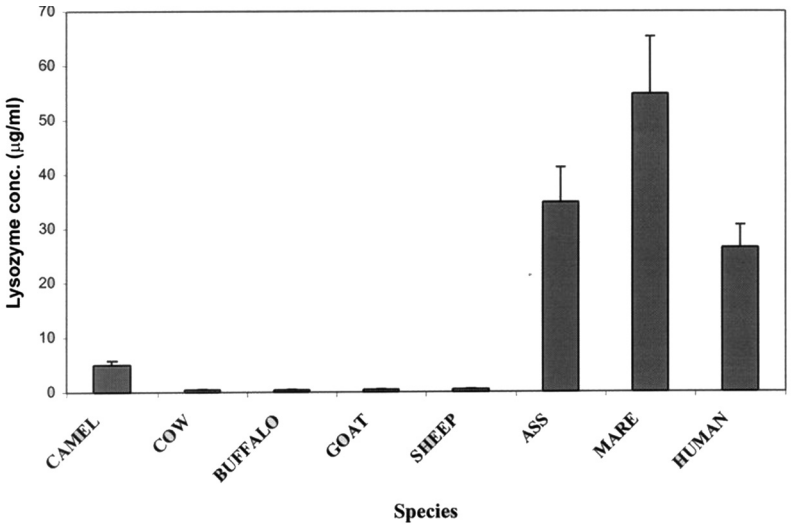

Figure 6.10. Lysozyme concentration in milk of different species. Bars indicate standard error of the mean (61).

Table 6.21. Changes in Lysozyme Contents in Camel and Cow Colostrum and Normal Milk (53,142)

	Lysozyme (μg/100ml)			
	Camel milk		Cow milk	
Days postpartum	Range	Mean	Range	Mean
1	43–197	103	14–70	40
2	69–202	128	20–70	55
3	54–198	106	57–78	65
4	52–192	90	45–80	66
5	57–196	93	45–85	69
6	54–193	92	55–80	64
7	46–188	87	56–90	72
14	42–135	73	07–60	37

milk. Camel milk lysozyme was highest on the second day after parturition, then declined, and on day 5 there was a slight increase followed by a decrease. The trend was different in cow milk lysozyme.

6.3 Peptidoglycan Recognition Protein

A novel protein is involved in the primary immune response of vertebrates and invertebrates on Gram-positive bacteria and other invading organisms such as nematodes (127, 240). Inactivation of pathogens probably occurs by binding to peptidoglycan structures in bacterial cell walls, thus the name was given peptidoglycan recognition protein (PGRP). It was isolated from camel whey by heparin-sepharose chromatography and probably serves the same function of specific pathogen inhibition in camel milk (128). It is found in higher amounts in camel milk than the concentrations of other protective proteins such as lactoferrin, lysozyme, or lactoperoxidase (128). It has 19.11 kDa MW and its N-terminal sequence of the reverse phase purified protein was determined as:

Arg-Glu-Asp-Pro-Pro-Ala-Cys-Gly-Ser-Ile

A full-length cDNA clone of 700 bp corresponding to the N-terminal sequence was found (128). The isoelectric point of camel PGRP was at pH 8.73 and higher than of human, or murine, which were at pH 7.94 and 7.49, respectively (128). The mature PGRP had 91.2% similarity with human protein, 87.9% with murine. Camel PGRP protein is rich in arginine, but poor in lysine, although the pI is highly basic. Its concentration in camel milk was determined as 370mg/L (128). The concentration of lysozyme in camel milk was found to decrease rapidly within the first months of lactation (17). In contrast, PGRP was isolated in major amounts from end-lactational milk. This indicated constant expression of the protein in camel milk in the course of lactation.

6.4 Lactoferrin

Lactoferrin, also named lactotransferrin, is a glycoprotein. It was purified on an industrial scale from whey by cation exchange and used as a preserving agent in food, drugs, and cosmetics (195). Lactoferrin belongs to the family of transferrins, together with blood serotransferrin (siderophilin), egg white ovotransferrin (conalbumin), melanotransferrin of malignant melanomas, the porcine inhibitor of carbonic anhydrase, and other proteins. The common property of this protein family is the binding of two metal cations, preferably (Fe^{3+}), at structurally closely related binding sites. Most lactoferrins are needed for storage or transport of iron. Lactoferrin serves for iron scavenging in body secretions (27). It is found in milk and other body secretions and in neutrophil leukocytes (153).

Camel milk lactoferrin was found to contain 6.2% carbohydrates in colostral milk and 5.6% in milk collected 15 to 30 days postpartum (147). The content of N-acetyl-glucosamine in camel milk lactoferrin was markedly higher than in ruminant milk lactoferrins (3.35% in colostral camel milk compared to about 1.75% in colostral ruminant milk). The carbohydrate content of camel lactoferrin from end-lactational milk was 6.2–6.8% of total protein mass (128).

Lactoferrin of colostral camel milk has a low iron saturation of 9% similar to lactoferrin of bovine colostral milk. In milk taken 15 to 30 days after parturition, camel lactoferrin was nearly completely iron saturated. Similar results were found for bovine lactoferrin from milk of the same lactational stage (147). Lactoferrin was purified from camel milk and its molecular weight was determined as 79.5 kDa (63) and 75.3 kDa (128). The corresponding molecular weights of cow, buffalo, and human lactoferrins were 80 or 89 kDa (214, 241), 78.5 kDa (169), and 82 kDa (214), respectively.

PCR amplification products of a full-length cDNA clone of camel lactoferrin were sequenced

(128). The study showed that the clone is 2,336 bp long and contains a 5′-untranslated region of 21 bp and a 3′-untranslated region of 191 bp. The mature lactoferrin is 689 amino acid residues long, and the unmodified peptide has an isoelectric point of 8.14. Camel lactoferrin shares 91.6% sequence similarity with bovine or human lactoferrin, and 91.3% with porcine lactoferrin. The high similarity in primary structures among lactoferrins of the three species indicates small variations in their functional aspects.

A comparative study (61) showed that lactoferrin concentration varied considerably between colostrum and normal milk (53) (Table 6.22), and among eight species (Figure 6.11). The highest level was in human milk (1.7 mg/ml), while ass milk had the lowest lactoferrin content (0.07 mg/ml). Camel milk contained a significantly ($p < 0.01$) higher level (0.22 mg/ml) compared to the other species except humans. Lactoferrin level in camel milk was 2.4, 2.6, 2.2, 1.8, 3.3, and 2.3 times that in cow, buffalo, goat, sheep, ass, and mare's milk, respectively. Other studies showed the concentration of lactoferrin in bovine milk to range from 0.02–0.35 mg/ml (142) and 0.10–0.50 mg/ml (174). Colostral camel milk has a high lactoferrin content of 5.1 mg/ml on the second day after parturition, compared to about 0.5 mg/ml in bovine colostral milk. At 30 days after parturition, the lactoferrin level in camel milk declined to 0.34 mg/ml, while in bovine milk it was 0.06 mg/ml (1). In another study, camel milk sampled at the end of lactation, 360 days postpartum, contained 0.22 mg/ml (128). Immunochemical studies (63) with camel lactoferrin showed no antigenic relationship with bovine lactoferrin, when anti-camel lactoferrin was used in immuno-diffusion analysis.

Table 6.22. Changes in Lactoferrin Contents in Camel Colostrum and Normal Milk (53)

	Lactoferrin (g / L)	
Days postpartum	Range	Mean
1	0.2–1.80	0.84
2	0.16–1.22	0.63
3	0.12–0.74	0.46
4	0.10–0.29	0.21
5	0.09–0.17	0.12
6	0.08–0.14	0.10
7	0.05–0.12	0.07
14	0.02–0.08	0.04

6.5 Lactoperoxidase (EC 1.11.1.7)

Lactoperoxidase is found in milk, tears, and saliva. It contributes to the non-immune host defense system, exerting bactericidal activity mainly on

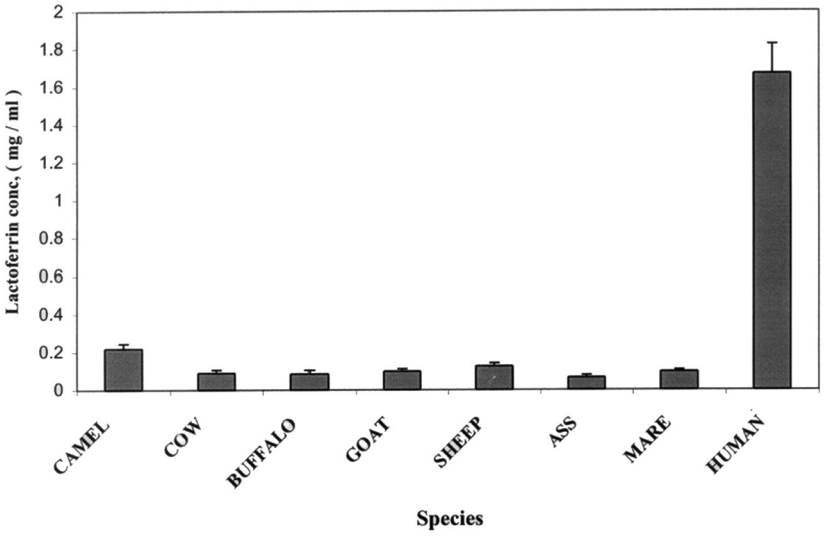

Figure 6.11. Lactoferrin concentration in milk of different species. Bars indicate standard error of the mean (61).

Gram-negative bacteria. The main function in milk is the protection of the udder from microbial infections (224). Lactoperoxidase is resistant toward proteolytic digestion and acidic pH. Lactoperoxidase activity is maintained at a high level throughout lactation; however, human lactoperoxidase is present only in colostrum and becomes undetectable within one week postpartum (224).

Lactoperoxidase was first isolated, crystallized, and characterized in 1943 (221). It has been demonstrated in milk from many species, including cows, goats, guinea pigs, murine, humans, and camels (51, 97, 177, 216). Bovine milk is rich in lactoperoxidase (30 mg/L) (177). It is a glycoprotein and contains one heme group (222). The iron content is 0.068–0.071%, and the carbohydrate content 9.9–10.2% (32). Camel milk lactoperoxidase is a monomeric protein, which has 79.3% sequence similarity to human myeloperoxidase, and 79.2% sequence similarity to human eosinophil peroxidase. Myeloperoxidase and eosinophil peroxidase are dimeric proteins (128). Lactoperoxidase was purified from camel (63) and bovine milk (241), and their molecular weights were estimated in these studies at 78 and 88 kDa, respectively.

PCR amplification products of a camel lactoperoxidase cDNA clone were sequenced (128). The study showed that the clone was 2,636 bp long, and contained a 3′-untranslated region of 497 bp and a 5′-untranslated region of 4 bp. The molecular weight of camel lactoperoxidase was determined at 69.46 kDa versus 69.57 kDa for bovine lactoperoxidase. The isoelectric point of camel lactoperoxidase was 8.63, whereas it was at pH 7.90 for bovine lactoperoxidase (46). Camel lactoperoxidase shares 94.9% sequence similarity with bovine lactoperoxidase and 94.1% with human salivary peroxidase. Immunochemical studies on camel milk lactoperoxidase showed that there is cross reactivity, that is, antigenic similarity with bovine milk lactoperoxidase when antiserum to camel milk lactoperoxidase was used in the test (63).

Antimicrobial activity of lactoperoxidase is performed by a so-called lactoperoxidase system (LPS), in which hydrogen peroxide (H_2O_2) is reduced, and a halide, for example, iodide (I^-) or bromide (Br^-), or a pseudohalide, for example, thiocyanate (SCN^-), is subsequently oxidized (86). Natural substrates of lactoperoxidase in milk are thiocyanate and iodide, of which milk contains trace amounts. Thiocyanate is provided by consumption of plants of the family *Cruciferae*, as cabbage contains up to 5g/kg thioglucosides, which are readily converted into SCN^- by enzymatic hydrolysis (25). Cow milk contains 1–15 mg/L of SCN^- (41).

Concentration of H_2O_2 is very low in normal milk. It can be generated through oxidation of xanthine by xanthine oxidase, or supplied by catalase-negative bacteria, such as lactobacilli, lactococci, or streptococci, which naturally are present in milk (185). The bactericidal action of the LP system is due to the effects of reaction products of the thiocyanate oxidation, OSCN- and HOSCN, which are able to oxidize free SH-groups of the cytoplasmic membrane of Gram-negative bacteria. The structural damage on bacterial cell membranes results in diffusion of potassium ions, amino acids, and polypeptides out of the cell, while the uptake of glucose and other metabolic substrates is inhibited. The action of the LP system on Gram-positive bacteria, such as streptococci, is different, since Gram-positive bacteria are protected from the action due to their rigid cell wall (185). The LP system could be used as an alternative method for the preservation of raw camel milk, which is produced under high ambient temperature and low hygienic conditions, and cooling processes usually are nonexistent.

6.6 Effects of Heat Treatment on Protective Proteins

Only one study has been carried out on the effects of heat treatments on protective proteins, such as immunoglobulins (IgG_S), lysozyme, and lactoferrin (54). Camel, cow, and buffalo skim milk samples were heated at 65, 75, 85, and 100° C for 30 minutes. Heating of the three kinds of milk at 65° C for 30 minutes had no significant effect on lysozymes and lactoferrins; however, significant loss in IgG_S activity was detected. The entire activity of IgG in cow and buffalo milk was lost at 75°C for 30 minutes versus 69% in loss of activity for camel IgG (Figure 6.12). The entire activity of lactoferrins was lost at 85° C for 30 minutes in the three kinds of milk, while at this temperature level the activity losses of lysozymes were 56, 74, and 82% for camel, cow, and buffalo milk, respectively. It was concluded that protective proteins of camel milk are significantly ($p < 0.01$) more heat resistant than cow and buffalo milk proteins. Among the protective proteins, the order of heat resistance found was lysozyme > lactoferrin > IgG_S.

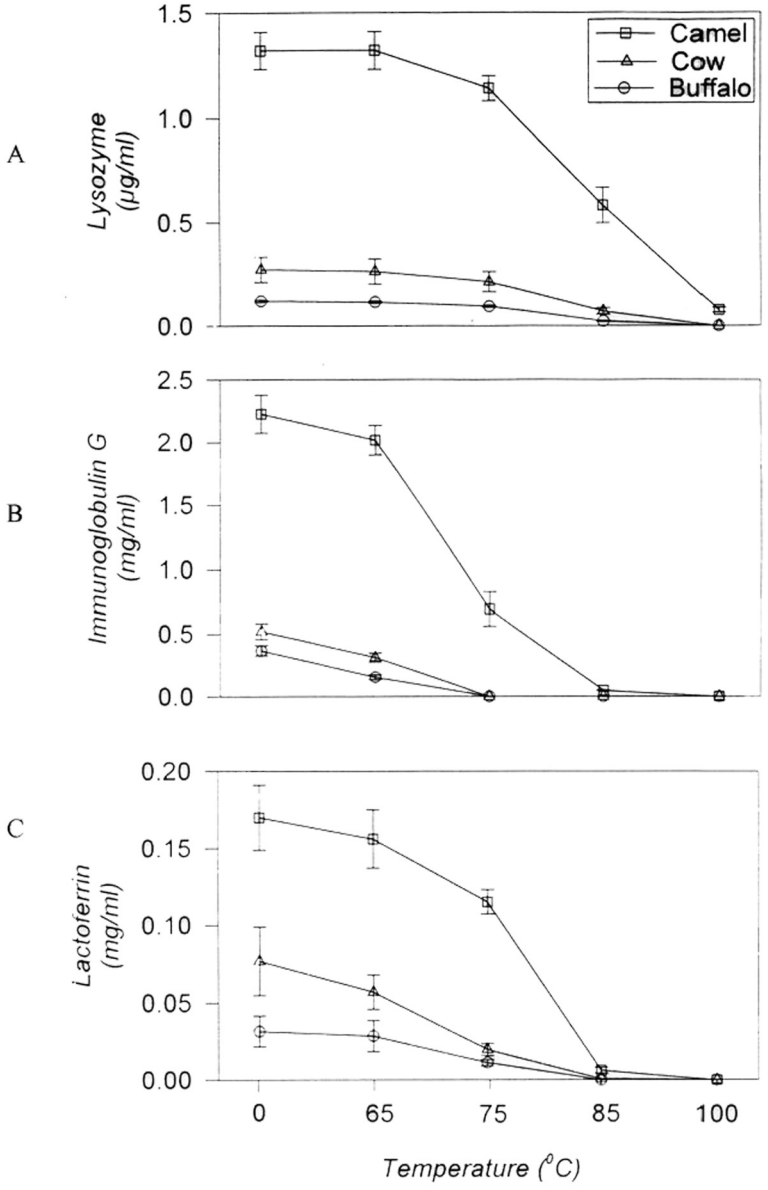

Figure 6.12. Effect of heat treatment on camel, cow, and buffalo milk lysozyme (A), immunoglobulin G (B), and lactoferrin (C) (54).

6.7 Biological Activity of Protective Proteins

6.7.1 Antibacterial Activity—Lysozyme

The inhibitory effects of camel milk lysozyme in 200 individual milk samples on pathogenic bacteria were examined (17), and the results showed that percentages of inhibition were 7.5, 4.0, 2.0, and 1.0% for *Clostridium perfringens, Staphylococcus aureus, Shigella dysenteriae,* and *Salmonella typhimurium,* respectively. However, none of the samples inhibited *Bacillus cereus* or *Escherichia coli.* The

Table 6.23. Sensitivity (Zone of Clearance, mm) of Different Bacteria to Camel and Bovine Milk Lysozyme in Comparison to Egg-White Lysozyme as Determined by Disc-Assay Technique (51)

Organisms	Camel milk lysozyme	Bovine milk lysozyme	Eggwhite lysozyme
Lactococcus lactis Subsp. *cremoris*	0.0	21.0	0.0
Escherichia coli ATCC 25922	0.0	0.0	0.0
Staphylococcus aureus	0.0	0.0	0.0
Salmonella typhimurium	22.2	0.0	20.2
Escherichia coli 0157:H7	0.0	0.0	0.0

inhibition effect of camel milk lyszoyme was also studied in comparison with egg white lysozyme and bovine milk lysozyme against some strains of bacteria (51). Results revealed that camel milk lysozyme had a higher lysis value toward *Salmonella typhimurium* compared with other lysozymes (Table 6.23). The results obtained by disc assay technique indicated that the clearance zone values were 22.2, 20.2, and zero mm for camel, eggwhite, and bovine milk lysozyme, respectively. Camel milk lysozyme had no effect on *Lactococcus lactis* subsp. *cremoris,* but the strain was highly affected by bovine milk lysozyme. All lysozymes were ineffective toward *E. coli* and *Staph. aureus.*

6.7.2 Lactoferrin

The inhibition effect of lactoferrin depends mainly upon iron requirements of microorganisms. For example, *E. coli* is much more sensitive than lactic acid bacteria (185). The inhibition effect of camel and bovine milk lactoferrins against some strains of bacteria was studied (51). Both types of lactoferrins were effective against *Salmonella typhimurium*, and the clearance inhibition zones were 18.2 and 17.4 mm for camel and bovine milk lactoferrins, respectively (Table 6.24). Meanwhile, neither camel nor bovine milk lactoferrin had a lysis effect toward *E. coli* and *Staph*. aureus.

Taken into account that inhibition rates of camel lactoferrin against microorganisms was determined in synthetic media, this effect is probably different when liquid media such as milk are used, because it was reported that citrate ions can counteract the bacteriostatic activity of lactoferrin, that is, compete for iron unless the bicarbonate concentration is high (185). Therefore, it can be expected that lactoferrin activity in camel milk will be higher due to the lower concentration of citrate ions (50). It can be assumed that the inhibition effect of lactoferrin in camel milk, when ingested by nomads in the desert, is due to two main factors: (a) the low content of citrate in camel milk, and (b) to the high bicarbonate concentration in the intestinal fluid, where bicarbonate is the main

Table 6.24. Sensitivity of Different Bacteria to Camel and Cow Milk Lactoferrins as Determined by Disc-Assay Technique (51)

Organisms	Camel milk lactoferrin	Bovine milk lactoferrin
	(2.5 mg / mL) Zone of clearance, mm	
Escherichia coli ATCC 25922	0.0	0.0
Staphylococcus aureus	0.0	0.0
Salmonella typhimurium	18.2	17.4
Escherichia coli 0157:H7	0.0	0.0

Table 6.25. Effect of Camel Milk Lactoperoxidase, Thiocyanate, H_2O_2 (Lactoperoxidase System), Immunoglobulin G (IgG), and Secretory Immunoglobulin A (SIgA) on Glycolysis Process of *Lactococcus lactis* subsp. *cremoris* CRA-1 (51)

Treatment	Acidity as lactic acid % Time (hours)			
	0	**2**	**4**	**6**
Control	0.125	0.180	0.198	0.200
Whole system without lactoperoxidase	0.125	0.175	0.189	0.194
Whole lactoperoxidase system	0.125	0.135	0.148	0.152
IgG with SigA	0.125	0.180	0.185	0.189

buffer (185). These two factors will provide the proper conditions for lactoferrin to bind iron and inhibit sensitive microorganisms such as *E. coli.*

6.7.3 Lactoperoxidase System (LPS)

Camel milk lactoperoxidase was purified and its inhibition activity against lactic acid bacteria (Table 6.25) and some strains of pathogenic bacteria was studied (62). The LPS had a bacteriostatic effect toward both *Lactococcus lactis* and *Staph. aureus* (Figure 6.13A); however, it was bactericidal against *E. coli* and *Salmonella typhimurium* (Figures 6.13B, 6.13C). The destructive effect of camel LPS on cell walls of these bacterial strains is shown in Figures 6.14 and 6.15.

6.7.4 Antiviral Activity

Rota viruses (Figure 6.16) are the most frequent cause of nonbacterial gastroenteritis in infants or calves in most parts of the world. In Egypt, the Bedouins use camel milk to treat diarrhea (personal observation). Camel milk immunoglobulin (IgG)

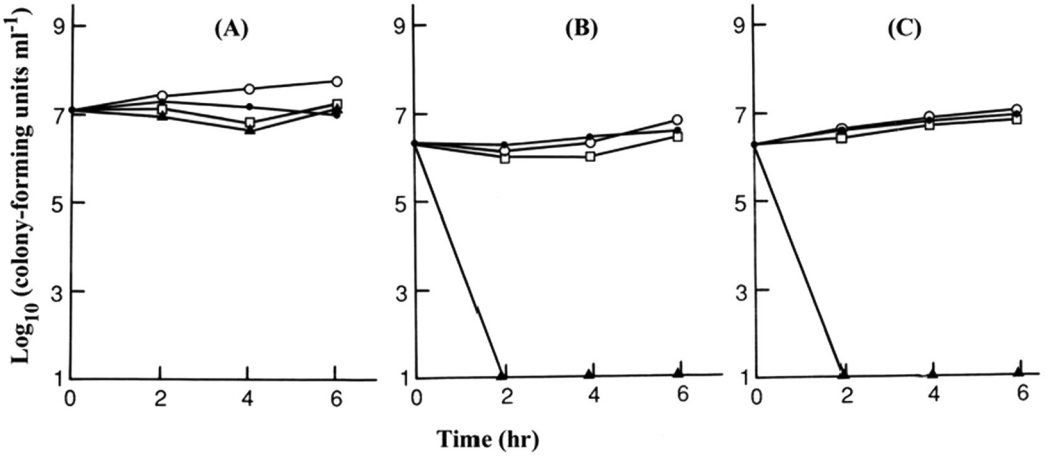

Figure 6.13. Bactericidal effect of camel milk lactoperoxidase (1.5U/ml), thiocyanate (0.225 mM), glucose (0.3%), glucose oxidase (0.1μg/ml), immunoglobulin G (2mg/ml) and secretory immunoglobulin A (2mg/ml) against *Staphylococcus aureus* B4 (A); *Escherichia coli* 0157:H7 (B) and *Salmonella typhimurium* ATCC 14028 (C). Control (○); whole lactoperoxidase system (▲); whole system without lactoperoxidase (□) and immunoglobulin G + secretory immunoglobulin A (●) (51).

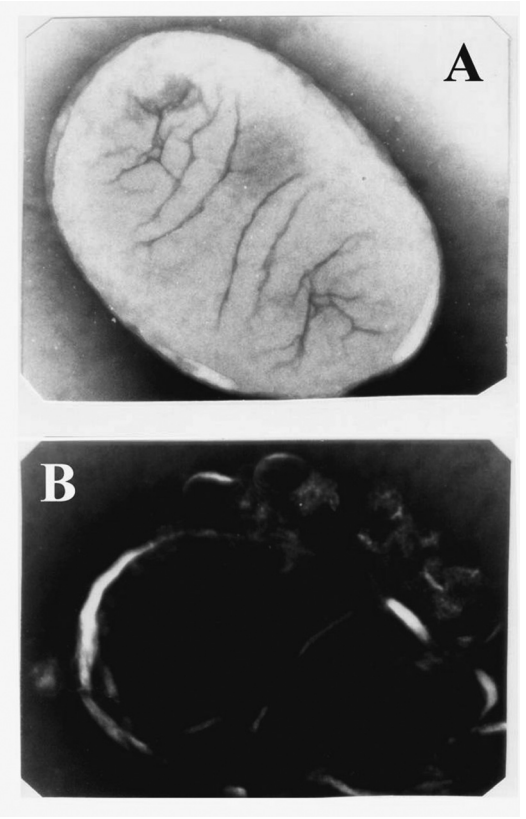

Figure 6-14. Electron micrographs showing the effect of lactoperoxidase system (LPS) on *E. coli* 0157:H7. The damage in outer membrane after exposure is shown. A: Intact cell; B: LPS-treated cell (51).

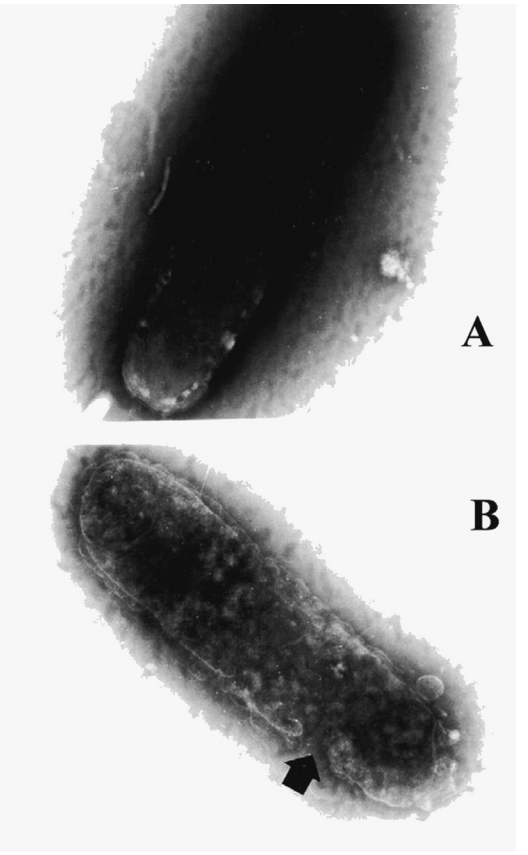

Figure 6.15. Electron micrographs showing the effect of lactoperoxidase system (LPS) on *Salmonella typhimurium*. The damage in outer membrane after exposure is shown by the arrow. A: Intact cell; B: LPS-treated cell (51).

and secretory immunoglobulin A (SIgA) were purified, and their neutralization activity against bovine (62) or human (55) rotaviruses were studied. Individual camel (*Camelus dromedaries*) colostrum and normal milk samples were tested for the presence of antibodies to rota and corona viruses. All samples were negative for anticorona virus antibodies, while some colostrum and milk samples had specific antibodies to rota virus. The antirota virus activity, that is, antibody titer in colostrums, was strongly due to IgG, while it was SIgA in normal milk (Figures 6.17a, 6.17b). This indicates that raw camel milk is considered a strong viral inhibitor to human rota virus. The high titer of SIgA against rota virus shows that camel mammary glands are able to synthesize a high concentration of such types of immunoglobulins as a defense factor. These findings may explain the reason for use of camel milk as a remedy to treat diarrhea by camel herdsmen (50).

The antiviral properties of freshly prepared or conserved "Shubat," a national drink of fermented camel milk in Kazakhstan, were studied (35). The results showed that shubat is characterized by virucidal and virus-inhibiting properties against ortho and paramyxoviruses, and these properties were not affected by shelf life. The antiviral activity of shubat

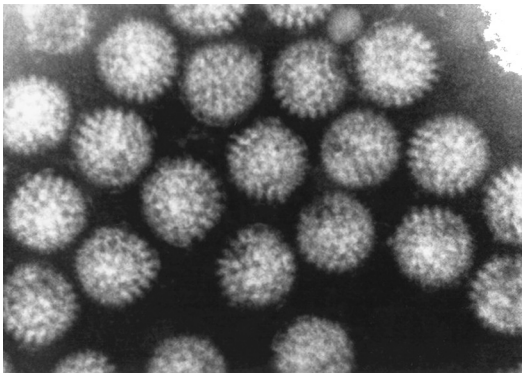

Figure 6.16. Electron micrograph of negatively stained human rotavirus particles from culture fluid of MA 104 cells (55).

is suggested by the presence of sialic conjugates and metabolic products of lactic acid bacteria and yeasts.

7 MEDICINAL PROPERTIES OF CAMEL MILK

Camel milk in the raw state and its fermented products are used as therapeutic agents to treat stomach ulcer, liver disorders, diarrhea, constipation, and wounds as well as to enhance the female's ovary for ovulation (personal observations). Camel milk is also given to children suffering from biliary atresia and postpartum respiratory insufficiency. They are kept alive until a liver transplant can be performed and the lungs developed (234). Fermented camel milk "shubat" is used as a therapy for treating tuberculosis in different countries, India (151), Libya (13), and Kazakhstan (180). Treatment of chronic diseases of the gastrointestinal tract using camel milk and shubat has been reported (43). Camel milk is used for chronic hepatitis and spleen inflammation (personal observations). Similar observations were recorded in the former USSR (208). It was reported that patients suffering from chronic hepatitis had improved liver functions after drinking camel milk. Camel milk is also successfully used for stabilization of juvenile diabetes (234). This is confirmed by the presence of insulin-like protein in camel milk (21). In different countries of Africa—Egypt, Sudan, Kenya, and Somalia—there is a common belief among herdsmen of camels, especially those grazing on herbs, that men who drink such camel milk become strong, swift, and virile (personal observations).

8 LIPIDS

Milk fat is secreted in the form of spherical globules of varying sizes surrounded by a membrane, that is,

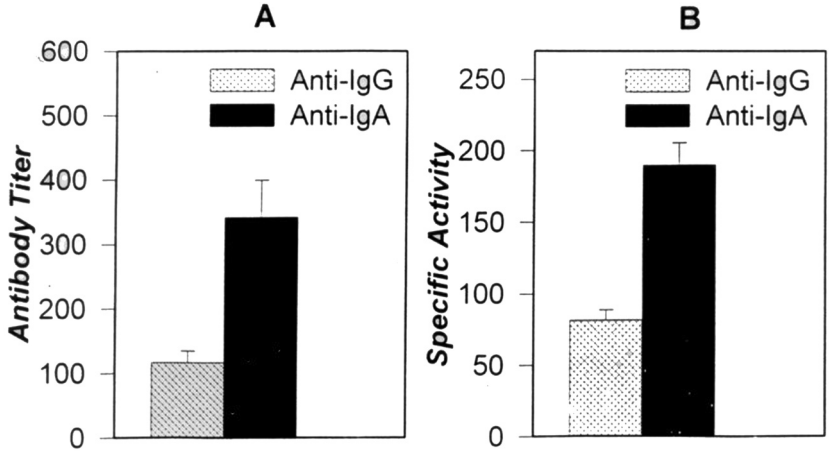

Figure 6.17a. Antirotavirus activity in camel-colostral whey expressed as antibody titer (A) or specific activity (B). Bars indicate standard error of the mean (55).

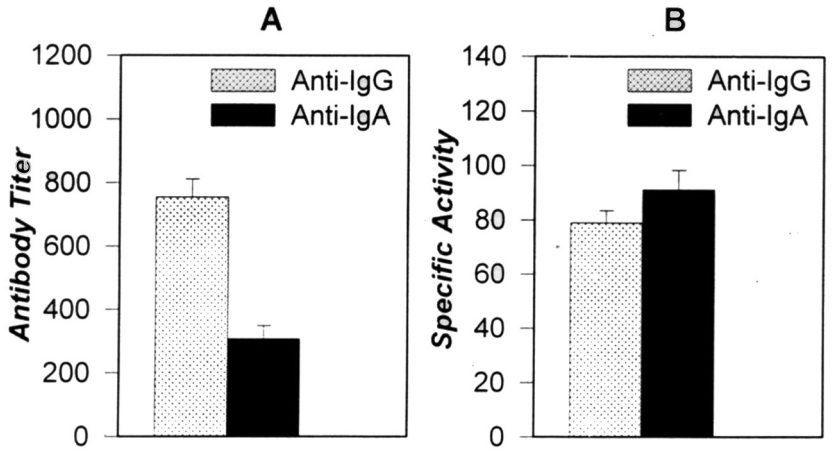

Figure 6.17b. Antirotavirus activity in camel normal-milk whey expressed as antibody titer (A) or specific activity (B). Bars indicate standard error of the mean (55).

the milk fat globule membrane, which maintains the integrity of the globules and renders them compatible with their aqueous environment (132). The fat globules consist almost entirely of triacylglycerols, while the membranes contain mostly the complex lipids.

8.1 Fat Globule Size and Creaming Properties

The size distribution of fat globules in milk of different species is markedly different. The average size of fat globules in milk of camels, cows, buffaloes, sheep, and goats is presented in Table 6.26. The largest diameter of fat globules is found in buffalo milk, whereas the smallest is in camel milk. Generally, camel, sheep, and goat milk fat globules are smaller in size compared to those of buffalo and cow milk. Therefore, these milks have poor creaming properties (82, 171). Some factors, such as heat treatment, can affect the fat globule size and numbers. It was found that some increase in size and decrease in number upon heating of cow, buffalo, sheep, and goat milk (211). Pasteurization at 61° C for 30 minutes increased average globule size in goat milk about 12% as a result of coalescence. The creaming properties of fat globules in raw and heated camel milk in comparison to cow milk have been studied (82). Camel milk was heated for 30 minutes at 55, 60, 62, 68, 70, and 77° C, left to cream at 4° C, and the cream layer was measured after 5 and 24 hours. Camel milk showed a very slow creaming rate at all temperatures similar to that of sheep and goat milk, which have an insufficient quantity of agglutinin (144).

8.2 Fatty Acid Composition of Milk Fat

The lipids of milk fat serve nutritionally as an energy source, act as a solvent for the fat-soluble vitamins, and supply essential fatty acids. In milks of all species studied to date, triacylglycerols are by far the major lipid class of milk fat, accounting for 97–98% of the total lipids (85% fatty acids and 12.5% glycerol by weight). Triacylglycerols, which contain a great variety of fatty acids, are accompanied by small amounts of diacylglycerols and monoacyl-

Table 6.26. Average Size of Milk-Fat Globules of Different Species

Species	Diameter (micron)	Reference
Camel	2.00–3.93	(50, 82, 98, 140)
Cow	3.00–4.50	(71)
Buffalo	4.07–7.50	(2, 17)
Sheep	3.02–3.14	(2, 156)
Goat	2.57–3.25	(2, 196)

glycerols, cholesterols, free fatty acids, and phospholipids.

Glycerol is a nonvarying component of all fats, whereas the fatty acids represent the significant variable on which the physicochemical properties of a particular fat depend primarily. Fatty acids in milk are derived from two sources, blood plasma lipids, and synthesis in the mammary gland. Fatty acids of plasma come from the diet but also include fatty acids released from body tissues. The compositions of fatty acids in camel, buffalo, sheep, and goat milk are listed in Table 6.27. Taking into account the influence of some factors such as diet, stage of lactation, and genetic variations in fatty acid composition in milk of each species, data from different sources for each milk were collected. Within these limitations the general pattern of camel milk fatty acids indicates that short-chain fatty acids, C_4–C_{12}, are present in very small amounts compared to other species, especially sheep and goats, but the concentrations of $C_{14:0}$, $C_{16:0}$, and $C_{18:0}$ are relatively high, and $C_{16:1}$ is present in greater proportions in camel milk fat than in other species (Table 6.28). Camel milk fat also has higher proportions of unsaturated fatty acids compared with other species, which may be the main reason for the waxy texture of camel milk fat (103). Appreciable amounts of the essential fatty acid linoleic C18:2_{n-6} are found in camel and buffalo milk fats. Mixtures of milks can be detected on the basis of fatty acid analyses.

8.3 Phospholipids

Phospholipids are a small but important fraction of milk lipids and are found mainly in the milk fat globule membrane. The phospholipid content in camel, buffalo, and goat milk was reported as 4.8 mg/g fat (8), 3.8–4.0 mg/g fat (112), and 8–10 mg/g fat (120), respectively, and their composition is shown in Table 6.29. Phosphatidyl choline (PC), phosphatidyl ethanolamine (PE), and sphingomyelin (SP) are the principal components. Phosphatidyl serine (PS), phosphatidyl inositol (PI), and lysophospholipids (LP) are also present, and there are similarities in the relative proportions of each phospholipid among the five species. The total concentration of phosphocholine-containing components is fairly constant (52–60%), presumably because they perform the

Table 6.27. Fatty Acid Components in Milk Fat from Various Species (Calculated Means from Various Sources)

Fatty acid C:	Camel (6, 8, 84, 95)	Buffalo (16, 94, 149, 212)	Sheep (4, 94, 150, 178)	Goat (4, 15, 148, 178)
4:0	0.83	3.84	3.47	3.78
6:0	0.37	1.38	3.29	2.92
8:0	0.28	0.91	3.14	3.40
10:0	0.37	1.54	8.44	8.51
12:0	0.66	2.07	6.33	4.93
14:0	10.98	9.38	10.33	10.58
16:0	29.05	28.62	23.65	21.52
18:0	12.38	16.32	9.83	9.41
20:0	0.70	1.95	1.90	3.69
22:0	—	—	—	—
Monounsaturated				
10:1	0.19	0.37	0.82	0.40
12:1	—	0.12	0.10	0.37
14:1	1.49	0.89	9.03	2.10
16:1	10.13	2.24	1.95	1.28
18:1	24.45	26.50	15.29	20.07
Polyunsaturated				
16:2	—	0.80	0.13	0.62
18:2	3.11	2.71	2.70	3.09
18:3	1.39	1.83	1.87	0.97

Table 6.28. Minimum and Maximum Values of Relationships Between Fatty Acids of Camel, Buffalo, Sheep, and Goat Milk

Relationships	Camel (6, 8, 77, 84, 184)	Buffalo (16, 94, 149, 206)	Sheep (4, 94, 150, 178)	Goat (15, 148, 178)
Saturated, %	61.40–65.41	64.13–76.31	71.42–77.70	70.77–74.56
Unsaturated, %	34.59–42.87	28.30–35.20	22.30–28.58	22.99–29.23
Unsat. / sat.	00.53–0.75	00.37–0.54	00.29–0.37	00.30–0.38
Polyunsat. / unsat.	00.08–0.14	00.09–0.13	00.13–0.15	00.07–0.12
Short chain FA (C_4–C_{14})	12.95–16.65	09.47–29.59	34.10–48.45	24.63–42.17
Long chain FA (C_{16}–C_{20})	83.35–87.05	70.41–90.53	51.55–65.90	57.83–75.37

same structural function in each species (164). Camel milk phosphatidyl ethanolamine is unusual in that it contains 15% plasmalogen, whereas the largest amount reported in other phospholipids is 4% in bovine milk phosphatidyl choline (166).

The phospholipid fatty acids of camel, cow, buffalo, sheep, ass, pig, and human milk were studied (165). Phospholipid fatty acids of camel milk are not entirely characteristic of those of ruminants, as they have branched-chain fatty acids with more than two double bonds. Their sphingomyelin contains a high proportion of tricosanoic acid (C23:0), but little nervonic acid (C_{24}:$I_{n\text{-}a}$). Camel milk phospholipid fatty acids have high amounts of linoleic acid ($18{:}3_{n\text{-}3}$) and long-chain polyunsaturated acids. Its sphingomyelin contains a higher proportion of nervonic acid, and a lower proportion of tricosanoic acid, than that of ruminants.

8.4 Fat Globule Membrane

The very existence of milk fat globules depends on their membranes. Studies of the membrane are important for many practical problems. All interactions between fat and plasma must take place through the membrane. The total area is considerable and the membrane contains many highly reactive materials and enzymes. Hence, it can react in many ways. The physical stability of fat globules depends largely on the compositional properties of the membrane. In spite of the relatively small quantities of the fat globule membrane (FGM) in milk, it plays an indispensable role in determining the properties of milk-fat-rich dairy products. Table 6.30 shows the phospholipid composition of the FGM in the milk of four species. Phosphatidyl serine and phosphatidyl inositol are minor components, and the major components, phosphatidyl choline, and phosphatidyl ethanolamine, differ among the four species.

8.5 Lipid-Soluble Vitamins

The lipid-soluble vitamins, A, D, and E, in milk are of great nutritional importance for the newborn, and contents for camel, cow, and goat milk are listed in Table 6.31. The low levels of vitamin A and E in

Table 6.29. Phospholipid Composition in Milk from Camels (164), Buffaloes (164), Sheep (164), Goats (131), and Cows (164)

Species	Amount (mol % of total lipid phosphorus)					
	PC	PE	PS	PI	SP	LP*
Camel	24.0	35.9	4.9	5.9	28.3	1.0
Buffalo	27.8	29.6	3.9	4.2	32.1	2.4
Sheep	29.2	36.0	3.1	3.4	28.3	—
Goat	25.7	33.3	6.9	5.6	27.9	0.5
Cow	34.5	31.8	3.1	4.7	25.2	0.8

*Mainly lysophosphatidyl choline but also lysophosphatidyl ethanol amine.
PC: Phosphatidyl choline. PE: Phosphatidyl ethanolamine.
PS: Phosphatidyl serine. PI: Phosphatidyl inositol.
SP: Sphingomyelin. LP: Lysophospholipids.

Table 6.30. Phospholipid* Composition of the Fat Globule Membrane (FGM) of Milk of Different Species (% of Total Phospholipids)

Species	Amount (mol % of total lipid phosphorus)					Reference
	PC	PE	PS	PI	SP	
Camel	23.00	35.50	4.60	5.50	28.00	(8)
Goat	27.60	25.50	9.60	1.40	35.90	(120)
Buffalo	27.90	29.42	12.91	4.97	21.39	(207)
Cow	33.60	22.30	2.30	2.00	35.30	(121)

*For abbreviations, see Table 6.29.

Table 6.31. Fat-Soluble Vitamins in Camel, Cow, and Goat Milk

Species	Vitamin A μg/L	Vitamin E μg/L	Vitamin D IU/L
Camel	150[(a)]	530[(d)]	—
Cow	170–380[(b)]	200–1000[(b)]	25[(c)]
Goat	700[(a)]	< 1000[(c)]	23[(c)]

References: [(a)] (198), [(b)] (36), [(c)] (106, 120), [(d)] (128).

camel milk are a disadvantage. A balanced diet with camel milk as basic food should consider this aspect, especially vitamin A, since green vegetables are a minor part in the diet in arid areas.

8.6 Sterols

Cholesterol is the major sterol component of most milks with at least 95% of the total sterols, but small amounts of other sterols have been identified. In ruminant milks, beta-sitosterol, lanosterol, dihydrolanosterol, delta-4-cholesten-3-one, delta-3,5-cholestadiene-7-one and 7-dehydrocholesterol have been isolated and characterized.

Cholesterol is needed by the infant in challenging the development of cholesterol metabolizing enzymes, and it contributes to the synthesis of nerve tissues and bile salts. Cholesterol in cow's milk is similar to that of human milk (140mg/L) (119). No data are available on the cholesterol content of camel milk; however, cholesterol is the major sterol in camel milk fat (76).

8.7 Milk Fat Constants

Physical and chemical constants have been derived for the characterization of the types of component fatty acids present in milk fats (Table 6.32). They also enable the detection of fat adulteration qualitatively and quantitatively. Marked variations among the four species are found. Compared to other species, camel milk fat is higher in iodine value, acid value, refractive index, and melting point, but lower in Reichert Meissl, Polenske, and saponification values. This reflects its higher content of long-chain fatty acids (C_{14}–C_{18}), and lower content of short-chain fatty acids (C_4–C_{12}) (Table 6.27).

8.8 Triacylglycerols

The composition of triacylglycerols (TG), defined by the kinds and amounts of fatty acids, is important because it is in the form of esters that milk lipids are processed, as well as presented to lipases. The structure of TG includes the distribution of fatty acids within its molecule and is responsible for the melting point, crystallization behavior, and rheological properties of milk fat in butter and butter oil (121).

Milkfat TG can be fractionated on the basis of their melting points by melt crystallization at different temperatures with or without the use of solvents (24). The resulting fractions with their varying functional properties have great technological potentials not only in improving existing dairy products but also in developing new products, such as cream and butter powders, besides certain dietary foods. Buffalo and cow butter fat fractions were compared following simple crystallization (215), and four fractions of each fat type were obtained at three different temperatures, 30° C (solid fraction), 25° C (solid fraction), and 18° C (solid and liquid fractions). The

Table 6.32. Physicochemical Constants of Camel Milk Fat and That from Buffaloes, Goats, and Sheep

Physico-chemical constant	Camel (6, 76, 84, 179)	Buffalo (9, 109, 115, 173, 193, 197)	Goat (4, 197)	Sheep (4, 26, 197)
Acid value	0.54	0.29	0.48	0.28
Iodine value	43.8–55.0	25.20–35.10	27.09–33.00	31.92–39.72
Saponification value	200–217	220–230	232–243	240–276
Reichert Meissl value	1.10–2.12	28.64–36.70	24.02–26.69	29.42–30.39
Polenske value	0.50–0.62	1.20–2.80	7.06–12.30	1.40–8.77
Refractive index	1.4490–1.4714	1.4533–1.4773	1.4511–1.4559	1.4536–1.4559
Melting point (°C)	41.4–44.1	33.4–38.8	28.1–30.2	30.9

buffalo butter fat fractions were harder than those of cow butter fat.

Ghee was made from camel milk and fractionated at 18.5° C into a solid (SF) and liquid fraction (LF). The melting points of each fraction were 49.3 and 37.9° C for SF and LF, respectively, whereas that of whole milk fat was 40.9° C. Average contents of short-chain fatty acids, unsaturated fatty acids, iodine value, saponification value, refractive index, and specific gravity of SF were lower than those of LF. Average contents of long-chain saturated fatty acids (62%) and odd-number fatty acids (8%) for SF and corresponding values for LF were 41 and 5%, respectively (6).

The ratio of SF to LF in camel milk fat has been studied (191) by differential scanning calorimetry. Melting thermograms were recorded in the temperature range of −50 to +50° C. Melting started around −26° C and was complete below 43° C. Figure 6.18 shows typical melting thermograms obtained with dehydrated butter fat prepared from camel and bovine milk. The thermogram for camel fat differs in shape and does not show the peak around 15° C, which is typical of the middle-melting fraction of cow milk TG. The different amounts of low, medium, and high melting fractions of TG are consistent with the differences in fatty acid composition between cow and camel milk. In camel milk fat, the proportion of high melting fractions is high, and those of low and medium melting fractions are low compared with cow milk fat. Figure 6.18 shows the melting curves of camel and bovine butter fat. From these curves, the differences in churnability between camel and cow milk fat can be explained. It also becomes evident that butter from camel milk contains a significantly higher portion of SF over the entire melting range relative to butter from cow milk. At around 25° C, that is, the temperature that gave the best churning results, 35% of the fat was still liquid. Temperatures commonly used for churning cow milk cream are in the range of 10–14° C. The best churning temperature for camel and cow milk cream has similar proportions of liquid fat, for example, about 35%. At the optimal churning tem-

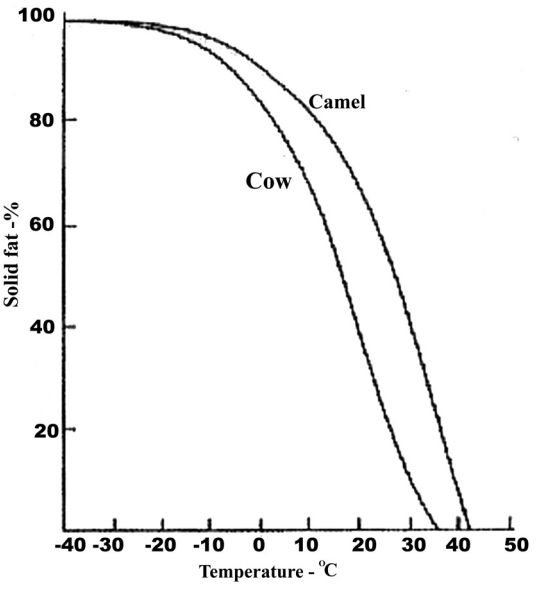

Figure 6.18. Melting curves of camel and cow butter fat. Percentage of SF as a function of temperature (191).

perature of cow milk cream of 10–14° C, the distribution between liquid and crystalline fat is approximately equal.

9 EFFECTS OF HEAT ON CAMEL MILK

9.1 Low Heat Treatment

The effects of heat treatment, like pasteurization or sterilization, has been extensively studied with bovine milk, but for camel milk similar studies are very limited. Two studies dealt with the effects on camel milk whey proteins. In the first study (77), camel milk was heated to 63, 80, and 90° C for 30 minutes, and the amount of undenatured whey proteins was determined. Camel milk whey proteins showed greater heat stability than those of cow milk. The degree of denaturation for camel milk whey proteins varied from 32–35% at 80° C, and 47–53% at 90° C versus 70–75% at 80° C, and 73–81% at 90° C for cow milk whey proteins. In the other study (54), camel milk was heated to 65, 75, 85, and 100° C for 10, 20, and 30 minutes, and compared with cow and buffalo milk. The effects of heat treatments were examined by SDS-PAGE technique (Figure 6.20). The three kinds of milk were affected by heat treatment. Heat-induced changes of whey proteins increased with increasing temperature and time of heating, but changes were more pronounced in buffalo and cow, than camel milk. Generally, camel milk whey proteins were more heat resistant than cow and buffalo milk proteins in the order of alpha-lactalbumin > beta-lactoglobulin > serum albumin.

9.2 High Heat Treatment

Early studies (50) revealed that heating of camel milk above 120° C for 10 minutes resulted in coagulation.

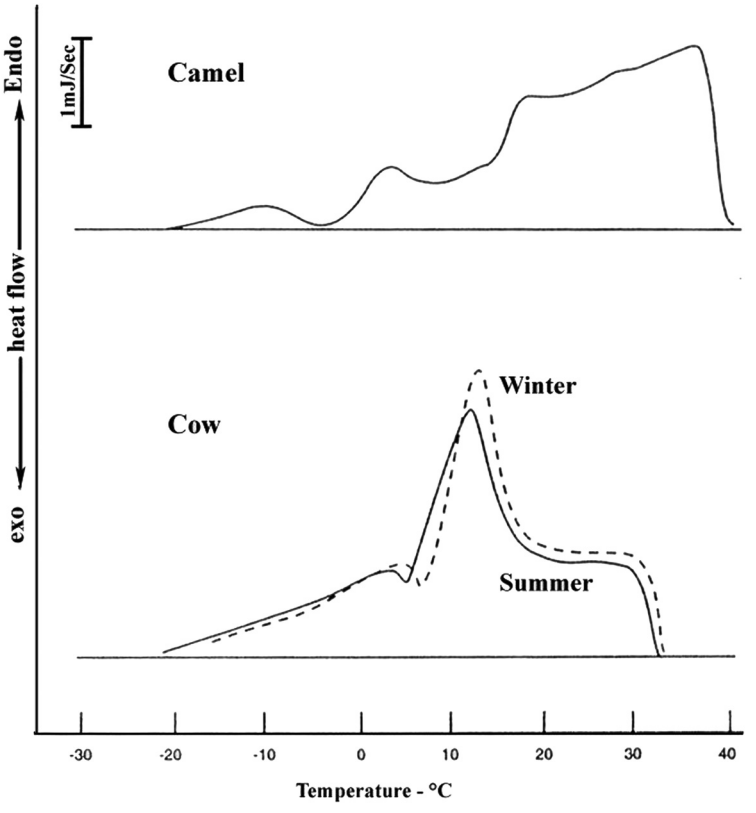

Figure 6.19. Differential scanning calorimetry thermogram of camel and cow butter fat (191).

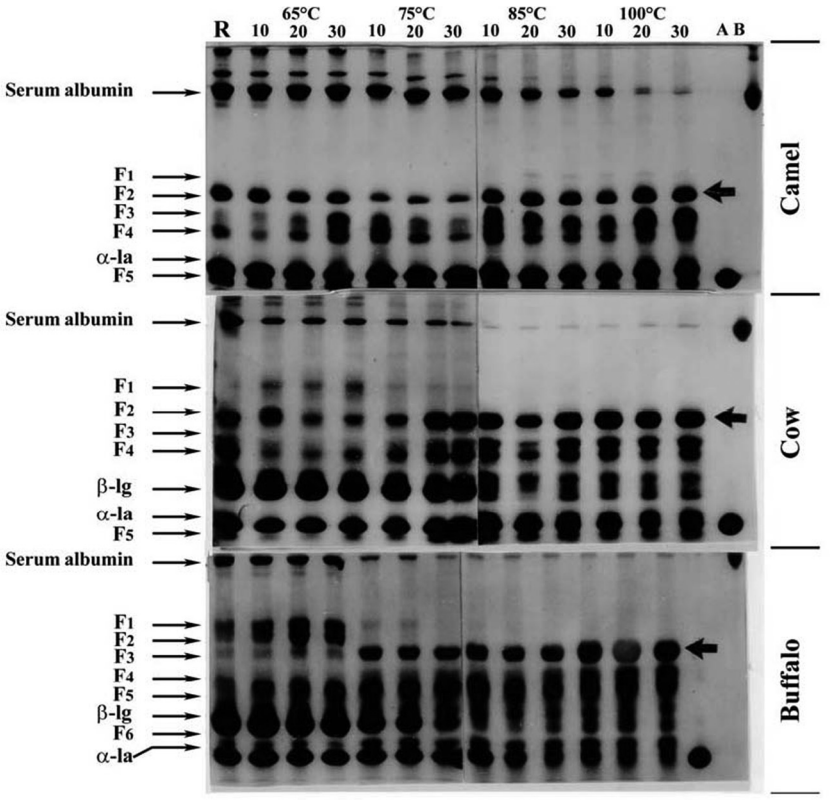

Figure 6.20. SDS-PAGE (12.5%T) of whey proteins prepared from camel, cow, and buffalo milk heated at 60°, 75°, 85°, and 100° C for 10, 20, and 30 min. R: raw; A&B: standard bovine α-lactalbumin and serum albumin, respectively. Anode is toward bottom of photo (54).

In other studies (70, 79), the heat coagulation characteristics of camel milk were examined in order to find its ability to withstand high processing temperatures. The heat coagulation time (HCT) at 100, 120, and 130° C was determined and compared with that of cow milk. The shape of the HCT/pH curve at the lowest temperature was different from that at high temperature for camel milk. Moreover, camel milk heated at 120 and 130° C was very unstable at all pH values (6.5–7.1), and coagulated in two to three minutes. The HCT/pH curve for cow milk showed a maximum around pH 6.7 and a minimum near pH 6.8, while camel milk showed no maximum and no minimum. Ovine and caprine milks have a maximum but no minimum (90). According to these findings, it can be concluded that camel milk has the lowest heat stability, which may due to: (a) the lower content of kappa-casein and the absence of beta-lactoglobulin (128), which are important in milk stabilization; and (b) the salt balance, that is, the ratio of Ca and Mg:citrate and phosphate, since the citrate level in camel milk is lower than that in cow milk (50, 82).

10 ENZYMATIC COAGULATION OF CAMEL MILK

The coagulation of milk proteins, mainly casein, depends upon the type of coagulant as well as the nature and composition of casein fractions in addition to other factors such as temperature and calcium salts. Different coagulants, that is, proteolytic

enzymes, have been used for milk coagulation. They are obtained from animal, plant, or microbial sources. Enzymatic coagulation of milk by proteolytic enzymes appears in steps. The first step is characterized by hydrolysis of kappa-CN covers of the predominantly hydrophobic core of the micelles by a C-terminal glycomacropeptide, which prevents micelle aggregation by steric hindrance and charge repulsion. This C-terminal part is specifically cleaved during the enzymatic reaction at a hydrophobic cleavage site, which is Phe^{105}-$Meth^{106}$ in cow kappa-CN. In the second step of the renneting process, an exponential increase in coagulation of casein micelles is found. Aggregation starts from the moment, when 60%–80% of kappa-CN is cleaved. The reduction of pH and addition of Ca^{++} increase curd firmness (39). Rennet coagulation of camel milk was found to follow a similar mechanism as that for cow milk (158).

Early studies showed that coagulation of camel milk was achieved after mixing it with goat, sheep, or buffalo milk (184, 234). Others reported that camel milk can be coagulated, if high amounts of calf rennet are added to obtain a desirable coagulum (34). With the same amount of rennet used, the coagulation time of camel milk was two to three times longer than that of cow milk; however, curd firmness could not be measured owing to the failure of curd formation (80). Effects of temperature, pH, and $CaCl_2$ on coagulation time were similar in camel and cow milk (80, 158, 181), while the difference in coagulation time still remained. To coagulate camel milk as quickly as cow milk, four times as much rennet had to be added.

With bovine chymosin at the same concentration, the coagulation time of camel milk was two to three times longer than for cow milk. Increasing chymosin concentration, the clotting time decreased in both milks, but it was still longer in camel milk (162). Clotting time of camel milk was significantly reduced, when camel calf rennet was used instead of bovine (229) or buffalo calf rennet (56, 58). Milk clotting activity of camel and buffalo calf rennets increased as pH decreased; however, their optimal temperatures were different, being 50° C and 45° C for camel and buffalo calf rennet, respectively (110). The proteolytic activity of camel calf rennet was higher than that of buffalo calf rennet and bovine pepsin towards camel and cow milk caseins (110). The main clotting activity of bovine calf rennet resides in the pepsin fraction, while it was chymosin for the camel calf rennet (229). Camel chymosin was characterized having 323 amino acid residues (128). Its molecular weight was determined as 35.629 kDa (128) or 35 kDa (56). Its *p*I is at pH 4.71, and shared 96.9% sequence similarity with bovine chymosin, 97.8% with porcine chymosin, 89.8% with camel pepsin, and 89.5% with porcine pepsin (128). Immunological studies (56) demonstrated that there is immunological similarity between camel and buffalo chymosins, when antiserum to camel chymosin was used.

All studies revealed that rennet coagulation of camel milk follows a similar mechanism as that for cow milk. However, the action of rennet on camel milk leads to coagulation in the form of flocs with no firm coagulum. This behavior is attributed to:

- In most studies, bovine chymosin had been used to coagulate camel milk; however, the clotting enzyme from a particular species is more effective with milk of the same species. This was confirmed for lambs (110), pigs (89), and camels (56, 58).
- Firmness of curd depends on the ratio of kappa-CN to whole casein, which in camel milk is 3.5%, while that of beta-CN is 65%, versus 13% for kappa-CN and 39% for beta-CN in bovine milk (128). In milks with higher amounts of kappa-CN than in cow milk, for example, buffalo milk with 130-200g kappa-CN/kg total casein (69), curd firmness was higher than in cow milk (18).
- Failure of coagulum formation is due to non-specific interaction of the protease with camel kappa-CN. Camel kappa-CN contains a distinctly different cleavage site for aspartic proteases as compared with bovine kappa-CN (128).
- Poor rennetability of camel milk may be related to the difference in size of casein micelles, because the size distribution of casein micelles in camel milk is significantly broader than in cow milk, with a greater number of larger micelles (82).

11 CAMEL MILK PRODUCTS

Camel milk, in most cases, is drunk as is, or left for souring. On a limited scale other products can be

made such as cheese, butter and pasteurized milk (78, 228).

11.1 Fermented Milk

Nomads usually leave excess camel milk to ferment and increase its shelf life under the hot conditions. Fermented camel milk is preferable for drinking and for medicinal purposes.

Kefir is a fermented milk made from camel milk in the former USSR (184). It is made by flash pasteurization at 85° C, cooling to 26° C, and inoculation with 3–6% of a kefir culture. A soft coagulum develops within incubation of 8–12 hours at 20–26° C. The coagulum has an acidity of 60 to 70° T. The product is further ripened for 24 to 48 hours.

Chal is a traditional fermented camel milk in Turkmenistan (152). Raw camel milk as such, or after dilution with warm water (1:1), is inoculated with previously fermented milk and incubated at 25–30° C. The coagulation takes 3–4 hours, but is held at the same temperature for eight hours to obtain the typical taste, which is due to the action of lactic acid bacteria as well as yeasts. Chall is made also in Iran from heated milk, subjected to lactic acid and alcoholic fermentation (129).

Shubat is a national drink of fermented camel milk in Kazakhstan. It is made from raw camel milk with the addition of 25% shubat culture, which consists of lactic acid bacteria and yeast. The product has acidity of 90–130° T, 1.0° alcohol, 4% fat, 3.8% protein, and 500 mg/L vitamin C (35, 180, 194).

Airag is a fermented milk in Mongolia. It is made from Bactrian camel milk. Milk is filtered, heated to 35–40° C, cooled to 25–30 C, and starter culture is added composed of *Str. thermophilus, Lactobacillus bulgaricus,* and *Saccharomyces* yeast. The milk is left to sour for 10–16 hours. The obtained fermented milk is consumed directly, or used for making a low alcohol drink through a special distillation technique. Sometimes the obtained fermented milk is used to make another drink known as "**butsalgaa**" by mixing **airag** with boiled hot camel milk.

Sometimes, the fermented milk is boiled to obtain low alcohol vodka "**arkhi**," or it is boiled directly to obtain a curd, which is known as "**tsagaa**," another fermented product consumed hot or cooled to treat simple symptoms of fatigue (242).

Oggtt is a dried fermented camel milk made and marketed in Saudi Arabia (11). The milk is left for fermentation in two days and then churned. The resulting buttermilk is boiled, while stirring until it becomes thick. The paste is allowed to cool to about 30–35° C, and then shaped by hand into small cakes, which are pressed and sun dried. The product is consumed either dry or after reconstitution with water.

Susa is a traditional fermented camel milk in East Africa. It is made by leaving raw milk for natural fermentation for one–two days. The product has different taste and flavor from batch to batch. Susa is also made from heated milk to 85° C for 30 minutes, then mesophilic starter culture is added at 2–3%, and incubation at 27–30° C takes place for 24 hours. The product has good organoleptic properties and acceptability (85).

Orom is a soured cream produced from Bactrian camel milk in Mongolia. It is made by heating milk at 75–85° C with mixing to make foams, cooling to 18–20° C, and leaving the milk for 10–15 hours to obtain soured cream (Orom), which usually is consumed fresh (116).

11.2 Cheese

Although cheese making from camel milk faces some problems, as discussed in section 10, some soft and hard cheeses have been successfully made from camel milk (163). For making hard cheese, camel milk was warmed to 32–35° C, rennet was added to coagulate the milk in 30 minutes, the curd was cut, and stirred for 10–15 minutes, then the temperature was raised to 42° C, held for 30 minutes, the curd was scalded for 15 minutes at 52° C, the curd was collected in cloths, pressed for six hours. And again for 18 hours, dry salt was rubbed on the surface of the cheese, which was left for 24 hours and then placed in 15% brine at 10° C for a week, after which it was kept at 18° C for five days. The cheese was turned every day, then removed to another ripening room for 5 days at 12° C, and finally stored at 8° C. The cheese yield was about 5%.

Soft cheese has been made from camel milk as follows: milk was heated to 62° C for two minutes, calcium chloride (0.01%), and starter culture (2%) were added. The milk was held for one hour at 35° C, then rennet (20–30 ml/100L) was added for coagulation in 60 minutes. The curd was left to settle for another four hours, after which it was pressed and salted. The yield of freshly made cheese was 12% versus 4.5% of the ripened cheese (124, 126).

Domiati cheese, a soft white cheese, was made from camel milk. In the manufacture, different percentages of fat, salt, and starter culture were used. The produced cheese was acceptable in sensory evaluations, especially with 1.5% fat and 3.0% salt. The yield of fresh cheese was 10–12% (157).

Another type of semi-hard cheese was also made from camel milk (226). The milk was heated to 65° C for 30 minutes, cooled to 35° C, followed by addition of 5% starter culture and citric acid (0.3g/L milk) until the pH reached 5.6–5.7. The renneting process took place at 35° C to coagulate the milk in 40 minutes. The curd was cut and the temperature raised to 45° C for 20–30 minutes. The curd was then collected in cloths, pressed, and placed in brine solution (10%) for two hours. The cheese was ripened for two weeks at 18° C; during this period, cheese was brushed with brine solution twice a day. The cheese was acceptable and the taste was comparable to blue cheese or Limburger, but after three weeks of storage at 25–28° C it became slightly bitter.

Other varieties of cheese were also made from camel milk (181, 182), such as fresh cheese, soft cheese, blue cheese, pressed cheese, and Ricotta (from whey). In the manufacture, bovine calf rennet or microbial rennet (*Mucor miehei*) was used with starter culture. Calcium chloride and calcium phosphate were also added to the raw milk. The cheese manufacture followed procedures for cow milk. The obtained cheeses were of good organoleptic quality. Yields were low as 7–10% for fresh cheeses and 3–3.5% for ripened cheese. Cottage cheese is made from fermented camel milk in Mongolia. Fermentation of milk for 10–16 hours occurs after using a starter culture. Afterwards, fermented milk is boiled, and curd is obtained, packed in less porous material, and pressed for 3–5 hours to draw off whey. The cheese is further cut into different shapes and processed into dried curds in the sun. Dried curd is softer and tastier than nondried curd. This type of cheese is called "**aarts**." The yield is about 25% (116).

11.3 Butter

Butter can be made from camel milk, but the method is different from that for cow or buffalo milk due to the nature of fat globules (size) and their dispersion in whole milk. Therefore, the churning of camel milk to obtain butter takes a long time, and the amount of resulting butter is low.

In North Kenya, nomads heat raw camel milk in a container, which has several stones. As a result fat droplets form and appear on the surface. The milk is then slowly cooled and beaten with a whisk until the fat droplets form small clumps of butter. Very small amounts of butter are obtained (83).

In Sudan, women make butter daily or every second day during the rainy season and the following short dry season. They heat camel milk to the boiling point and then, when it is cooled down, pour it into a butter-cask, often an impermeable basket, or sometimes a calabash, where it is left to sour. The process of souring is initiated by fermented milk left over from the last churning done in the basket. Souring takes one day or night, when it is hot; two days when it is cold. For churning, the sour milk should be at a temperature of 12–18 C. Therefore, butter is usually churned in the late morning, and never later than 1 p.m. because it is too hot by then. Many women add small pieces of dried red pepper and hold smoking wood several times over the sour milk in the covered basket. This process is said to accelerate the formation of butter, to give the butter a good flavor and make it better. The formation of butter itself takes 50–70 minutes. Buttermilk is not kept longer than two days. Approximately 8 liters of camel milk yields about 250 g of butter (113).

In the desert of Egypt, nomads usually make butter from camel milk after fermentation, because the churning process is easier and takes a shorter time. They put milk in a container to ferment, which takes one night in summer and 2–3 days in winter. The churning of fermented camel milk can be done in the same container of fermentation, or milk is transferred to a basket made from animal skin, and the churning process takes place by hand after the basket is hung on a tent pole and is swung to and fro until a special sound is heard. Some water is added to milk to help in butter separation. As in the Sudan, the yield is very low (*personal observations*). Butter is made also after separation of camel milk cream, churning it at 21–24° C for 30–40 minutes, and then raising the temperature to 32° C by adding warm water. A high recovery of butter is obtained (135).

In Pakistan, butter is made from boiled camel milk, and after cooling, starter is added and left for one night. The sour milk is then churned for 30 minutes with an electric churner. During churning, cold water is added to increase the yield of butter (3).

A more controlled method for butter manufacture from camel milk was carried out in North Kenya. Milk was heated to 65° C and separated with a hand centrifuge. The remaining content of cream was adjusted to a concentration between 20–30%. Afterward, the cream was churned at temperatures between 15–36° C. After churning, the butter was washed with water at 27° C. A high recovery of 85% of butter fat was obtained, calculated on the basis of milk fat (84).

11.4 Pasteurized Milk

Nowadays, pasteurized camel milk is presented in markets of some countries such as Mauritania and Saudi Arabia. Pasteurized milk is processed with modern equipment and machines of the Alfa Laval Company and on a large scale (3,000 L/day) in Mauritania (74).

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7
Yak Milk

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1 INTRODUCTION

Yak are members of the subfamily of cattle, *Bovinae,* and are classified as *Bos grunniens* or *Poephagus grunniens* (Figure 7.1). Yak, the ship of cold regions, serves the needs of foods and well being of people in the mountainous regions of China, Mongolia, Tajikistan, Uzbekistan, Russia, India, Nepal, and Bhutan (14). They are very unique in their ability to live under extreme environmental conditions (13). They originated on the Qinghai-Tibetan Plateau and were domesticated about 4,500 years ago (15). Inhabiting high-altitude plains (3,000–5,000 m above sea level and higher), these animals are able to survive unsheltered through several winter months, exposed to harsh snowstorms and temperatures below −40° C. Their adaptation with an outer coat of long, shaggy, thick hair, a dense undercoat of fine down, and large lungs relative to their body size provide a unique edge for survival. Adult females (≥ six years of age) weigh approximately 200–300 kg after summer grazing, and size differences are noted depending on whether the animal is wild or domesticated (27). Breed also influences productivity in various geographic regions.

Figure 7.1. A Chinese Yak in Sichuan Province, China (provided by Yucai Zheng).

Herdsmen/women and their families rely very heavily on these animals. They provide many essentials including milk, meat, transportation, fur and hide for clothing and shelter, as well as fuel in the form of dung (27). It is estimated that there are approximately 14 million yak in existence, with the majority living at high altitudes in cold climates or at cooler northern latitudes (3). Numbers in China are estimated at 13 million (23), with the largest population in the Sichuan Province, followed by Qinghai Province, the Tibet Autonomous Region, Gansu, Xinjiang, inner Mongolia, and Yunnan Province (15, 27). The largest population outside China exists in Mongolia with numbers of approximately 600,000. Wild populations of yak are estimated to be approximately 150,000 (9).

2 MILK PRODUCTION

Yak milk production has been described as no more than that needed for the development and normal growth of its calf, and use of milk by herdsmen and their families, taken at the expense of the calf (18).

In comparison to dairy cows, yak produce on average low milk yields of approximately 1.5 kg/day after suckling the calf, or 300 kg per lactation, with lactation periods of five to six months (9). Yak depend solely on natural pasture, but when herdswomen can sell yak milk to processing plants, as for milk powder, they can afford buying and feeding supplements (15). Providing 1.5 kg concentrate per yak cow per day can double milk production yields to 500–600 kg per lactation. Many yak are owned and managed by nomadic "minority" people grazing their animals during a short growing season of five months (15). However, the Chinese government with its technical extension service is helping the nomads to improve yak productivity with cultivated pastures, pasture harvests for winter feeding at valley farms, breeding with frozen semen, and selection programs.

Hybrid yak, crossbred with Holstein or other cattle breeds, are capable of producing higher levels of milk (Table 7.1). However, sterility is a problem in male hybrids (15). Therefore, it is impossible to make reciprocal crosses. The mechanism of this sterility is not clear. In addition, the hybrids often show a poorer adaptability to the harsh environment on the high plateau, especially in winter when supplement feeding is needed. Sarkar et al. (18) determined lactation curves from several multiparous yaks, which had completed three lactations. They found that yield varied from 0.45–3.25 kg/animal/day after suckling the calf, which consumes about the same amount of milk as collected by the farmer (3). Therefore, actual milk yield performance is about double those data. Herdswomen normally milk yak cows once per day, but when milk can be sold, they will milk twice a day (15). Milk yield was found to be minimal during onset of lactation and peaked at approximately 12 weeks after parturition in July to August. Peak production lasted until week 16–17, and then production declined toward the end of lactation. It was noted that the quantity of milk is related to the nutritive value of available herbage. It was also reported that milk yield is lower (about two-thirds) during a second lactating season, if there is no further calving (27).

Table 7.1. Milk Performance of Chinese Yak and F1 Hybrids in First Lactation of 149 Days after Suckling Calf (15)

	Yield kg	Fat %	Daily yield Kg
Yak	256	7.32	1.52
Holstein x Yak	687	5.31	4.01
Simmental x Yak	705	4.91	4.73
Murray Gray x Yak	463	4.95	3.11
Angus x Yak	507	5.02	3.40
Hereford x Yak	648	4.81	4.36

2.1 Milking Regimen

Cai (2) indicated that there are three milking regimens existing in different localities in China: once-daily milking in the mountain areas of the Northern Plateau, twice-daily milking on the grasslands of the Central Plateau, and thrice-daily milking along the valleys of the Eastern Plateau. These three types of diversity in the milking regimens depend not only on the geographical difference but also on the herders' convenience, custom, labor availability, and conditions of the yak herd (1).

Little machine milking is practiced in yak farming systems of the Qinghai-Tibetan Plateau, because of the poor infrastructures on the summer pastures (5). Pastures near the herders' houses are kept for winter grazing, those far from the herders' houses are kept for summer grazing, and the yak herds are normally milked on the summer pastures (6). In yak milk production, hand milking is more practical because of low labor cost in low-producing yak farming systems, regardless of milking regimens and herd management (5).

It was observed that two- to three-times-a-day milking increased milk yield by 30–50%, while the fat content of yak milk declined (31). The once-daily milking regime doubled the weight gain of the newborns, which would be attributable to the consequence of differences in milk intake by the calves (29). Twice-daily milking allowed the calves only four to five hours' suckling with their mothers, which reduced the milk intake. Two to three times milking per day reduced the cow's time on grazing and forage selection (21), which appears to be closely related to the low reproductive rate of the cows (28).

2.2 Herd Management

Dong et al. (5) reported that grazing and tethering (fencing) are two important aspects of milking yak

herd management, where grazing management is related to the milking regimens. No matter what type of milking regimen is adopted, the calves must be separated from the cow at milking and for night grazing (5). In case the calf is tethered, the cow also has to be tied up, whereas if the calf is kept in a closed corral, the cow is not tied (5).

Under the once-daily milking regimen, the cows are recalled from their night grazing to the campsite, where they are mustered without tethering from around 5:00 to 7:00 in the morning, and milked from 7:00 to 9:00 a.m. (5). The calves are released from their overnight wooden closure (tethering) to graze with their mothers and suckle from around 9:00 a.m. to 6:00 p.m. The herds are brought back to the campsite and the calves are separated into a wooden corral (or are tethered to a long rope) from around 6:00 to 8:00 p.m. The milking yaks are placed on the pasture near the campsite for free grazing without the company of their calves during 8:00 p.m. to 5:00 a.m. (3, 5).

For twice-daily milking, cows are milked during 7:00–9:00 a.m. and 8:00–9:00 p.m., while for thrice-daily milking regimen, cows are milked during 5:00–8:00 a.m., 1:00–3:00 p.m., and 7:00–9:00 p.m., respectively (5). Calves are allowed to access mothers during daytime for the period of pasturing, but they remain tethered overnight.

The labor requirements vary among different milking regimens. Under the Tibetan yak milk herd management, one adult woman can usually finish grazing, tethering, and milking a herd of 40–50 cows in a once-daily milking system (5). For the twice-daily milking regimen, a child can perform grazing and tethering the herds of both cows and calves, and one adult woman can handle milking the cows and processing the milk products (5).

2.3 Yak Breeding and Cross-Breeding

Breeding season for yaks in Nepal is usually from mid July to November (20). The breeding patterns of yaks reflect seasonal shifts in the availability of forage. In Nepal, cross-breeding is more popular, although yaks are purebred (19). *Chauri* breed is produced by cross-breeding of yaks with hump cattle (*Bos indicus*) and humpless cattle (*Bos Taurus*). Hump cattle, or *aule*, are raised from 1,500 to 3,000 m above sea level, while humpless cattle (called *kirko* in the east and *lulu* in the midwestern belt) are raised at slightly higher elevations (19). In order to produce cross-breeds called *urang jhopkuo* (male) and *urang jom* (female), farmers usually cross yaks for the first three to four generations with *aule* cows (Table 7.2). Sherchand and Karki (19) further noted that the male offspring of the crossbreed are sterile, while females can reproduce. *Urang jom* are then back-crossed with purebred yaks. When female purebred yaks (*nak*) mate with *kirko* bulls, the offspring are called *lang dimzo jhopkyo* (male) which are sterile, and *dimo jom* (female), which are fertile.

In milk production levels, *chauri(s)* exceed those of purebred *nak*. *Jom(s)* are particularly milk producers of yak. *Jom(s)* can produce 1.5–3 liters milk

Table 7.2. Traits of Yak and Yak Cross-breeds in Nepal

Traits	Nak Jom	Dimzo Jom	Urang Jom	Brown Swiss Cattle	Aule
Milk yield (MY)					
MY/lactation (liter)	220	300–540	300–540	1045	300
Milk days	167	120–180	120–180	305	300
MY/day	1.3	1.5–3.0	1.5–3.0	3.4	1.0
Milk fat (%)	6.6	5.7	5.7	NA	3.8
SNF (%)	11.5	11.1	11.1	NA	NA
Age at first calving (yr)	4.3	3	3.7	4	4
Herd calving rate (%)	55.4	NA	NA	NA	NA
Calf mortality (%)	22.5	NA	NA	NA	NA
Herd mortality (%)	9.3	NA	NA	NA	NA
Calving interval (d)	689	425	425	NA	NA
Gestation period (d)	254	270	270	270	280

Adapted from Sherchand and Karki (19), Shrestha (20), and Robinson (17).

per day, whereas the *nak* and *aule* cattle produce only 0.9–1.8 and 0.5–1.0 liters per day, respectively (Table 7.2). When *nak(s)* are artificially inseminated by Brown Swiss cattle, the female hybrids (BS *Joms*) produce even an higher volume of milk, yielding 3–4 liters/day (Table 7.2). In many places throughout Nepal, *chauri(s)* are considered more versatile than purebred yaks (19). *Chauri(s)* are more manageable draught and pack animals and tolerate slightly lower altitudes than yaks. Depending on the season, *Jhopkyo* are used as pack animals and can carry between 60 and 80 kg (19).

3 MILK COMPOSITION

Yak milk has a golden rich color (16) and is described as being dense with a sweet fragrant smell (27). Quality is often defined as "thickness" or "richness," referring to the fat content of yak milk. Composition of the milk from yak in China, Mongolia, and Nepal is shown in Table 7.3 (9, 15, 27). Total solids levels were found to range from 15.70–18.36%. Fat levels, almost twice the average in cow milk, ranged from 5.45–8.60%, depending on factors such as season, time of milking, and availability and utilization of supplementary feed. Protein levels were between 4.20% and 6.50% in yak milk from China to Nepal. An inverse relationship between milk yield and fat and protein composition has been documented (18). Lactose levels in yak milk have been found to range from 3.3–5.8% (15), and ash levels between 0.4% and 0.9% (9, 27). Table 7.3 also shows yak milk composition data for mineral levels and whey proteins in total protein contents (27).

According to analyses of amino acids in yak milk by the Animal Product Processing Laboratory of Southwest National College in Chengdu, China, the total content of 17 amino acids in yak milk was found at 2,341 mg/100 g protein, and the levels of leucine and lysine were higher than in cow milk and goat milk. The values of essential amino acids are shown in Table 7.4 (9).

4 PROCESSING TECHNOLOGY AND TYPES OF YAK MILK PRODUCTS

Traditionally, yak milk has been a major staple for herders and their families in the highland plains. Milk in its full-fat form is consumed by children and the elderly (24). Yak milk is concentrated to form products such as butter and ghee, and the milk is also fermented to form yogurt-type products. The ability to process perishable milk into products that have a long shelf life allows products to reach more distant markets. In some areas where herders have access to roads, milk can reach markets where it is processed into powder, providing up to 60% of the total income for herders (27). In addition to being

Table 7.3. Composition of Normal and Colostrum Yak Milk from Different Regions (9, 15, 22)

	China range	Mongolia	Nepal	China colostrum
Total solids, %	15.70–18.36	16.00	17.40	33.01
Fat, %	5.45–8.60	5.60	6.50	14.00
Protein, %	4.20–6.40	4.23	5.40	16.14
Lactose, %	3.30–5.80	5.29	4.65	1.86
Ash, %	0.40–0.90	0.91	0.85	1.01
Energy, Kcal/L	871–957			
Density	36.58			
α-lactalbumin, % of protein	3.8			
β-lactoglobulin, % of protein	15.3			
serum albumin, % of protein	2.2			
Calcium, mmol/L	36.8			
Phosphorus, mmol/L	24.8			
Potassium, mmol/L	27.6			
Sodium, mmol/L	20.8			
Magnesium, mmol/L	2.5			

Table 7.4. Essential Amino Acids (g/100 g protein) in Yak, Cow, and Goat Milk (9)

Amino acid	Yak	Cow	Goat
Lysine	8.8	8.2	8.1
Tryptophan	1.6	1.7	1.3
Phenylalanine	4.8	5.0	6.0
Leucine	12.0	9.2	9.9
Isoleucine	4.3	6.1	4.3
Valine	6.4	7.2	5.7
Methionine	2.7	2.8	3.5
Threonine	4.2	4.9	5.7

dried into powder, yak milk may be processed into cheese or cheese-like fermented products.

4.1 Milk Tea

As a drink, boiled milk is used mainly for the beverage known as "milk tea," which is a mixture of tea and yak milk, drunk at all times of the year (5, 7). To make the milk tea, tea leaves are cut from a tea brick, added to water, and boiled for a few minutes. Boiled milk is added to the brewed tea in the proportion required, and boiling continues for a few more minutes to complete milk tea (10). This yak milk tea is similar to Mongolian milk tea, which is a mixture of tea and Mongolian cattle milk (11).

A little salt may be added to the milk tea, but sugar is never added, due to the existence of sweet taste in the original milk. Some roasted oat or barley flour, or mixture of the two, is often added to the brewed milk tea, making it both a food (Zanba) and a drink for Tibetan people and their guests (4, 5). In Tibet, this drink is a staple part of the diet of yak herders and their families (30). When plenty of milk becomes available during the warm season, or when served to guests, the brewed tea will contain 20% milk or even more, and the color of the drink is yellow. However, yak herdsmen and their families more often drink a light tea with only 5% yak milk added, which is then milky white with a little yellow color (5, 10).

4.2 Yak Milk Cheese

In 1952, through the Food and Agriculture Organization (FAO) of the United Nations, Swiss technology to produce cheese in the Alps was transferred to Nepal (24). This technology transfer allowed the use of yak milk to produce a Swiss Gruyere type cheese. Nepal became the first country in Asia to engage in a cheese industry, and prior to 1980 was the only country in the world to produce yak cheese (24). During 1998 and 1999, Nepal produced approximately 150 tons of yak cheese from yak and hybrid yak milk. A statistical breakdown of Nepalese yak cheese production indicates that 88 tons were from private sector processors and 60 tons were from six Nepal Dairy Development Corporation plants (24).

Thapa (24) outlines a standardized method for the production of the Gruyere type cheese. In brief, raw yak or hybrid yak milk (7–8% fat, 9.5–10% solids non-fat) is standardized to 3.5% fat. Cheese milk is then pasteurized at 65° C for five minutes and cooled to 33–35° C. Cheese milk is transferred to copper kettles and placed on a traditional fireplace. A 1:1 ratio of *Streptococcus thermophilus* and *Lactobacillus helveticus* is added at 0.5%. Rennet is added and the cheese milk is allowed to set at 33° C. Following curd formation, the curd is heated to 50–53° C within 30 minutes. Curd is then stirred, molded, and pressed. Cheese blocks are brined and then ripened at 10–12° C and 85–90% humidity for two weeks. Cheese is further ripened at 20–22° C and 75–80% humidity for two to eight weeks. Cheese is allowed to mature at 8–10° C, and good flavor development can be noted after five months of ripening. With 10 kg milk yielding 1 kg yak cheese, Wiener (27) reports that the chemical composition of three-month-old Nepalese yak cheese tested 5.75 pH, 31.8% water, and 68.2% total solids contents. Butter fat on a dry mass basis was 49.4% and salt 1.37%. Estimates for corresponding three-year-old yak cheese were 23.1% water, 76.9% total solids, 46.8% fat (dry mass basis) and 3.12% salt.

Another yak milk cheese-type product is chhurpi, which is described as a dried, hard, casein product. Chhurpi contains 8–10% moisture, 8–9% fat, and 80% protein on a dry matter basis (27). This product, traditionally produced and consumed widely by Himalayan people in the northern parts of Nepal and northwest India, has served as a source of nutrients and was chewed while mountain climbing to promote salivation (24). Commercial production of chhurpi, outlined by Thapa (24), includes skim yak milk that is heated to 60–65° C, followed by the addition of fermented milk. The mixture is then

cooked by boiling until threads or chains form. Whey is drained and the curd is pressed. Curd is then air dried for approximately 12–15 days; alternatively, smoke can be used for drying after 10 days of air drying.

In Bhutan, two types of dried cheeses (*chuto* and *hapiruto*) are made, depending on the market for which they are intended (26). *Chuto* is made by slicing the circular cheese into small pieces and hanging them in strings of twenty pieces. After they are boiled in milk, the strings are hung on a pole in the tent and allowed to dry until they become hard. *Hapiruto* is made in larger pieces and dried in 20-piece strings until it is rock hard (26). Whey is consumed by yak herders or fed to calves. The average annual production from a female yak is 25 kg of butter and 30 kg cheese (25).

4.3 Butter

Butter is the major product from yak milk in China, and it has been used as one of the staple foods for local people (27). The traditional method of butter making starts with gravity creaming. Milk separators are being used in some areas to obtain cream. The milk is first heated to about 35° C and then filtered. The mechanical separator is operated by turning a handle, and cream is collected from the top outlet (Figure 7.2). The cream is naturally fermented for a day or so and then is transferred to a wooden churn. A stick for stirring is held in the center of the churn by the lid. The cream is stirred/churned by rotating the stick until the fat solidifies and further churning becomes difficult. The milk fat floating on the surface is then removed by hand and washed in water. Water is then squeezed out, and butter is made into differently shaped blocks (cylinder or cube) using wooden molds. Butter is used for many different purposes in Sichuan, Qinghai, and Tibet, such as lamp fuel on family altars, as an ingredient for medicine, for tanning and polishing fur coats, molded scriptures for religious ceremonies and celebrations, as well as for different foods. Butter tea is especially popular with yak herdspeople in China and Tibet.

4.4 Other Yak Milk Products

Raw yak milk is being used and often mixed with cow milk for sweet milk powder production in the Sichuan and Qinghai region in China.

Yak milk cake is a product made of mainly whole yak milk, or sometimes skimmed yak milk. It is harder in texture than "milk residue" and looks like a "cake." Milk cake is usually eaten with butter and sugar to enhance more flavor for yak herdsmen, and it is served to guests (2).

As a preproduct of milk residue, milk curd is also widely consumed as a dessert by the yak herding people on the Tibetan Plateau (8). Whey is rarely used, whereas it can be used to feed pigs in the agricultural-pastoral areas. The yak milk whey is also used in traditional processes for making leather (10).

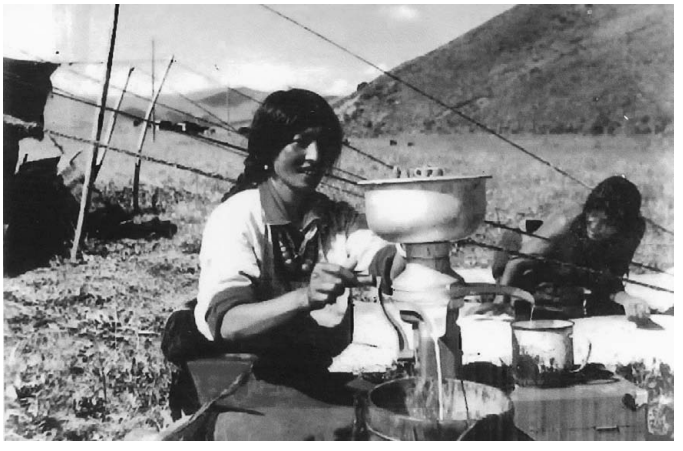

Figure 7.2. A mechanical milk separator for cream separation (provided by Yucai Zheng).

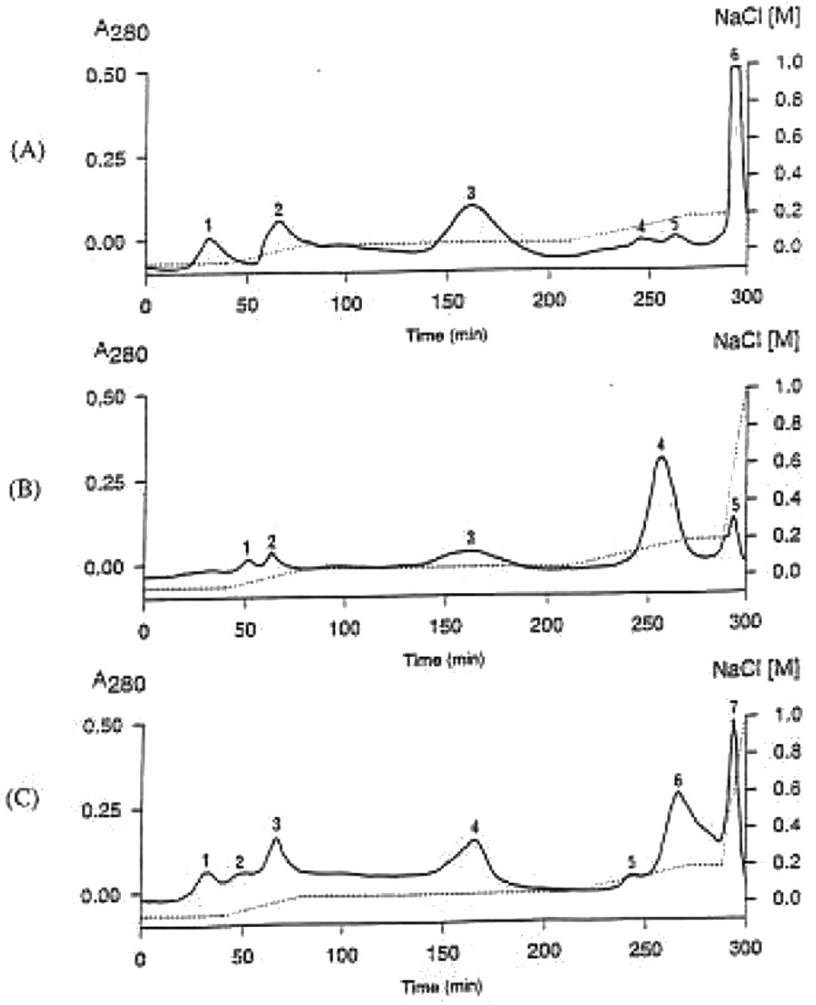

Figure 7.3. Fractionation of the total whey protein fractions of bovine (A), Yak (B), and Khainak (C) milk by ion-exchange chromatography on DEAE-Sephacel. Adapted from Ochirkhuyag et al. (12). (Fractions 6.8 ml were collected at a flow rate 150 ml/h.)

Demand for yak milk products exceeds production. Yak cheese has a well-established market in tourist areas and provides an opportunity to generate a sustainable income. There is a great need for further diversification, which will require practical training and technology transfer (24). Yak milk products are considered to be specialties. However, there are very little available data on yak milk chemistry. Therefore, systematic studies on chemical composition of yak milk and processing technology are needed in order to better utilize this valuable resource, and more emphasis on studies is under way in China.

5 OTHER RECENT STUDIES ON YAK MILK AND GENETICS

The characterization of yak milk protein in comparison with milk of other species by PAGE revealed that elution profiles and electrophoretic mobilities of

the main components of yak and khainak caseins were nearly identical to their cow milk counterparts (12). Protein separation by anion exchange chromatography on DEAE-Sephacel using a stepwise NaCl gradient showed that β-lactoglobulin of yak and khainak co-eluted with a protein of higher molecular mass (Figure 7.3). The chromatographic data for α-lactalbumin and β-lactoglobulin of yak and khainak agreed well with those of their bovine counterpart (12).

Polymorphism of the 5'-untranslated region and exon 4 of k-casein gene was studied in Yakutian and Black Pied cattle, yak, European bison, and buffalo by means of a polymerase chain reaction (PCR) and subsequent restriction fragment length polymorphism analysis (PCR-RFLP) (22). The use of several restriction endonucleases allowed three alleles of k-casein (k-CnA, k-CnB, k-CnF) to be typed and new allele variants in yak, European bison, and buffalo to be revealed (22). Sulimova et al. (22), studying the nucleotide sequences of the fragments of exon 4, determined two new alleles of the gene: k-CnG in yak and European bison and k-CnH in buffalo.

Immunologic studies focused on the genetic resource of yak in the cold mountainous regions indicated that the characteristics of yak erythrocyte antigens had the presence of A(2), Y, X-2, J, and Z antigens in high proportion (14). Twenty-nine bovine red cell antigens were detected on yak erythrocytes. Yak has 30 pairs of chromosomes, of which 29 pairs are autosomes, which are acrocentric, and the Y chromosome is submitacentric (14).

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8
Reindeer Milk

Øystein Holand, Hallvard Gjøstein, and Mauri Nieminen

1 INTRODUCTION

The reindeer herders are the pastoralists of the north. Reindeer husbandry is a single-species production system in which only reindeer are able to thrive. Reindeer herding originated thousands of years ago in the northern part of Eurasia, probably as a result of resource depletion of the wild fauna, especially the wild reindeer populations (23). Traditionally, the reindeer husbandry was characterised by small, tame, multipurpose herds, often combined with hunting, fishing, and gathering. Chinese annals from AD 499 describe this form of reindeer husbandry, indicating that it is at least 2,000 years old (20, 45). The resource niche of the vast Eurasian tundra and northern taiga varies in time and space, and four main types of herding practice may be distinguished (63), all characterized by a nomadic lifestyle, although on different scales. This suggests a multicentric origin of reindeer husbandry (63) based on different natural as well as cultural conditions. Still, reindeer herding is practiced in about 20 ethnic groups spread all over the continent, involving about 50,000 people and 2–2.5 million semi-domestic reindeer (*Rangifer tarandus*) (31, 65). For these people, reindeer herding is the backbone of their economy and an essential part of their cultural identity.

In two widely separated regions, around Lake Baikal and in northern Fennoscandia, milking evolved as an integrated and important part of the production system. This was probably a function of ecological adaptations based on available natural resources and topography, influencing herding techniques, herd size, and deer breeds, as well as cultural influx. Milking was abandoned in the early 1900s as the subsistence economy was replaced by an extensive meat production system. Still, remnants of this practice can be found in southeastern Siberia (20).

This chapter describes the traditional milking regime. It further dissects biological constraints of the production, reindeer milk composition, and the potential yield. Based on these findings, this chapter discusses the potential of establishing a new niche-based milking industry taking ecological as well as economical considerations into account.

2 HISTORY

2.1 Geographical Distribution

Reindeer pastoralism, where milking was an integrated part, evolved at least two thousand years ago in the taiga region of eastern Siberia around Lake Baikal and spread to the nearby ethnic groups (20) (Figure 8.1). The most intensive milking regime developed along the border between Russia, Mongolia, and China. Cultural exchange and the expansion of pastoral nomads living on the northern fringe of the Asian steppe probably triggered this development. The famous horse and cattle breeders, the Yakuts, adapted reindeer husbandry as they pushed north and introduced an advanced milking culture into the region (20). The subsistence-based economy in Siberia persisted basically up to the Socialist Revolution in 1917. The collectivization and rationalization in the 1930s transformed these societies

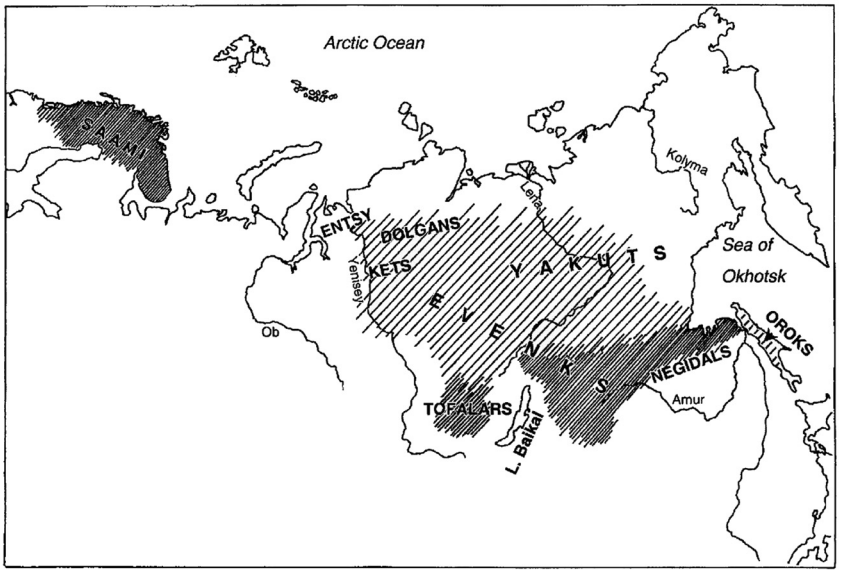

Figure 8.1. Geographical distribution of ethnic groups in Siberia (east) and Finland (west) Eurasia where reindeer milking traditionally was an integrated and important part of the production system (heavily stippled), and area (lightly stippled) where milking was regular but manufacturing rare. Adapted after Holand et al. 2002 (28).

into market-oriented economies, and the close bond between the herders, their households, and the animals, a prerequisite for keeping tamed milking animals, was weakened. However, in the late 1920s, researchers started exploring the industrial potential of reindeer milking (64). Experiments were set up for commercial production of butter and cheese. In the late 1930s, the production was shut down (20). The low yield indicated that this labor-intensive industry was not profitable. Parallel with the large collective herds, small, privately owned milking flocks persisted, and remnants of these can still be found in remote areas in southeastern Siberia (20). The recent privatization and ongoing de-collectivization of the reindeer industry in Russia, where about 50% of the semi-domestic reindeer are found, will again alter the livelihood of the people involved.

The milking practice evolved independently, although at a later stage, among the westernmost reindeer herding ethnic group, the Saami (18, 63) (Figure 8.1), probably influenced by the Nordic milking husbandry culture expanding north into the traditional Saami areas (48, 63). Still, in the late 1800s the Saami reindeer herding families living in the southern area of their range practiced small-scale reindeer pastoralism, where milk was manufactured into cheese and butter for their own consumption as well as for sale. The milking was abandoned in the early 1900s because the milking pastoralists were not able to protect themselves against the aggressive form of reindeer husbandry based on larger meat-producing herds. In some areas, milking continued up to the 1940s and locally up to the 1960s. However, the intensive production was doomed as new technology, especially the snowmobile and later the four-wheeler, made it possible to control even larger herds.

2.2 Management Regime

The reindeer herders adopted methods of milking from their neighbors and developed it further as part of their semi-nomadic reindeer husbandry. Normally, milking started a month after calving, which takes place during May, depending on latitude and environmental conditions (18, 20), and continued up to the rut in late September and early October. Among the advanced southeastern Siberian milking

societies, the calves and females were normally tethered during alternate periods to ensure that both remained close to the campsite and kept separated during part of the day. The females were milked up to three times daily, and the separation time of the calves from their mother varied depending on lactation stage (20). To ensure adequate pasture quality near the campsite, frequent small migrations were practiced.

The most efficient form of Saami milking regime, but also the most labor intensive, was to "kjevle" the calf (18, 68). Small herds were driven into a restricted fence or onto small peninsulas or snow patches, where the calves were caught and equipped with a small wooden stick (preferably made of *Juniperus communis*) in the mouth, which prevented them from suckling but did not hamper grazing seriously. The herd was released and herded until next morning, when the herd again was gathered. The females were milked and the calves released from the sticks. This practice continued throughout the summer up to rut, normally twice a week, and was a flexible and easy adjustable milking system, securing the growth of the calves and a decent milk output for human consumption. Mobile milking camps secured access to high-quality forages and reduced the risk of contagious diseases spreading in connection with the heavily used milking fences.

The production system was based on selection of good milking females, characterized by large udders and other morphological traits. Also, behavioral traits such as homing ability, herding affiliation, and handling acceptance were favored. These animals were easily trained. A skilled milker emptied the udder within 10–15 minutes (18, 20), depending on udder characteristics and quantity of milk, and could easily milk 30 females by hand during a day. Often the animals were given salt and other highly preferred supplements, and during periods of insect harassment, smoking fires were created to protect and calm the animals. The milkers stimulated the udder by imitation of the calf's butting by hand to induce ejection. Some groups covered the back two teats, allowing the calf to approach and suckle the front teats for a short period and thus priming the udder.

An extensive form of milking, practiced both among the Saamis and some Siberian reindeer people, took advantage of the synchronous activity pattern of the animals. At the end of a long resting period, normally during the middle of the day, the flock was directly herded into pens, not allowing the calves to suckle before the females were milked (55, 68).

2.3 Utilization

The animals provided milk both for immediate consumption and processing. Children drank it fresh and adults consumed it in tea and coffee. The milk was dried and processed into cheese, butter, and sour cream, as well as used in medication (Table 8.1). The milk products were used primarily within the household. However, the most advanced milking societies used cheese and butter as trading goods (18, 20). The processing techniques were the same

Table 8.1. Traditional Products and Uses of Reindeer Milk (28)

Fresh milk	Consumed by children, often diluted with water; used in tea and coffee and in medical treatments
Stored milk	
Frozen	Stored for consumption during winter; ice cream mixed with berries
Fermented	
Short	Sour cream and cultured milk inoculated by a bacterial starter; for consumption
Long	Stored in wooden container, often mixed with herbs, curdled, consumed during winter and spring migration, both the liquid and solid phase
Dried	Tent-dried in stomach compartment, reticulum, for a longer period; winter consumption
Manufactured milk	
Cheese	Curdled by heating or dried *abomasums*; dried and stored for consumption and sale
Butter	Churned both from fresh and fermented milk; consumption and sale
Rest of products	Buttermilk and whey, consumed fresh and reduced and eaten as soup

as those practiced by their neighbors, and were developed further and adapted according to local conditions. They also stored the milk on cool sites in wooden containers for use the next winter or during spring migration (18). The milk curdled, and often they mixed it with tasty herbs (*Oxyria* spp. and *Angelica* spp.). The milk was also stored by freezing it, and it was sometimes mixed with berries (*Vaccinium* spp., *Empetrum nigrum*) (19, 20).

During the lactation period, the chemical composition of the milk changes substantially, reaching a dry matter content of about 30% including a fat content of 15–20% late in the lactation period (38, 74). This influences the processing properties of the milk. Normally the milk from the first part of lactation was consumed fresh; the second part was mainly used for cheese production, whereas the last part of lactation was more appropriate for churning butter (18, 20). Reindeer milk and its products were highly priced and also used as a medical remedy to cure digestive problems (the milk has antidiarrheic properties) and to heal wounds (68). Fat oozed by heat from reindeer cheese was also used to cure nursing pains, frostbites, and other injuries. In addition, colostrum was used for children's ailments (20).

3 ECOLOGY AND LIFE HISTORY

3.1 Constraints and Management Implications

The reindeer is the only cervid with a long and continuous history of domestication (23). For the reindeer hunters, the seasonal regular harvest of the abundant migratory herds represented a staple food resource, and by-products (skins and bones) were excellent raw material for production of functional cloths and tools. With the decreasing size of the herds in the early Holocene (23), the hunters could no longer rely on the efficient harvesting of reindeer by intercepting the migration routes. A nomadic life style, following the herds year round, evolved as an adaptation to the reindeer's migratory pattern and the depletion of the resource base (23). Gradually the domestication process started, using tamed animals as decoys during hunting operations and for transportations.

The caribou, the North American equivalent to the Eurasian reindeer, was not domesticated. This suggests that the wildlife resource depletion was not that severe in the northern part of the New World. The fact that no ruminants of the North American fauna have been domesticated indicates hunting societies with rich resource bases and no cultural intermingling with pastoralists. The vast tundra and taiga zone of North America implies normally very long migration routes of most caribou herds, and made it difficult for the hunters to follow the herds year round. This may have hampered the evolution of a nomadic lifestyle. Geist (23) suggests that the Eurasian tundra reindeer, which is the main ancestor for the semi-domestic reindeer, is a highly advanced subspecies as far as social organisation and gregarious behavior are concerned, compared to the tundra caribou. However, in the southern part of the range, the forest reindeer type has also probably been domesticated (23). Early in life the reindeer is easy to train (7, 63). As the juveniles get older they harden into stubborn individuals with traditional habits. Hence, early training of potential milking females and early separation from the rest of the herd is a prerequisite for success.

The nomads had to protect their small, semi-domestic herds from mixing with wild reindeer by intensive herding. This favored close bonds between the herders and their reindeer, and a mutual relationship evolved characterized by multiple use of the animals, primarily based on living products (decoys, transportation, hair, milk, and antlers), whereas the herders provided protection against predators and insects and occasionally supplied feed and salt. As the wild reindeer population was eradicated from most of its natural range, the control over the semi-domesticated herds could be more relaxed, a prerequisite for development of a more extensive form of reindeer husbandry. This allowed bigger herds, where the reindeer could roam more freely, at the same time being kept under control. Traditional knowledge underlines that reindeer perform best if not disturbed or herded too tightly, because they are better able to express and realize their growth potential (68). Still, mixing between wild and semi-domesticated reindeer, especially in Siberia, which harbors most of the wild reindeer population of around 1 million animals, is of major concern for the reindeer owners (7, 67).

The semi-domestic reindeer differs only slightly from its wild ancestor in morphological and physiological traits as well in life history strategy. This can

be accounted for by its nomadic way of life, the extensive herding practice, and by the interbreeding with wild reindeer in most areas up to recently. The high degree of phenotypic plasticity and behavioral adaptations, probably as a consequence of the highly stochastic arctic and subarctic environment both on short (ecological) and long (evolutionary) time scales (23), will also reduce the differentiation. In this free-ranging system, where the semi-domestic reindeer are under partial control and the herders are not able to manipulate the environment to any large extent, natural selection is the driving force and artificial selection may have limited potential (58). Still, remnants of a more intensive selection regime are found. In the Tofalar region (west of Lake Baikal), where an intensive milking regime was practiced up to recently, the udder of the reindeer is said to be 25% larger relative to their body size compared to their "neighbors" (20). Anecdotal information about remnants of a Norwegian coastal milking breed exists, suggesting a strong selection for high milk yield and intensive care of these animals up to the 1900s (Kalstad, pers. comm.). As supplementary winter feeding is spreading into many regions (33), new avenues of domestication, including intensive selection for milk yield, may open.

Semi-domestic reindeer do differ in their behavior compared to their wild counterpart; they show a higher degree of tolerance towards humans and are easily trained. The behavioral characteristics of semi-domestic reindeer suggest that the domestication process started early. The free-ranging herding system practiced today in most areas is not compatible with milking, which requires small, intensively controlled herds. Before the snowmobile era, transportation by means of reindeer was essential for the nomadic herders. Hence, training of the animals was an integrated part of the management regime and favored milking as an important component of the subsistence-based economy.

Reindeer/caribou have evolved in a harsh environment with a short summer season, indicating a rapid and affluent transmission of energy and protein from the mother to the calf to optimize lifetime reproductive success, typical for capital breeders (32). The does produce only one offspring per reproductive event, underlining the resource limitations. Most of the preweaning mortality in cervids occurs within one month of birth (21). The high intake of energy and protein during early lactation in reindeer favors early survival, and the calves develop rapidly and are able to take advantage of the lush green summer vegetation at an early stage. The females are released earlier from the heavy burden of lactation and can start their build-up of reserves toward the next reproductive cycle. Rapid growth and fat deposition in neonates are also crucial for reaching a body mass in autumn, enabling the calves to survive the harsh winter. Normally the calves are weaned before rut, reaching around 60% of their mothers' body mass, which is within the normal range in cervids producing one offspring per reproductive cycle (23).

3.2 Lactation Strategy

Lactation is the major energetic component of maternal investment in mammals (60), implying biological constraints and trade-offs influencing milk yield and chemical composition (34, 74) as well as reproductive (12, 14, 46) and behavioral traits (35, 42). The amount of milk produced is the parameter of the lactation cycle, which shows greatest plasticity in response to unfavorable conditions (74). Calves are born at the end of the northern winter, and lactation usually ends in early October just before rut. The species has a follower-type mother-young relationship (23), apparently because of its migratory habits. The relatively small udder in reindeer compared with other ungulates (74) is advantageous, considering the great mobility of this species, and the secretion of concentrated milk is adaptive. The mix of high protein, high fat, and low lactose is optimal to meet both the growth and energy requirement of the calf in a harsh environment (74).

The young could easily withdraw all the milk available in the cisterns, making it more profitable to suckle frequently, as opposed to a "hider" strategy seen in many deer species (for example, red deer [*Cervus elaphus*] and roe deer [*Capreolus capreolus*]). The suckling pattern is characterized by frequent bouts of short duration, but the frequency declines rapidly with age (17), reflected in the daily nursing time: from about one hour at peak lactation to less than 10 minutes after eight weeks (Gjøstein et al., unpublished data). Peak lactation occurs three to four weeks after calving and is estimated to be about 1 liter per day (24, 74). The production declines linearly after the peak is reached and is reduced to around 50% of peak production after 12 weeks and to 25% after 20 weeks (24). However, the

increase in milk nutrient content during the same period partly compensates for the decline (11). This underlines that also during the last part of the lactation the nutritional transfer of resources from doe to offspring is energetically demanding (11, 13, 24). Through selection and supplementary feeding, the lactation curve could probably be elevated and the tail flattened out (29). Whether the lactation period can be extended remains untested, although anecdotal information suggests that does were milked through the winter. However, the reproductive status of these females is unclear.

Lactation strategy in reindeer is primarily constrained by habitat quality and requirement for high locomotion efficiency (74). Lowered milk intake and decreased time suckling has been observed when the mother is on a low plane of nutrition (74). The reduced milk intake seems to be a matter of limiting the accessibility, which is under female control (74). The short lactation period and rather rapid decline in milk production after peak lactation is an adaptation to the short arctic summer and the marginal environment. Given the short summer, it is in the mother's best interest to control the weaning so that she is able to improve her body condition to ovulate during the rutting period. The future reproductive cost of lactation in reindeer/caribou has not been assessed accurately, but may in extreme situations induce reproductive pauses in caribou (56). In red deer, the cost of lactation reduced the chances of next year's reproduction (11). It may be expected that the transfer of milk will be traded against requirements to replenish body reserves, to secure survival and future reproduction. Especially in a semi-selected species in marginal environments, where fecundity normally is reached at an age of 1.5–2.5 years, only one offspring is produced per reproductive cycle, and female senescence sets in at around 10 years of age (71).

4 MILK COMPOSITION

There is no obvious correlation of milk composition to either body size or habitat in ungulates (53). In general, wild and semi-domestic ruminants give richer milk, particularly in late lactation, than do the domesticated species (53). Arman (4) suggested that the selection for high yield has been accompanied by reduction in concentration.

Although reindeer (6, 8, 11, 24, 29, 38, 39, 62, 64, 69, 73, 74, 75) and caribou milk (11, 50) have been extensively analyzed, it is difficult to typify its composition, due to limited sample sizes, individual variation, differences in sampling techniques, as well as feeding regime and variation in lactation stage, examined in the different studies. Here data only from studies, where individual samples from several animals are involved and the lactation stage can easily be defined, have been selected. The milk of reindeer from peak and mid-lactation is relatively high in fat (11–15%) and protein (7–10%), but moderately low (about 3.5%) in lactose (Table 8.2), as compared to most ungulates (53). The progressive rise in dry matter as compared to other cervids is especially pronounced in *Rangifer* (39, 53, 74). Especially the increase in fat content is prominent as lactation progresses (24, 38, 39). This is also reported in caribou (11, 50). In late lactation, the milk is creamy with a fat content of around 20% and a protein content of around 12–13% (11, 24, 29, 38). Similar trends (although not that distinct) are reported in red deer (37), Iberian red deer, *Cervus elaphus hispanicus* (34), moose, *Alces alces* (51), and North American elk, *Cervus elaphus nelsoni* (52).

The ratio of protein to fat throughout the lactation follows the interspecific relationship typical of ruminants (9, 39). This interspecific relation is thought to indicate a general optimal balance between resources for growth and energy requirement (46).

Table 8.2. Gross Composition (% of Wet Weight) of Reindeer Milk; Only Data from Peak Lactation (3-5 Weeks After Birth) and from Several Individuals (n) Are Reported

Week of lactation	N	Dry matter	Fat	Crude protein	Lactose	Ash	Reference
4–5	8	27.1	11.1	11.1	3.0	1.5	(2)
4	3	23.7	10.2	7.5	3.7	1.2	(29)
5	5	38.1	19.6	13.0	3.7	2.7	(38)
3–5	7	31.6	15.5	10.7	3.7	1.3	(39)
5	2	32.8	17.1	10.9	2.8	1.5	(73)

The ratio of protein to fat decreased during the course of lactation (11, 24), which also is reported for Iberian red deer (34). This is probably due to high protein demand for growth in calves during the early stage of life, as muscles are developed earlier than fat tissues. Fat deposition to meet the harsh winter probably becomes more important as the lactation progresses (11, 28, 34). Chan-McLeod et al. (11) suggested that the maternal protein deposition might be energy limited, resulting in directing only surplus protein, not utilized for maternal tissue, to milk production, especially in late lactation. Interspecific differences occur not only in the relative proportions of the major nutrient components (fat, protein, lactose, and ash) but also in the specific components within each category (53).

4.1 Protein

The relative composition of the different amino acids in reindeer milk is rather constant throughout the lactation (38), although the protein content increased from around 9% in early lactation to around 11% in late lactation (29, 38). The amino acid composition of the protein fraction in reindeer, reported by Luhtala and coworkers (38), is strikingly similar to that determined by Holand et al. (unpublished data) (Table 8.3), with somewhat higher values of lysine and histidine, and lower value of proline. The amino acid profile resembles what is found in small ruminants (sheep and goats) (26), except for the relative low value of cysteine and high value of tyrosine (Table 8.3). Hatcher et al. (27) reported a similar amino acid profile in caribou, based on one sample in early lactation from one female, suggesting small individual differences, as also confirmed by Luhtala et al. (38) and Holand et al. (unpublished data). Casein is the predominant protein fraction in reindeer milk (16), with a content of 7.6–8.9% (40). Beta-lactoglobulin is the main whey protein, containing 162 amino acids and three cysteines, but only one free cysteine (57). Beta-lactoglobulin is not glycosylated and its isoelectric point is 4.7 (57). The amino acid composition in milk of red deer, roe deer, and fallow deer (15) seems to be higher in methionine than in reindeer; otherwise, the differences in composition are marginal. The high absolute content of almost all amino acids, as compared to other dairy

Table 8.3. Mean Amino Acid Composition (Weight % of the milk Protein Fraction) in Reindeer Milk Based on Samples from (1) Five Animals Fed Pelleted Concentrate (Poronherkku) (39); (2) Eight Animals Fed Poronherkku (40); (3) Four Animals During Three Lactational Stages (Early, Mid, Late) Fed a Pelleted Concentrate (Formel Favør 20) (Holand et al., unpublished data); and (4) in One Caribou (Weight % of the Casein Fraction) (27)

Amino acid	(1)	(2)	(3)	(4)
Alanine	2.92	3.1	3.26	2.5
Arginine	3.58	2.6	2.75	2.6
Aspartic acid	5.99	6.7	6.70	6.0
Cysteine	0.74	0.8	0.73	7.0
Phenylalanine	4.38	4.5	4.63	4.0
Glutamic acid	21.67	20.6	18.97	22.8
Glycine	2.12	2.3	2.34	2.0
Histidine	3.39	2.5	2.54	2.0
Isoleucine	4.34	4.6	4.38	3.4
Leucine	8.95	9.5	9.69	8.4
Lysine	10.27	7.9	8.08	6.6
Methionine	2.27	2.9	2.71	2.2
Proline	8.79	9.2	9.93	10.0
Serine	5.18	5.7	5.58	5.8
Threonine	4.24	4.7	4.73	4.4
Tryptophan	—	1.3	1.52	—
Tyrosine	5.28	5.4	5.63	5.2
Valine	5.89	5.7	5.97	4.0

animals, indicates that reindeer milk is suitable for spiking the intake of milk protein. This could be important for athletes. It is well documented that high intake of glutamin could be important for athletes engaged in heavy training periods, because the level is depleted after heavy exercises and the propensity for infection is high after hard workouts. Reindeer milk contains many non-protein N compounds (NPN) (urea, ammonium, carnitine). The NPN content is 84–118 mg/100 ml, urea content is 48 mg/100 ml, and free carnitine content is 71 mg/kg (40).

4.2 Fat

Fat is the major energy component in milk, representing two-thirds of the energy content at peak lactation and three-fourths at late lactation in reindeer milk (24). The fat composition of cervids' milk is similar to cow's milk, containing high levels of palmitic, stearic, oleic, and myristic acids along with smaller amounts of short-chain fatty acids (53). The effect of rumen fermentation is to make the milk of all ruminants rich in short-chain and saturated fatty acids. In reindeer milk the fatty acids are dominated by palmitic (16 : 0), accounting for one-third of the total fat; stearic acid (18 : 0) oleic acid (18 : 1) and myristic acid (14 : 0) contribute around 13%. The content of short-chain fatty acids, especially byturic (4 : 0) and capric (6 : 0) acids, seems to be higher in reindeer (Table 8.4) than in red deer, roe deer, fallow deer (15), moose (14), and other dairy animals. The technique of gas chromatography has made substantial progress in the last decade, easing the identification of the low carbon fatty acids, and is probably a reason for discrepancies in data. The fatty acid composition is strongly influenced by precursors in the bloodstream, which will vary according to forage quality and composition, available to the mammary gland. Because all studies of the fatty acid composition of reindeer milk is based on "artificial" feeding, the composition of milk fat of reindeer on natural summer pastures will probably differ, including a larger proportion of conjugated linoleic acid (CLA), known to have anticarcinogenic and antiatherogenic properties. Their precursors, especially linoleic acid (18:2), are found in natural forages.

4.3 Lactose

Lactose is the main carbohydrate in the milk of most mammalian species. The average lactose content in reindeer milk at peak lactation is 3–3.5% on wet weight basis (24, 29, 38, 39), slightly lower compared to what is found in other wild ungulates (53). In reindeer, the lactose content is reported to decrease (24, 74) during the lactation cycle, confirming its role as an osmotic regulator and a compensator for variation in all other components (74). Decline in lactose content has also been reported in black-tailed deer, *Odecoileus hemionus*, (44) and moose (51). The Saami people are rather intolerant toward lactose because they have little or no lactase enzyme to break down lactose (66). Hence, reindeer milk, low in lactose, is well suited for the Saami.

Reindeer milk also contains small amounts of oligosaccharides (3), which are known as prebiotics. Hence, reindeer milk may have potential in developing functional foods. Further research to quantify these components is needed.

4.4 Minerals

The mineral content of cervids' milk is moderate to high (1–1.5% per unit of fresh milk) (14, 15, 38, 53), as compared to most other ungulates. The ash content of the dry matter is around 5% (15, 53). The relative concentration of the main minerals, calcium and phosphorous, is rather similar in milk, accounting for around one-fourth and one-fifth of the ash, respectively (15, 39, 53), whereas sodium and potassium are normally markedly lower in milk ash of cervids as compared to cows (15, 39, 53). Increased concentration of osmotic active salts may compensate for the decrease in lactose content, as suggested by the increased content of ash during progressing lactation in reindeer (3, 39). Selenium content of reindeer milk varies betweeen 0.04–0.08 mg/kg (2).

4.5 Vitamins

Reindeer milk is rich in fat-soluble (1, 38) and water-soluble vitamins (6, 38). Ten days after birth, Aikio and Nieminen (2) measured vitamin A level at 51–141 RE μg/100 g, vitamin E 19–88 μg /100 g, and vitamin D 0.07–0.14 μg/100 g. However, little detailed information is known. Vitamin C is an important antioxidant and hence important for the storage quality of fresh milk as well as milk products. According to colorimetric methods, the vitamin C content was around 2 mg/100 ml (3), which agrees with measurements in red deer and fallow deer (15). Cervids' milk is several times richer in D_3

Table 8.4. Fatty Acid Composition in Reindeer Milk (Weight % Based on (1) Milk Samples from Eight Females Fed Pelleted Concentrate (Poronherkku) During Mid Lactation (40); (2) Five Reindeer (Unspecified Feeding Regime) (Glass et al., 1967) ; (3) Six Females Fed a Pelleted Concentrate (Poronherkku) During Mid Lactation (Holand et al., Unpublished Data); and (4) Caribou (22).

Fatty acid C:	(1)	(2)	(3)	(4)
4:0		5.0	6.77	6.6
6:0		1.1	2.42	2.4
7:0			0.09	
8:0	0.25		0.47	0.8
10:0	0.58	0.6	0.79	1.0
11:0			0.06	
12:0	0.84	1.0	0.99	1.4
13:0			0.07	
iso-14:0		0.11		
14:0	13.02	11.7	12.68	11.4
iso-15:0	0.16		0.21	
Anteiso-15:0	0.46		0.36	
14:1			0.22	
15:0	0.93	1.0	0.78	1.0
iso-16:0			0.24	
16:0	45.01	36.4	35.47	34.9
iso-17:0	0.25		0.32	
16:1n-9/anteiso-17:0	0.62		0.48	
16:1n-7	0.89		0.90	
17:0	0.42		0.41	0.36
iso-18:0			0.05	0.04
17:1n-8			0.07	
18:0	12.47	16.0	13.87	17.7
trans4,18:1			0.04	
trans5-6,18:1			0.17	
trans7-8,18:1			0.30	
trans9,18:1			0.27	
trans10,18:1			0.33	
trans11,18:1	1.17		0.88	
trans12,18:1			0.30	
cis9,18:1	15.47	26.2	13.38	18.9
trans15,18:1			0.17	
cis11,18:1			0.54	
cis12,18:1			0.19	
cis13,18:1			0.07	
trans16,18:1/cis14-18:1			0.35	
18:2n-6	3.87	1.2	2.26	2.0
20:0			0.26	
18:3n-6			0.05	1.8
20:1n-7			0.08	
20:1n-9			0.07	
18:3n-3			0.27	
cis9,trans11,18:2			0.31	
22:0			0.09	
20:4n-6			0.19	0.16
22:5n-3			0.08	0.06
Others			1.52	

(0.5–2.0 mg/kg) as compared to cow milk (1, 15), and around double as high in K_3 (0.06–0.08 mg/kg) (1, 15). The milk of reindeer contains slightly more of the essential vitamins as compared to red and fallow deer (1, 15, 38).

5 MILK YIELD

5.1 Potential

Most studies of the potential milk production in reindeer and caribou (11, 30, 43, 50, 74) have been carried out using isotope tracer techniques. This method is accurate, but elaborate and rather expensive. Hence, lactation curves of reindeer have been based on measures of milk yield during few selected stages of the lactation. The timed milking method in combination with machine milking is, using trained animals and appropriate milking procedures, an accurate and labor-saving method of assessing potential milk production (24, 29).

The shape of the lactation curve in reindeer (Figure 8.2) agrees with the curves found in most wild ungulates exposed to a seasonal environment. Gjøstein et al. (24) reported a daily output at peak lactation, which occurs during week two to four, of around 1 liter, whereas McEwan and Whitehead (43) found a daily yield of 1.5 liter, and Parker et al. (50) measured a daily production of 1.8 liter in caribou. These differences might partly be due to differences in body weight of animals used in the studies. Gjøstein et al. (24) estimated total milk yield during lactation to about 100 kg, which is lower than the estimate (118 kg) of Oftedal (47) based on data presented by White and Luick (74). Estimated milk yields of does on a low plane of nutrition equaled only 57 kg (47), confirming that variation in nutritional state of the mother may have a marked effect on milk production (74), as also reported in red deer (34, 36). The estimated total milk yield of reindeer is lower than that reported for red deer: 150 kg (5); Iberian red deer: 224 kg (34); North American elk: 410 kg (52); but is slightly higher than reported for black tailed deer: 93 kg (59).

5.2 Actual Yield

Domesticated species are adapted to releasing their milk under stimuli, and the amounts extracted may be as high as those with suckling. The biological potential of a species as a milk producer should be assessed from suckling rather than from artificial extraction, and progress along the path toward domestication could be measured by the convergence of the two measurements. As habituation through

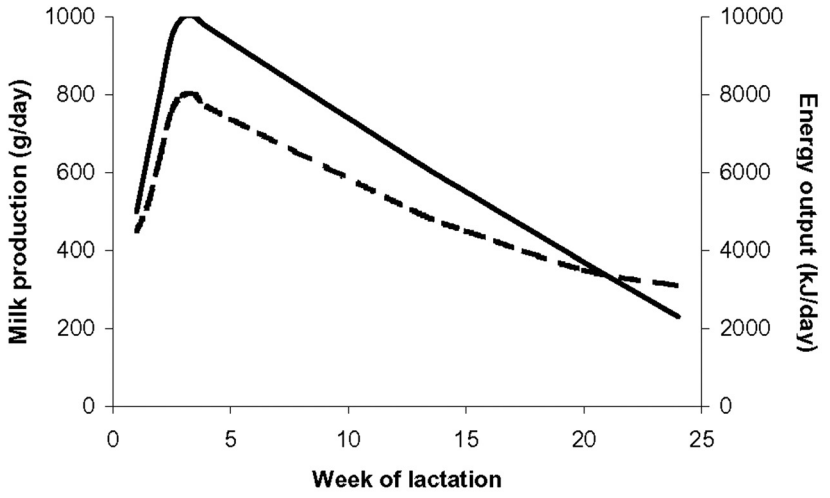

Figure 8.2. Schematic curve of daily mean potential milk production (continuous line) and energy output (dotted line) of an average reindeer female (75 kg) through lactation. Based on data from Gjøstein et al. 2004 (24), Holand et al. 2002 (29), and Gjøstein et al. (unpublished data).

the lactation cycle occurs, smaller proportions of residual milk in late compared to mid-lactation are encountered (3).

Previously published estimates of milk yield in reindeer are hard to interpret and should be handled with caution, basically because of lack of information about milking practice, including separation time, lactation interval, stimulation regularity of milking, stage of lactation, and nutritional status of the reindeer cows. Reliable Russian measurements report an average daily yield of 250–300 g (64) with calves partly separated. Anecdotal information reports a yield per milking event of 200 g (19), and 300 g (55). In a series of experiments, a yield of 100–200 g was reported 2-3 months after parturition with a separation time of 8–12 hours (3). Furthermore, the relative residual milk volume decreased from around 75% to 50%, as the total udder fill was increased from 150 ml to 500 ml. Delayed emptying of the udder may induce reduced secretion (61). However, the secretion rate was independent of udder fill up to a total milk amount of 500 g in the udder (3).

6 ENERGY CONTENT AND OUTPUT

Most wild cervids, including reindeer, tend to produce energy-dense milk at peak lactation (5.5–7.5 kJ/g) similar to most wild bovines (47), and the fat constitutes 55–65% of the total energy content (47). In reindeer, the energy content at peak lactation is around 7 kJ/g (24, 74). The daily energy output at peak lactation was about 8,000 kJ (21), whereas Oftedal (47) estimated a daily energy output in milk of 11,000 kJ by reindeer, comparable to interspecific regression of ungulates with single young (47). Compared to most wild ungulates producing a single offspring, the daily milk production per unit metabolic weight at peak lactation in reindeer is low, but the energy output per unit metabolic weight is comparable because of high fat and protein content in reindeer milk (47, 74). The daily energy output of around 300 kJ/kg$^{0.75}$ (24, 74) at peak lactation is remarkably high after a tough winter, and the females have to draw on their body reserves to accomplish this provision for the calves' needs. The total energy yield during the entire lactation per unit metabolic weight is somewhat less in reindeer than in red deer and North American elk (47) and is estimated to be about 30 MJ/kg$^{0.75}$ (24, 47).

The change in milk energy content during the lactation cycle varies among species, with reindeer being one of the most pronounced by a 50% increase from peak lactation to preweaning (24, 39, 54), mainly due to a pronounced increase in fat content (24, 39) as compared to black tailed deer (44), North American elk (52), moose (53), and muskox, *Ovibos moschatus* (50).

Although the content of fat and protein increased with stage of lactation, the total production of fat, protein, and lactose decreased because of the decline in milk yield (24). From peak lactation, the energy output decreased markedly, whereas from mid-lactation (week 12) the energy output declined at a slower rate than the milk yield (Figure 8.2) (24). This suggests that the increasing content of the milk in nutrients does not fully compensate for the decline in milk production, and the overall transfer of energy and nutrients is reduced after peak lactation. Chan-McLeod et al. (11) reported that in reindeer and caribou the declining milk volume with time and undernutrition were partly compensated for by increased milk nutrient content at least between 60 and 100 days postpartum. This was mainly attributed to an increase in milk fat content. In contrast to the milk fat and energy output, the milk protein output was reduced during the same period (11).

7 CHALLENGES

7.1 New Setting

In the mid 1990s new interest emerged for establishing reindeer dairy milking as a niche production in Fennoscandia. This was a reaction to the rapid modernization process that started in the early 1960s, resulting in increased external input and reduced numbers of people fully engaged in reindeer husbandry. To keep the Saami reindeer herding culture viable, a minimum number of people have to be engaged in the business. Milking is labor demanding and may contribute to getting more people, especially women, actively involved in reindeer husbandry. However, such a niche production is dependent on a segment of the market being willing to pay for the exclusiveness of reindeer milk products, and hence for the labor input involved in milking and processing.

The new interest in reindeer milk is based on an awareness of the expanding market for new niche

products. The marked potential lies in an exclusive niche within the gourmet market, pharmaceutical and cosmetic industry, as well as in the tourist industry. Based on this setting, an initiative was undertaken to develop a modern milking regime of reindeer. A milking machine for reindeer has been tested. The udder health of the reindeer was unaffected by long-term regular machine milking applying a vacuum pressure of 25 kPa and a pulse rate of 100 pls/min with a suckling:massage ratio of 60:40 (1, 29). Also, basic lactation physiology and behavioral studies have been carried out and different management regimes tested (3, 24, 25, 29).

7.2 Milk Ejection

To achieve efficient milk ejection is a recurrent problem when machine milking of reindeer is performed (25, 28). The importance of the ejection for milk yield is well documented, and various stressors, such as aversive handling, novel environment, and emotional stress, may inhibit or suppress milk let-down among traditional dairy animals (10, 72).

The high proportion of residual milk suggests that the traditional stimulation methods of washing and massaging the udder are inadequate for milk ejection in reindeer (25). However, the proportion of residual milk seemed to be reduced as lactation progressed (Gjøstein et al. unpublished data), and condition-induced responses have also been reported (28), suggesting that habituation and training are important factors for triggering ejection. Suckling of the calf is regarded as the strongest stimulus inducing the ejection reflex (61). A two-second suckling event was sufficient to induce the milk let-down and enabled a complete emptying of the udder in reindeer (25). Traditional milking practice has taken advantage of this by letting the calf suckle the two front teats when milking the two others (20).

The ratio between cistern milk and total milk volume in the mammary gland varies between ruminants. In small milking ruminants, the proportion of cistern milk is high, such as 72% in certain breeds of ewes, and 75% in Alpine goats with a 12-hour milking interval (41). The volume of the cistern in reindeer udders has not been measured. However, Gjøstein et al. (25) reported that the proportion of residual milk after six hours' separation from the calves in mid-lactation with inadequate ejection was around 57%.

Contact with the calf combined with washing of the udder is a strong stimulus for let-down in dairy cattle (49, 61). The presence of the calf during milking did not affect the let-down mechanism in reindeer (25). However, absence of physical contact with the calf may have induced emotional stress. If reindeer are stressed because they are able to see and hear the calf without opportunity of physical contact, the calf's presence may fail to have an effect on the let-down mechanism.

Inhibition of milk ejection may be attributed to stress and an increased level of adrenalin in the blood, blocking the effect of oxytocin. Reindeer can rapidly habituate to the milking environment (3). Reindeer entered the milking ramp easily, where they were fed highly palatable lichens. No negative reaction was observed during the stimulation, put-on, milking, and off-take phases, and it was concluded that the females showed only low levels of stress and discomfort during the milking session (3). This was confirmed by only a slight increase in heart rate when entering the ramp, indicating low degree of stress (3). The increase in heart rate during the milking session was in the same range, as when the calves were suckling, from around 75 beats to 100–125 beats per minute (3).

7.3 Domestication and Management Regime

Semi-domestic reindeer is the only domesticated species whose wild ancestor has evolved in the harsh northern environment. No other cervids have a long and unbroken history of domestication, although moose, fallow deer (*Dama dama*), and red deer have been under domestication for shorter periods in historical times (4). Lactation studies have been carried out in red deer/elk, moose, and reindeer/caribou. Moose has even been trained as a milking animal in Russia (4, 70). Domesticated dairy species are fully adapted to releasing their milk under the stimuli given at milking time. The milk ejection problems in reindeer may be related to degrees of domestication. Maintenance of lactation requires repeated exposure of the mammary cells to hormones released during milking, in addition to a continuous removal of the secretory products. In semi-domestic species, it may not be possible to maintain normal secretion rate in the absence of the young. It could be preferable to develop a milking regime including the calf. However, a more ad-

Figure 8.3. Machine milking of reindeer in Norway. Courtesy of O. Holand.

vanced domestication based on an intensive selection scheme and isolation from free-ranging animals may transform reindeer rapidly into a fully domesticated species. An example of machine milking on a reindeer is shown in Figure 8.3.

A new milking regime has to adapt new techniques and management regimes within the biological and ecological constraint set by the animals, the environment, and within the framework accepted by the ethnic group involved. Although reindeer are privately owned, the reindeer herding is organized in herding units with collective grazing rights within defined geographical boundaries. Reindeer milking is an intensive form of reindeer husbandry and is hardly compatible with the extensive meat production practiced today. Hence the collective herding organization may hamper the development of functional milking units, because all herders within a unit have to agree in order to change their herding practice.

Within an extensive free roaming management system, the potential of a dairy industry is limited, because selection for milk yield and training of the milking reindeer is severely restricted. In marginal habitats, a partly free-ranging system maybe considered to reduce the cost of fencing, in which the animals are allowed to roam in the charge of a herdsman during daytime and be fenced close to the camp at night, and milked in the morning and evening. This would also secure an ecologically sound production. To secure the homing ability, the calves could be kept separated and close to the milking camp. After some training, the milking reindeer would probably return to the milking camp on their own. The summer milking farm has to be highly mobile in response to high-quality natural forages.

7.4 Products and Properties

The traditional use of reindeer milk has been the basis for developing new, exclusive, edible products. Also, new avenues have been tried (3) but the exploration is in an early stage.

The fat globules of reindeer milk are of the same size as in cow milk (3), but the fat globules of cow milk have a stronger tendency to flocculation. The fat globules in reindeer milk form a more stable emulsion, confirmed by the higher zeta potential,

reflecting the electric characters of the surface layers of the particles (3). It is easy to separate the fat from reindeer milk. This is important for production of cosmetics (for example, skin lotions), in which the fat fraction is regarded as highly valuable.

Reindeer milk curdles quickly, and the curdle is highly elastic and can be handled almost like a dough, easing the cheese production, both fresh and dried (3). Also, a white mold cheese has been developed. The taste of the cheese is delicious and distinctly different from fresh cheese made from cow, goat, or sheep milk.

8 CONCLUSION

Knowledge of the potential milk production and milk composition, and the individual variation within these traits, is important when comparing different lactation strategies and levels of maternal investment in mammals. This is the basis for evaluating a species' potential as a dairy animal. The biological constraints have to be taken into account when testing different management regimes. The potential milk production in reindeer is about 100 kg per lactation cycle. The main challenge is to develop a milking regime that secures complete emptying of the udder through appropriate stimuli of the ejection mechanism, and to keep the production on a reasonably high level throughout the lactation. Permitting limited suckling by calves may be a viable strategy for keeping up the milk production. Supplementary feeding, early training of the animals, and selection of the best milking animals are the keys to further progress. The milking herds have to be separated from the extensive meat-production herds, and the organization of functional milking units is crucial for further success. Reindeer milking is an intensive form of reindeer husbandry and should be based on mobile summer camps, where the natural forages can be utilized. The quality of reindeer milk differs from all other commercial milk available. Reindeer milk is and will be a valuable special product, but a commercial production is dependent on highly priced products.

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9
Sow Milk

Young W. Park

1 INTRODUCTION

Literature on the production and human consumption of sow milk is almost nonexistent. However, research on the production and composition of sow milk has important implications for the nutritional and medical well-being of humanity. Humans and pigs have similar digestive and physiological systems. Therefore, knowledge of the physiology of sow milk production and its composition provides insight into the contribution of mammary secretions to growth, development, and health of animals and humans.

Milk production in sows is one of the most important factors limiting growth of piglets (18). Their high mortality is associated with low milk production during the first few days after birth (7). Hypoglycemia and death due to low milk production is not uncommon in neonatal pigs (6). Achieving maximal quantity and quality of sow milk through adequate sow nutrition during gestation and lactation improves survival and growth of the offspring (30).

The fact that heavier weaned piglets attain market weight faster than lighter weaned piglets (28) has sparked interest in exploitation of lactation to enhance overall piglet growth and pork production. Milk is a pivotal factor in piglet survival, growth, and body composition prior to weaning, as would also be applicable to situations in human infants. Variation in growth of pre-weaning piglets is largely attributable to the variability in milk volume and total milk solids produced by the sow (25), while other variation may be due to genetic and environmental factors. It has been shown that piglets raised on a milk replacer diet offered ad libitum can grow at a substantially higher rate than sow-reared piglets (19, 46). Therefore, the ability to enhance milk quantity and composition to optimize growth rates and lean mass deposition of piglets is of great importance to the swine producer. From a practical point of view, this same concept can also hold great value for scientific research in human nutrition, medicine, and food science.

2 ANATOMY OF PORCINE MAMMARY GLANDS

Mammary glands of the sow have two anatomically parallel rows of glands and teats that extend over the entire abdominal wall from the pectoral to the inguinal regions (Figure 9.1). A series of the parallel glands are located at the entire abdominal wall extended to the pelvic region, and the first pair of the glands lies immediately behind the connection of the ribs with the sternum (43).

Each of the sow mammary glands is separate and appears as a half-spherical-shaped elevation of the body. Sows have variable numbers of teats and glands, which are between 8 and 18, with 12 teats being most common. The majority (more than 95%) of sows has between 10 to 14 teats, which are usually free of hair and sebaceous glands (47).

Unlike in cows, the sow's teats are each transversed by two streak canals and two small cisterns. The lengths of the streak canals are 3–4 mm and are tightly closed by longitudinal folds originating from

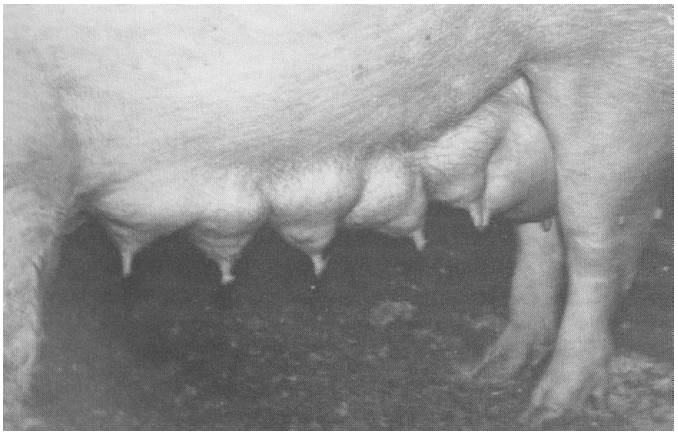

Figure 9.1. Mammary glands of sow. Adapted from Schmidt (43).

the teat cistern (43). In contrast to the teat cistern in ruminants, the sow's teat cistern is an elliptical dilation or sinus of the milk duct instead of a larger cistern. Many longitudinal folds are contained in the walls of the cistern. The sow's cisterns are extended into the glands to become the gland cisterns. The milk ducts are formed by these cisterns to drain the milk from the alveoli, which are clusters of milk secretory tissue. A number of alveoli are joined by a common duct and are surrounded by connective tissue to form the lobules and lobes. Each mammary gland has two separate duct systems within its gland (47).

Blood is supplied to the anterior mammary glands from the external thoracic arteries (anterior mammary arteries). The posterior mammary glands receive blood from the external pudendal arteries similar to those in cattle (43). The external pudendal arteries become the posterior abdominal arteries and continue anteriorly to supply the abdominal and inguinal mammary glands. They then anastomose with the external thoracic arteries (43). Blood leaves the mammary glands by veins that parallel the major arteries. These are the external thoracic veins and the posterior mammary veins (47).

Lymph from the mammary glands is filtered through three groups of lymph nodes. They are the superficial inguinal nodes (supra-mammary) located between the posterior mammary glands and the abdominal wall; the mediastinal cranial lymph nodes situated ventral to the anterior vena cava at the entrance to the thoracic cavity; and the ventral superficial lymph nodes located cranio-dorsal to the shoulder joints. These lymph nodes receive lymph from the skin, the teats, and the glandular tissue (47).

3 SECRETION OF MILK FROM MAMMARY GLANDS

There are two main processes by which milk constituents are produced in the epithelial cells of the mammary gland, synthesis and diffusion: One group of milk components, which includes fat, most of the proteins, and lactose, is synthesized in the epithelial cells from blood precursors and then secreted into the lumen of the alveolus. The other milk constituents, water, vitamins, and minerals, are diffused from the blood and move across the epithelial cells or between them into the alveolar lumina without alteration by the cells. Blood precursors of milk constituents are shown in Table 9.1.

Lactose is synthesized primarily from glucose, while protein components (casein, β-lactoglobulin, and α-lactalbumin) are synthesized from amino acids. Milk serum albumin and immunoglobulins are not synthesized in the mammary gland but transferred from the bloodstream (43). Acetate and β-hydroxybutyrate are precursors of fatty acids up to 16 carbon chain length (C:16).

Table 9.1. Blood Precursors of Milk Constituents in Ruminants

Milk constituent	Blood precursor
Water	Water
Lactose	Glucose
Protein	
Casein	Amino acids
β-lactoglobulin	Amino acids
α-lactalbumin	Amino acids
Milk serum albumin	Blood serum albumin
Immunoglobulins	Immunoglobulins
Fat	
Fatty acids	Acetate, β-hydroxybutyrate, blood lipids
Glycerol	Glucose, glycerol from triglycerides
Minerals	Minerals
Vitamins	Vitamins

Adapted from (43).

The α-lactalbumin is a Ca^{2+}-binding protein, which is synthesized during lactogenesis and functions as the modulator protein for galactosyl transferase in the lactose synthase complex (10). Calcium is important for the regulation of insulin secretion from pancreatic islets and for the formation of milk protein complexes such as casein (41).

4 FACTORS AFFECTING THE YIELD OF SOW MILK

4.1 Stage of Lactation

Daily yield of sow's milk ranged in a study with litter substitution from 426 ± 73 to 1,500 ± 56 ml (15). Treatment × day-in-lactation interaction for yield per milking showed that milk yields peaked about day 19 postpartum and declined to day 45 for sows with their own litter, but sows with a replacement litter peaked at day 17 and had a more dramatic decline after the change to a younger litter at day 25 postpartum (Figure 9.2). Sows with the replacement litter declined in yield per milking to day 43 and then increased in milk yield. Sows having replacement litters declined more in daily milk yield after the change of litters on day 25 postpartum (15).

4.2 Suckling Frequency

Frequency of suckling influences the production volume of sow milk. Increased suckling frequency played a role in increased mammary gland mass and milk production during lactation (1, 22).

4.3 Sow Body Weight and Metabolic State

Metabolic state of the sow also reflects the amount of milk produced during lactation. In early lactation, the composition of milk depends on the body condition of the sow. Body composition of sows at farrowing influence the quantity of milk produced in the lactation (39). Piglet growth correlated positively

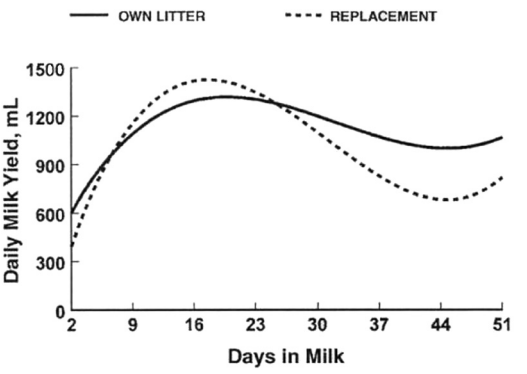

Figure 9.2. Daily milk yield (cubic order regression) for 51 days postpartum of sows with own litter or replaced litter at 25 day postpartum. Adapted from Garst et al. (15).

with sow weight loss during week 3. The ability of a sow to reverse catabolism soon after parturition decreases piglet mortality risk, when the catabolism increases during the first 3 weeks of lactation.

4.4 Litter Size

A lactating sow utilizes much of the dietary fat and protein to improve its body composition, in turn to increase milk production (29). This efficiency of utilizing dietary nutrients depends upon the litter size, suggesting that sows nursing large litters utilize dietary nutrients more efficiently than sows nursing small litters. It is also interesting that sows generate the milk with enriched nutrients depending upon litter size (32). Litter size appeared to be a major determinant of net mammary amino acid uptake from daily mammary plasma flow.

4.5 Ambient Temperature

Ambient temperature also affects milk composition and yield of milk produced during that phase of nursing, when it depends on proportions of blood flow irrigating skin capillaries in order to dissipate body heat (37, 38).

4.6 Amount of Mammary Tissue

Milk yield is determined by the amount of mammary tissue present in the gland (22), which in turn depends on whether the gland was nursed or not during the previous lactation.

5 COMPOSITION OF SOW MILK

Sows can produce large amounts of milk throughout their lactation. Sows have been milked either by hand or with a milking machine (13, 17). These machines were mostly designed only for sporadic milk sampling and not for entire lactation cycles. Williams et al. (48) developed a milking machine that can be used for milking sows throughout lactation, and Garst et al. (14) obtained milk during a 60-day lactation period.

Many investigators (2, 12, 24, 36) have reported the composition of sow milk. However, these milk samples usually were obtained by hand milking and after intramuscular injection of oxytocin at relatively few sampling periods throughout early lactation (15). Milk fat was influenced by route of oxytocin administration (6.53 $\pm$ 0.12% for intravenous vs. 7.21 $\pm$ 0.19% for intramuscular administration ($P < 0.05$) (15).

Total solids, protein, and ash contents are higher in colostrum of most mammalian species compared to the milk obtained two to three weeks after farrowing or calving (Table 9.2). The most striking difference is the high protein percentage in colostrum, in which large parts of this protein are globulins (lactoglobulins and immunoglobulins).

Sow milk fat and protein levels varied in a curvilinear manner throughout lactation. Milk fat was highest at the onset of lactation and lowest at around day 20 (Figure 9.3). Levels of protein in sow milk followed a similar pattern to that of fat but did not vary as much as the fat percentage. Holstein cows show quite different lactation curves of milk yield, milk fat, and protein percentages compared to those

Table 9.2. Comparison of the Composition of Colostrum with Normal Milk Obtained 2–3 Weeks after Parturition

	Sow		Holstein cow		Mare	
Nutrients/SG	Colostrum	Milk	Colostrum	Milk	Colostrum	Milk
Total solids (%)	20.5	16.9	23.9	12.9	25.2	11.3
Fat (%)	5.8	5.4	6.7	4.0	0.7	2.0
Protein (%)	10.6	5.1	14.0	3.1	19.1	2.7
Lactose (%)	3.4	5.7	2.7	5.0	4.6	6.1
Ash (%)	0.73	0.71	1.11	0.74	7.72	0.50
Specific gravity	—	—	1.056	1.032	1.076	1.035

Data from (43).

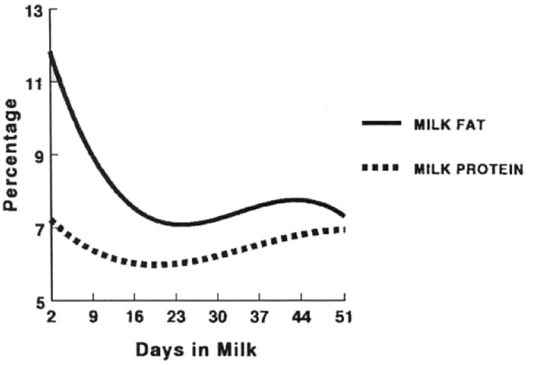

Figure 9.3. Profiles of milk fat and protein percentages in sows through 51 days of lactation (cubic order regression). Adapted from Garst et al. (15).

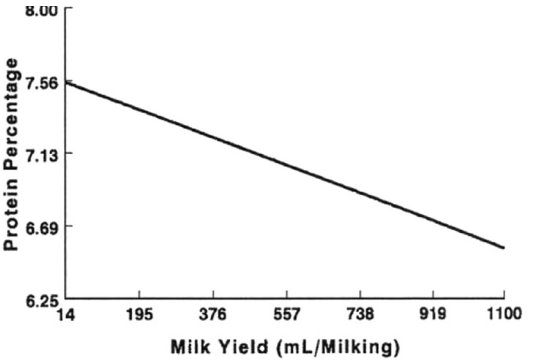

Figure 9.5. Relationship between milk yield and milk protein percent and yield of sow milk. Adapted from Garst et al. (15).

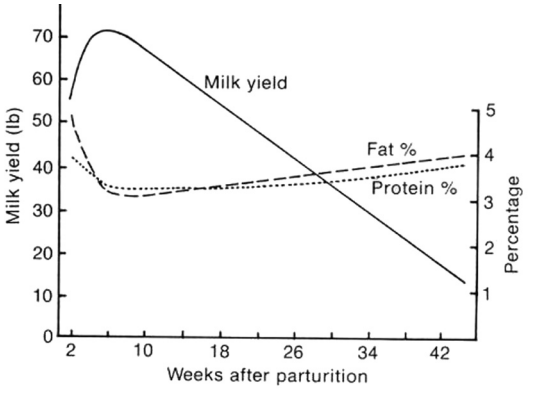

Figure 9.4. Lactation curves of milk yield and milk fat and protein percentages of Holstein cows. Adapted from Schmidt (43).

of sows (Figure 9.4). Fat and protein contents usually increase toward the end of lactation in cow milk. Sow milk protein varied and gradually declined with the advanced lactation in a linear manner as the yield of milk (Figure 9.5). These trends of fat and protein in sow milk are somewhat different from those of ruminants such as cows and goats, in which the levels of fat and protein in milk usually increase at the later stage of lactation (Figure 9.4).

For milk within breed (that is, cow), there is a close inverse relationship between lactose content and the molar sums of potassium and sodium concentrations (31, 43). Lactose alone is responsible for more than one-third of the osmotic pressure of normal milk.

Although breed differences exist for ash, calcium, and phosphorus concentrations in bovine milk (27), there is a dearth of information available on the effects of genetics on mineral concentrations of porcine milk. Cholesterol accounts for less than 0.5% of total lipids in bovine (4) and porcine milk (11).

Somatic cell counts in sow milk were influenced by litter replacement ($P < 0.05$) and oxytocin administration ($P < 0.01$) (15). There was a linear increase in somatic cells from about 8×10^6 cells/ml milk at day 2 to more than 12×10^6 cells/ml milk on day 51 postpartum (Figure 9.6). Pig litter replacement significantly affected somatic cell counts and amount and composition of sow milk throughout lactation.

6 DIETARY MANIPULATION OF SOW MILK COMPOSITION

The provision of adequate amounts of nutrients to sows during lactation is important for achieving maximum milk production (22). Protein and energy intake of sows affects mammary gland growth during lactation (22). By increasing the fructose level in sow's diets, the piglet mortality was decreased considerably.

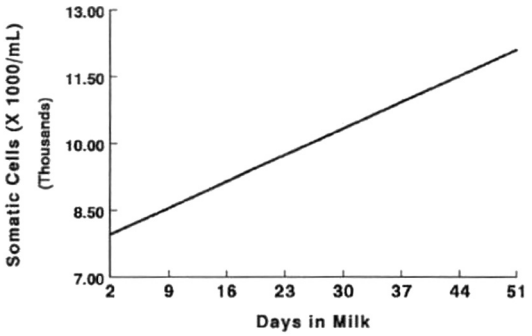

Figure 9.6. Profile of somatic cell counts in sow milk throughout 51 days of lactation. Adapted from Garst et al. (15).

Multiparous sows and primiparous sows must be fed with different dietary regimens. Unlike multiparous sows that show an increase in milk yield when made anabolic during lactation, primiparous sows seemed to partition extra energy into body growth rather than into milk production (35).

Without considerable improvement in sow's body composition, the milk of sows can be manipulated to decrease piglet mortality (3). By decreasing the amount of fat in the milk, a sow's body condition for the next lactation can be maintained, as the fat in milk reflects the amount of fat lost by the sow. The sow's body condition is related to the amount of milk produced during subsequent lactations.

Addition of conjugated linoleic acid in a sow's diet reduced milk fat content without affecting piglet growth and the energy demands of lactation (16). Sows typically lose weight during lactation by mobilizing body stores to support milk production, thereby supplemental dietary fat has become an attractive method to augment energy intake during lactation. Sows consuming diets supplemented with tallow not only showed increased metabolizable energy intake but also the milk composition was changed and litter energy gain was increased (Table 9.3) (44).

Addition of caffeine to the lactating sow's diet had positive effects on porcine mammary glands and milk yield (26). This indicates that caffeine as a potential feed additive could be used by pork producers to reduce pig losses from starvation, reduce creep feed costs, and produce heavier and more vigorous piglets at weaning.

Active dry yeast containing more than 15 billion live cells/g was effective in improving daily body weight gain and efficiency of feed utilization when supplementing the diets of sows and piglets before and after weaning (20). Yeast supplementation to sow lactation diets resulted in greater amounts of gamma globulin in sow milk when measured at the time of 21-day weaning.

Immunoglobulin IgA is the major whey protein present in sow milk. The IgA in milk helps in absorption of more water through osmosis into the milk, whereby the quantity of milk increases. In addition, IgA is responsible for neutralizing bacterial enterotoxins and infectious enterotropic viruses. IgG is necessary for successful transfer of maternal immunity to the piglets, because IgG levels are highest in colostrum and gradually decrease as the colostrum changes to normal milk (5).

Sow productivity during lactation was dependent on both lysine and metabolizable energy intake, because the influence of one is contingent on the level of the other (45). Therefore, energy intake

Table 9.3. Effect of Added Fat on Litter Performance, Milk Production, and Composition[a]

Criteria	Control	Tallow	SE
No. of sows	17	17	—
Litter size at day 21	9.60	9.21	0.25
Litter weight, kg[b]			
Day 0	15.54	15.02	0.44
Day 21	58.76	57.34	1.69
Day 28	75.24	74.08	2.14
Milk production, kg/d[bc]	9.25	8.97	0.87
Milk composition			
Solids, %	19.48[d]	21.16[e]	0.21
Protein, %	5.31	5.13	0.09
Fat, %	7.72[d]	9.59[e]	0.21
Ash, %	0.79[d]	0.83[e]	0.01
GE, Mcal/kg	1.19[d]	1.37[e]	0.02

[a]Data are reported as least squares means.

[b]The number of pigs nursed was used as a covariate in the analysis.

[c]Milk production was determined by the weigh-suckle-weigh technique using four sows and four gilts per dietary treatment.

[d,e]Within row, treatments with different superscripts are different ($P < 0.05$).

Data from (44).

Table 9.4. Effects of Valine, Isoleucine, and TBCAA on Sow Milk Composition (%)[a]

	Valine, %		0.72			1.07		1.42	CV
Nutrient	Isoleucine, %	0.50	0.85	1.20	0.50	0.85	1.20	0.50	
	TBCAA, %[b]	2.57	2.92	3.27	2.92	3.27	3.62	3.27	
DM		16.17	16.80	17.10	15.86	17.02	17.33	17.60	5.1
CP		5.16	5.31	5.61	4.94	5.39	5.33	5.30	9.5
Fat		5.76	6.00	6.67	5.87	6.38	6.66	6.89	14.7
Lactose		4.47	4.48	4.24	4.50	4.29	4.45	4.23	7.6
Ash		0.78	0.77	0.77	0.79	0.80	0.75	0.76	6.5
N fractions									
Casein		53.9	55.2	57.1	51.6	55.3	57.9	53.9	11.5
Whey		35.5	35.0	33.2	36.2	34.7	31.9	34.9	17.1
Others[c]		10.6	9.8	9.7	12.3	10.0	10.3	11.2	18.5

[a]Litter size cross-fostering used as a covariate.
[b]Total branched-chain amino acids (isoleucine + valine + leucine).
[c]Other = all other N (free amino acids, urea N, sloughed cellular N).
Data from (40).

must be considered when one recommends lysine levels for lactating sow diets. Increasing valine, isoleucine, and total branched-chain amino acids for lactating sows increased litter weights (40). As shown in Table 9.4, increasing dietary valine increased milk solids and fat ($P < 0.01$), and increasing dietary isoleucine, increased milk solids, protein, and fat ($P < 0.01$). The casein fraction of milk protein increased ($P < 0.01$) and whey and nonprotein N fractions decreased as dietary isoleucine increased (40).

7 UTILIZATION OF SOW MILK AS A MODEL FOR HUMAN NUTRITION AND HEALTH RESEARCH

The pig is an omnivorous animal and shares with humans its commonality of body functions and metabolism such as digestion, physiology, nutrition, and circulatory systems. Because of these commonalities, scientific studies using sows as the laboratory research model on production, composition, and utilization of sow's milk in human nutrition, medicine, and health can be of great value.

Numerous studies have reported on sow milk production, yield, composition, and nutritional and lactational physiology toward application for human medical and metabolism research. Much has been documented on effects of dietary and genetic factors related to milk composition, carcass composition, piglet growth, and pork production. Transgenic sows have been created to produce nutritionally healthy milk, which is applicable in human nutrition and genetic studies.

High activation of chronic immune systems can generate lactogenic hormones, which result in the reduction of milk yields and milk nutrients (42). The endocrine shifts induced by immune system activation have been shown to depress voluntary feed intake, proteinaceous tissue growth rates, and efficiency of feed utilization in growing chicks (23) and pigs (49).

The heritability of cholesterol in milk, blood, and brain has been investigated for cholesterol absorption and metabolism as a model for human nutrition and medical studies. A positive correlation ($r = 0.78$; $P < 0.01$) was observed between milk cholesterol concentration of sow and serum cholesterol as well as milk fat levels at eight weeks of age (Table 9.5) (21). Sows having low or high levels of serum cholesterol at eight weeks of age induced corresponding changes in milk cholesterol and fat concentration in third-generation-offspring sows, but not in any other milk constituents. Mean levels of milk cholesterol for the third generation of low, unselected control and high serum cholesterol groups were: 25.3, 35.7, and 41.4 mg/100 g, respectively (21).

Genetic selections of sow groups for serum cholesterol did not affect macro mineral contents of the sow milk, whereas milk sulphur of the high serum cholesterol group was higher ($P < 0.05$) than that of

Table 9.5. Concentrations of Sow Serum Cholesterol and Milk Nutrients, and Cholesterol of Control (C), Low (L), and High (H) Serum Cholesterol Groups at 20 or 21 Days of Lactation

		Serum		Milk			
Sow group	No.	Cholesterol mg/100 ml	Ash %	Cholesterol mg/100 g	Fat %	Lactose %	Protein %
L	27	66.1 ± 8.1	0.77 ± 0.15	25.3 ± 3[a]	5.7 ± 1.3[a]	5.1 ± 0.3	5.0 ± 0.4
C	7	93.7 ± 13.7	0.78 ± 0.15	35.7 ±8[b]	7.2 ± 8[b]	5.0 ± 0.6	5.2 ± 0.4
H	22	126.2 ± 9.7	0.89 ± 0.19	41.4 ±6.9[c]	7.0 ± 0.8[b]	5.0 ± 0.4	5.3 ± 0.5
	—	—	NS[d]	$P < 0.01$	$P < 0.01$	NS	NS

[a,b,c]Means with different superscript in the same column are different.
[d]NS = not significant.
Data from (21).

Table 9.6. Comparison of Mean Milk Cholesterol (mg/100 g) and Mineral (ppm) Levels Between High, Low, and Unselected Control Groups of Third-Generation Sows

	High[a]		Low[b]		Control[c]	
Variable	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD
Milk cholesterol	41.7[d]	6.46	24.4[f]	3.62	33.8[e]	6.84
Ca	1,433.5	371.6	1,624.0	402.9	1,510.5	193.9
K	346.6	126.2	393.4	99.3	356.2	108.4
Mg	75.4	18.6	80.7	13.4	78.9	11.2
Na	344.9	80.4	360.4	58.7	390.9	64.0
P	961.6	236.0	1,379.3	137.5	1,041.9	135.9
S	53.4[d]	21.8	46.2[d,e]	19.1	36.1[e]	10.2
Al	1.38[e]	0.60	2.00[d]	0.76	1.79[d,e]	0.23
B	1.27[e]	0.48	3.11[d]	1.10	3.45[d]	0.40
Cu	0.94[e]	0.43	1.16[e]	0.56	2.01[d]	1.24
Mn	0.12[e]	0.17	0.37[d]	0.30	0.10[e]	0.05
Mo	0.03	0.03	0.41	1.61	0.10	0.07
Zn	6.54	2.61	7.01	1.54	7.35	1.88

[a,b,c]Number of observations were 21, 21, and 8, respectively.
[d,e,f]Means with different superscripts within the same row differ ($P < 0.05$).
Data from (34).

the unselected control group (Table 9.6) (34). Sow groups genetically selected for high and low serum cholesterol had significantly different concentrations of barium, aluminum, copper, and manganese in their milk, but no effects were observed for molybdenum and zinc. Milk cholesterol content was negatively correlated with milk aluminum and manganese, while no relations were found for other minerals.

A transgenic sow was produced by introducing α-lactalbunin (α-LA) into a pig's embryo, where the transgenic sow yielded more α-LA in the milk (33). The α-LA is a primary whey protein and forms a major proportion of milk solids. When piglets suckled this milk, their weight gain increased because the milk contained more milk solids. The expression of the transgene was associated with alterations in composition of mammary secretions, especially in early lactation (33). Lactose concentrations were greater ($P < 0.05$) in mammary secretions of transgenic gilts during the first 12 hours postpartum compared with controls. Transgenic gilts produced higher amounts of milk than controls on days 3, 6, and 9 of lactation ($P < 0.01$) (Table 9.7). The intake of

Table 9.7. Milk Production by First-Parity Control and Transgenic Gilts and Milk Component Intake by Litters[a]

	Days of lactation			
Item	3	6	9	12
Milk production, kg/d[bc]				
Control	4.33 ± 0.13[g]	5.86 ± 0.17[g]	6.68 ± 0.19[f]	6.94 ± 0.22
Transgenic	5.06 ± 0.13	7.19 ± 0.17	7.56 ± 0.19	7.10 ± 0.24
Lactose intake, g/d[c]				
Control	200 ± 18	292 ± 25[e]	350 ± 25	388 ± 28
Transgenic	242 ± 16	373 ± 22	402 ± 21	388 ± 24
Protein intake, g/d[d]				
Control	182 ± 18[f]	245 ± 25[e]	302 ± 25	314 ± 30
Transgenic	255 ± 15	316 ± 21	316 ± 21	302 ± 25
Total solids intake, g/d[c]				
Control	832 ± 46[e]	1125 ± 64[e]	1288 ± 108	1330 ± 109
Transgenic	970 ± 42	1310 ± 61 4	1386 ± 103	1375 ± 10

[a]Least squares means ± standard error.

[b]Milk production was determined by the weigh-suckle-weigh method. Mean hourly milk yield was used to determine daily milk yield, assuming 24 suckling periods per day.

[c]n = 20 gilts for each treatment group at each time.

[d]n = 15 litters for each treatment group at each time. Intakes are per litter per day.

[e,f,g]Control vs. transgenic differ, $P < 0.05$, $P < 0.01$, $P < 0.001$, respectively.

Data from (33).

lactose, protein, and total solids for transgenic litters was significantly greater than for controls on days 3 and 6 (Table 9.7), which in turn caused greater weight gains in transgenic litters compared to the controls. The day × genotype interaction on litter weight gain after birth was highly significant, with transgenic-reared litters gaining weight at a greater rate than control-reared piglets. Expression of the transgene was associated with increased milk production in lactating gilts and increased growth of transgenic-reared piglets (33).

The elevation in polymeric Ig receptor (pIgR) expression in the sow's mammary tissue coincides with the time of lactogenesis, as opposed to being related to prepartum colostrum formation (9). There is a strong positive correlation between α-LA mRNA abundance, a marker of lactogenesis in mammary tissue, and pIgR mRNA abundance, suggesting that pIgR gene expression may be controlled as part of the process of lactogenesis. In late gestation period, only small amounts of α-LA are present in the porcine mammary gland (9), which corresponds to the time of colostrogenesis. Subsequently, the α-LA protein levels are increased on the day of parturition, corresponding to lactogenesis, and remain high throughout the lactation period (8).

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10
Llama Milk

Moshe Rosenberg

1 INTRODUCTION

Domesticated camelids have had a significant impact on Old and New World cultures. Populations of camels and South American camelids (SACs), also called New World camelids, declined during the nineteenth and twentieth centuries. This could be attributed to negligence by governments that failed to recognize the value of these animals to the economy and culture of indigenous populations, and to attempts to replace the SACs with other domesticated animals (13). In recent decades the value of SACs has been recognized anew, and efforts to restore their populations have been made (13). Llama (*lama glama*) is one of the four main species of the New World camelids (13, 25). Fossil footprints found in the United States indicate that the *Camelidae* originated in North America about 50 million years ago. Their ancestors evolved to the sheep-sized *Poebrotherium* around 30 million BC. During the Miocene period, as global warming led to arid climates and the expansion of grasslands, the camelids grew in size, adapted to marginal quality feeds, and developed a pacing gait suited to migration across the expanding steppes. About five million years ago, camelid herds moved to South America and, over the Bering Strait land bridge, into Asia. Subsequent evolution yielded two distinct genera: the *Lama,* now native to the Andes of Bolivia, Chile and Peru, and the *Camelus*—in one- and two-humped varieties—of Africa and Central Asia. While their forebears in North America were hunted to extinction, both animals of both species were domesticated between 4,000 and 7,000 years ago. The camelids that migrated to Asia evolved to the dromedary camel (*Camelus dromedarius*) and bactrian camel (*Camelus bactrianus*), and those arrived in South America evolved to wild guanaco (*Lama guanacoe*) and wild vicuña (*Lama vicugna* or *Vicugna vicugna*). Llamas (*Lama glama*) and alpacas (*Lama pacos*) were domesticated from their wild relatives. The scientific classification of the llama species is as follows: Class *Mammalia* (they nurse their young); Order *Artiodactyla* (even-toed animals, they have two toes per foot); Suborder *Ruminantia* (they are modified ruminants and chew their cud); Infraorder *Tylopoda* (they have padded feet); Family *Camelidae* (part of the camel family); Tribes: *Lamini* (lamas) and *Camelini* (camels). The genus classification for llamas, alpacas, guanacos, and vicuñas is *Lama* and the genus classification for camels is *Camelus* (13). Two breeds of llama are recognized in Peru: the more wooly varieties are called ch'aku and those with fewer fibers are called q'ara (13).

The llama was domesticated in the Andean puna (elevation 4,000–4,900 m), probably around Lake Titicaca, at about 4,000–5,000 B.C. Following their domestication, llama herding economies spread beyond the limits of the puna and became a major component in the economy of Andeans (13). The Incas depended upon llama (and alpaca) for food, fuel, fibers, transport of commodities, and religious rituals (5, 13). Nothing appears to be known about any use of llama milk or its products for human consumption in Inca time. During the Inca era all lamoids were the property of the government, and the

production of domestic species and breeding was strictly regulated (5, 13). The dependence of the Incas on the llama as a source for food and fiber has been compared to relationships between the Indians of North America and the bison (25). With the collapse of the Incan civilization, during the sixteenth century, llamas were almost extinct and survived only in the high elevation of the Andes. During recent decades the camelid industry in the high altiplano regions has recovered (5, 13). Llamas have been gaining increasing interest as a fiber-producing animal, "watch dog" for sheep and goat herds, show animal, pack animal, and companion animal, in various parts of the world (21), especially after the legislation that banned exportation of the llama from all Andean countries had been lifted in the 1980s. In recent decades, llamas have gained increasing interest in the United States and Canada, and the llama industry in these countries continuous to grow. The number of registered, owned animals increased from about 70,000–75,000 in 1994 (21) to about 155,000 in 2003 (17).

Llama is considered a herbivorous pseudo-ruminant (1, 13). The digestive system of llama has evolved to utilize the ingested plant materials in a compartmentalized stomach. Although from the functional point of view the llama's stomach is similar, but not analogous, to that of true ruminants (cow, goat, sheep), it differs anatomically from that of true ruminants by having only three compartments (1, 13). The first two compartments in the llama's stomach, comprising 89% of the total stomach volume, represent a large mixing and fermentation unit, similar to the rumen and reticulum of true ruminants. The microbial and parasite flora residing in these compartments is similar to that found in true ruminants. Llamas regurgitate their food and chew the cud, similar to ruminants, but are more efficient than ruminants in extracting protein and energy from poor-quality forages (13). Plant material is hydrolyzed by microbial and enzymatic activities into basic nutrients that can then be digested in the lower parts of the gastrointestinal tract, namely, in the third compartment of the stomach (comprising 11% of the total stomach volume) and the intestine, prior to absorption. Other than the aforementioned differences in stomach structure, the digestive anatomy and physiology of llama is similar to that of true ruminants (1).

Data about composition and properties of llama milk are of prime importance from the animal development and growth point of view. The diet of neonatal llamas has to be complemented with supplemental milk, when the dam produces insufficient milk or when milk of poor compositional quality is produced. In such situations, the well being of the neonatal depends on milk supplements that best simulate the composition of the natural llama milk and thus meet the nutritional needs of the neonatal. Current understanding about milk replacers for neonatal feeding has been mainly developed for cow's calves, goat kids, or ewe lambs. Current recommendations call for utilization of cow or goat milk or lamb milk replacer in supplemental feeding of llama neonates (cria) (12, 13, 20). However, llamas with their different digestive system have different nutrient requirements and dietary habits than other domestic ruminants. These differences as well as the composition and properties of llama milk have to be considered in developing understanding about supplementary milk replacer and feed for llama neonate crias (21).

Data pertaining to composition of llama milk are very limited and challenging. In most cases, such data have been established by using milk of only few animals (of different breeds) and by utilizing different research methodologies and approaches (10, 13, 20, 21). To this date, a systematic study aimed at investigating and documenting the composition and properties of llama milk has not been conducted. This chapter discusses what has been reported about composition of llama milk and highlights directions where research is needed.

2 MILK PRODUCTION YIELD

The milk production system of llamas consists of four mammary glands, similar in their structure to those of cattle (12, 13). There are four nipples on the udder, each having two streak canals, which enter into separate teat and gland cisterns (13). Variable numbers and sizes of milk ducts collect milk from the gland and empty into the gland cistern. The streak canals of llamas are short (2 mm) and narrow, and they may exit the teat on a conical surface, or they may exit into a sinus at the tip of the teat (13). The right and left halves of the mammary gland are separated by an incomplete suspensory ligament of

the udder. The front and rear quarters cannot be separated, visually or surgically, but there is no connection between the collecting systems of the two quarters. Hand milking of a llama is challenging, due to the short teat. In some cases, the cria may fail to grasp the teat and thus feeding may be compromised (13).

Information about llama milk production yield and composition was reported by Morin et al. (21). This information was established using milk collected during the fall and spring of 1993 from 83 llamas, ranging in age from two to 18 years, located on eight farms in different states of the United States. Of these animals, eight were in the first lactation, while the other 75 animals were lactating at least a second time.

The study of Morin et al. (21) indicated that the amount of milk produced daily by individual llamas varied significantly and ranged from 16 to 413 ml per animal. Milk yield from the rear quarters differed from that obtained from the front quarters, and milk yield per llama varied significantly between the investigated farms. The latter may reflect the influence of breed, feeding, climate, animal age, lactation status, and number of lactations on milk yield, similar to what has been established for other species (26). A systematic research aimed at establishing information about the influence of these variables on milk production by llamas has yet to be conducted.

3 MILK COMPOSITION

3.1 Major Constituents

The limited data about llama milk composition are listed in Table 10.1. Morin et al. (21) reported from studying 83 U.S. llamas, and Fernandez and Oliver (10) from 18 animals in two regions of Argentina. Some additional data of llamas in the United States were published by Fowler (12) and by Johnson (19). Results of Morin et al. (21) indicated that the milk of llamas had an average content of 13.1% total solids, 6.5% lactose, 3.4% protein, and 2.7% fat. The average composition of milk produced by llamas in Argentina (10) consisted of 15.5% total solids, 4.7% fat, 5.9% lactose, and 4.2% proteins. Data depicted in Table 10.1 may suggest significant differences between llama milk produced in the United States and that produced in Argentina. Although the data were established using different population sizes and methodologies, the observed differences suggest effect of locality on llama milk composition, similar to what has been established for milk of other ruminants (26). It was interesting to note the wide range of variation of milk constituents in the study

Table 10.1. Approximate Average Composition (% w/w) of Milk Produced by Some Mammals

Animal	Total solids	Fat	Total proteins	Serum proteins	Casein	Ash	Lactose
Llama[1]	13.10	2.70	3.40	NA	NA	0.50[2]	6.50
Llama[3]	15.61	4.72	4.24	1.012	3.16	0.55	5.92
Llama[4]	17.00	4.10	6.9	NA	NA	1.0	5.00
Llama[5]	13.8	5.66	4.25	NA	NA	0.8	3.34
Cow[6]	12.70	3.90	3.20	0.60	2.60	0.70	4.60
Goat[6]	13.30	4.50	3.60	0.60	3.00	0.80	4.30
Camel[6]	13.40	4.50	3.60	0.90	2.70	0.80	4.50
Camel[7]	13.10	4.10	3.40	NA	NA	0.70	3.70
Ewe[6]	18.80	7.50	5.60	1.00	4.60	1.00	4.60
Yak[6]	17.70	6.70	5.50	NA	NA	0.90	4.60

[1]According to Morin et al. (21).
[2]Calculated based on data of Morin et al. (21).
[3]According to Fernandez and Oliver (10).
[4]According to Fowler (12).
[5]According to Johnson (19).
[6]According to Walstra et al. (26).
[7]According to Alhadrami (2).

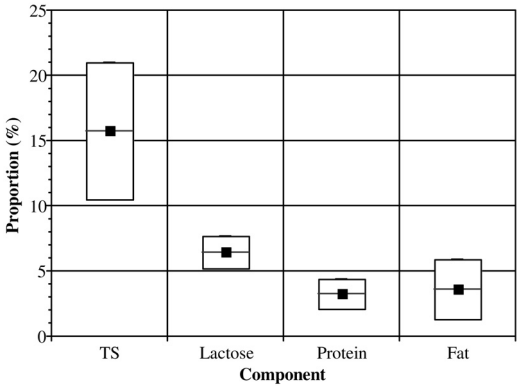

Figure 10.1. Proportions of major constituents in llama milk. Bars depict the concentration range and symbols represent the average value, per constituent. Developed from Morin et al. (21).

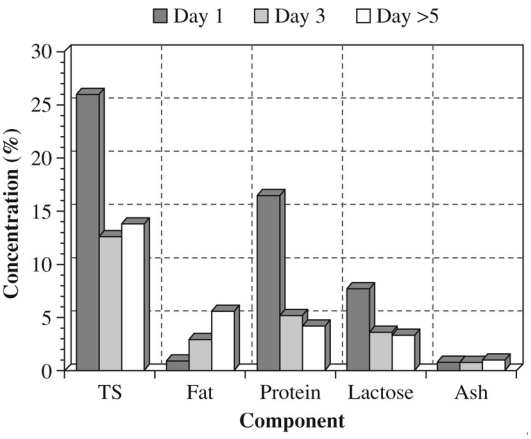

Figure 10.2. Composition of llama colostrum milk (day 1), transitional milk (day 3), and mature milk (day >5). Developed from Johnson (19).

by Morin et al. (21) (Figure 10.1). However, neither stage of lactation nor body score seemed to be associated with significant differences in any of the milk constituents (21). Although only 83 animals were studied, the apparent absence of effects of stage of lactation on milk composition differed from that reported for other dairy animals (26). Llamas seem to produce milk of a relatively consistent composition throughout lactation, although the experimental design (21) may also have masked effects of lactation stage on milk composition. It has been widely reported (26) that stage of lactation is by far the most important physiological variable affecting milk composition. In light of the latter, additional data, depicting the relationships between stage of lactation and llama milk composition, need to be determined by repeat sampling of milk by a given group of llamas throughout an entire lactation from parturition through weaning and until drying up.

Some data about the evolution of milk composition from colostrum to mature milk have been reported (19). Similar to what has been established for other mammals, the composition of llama colostrum differs significantly from that of mature milk (Figure 10.2). The most dramatic change is in the concentration of protein that drops from about 16.5% in the colostrum milk produced on the first day after parturition to less than 5% in mature llama milk produced five days later. The content of fat in llama milk increases from about 1.0% in colostrum to about 5.5% in mature milk (19). Comparing the composition of first colostrum of llama to that of cow colostrum reveals that both have similar protein concentrations; however, the contents of fat in cow colostrum (3.0%) is about three times higher than that in llama colostrum (19).

Results of Morin et al. (21) indicated that both lactose and total solid contents were significantly affected by the number of lactations. Lactose and total solids contents in milk produced by first-lactation llamas were 6.3 and 12.8%, respectively, while for later-lactation llamas, lactose and total solids content of 6.6 and 14.4%, respectively, was found. As expected, significant between-farms differences in milk protein and lactose contents were also determined (21), which were attributed to the influence of diet, climate, and so on, similar to what has been reported for other ruminants (26). This aspect also needs to be further investigated. Some correlations between milk constituents showed fat and protein contents positively related to total solids, and lactose and fat contents negatively correlated (21).

Data in Table 10.1 also depict significant differences in the composition of llama milk from different studies, which may be attributed to a relatively small number of animals included in each of the studies as well as to the influence of locality, feed, lactation stage, animal age, and number of lactations. A com-

parison between composition of llama milk and that of other animals is presented in Table 10.1. The total solids content of llama milk that was reported by Morin et al (21) is similar to that in cow, goat, and camel milk. However, total solids in the Argentinean llama milk (10) was higher than that of cow, goat, and camel milk. Lactose contents in llama milk reported in different studies ranged from 3.3% to 6.5%. Data in three of the four studies shown in Table 10.1 suggest that lactose content in llama milk is significantly higher than in milk of other domestic ruminants. Two of the reported studies (10, 21) suggest that lactose content in llama milk is similar to that reported for donkey milk that contains about 6% lactose (26). The high lactose content of llama milk suggests that the nursing cria receives more energy from it and less from lipids in comparison to what is known for other ruminants (21). As long as data suggesting the presence of other carbohydrates besides lactose in llama milk have not been established, the total carbohydrate content in llama milk is assumed to consist of only lactose (21). However, the high content may suggest the potential presence of other carbohydrates. This aspect has to be further investigated.

The fat content in llama milk that was reported in different studies ranged from 2.7% to 5.7% (Table 10.1). The fat concentration in the study of Morin et al. (21) was significantly lower than that reported by all other studies (Table 10.1), as well as lower than in the milk of other mammals (Table 10.1). The milk fat content reported for the Argentinean llamas (10) and llamas from the United States by Fowler (12) was similar to that in goat and camel milk (Table 10.1). It has to be mentioned that Morin et al. (21) reported that the low fat content in llama milks in their study was not related to incomplete evacuation of the mammary glands of some of the investigated llamas and thus to differences between milk fat content in foremilk and strippings.

The protein content in llama milk was similar (21) to that reported for cow, goat, and camel milk (Table 10.1), but lower than for ewe and yak milk. However, Fernandez and Oliver (10) reported about 25% higher contents and also somewhat higher than for cow, goat, and camel milk (Table 10.1). Llama and camel milk appear to contain similar contents (21, 9) of proteins and total solids, but lactose is higher than in camel milk. Fernandez and Oliver (10) reported that the ratio between casein and serum protein was about 2.8 : 1.

The overall energy content of llama milk varied between 50.0 to 95.8 kcal/100 g (21). It was suggested (21) that the average energy content of llama milk (70.0 kcal/100 g) is lower than that of cow, goat, and ewe milk (85.2, 103.6, and 155.6 kcal/100 g, respectively). Johnson (19) reported an 81.3 kcal/100 g gross energy content of llama milk.

A few physical properties of llama milk have been reported by Fernandez and Oliver (10) indicating milk density of 1.033 g/ml, milk fat density of 0.935 g/ml, and milk pH of 6.52 at 20° C.

3.2 Minerals in Llama Milk

Mineral contents in llama milk (Table 10.2) indicate that unlike in human and cow milks, where potassium is the most abundant mineral (11), calcium is the main mineral in llama milk, followed by phosphorous and potassium. However, the data have to be addressed with care because they represent results of different studies, where milks from different localities were investigated by different analytical approaches. In addition to these obvious influences, it has been reported that mineral contents in milk are significantly affected by stage of lactation, diet, season, and health status of the animal (14). It is likely that the data in Table 10.2 reflect the overall combined influence of all these variables, due to the heterogeneous nature of the animal population in the differently cited studies.

Calcium content of llama milk (Table 10.2) was higher (1,310 to 2,210 ppm) than in human, cow, and goat milk (280, 1,120, 1,400 ppm, respectively) (11, 18), but similar to that in camel milk (2, 21). Sodium concentration in llama milk (193 to 413 ppm) seems to be lower than in cow milk (530 ppm), but higher than in human milk (180 ppm).

The most abundant trace element in llama milk is zinc (Table 10.2), similar to what has been reported for milk of other species (3). The mean zinc content in llama milk (about 4.2 ppm) (21) was higher than in human milk (1.2 ppm) (11) and similar to cow milk (3.9 ppm) (11) and camel milk (4.0–5.0 ppm) (2). Barium concentration in llama milk (0.278 ppm) seems to be higher than that reported for cow milk (188 ppm) (3). The mean copper concentration in llama milk (0.109 ppm) (21) appears to be lower than in mare (0.155 ppm), human (0.250–0.314 ppm), or guinea pig (0.500 ppm) milk (3, 11, 21). The relatively low copper concentration in llama milk agrees

Table 10.2. Mineral Composition of Llama Milk

Mineral	Content	Mineral	Content
P	922–1630 ppm[1a] 0.50 (in dry matter)[3]	Mg	108–194[1a] 0.073 (in dry matter)[3]
K	751–1790 ppm[1a] 0.98 (in dry matter)[3]	Ba	0.278 ppm[1b]
Cl	282–1440 ppm[1a]	Cu	0.109 ppm[1b] 2.57 ppm[3c]
S	338–543 ppm[1] 0.12 (in dry matter)[3]	Fe	0.65 ppm[1b] 7.87 ppm[3c]
Na	193–413 ppm[1a] 0.38% (in dry matter)[3]	Mn	0.071 ppm[1b] 8.28 ppm[3c]
Ca	1310–2210[2] ppm[1a] 1694–2696 ppm[2a] 0.89% (in dry matter)[3]	Zn	2.55–7.10 ppm[1a] 15.80 ppm[3c]

[1,2,3]Developed from Morin et al. (21), Fernandez and Oliver (10), and Johnson (19) data, respectively.

[a]ppm in milk.

[b]Mean concentration value for milks in which the specific mineral was above the detection level.

[c]ppm on dry basis.

with low blood serum copper concentrations in llamas compared to other domestic animals (21). The mean iron concentration in llama milk (0.65 ppm) (21) is comparable to that in cow milk (0.50 ppm) (11), but higher than in human milk (0.3 ppm) (11) and lower than in camel milk (1.3–2.5 ppm) (2).

Overall and similar to the review of other llama milk constituents, the extent to which detailed information about mineral composition of llama milk has been established is very limited and more research is needed.

3.3 Protein Composition of Llama Milk

The protein composition of llama milk has been investigated only to a very limited extent, and conflicting information about the identity and concentration of the constituent proteins exists. In addition, a variety of protein fractionation methodologies have been used. Some of the protein fractions have been identified to various degrees, while others have not been identified yet. It is thus impossible at this time to draw definite conclusions about protein composition of llama milk.

A systematic attempt was made by Fernandez and Oliver (10). Results suggest that casein constitutes 74.5% and whey proteins 23.8% of total proteins in llama milk, which does not account for 100% of total protein content. This could be attributed to the presence of unidentified protein fractions (10) as well as to errors in the different analytical procedures. Results (10) suggested that α-casein (α-CN) and β-casein (β-CN) accounted for 38.5 and 35.4% of total casein, respectively, and that 27.2% of the total proteins in the casein fraction in llama milk could not be identified. The molecular weight (MW) for llama casein was 38 kDa and 42 kDa for α-CN and β-CN, respectively (10). These values are higher than those reported for casein in milk of other species. The differences could be attributed to interactions between the proteins and the separating gel (10). It has to be noted that in the presence of 2-mercaptoethanol, electrophoretic separation of the casein fractions of llama milk yielded a series of 10 bands, of which six were identified as γ-casein (10).

Electrophoretic separation of the whey fraction of llama milk, using a urea-starch gel, revealed 4 bands (10). The first band was identified as α-lactalbumin (α-LA), with a molecular weight of 14 kDa. The second band consisted of three protein constituents of the proteose peptone fraction. These were denoted as proteose-peptone 1 (MW 34 kDa), proteose-peptone 2 (MW 25 kDa), and proteose peptone 3

(MW 16.5 kDa). The third band reportedly (10) consisted of serum albumin (MW 72 kDa), and the forth band (MW 135–150 kDa) consisted of immunoglobulins. The reported concentration of the different protein fractions in whey of llama milk (Figure 10.3) suggests that the α-LA, serum albumin, proteose peptone fractions, and immunoglobulins account for 36.6, 23.2, 27.0, and 14.3% of total protein content of llama milk whey, respectively.

The protein composition of llama whey proteins was also investigated by Cantisani et al. (8). Results indicated the presence of three glycosylated α-LA forms. The relative molecular mass of the isolated α-LA was almost identical to that of bovine α-LA. It has to be noted that several other α-LA have been reported to be either partially glycosylated, such as bovine α-LA (4, 16), or totally glycosylated, such as rabbit (15) and rat α-LA (23). The latter has also been shown to exhibit three forms, differing only in their carbohydrate content (24). The amino acid sequence of the N-terminal domain of the three forms of llama α-LA (8) was identical to that of camel α-LA; however, a glycine in llama α-LA substitutes asparagine in camel α-LA (6).

Results of the studies of Cantisani et al. (8) indicated the presence of a protein fraction with a relative MW 30 kDa. The first 18 amino acids of this protein were identified and revealed a homology with the so-called "heterogeneous camel milk noncasein protein" (7). Unlike camel milk, in which two species of this protein were identified (7), Cantisani et al. (8) indicated the presence of only one homogeneous component. The latter might imply that the llama protein component represents the parent species from which the two forms present in camel milk have evolved (8).

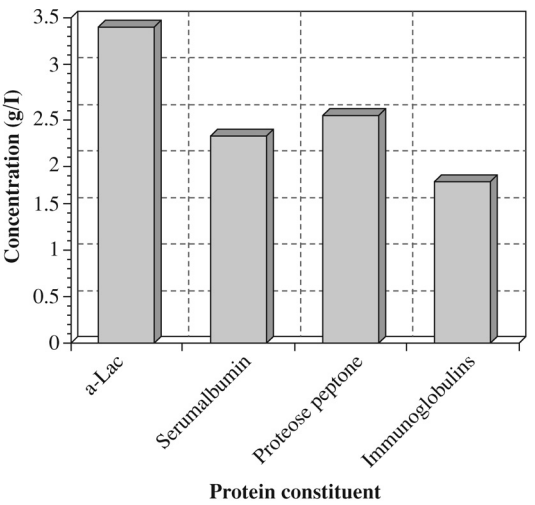

Figure 10.3. Concentration of protein constituents of llama milk whey. Developed from Fernandez et al. (10).

Studies by Fernandez and Oliver (10) and Morin et al. (21) suggest that llama milk does not contain β-lactoglobulin (β-LG), which was also investigated by Napolitano et al. (22). Separation of llama whey proteins by size exclusion HPLC followed by purification through preparative isoelectric focusing and RP-HPLC yielded a protein fraction that reacted positively with polyclonal antibody anti-bovine β-LG in an immuno double diffusion assay. Further investigation of this fraction by amino acid sequencing of its N-terminal segment revealed some homology with internal segments of human K-CN, with segments of human lactotransferrin and an interesting identity with identified β-LG in positions proline 4 and leucine 10. Although this study (22) provided some indications about the presence of a protein related to β-LG in llama milk, more data, including a complete amino acid sequencing of the protein fraction, is needed in order to prove the hypothesis about the presence of this protein in llama milk.

The extent to which proteins in llama milk are glycosylated was investigated by Fernandez and Oliver (10), who reported that carbohydrates were associated with α-LA, proteose peptone protein fractions, immunoglobulins, α-CN, and β-CN. The distribution of sialic acid among protein fractions of llama milk was 84.4% in the milk whey fraction and 15.6% in casein (10). Llama milk proteins contain significant proportions of phosphorous, being 0.36, 0.45, 0.30, and 0.15%, for α-CN, β-CN, γ-CN, and the proteose peptone fraction, respectively (10).

4 CONCLUSIONS

Llama milk has been investigated only to a limited extent, and the level of understanding pertaining to the composition and properties of llama milk that has been established is significantly less than that of milk of other domestic ruminants. The information reviewed for this chapter suggests similarities between some of the properties of llama milk and

those of milk of other species; however, it also suggests that llama milk has some unique properties. Basic understanding about the structural elements in llama milk, such as the milk fat globule and casein micelle, has not been determined yet, and only limited information about the physico-chemical properties of this milk has been reported. Protein composition of llama milk has been investigated to a limited extent, and our understanding about the composition and physico-chemical properties of the constituent proteins is by far poorer than that pertaining to proteins in milk of other species. The fatty acid composition of llama milk has not been reported yet, and only limited information about the carbohydrate composition of this milk exists. It is therefore clear that a focused and systematic research effort, aimed at closing the information and understanding gap, is critically needed.

It is well known that feed, genetic, animal health, and physiological status as well as environmental differences significantly affect milk composition and properties. The reported information about composition of llama milk comes from different parts of the world using a variety of methodologies and different numbers of animals. A basic understanding about the influence of these variables on composition and properties of llama milk has yet to be established.

Although llamas are not likely to become a significant milk source for human consumption in the United States of America and Canada, they may offer unique opportunities in poor areas, such as in the high-elevation regions of the Andes. The nutritional status of human populations, especially of children, residing is these areas is significantly lower than desired. The availability of relatively large populations of llamas in these areas may offer opportunities to overcome some of the difficulties by directing llama milk to human consumption. Success in meeting the nutritional need of both humans and animals is dependent on developing a thorough understanding of the composition and properties of llama milk.

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11
Minor Species Milk

Young W. Park

1 INTRODUCTION

All the foregoing chapters have covered the milks of most frequently used and domesticated mammals for human consumption and nutritional and health research. However, some other domesticated and wild minor mammalian species such as moose, musk ox, caribou, alpaca, ass, elk, pinniped (seal and sea lions), polar bear, zebra, and pony, among others, have not been described or illustrated in those aforementioned chapters.

The literature on these minor domesticated or wild mammals has been very scarce because milks of these mammalian species are produced for human consumption only at certain specific regions of the world; also, very little data is available due to the extremely limited studies that have been conducted on such rarely domesticated minor species mammals.

During the past decades, however, a surge of interest has occurred in energetics of nonfarm mammalian reproduction as well as a particular emphasis on more systematic studies of lactation in marsupials, primates, pinnipeds, and ungulates (48). The data base on rodents, carnivores, bats, and cetaceans still remains meager.

Although quite a few data are available on milk compositions of wild and less domesticated animals, considerable inaccuracy may remain in many species due to the small number of samples, difficulties in defining stage of lactation, biases introduced during sampling, and flawed analytical procedures (48, 49).

2 GENERAL ASPECTS OF COMPOSITION OF OTHER MINOR SPECIES' MILKS

The basic nutrient compositions of milk of other domesticated mammalian species for human consumption are listed in Table 11.1. The chemical composition of milks from different species of mammals is designed by natural selection to provide the nutritional needs of neonates of the specific species. There are considerable differences in milk composition among less used minor mammalian species (Table 11.1). Not only are the data on the uncommon domesticated mammals or wild species very scarce, but frequently little is known about lactational stage and when milk was previously removed from the gland. If stage of lactation is not controlled for in comparing one species to another, intraspecific (and intraanimal) variation may be confounded with interspecific differences, leading to erroneous or misleading conclusions (46). Even under standard conditions of removal of milk from the gland, there are substantial short-term (diurnal and day-to-day) variations in composition. The composition and yield of milks of other minor species mammals will also vary with breed, animals within breed, environmental conditions, feeding and management conditions, season, locality, and stage of lactation, as in the case of major mammalian species (50, 59).

Milk of mammary glands is produced by two secretory processes: synthesis and diffusion by the mammary epithelial cells. The major milk nutrients, milk fat, proteins, and lactose are synthesized by the

Table 11.1. Composition of Milks (g/100 ml) of Domesticated Other Minor Mammals

Mammals	Days of lactation	No. samples	Total solids	Protein	Lactose	Fat	Ash	Ref. no.
Ass (*Equus asinus*)	60–120	9	8.5	1.4	6.1	0.6	0.4	4
	—	—	9.7	1.8	6.2	1.3	0.4	3
Moose (*Alces alces*)	> 2	15	21.5	8.5	3.0	10.0	1.5	32
	—	—	25.7	13.5	3.6	7.0	1.6	8
Caribou (*Rangifer arcticus*)	?	3	23.6	7.6	3.7	11.0	1.3	28
Dromedary (*Camelus dromedarius*)	?	15	13.6	3.6	5.0	4.5	0.7	20
Musk ox (*Ouibos moschatus*)	—	1	16.4	5.3	4.1	5.4	1.6	64
	—	—	21.7	5.3	3.6	11.0	1.8	21
Elk (*Cervus elaphus*)	14–77	28	19.0	5.7	4.2	6.7	1.3	58

mammary epithelial cells using the precursors absorbed from the blood. The water, minerals, and vitamins are secreted into the lumen of the alveolus via diffusion process from the blood (53, 59, 62).

The total solids, protein, and ash contents are expected to be higher in colostrum than in the milk obtained two or three weeks after parturition in the minor mammalian species as in the cases of cow and other major dairy species. The most striking difference is the high protein percent in colostrum, where the large part of this is due to the globulin contents that contain the antibodies (59, 62). Mammals such as cow, sheep, goat, horse, and pig require passive immunity from colostrums, which contain β-lactoglobulins and immunoglobulins. The antibody titer of blood of the newborn animal is extremely low, but immunoglobulins are absorbed by the newborn during its first day of life for most mammals.

In ruminant mammals, diets that decrease in roughage percent depress the milk fat percent and cause characteristic changes in rumen fermentation. This situation is attributable to a decrease in molar percentage of acetic acid while increasing molar percentage of propionic acid (67).

3 COMPARATIVE ASPECTS OF MILK PRODUCTION AND COMPOSITIONS OF OTHER MINOR SPECIES

3.1 Moose

Moose milk has the consistency of thick cream and has the odor of fresh bovine milk (17). As shown in Table 11.2, Cook et al. (17) reported the gross composition of two moose milk samples in comparison with that of black-tailed deer milk (37) and caribou milk (28). The two moose milk samples had similar levels of total solids, ash, and lactose, whereas the sample No. 1 contained 2.5 times more fat and 25% less protein than sample No. 2. The authors postulated that the observed differences in the protein and fat contents in the moose milk were accounted for by individual animal differences rather than by the stages of lactation of the animals. The moose milk also contained much less lactose than deer milk or caribou milk and most other ruminant species (21).

In a later study with singleton moose calves (*Alces alces gigas*) during the first four months postpartum, milk composition at peak output was: total solids, 20.5 ± 1.5; fat, 7.9 ± 1.5; protein, 7.2 ± 0.4; ash, 1.4 ± 0.1; carbohydrate, 3.7 ± 0.2 (56). This result indicates that total solids and gross composition of moose milk at peak season are considerably lower than other stages of lactation, compared to the previous reports (17).

Mineral composition of moose milk is not markedly different from that of other arctic species milk (40), whereas the potassium content is lower than other milks except human milk (17). With respect to fatty acid composition, 23 fatty acids were identified in No. 1. sample, and 25 in No. 2 sample (Table 11.2), where about 53% of the fatty acids of moose milk are saturated, which is slightly lower than the saturated fatty acid content of the milks of most ruminants (17, 43). In a study of 21 Alaskan moose at the Kenai Moose Research Center, Soldotna, Alaska, Franzmann et al. (24) reported that bovine milk had a factor of 1.6 to 290 higher than moose milk in Al, Fe, Se, and Zn, respectively. Among min-

Table 11.2. Gross Composition of Moose Milk Compared with That of Deer and Caribou[a]

	Moose		Black-tailed deer[c]	Barren-ground caribou[b]
	No. 1	No. 2		
Total solids, %	24.9	24.8	25.0	31.8
Water, % (by difference)	75.1	75.2	75.0	68.2
Fat, %	10.5	3.9	10.4	16.9
Solid-not-fat, % (by diff.)	14.4	20.9	14.6	14.9
Ash, %	1.6	1.6	1.5	1.15
Protein, % (N × 6.38)	12.3	16.4	8.7	9.7
Lactose, %	0.56	0.65	4.4	2.55
Specific gravity (20° C)	1.036	1.075		
pH	6.4	6.3		6.55

[a]Adapted from Cook et al. (17).
[b]Hatcher et al. (28).
[c]Kitts et al. (37).

erals, Ca and Mg were the only minerals in lower levels in hair than in milk of moose.

The maternally raised singleton moose calves showed significantly higher milk intake than the bottle-raised calves (Figure 11.1). Although the weight gains of bottle-raised moose calves generally increased as they began consuming significant quantities of forage, poor early growth rates relative to maternally raised calves (790 ± 120 g/day) confirmed the inadequacy of the bottle-feeding protocols (60). High mortality rates associated with bottle-raised neonatal moose are frequently attributable to improper nutritional management and poor husbandry techniques. Dietary-induced diarrhea caused by inappropriate milk replacers was commonly observed in moose calves raised in captivity. Calves are often underfed to avoid diarrhea, resulting in poor growth rates during the first four weeks when the young are usually entirely dependent on mother's milk for their growth and survival (60).

3.2 Musk Ox

Historically, musk ox ranged across northern Alaska, Canada, and Greenland (26). This species was extirpated within Alaska by the mid-1800s, possibly due to hunting by native peoples, explorers, and whalers (64). The worldwide population of musk ox

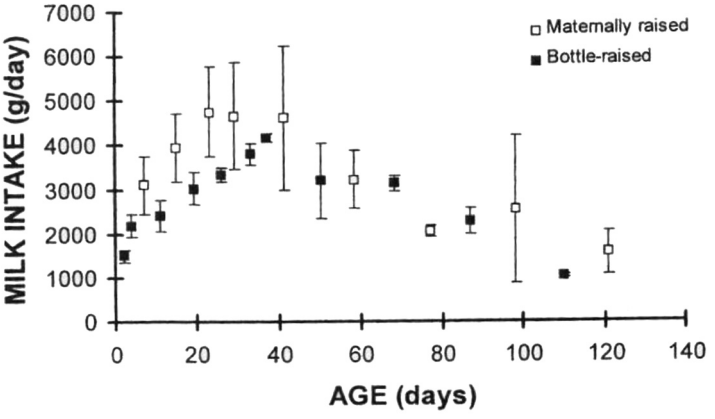

Figure 11.1. Daily milk intake (mean ± 1 SD) of four maternally raised, singleton moose calves (reference 56) and four bottle-raised calves during 1995–1996.

was thought have declined to as few as 5,000 animals in the early 1900s, and the species was considered to be in danger of extinction (26). The Canadian government granted the species protection from hunting and made efforts to save musk ox beginning in 1917 (12). Muskoxen were translocated from Greenland to Alaska and were held in captivity in Fairbanks for feeding, growth, and breeding studies until 1935–1936, when they were released into the wild on Nunivak Island (38).

Muskoxen and caribou live in similar arctic environments, often eating similar forages. However, their lactational strategies are very different in length. Muskoxen in good body condition continue to nurse their young throughout the rutting period, until December to February, and in the field may lactate throughout the winter (69).

Three subspecies of living musk ox have been recognized (1), which are *Ovibos moschatus moschatus, Ovibos moschatus niphoecus,* and *Ovibos moschatus wardi*. Muskoxen in Alaska are descendants of transplanted animals from Greenland and are thus *O. m. wardi*. A comparative study of Alaskan and Greenlandic musk ox showed that there was little nuclear genetic vatiation within and between populations based on allozyme electrophoresis (22).

The gross composition of musk ox milk is shown in Table 11.3. Total solids, solid-not-fat, and lactose contents of the musk ox milk significantly increased from day 1 to three months of lactation. Unpublished data (R. White) showed that the fat and protein content at week 1 were significantly higher than the day 1 milk sample (Table 11.3). Table 11.1 shows that there were apparent variations in gross composition of musk ox milks.

Table 11.3. Gross Composition of Musk Ox Milk at Time Intervals Post-Calving

	1 day[a]	1 week[b]	3 months[c]
Water, %	78.5	—	72.9
Total solids, %	21.54	—	27.1
Fat, %	11.0	15.45	10.9
Solid-not-fat, %	10.6	—	16.2
Protein, %	5.3	15.63	11.9
Lactose, %	3.6	2.89	2.1
Ash, %	1.8	3.28	1.2

[a]Tener (65).
[b]White, R. (unpublished).
[c]Baker et al. (6).

Highest milk production for musk ox occurs three weeks postpartum (Figure 11.2). Production remains high for about one month and then tapers off gradually (69). Supplemental feedings can be lowered to corresponding decreased levels of milk production as long as the cows maintain their weight.

3.3 Caribou

Caribou (*Rangifer tarandus granti*) and reindeer (*Rangifer tarandus tarandus*) are very close to each other in terms of species and ancient association in northern lands. Caribou have provided meat, skins for clothing and shelter of exceptional warmth and

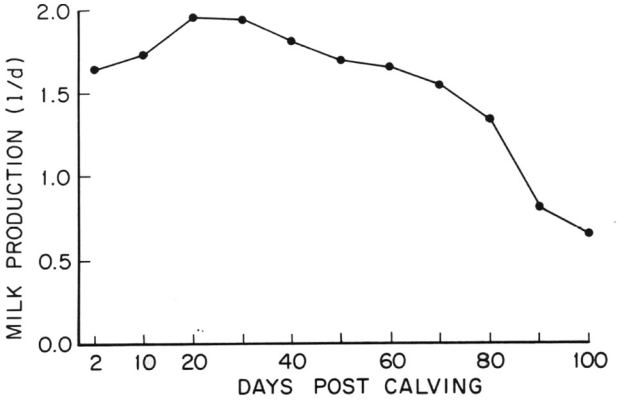

Figure 11.2. Musk ox milk production. Average daily milk production over three years from musk ox cows. Cow can continue to lactate for more than one year and can conceive while lactating. Adapted from White et al. 69).

lightness, and implements made from bones and antlers for the indigenous northern Americans (31). The fur trade that led to early exploration and exploitation of northern American lands was provisioned from caribou.

There are several distinguishable kinds of caribou in North America. There are herds that differed in migratory programs in each of the caribou populations (31). Caribou of the Porcupine herd are the subspecies *Rangifer tarandus granti* (7). Major movements of the Porcupine herd take place between Canada and Alaska at least twice annually. The Nelchina herd ranges over south central Alaska, which is a diversified area of ragged, glacier-capped mountains, rolling uplands, and broad, forested plains. Estimated population of the Nelchina herd was about 10,000 caribou for 1948 (29). The Kaminuriak population of barren-ground caribou ranges over northern Manitoba, northeastern Saskatchewan, and southeastern District of Keewatin, Northwest Territories of Canada, an area of about 282,310 km^2.

Caribou in good condition usually terminate nursing during the rutting period. The neonates of caribou and musk ox are followers, accompanying their mothers most of the time, and are characterized by frequent nursing bouts of short duration (51). Caribou are known for their long migratory routes and usually use flight as the mechanism to escape predation.

Caribou milk is significantly higher in protein, dry matter, and energy content than that of musk ox (Table 11.1 and Figure 11.3). Part of this difference toward the end of summer may be attributed to weaning date. The two caribous weaned their calves in early October, whereas the musk ox continued to nurse their young until the third week of January (51). It was observed that milk quality typically increased in ungulates prior to weaning (46). Milk intake by caribou neonates gradually declined throughout the summer from a peak value during the first week of age at 1792 $\pm$ 51 ml/day (51).

In a captive-caribou and -reindeer study, it was observed that energy intake increased protein deposition in lactating animals but increased fat deposition in nonlactating females, and that milk water volume increased with maternal energy intake and decreased with calf age (14). The same study also showed that production of milk dry matter, milk fat, and milk energy were not affected by maternal energy or protein intake, maternal body condition, or calf age. Production of milk lactose was correlated

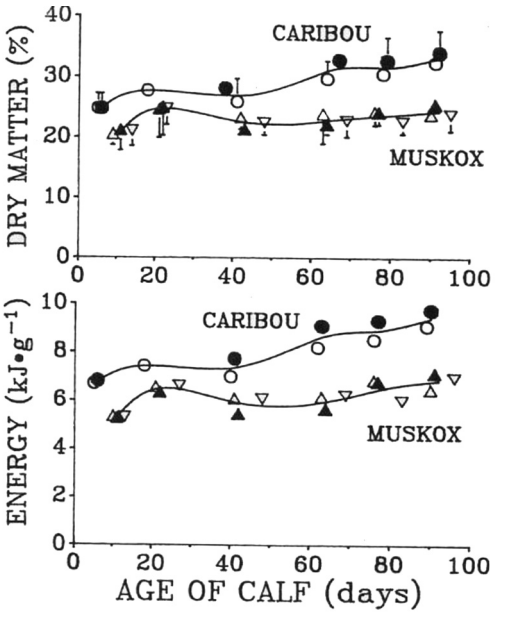

Figure 11.3. Dry matter and energy content of milk from caribou and musk ox during the 100 days following parturition. Adapted from Parker et al. (51).

with maternal energy intake, while production of milk protein correlated with the maternal dietary protein:energy ratio (14). Body mass changes over the experimental period varied dramatically between individuals, ranging from a net loss of 6.4 kg to a net gain of 31.1 kg (Figure 11.4). All caribou gained mass by the end of the 12-week period, while two lactating reindeer had net mass losses and one nonlactating reindeer gained only 2.2 kg.

In another study using captive woodland caribou, growth rates of the woodland caribou from birth to 45 days were shown to be positively correlated with suckling rate during the first 35 days (42). The study also reported that from 46 to 100 days, growth rates of the young caribou were positively correlated with time spent feeding on pelleted ration and on hay.

3.4 Alpaca

Alpaca is one species of South American camelids, which are a critical part of the village economy of countries including Chile, Bolivia, Peru, and Argentina (13). Alpacas are a source of income, providing

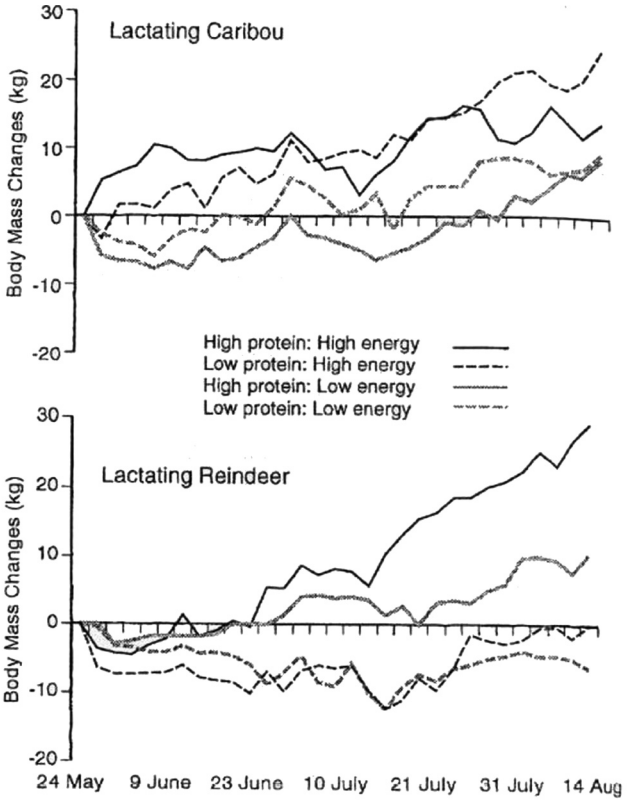

Figure 11.4. Body mass changes in lactating caribou and reindeer during the 12 weeks' experiment between May and August (one animal per dietary treatment). Adapted from Chan-McLeod et al. (14).

food and wool for the native people that live on high altiplano regions (13). Most alpaca producing areas have a 50% or lower conception rate and a 20% mortality rate of the young called "cria." These reproductive problems can be attributed to nutritional inadequacies, infectious diseases, or changes in the environment (55).

There are four species of existing camelids. The vicuna and guanaco are wild species. The vicuna is native to the altiplano regions of Chile, Bolivia, and Peru (13). The guanaco is native to the Patagonia regions of Chile and Argentina. Llamas and alpacas are the two domesticated species in this family. They are found in Peru, Chile, Bolivia, and Ecuador (23).

An unpublished research (52) on colostrum composition at 48 hr postpartum for Andean high plateau and Patagonia alpaca breed milks were: dry matter, 20.7, 19.1; protein, 9.84, 9.24; fat, 4.80, 2.71; lactose, 4.41, 5.33; ash, 1.63, 1.78, respectively. The data suggest that the colostrum at altiplano had higher dry matter, protein, and fat, but lower lactose than Patagonia-region alpaca breed. They also indicated that a similar trend had been observed in the major constituents of alpaca mature milk up to five months of lactation from the previous report.

Colostrum is the source of IgG in livestock species, including horse (33), cows (54) and sheep (30). The main immunoglobulin found in alpaca crias was IgG (25). Bravo et al. (11) reported that there was no difference in mean IgG concentrations (mg/dl) between species, llama (2370.6), and alpaca crias (2347.1) (Table 11.4), and no difference in mean values between male and female crias. There were no changes in IgG levels of pregnant females, while changes occurred after parturition in mammary secretions. The study also showed that llama and

Table 11.4. Concentrations of IgG in Serum and Mammary Secretion of 15 Periparturient Llamas and Alpacas (mg/dl)[a]

Periods	Llamas	Alpacas	Range
IgG in serum			
1 wk before parturition	3174 ± 264	3462 ± 111	2102–5450
At parturition	3126 ± 112	3001 ± 112	2101–4259
1 wk after parturition	3119 ± 339	2988 ± 155	1200–6013
IgG in mammary secretion			
1 wk before parturition	21077 ± 2722	25830 ± 1125	17651–35943
At parturition	22313 ± 3806	21792 ± 786	17651–28442
1 wk after parturition	2004 ± 894	4699 ± 1030	573–6052

[a]$P < 0.05$ between species; $n = 30$ per day.
Data from Bravo et al. (11).

alpaca crias were born agammaglobulinemic, with IgG concentrations increasing after suckling.

3.5 Ass

Although much research has been devoted to milk composition in the domestic horse, relatively little is known about other Equidae family species such as asses (donkey) and zebras (49). Human consumption of ass milk has stimulated some interest in this domestic species, but the few reports on wild equids refer to only one or two milk samples per species (4, 8, 34, 49).

The equids are a relatively homogeneous group of moderately large, cursorial grazers adapted to grassland and semi-arid conditions (27). Oftedal and Jenness (49) found that there was a remarkable similarity in gross composition of the milks of the ass, mountain zebra, plains zebra, and Przewalski horse and pony (Table 11.5). They reported that the apparent variation in TS, from a mean of 10.0% in the mountain zebra to 11.3% in the plains zebra, reflected a similar variation in fat (1.0-2.2%), but interspecies differences in these constituents were not significant (Table 11.5). In all species the calculated SNF were virtually identical: 8.9% in the pony, 9.0% in the ass, mountain zebra, and Przewalski horse, and 9.1% in the plains zebra. Mean values for true protein (range: 1.6–1.8%) also were not significantly different. Ass milk appeared to contain somewhat more Ca and P than the other equid milks. All equid species produced milk containing about 0.04–0.05% NPN, which is equivalent to 13–17% of total nitrogen.

In many parts of the world, the ass serves as pack animal. Ass milk is rarely consumed, but people in some regions believe that ass milk has certain therapeutic properties (63). Ass milk has a lower fat and protein but a relatively high lactose content (Tables 11.1 and 11.5). Total nitrogen (TN) content of buffalo milk was significantly higher than that of camel milk (36, 63). However, TN of ass milk was even substantially lower than that of camel milk (Table 11.6) (35, 63).

The ratio of casein-N to whey protein-N in camel milk and buffalo milk was 3.8 and 8.2, respectively.

Table 11.5. Composition (%) of Equid Milks at Mid to Late Lactation

Species (Mon. lact.)	Dry Matter	Fat	True protein	Lactose	Ash	Ca	P	Gross energy (kJ/g)
Ass (1–6)	10.8	1.82	1.74	5.87	0.44	0.115	0.073	2.1
Mountain Zebra (3–12)	10.0	1.02	1.56	6.92	0.32	0.084	0.055	2.0
Plains zebra (3–8)	11.3	2.20	1.63	7.00	0.38	0.075	0.053	2.4
Przewalski horse (3–12)	10.5	1.50	1.55	6.72	0.33	0.082	0.043	2.1
Pony (1–6)	10.4	1.46	1.82	6.74	0.47	0.084	0.053	2.2

Adapted from Oftedal and Jenness (49).

The respective average casein percent from pure protein for camel and buffalo milks were 79 and 89%. Ass milk contained considerably lower proteose-peptone-N and NPN than camel and buffalo milks (Table 11.6). The same study also showed that ass milk contained significantly higher peptide-bound and free amino acids compared to cow, mare, camel, and buffalo milks (63).

In a study of identification and quantification of the major protein components in ass and different breeds of mare's milk using SDS-CE (SDS-capillary electrophoresis), at least six important peaks corresponded to whey proteins (α-lactalbumin; α-la) lysozyme (Ls), β-lactoglobulin (β-lg), equine serum albumin (ESA), immunoglobulin (Ig), and casein fractions (CN) (15). The electrophoretic diagram (Figure 11.5) showed that ass milk contained higher whey proteins such as α-la, Ls, and β-lg than all breeds of mare's milk. The SDS-CE data also showed that ESA and β-lg contents decreased by about 15 and 32% during the first 24h, respectively. Conversely, casein, lysozyme, and α-la contents were proportionally increased by 9, 14, and 30%, respectively. The authors (15) observed that β-lg was not affected by lactation stage, while a significant increase in casein occurred at 90 and 120 days of lactation.

3.6 Elk

The reports on elk milk and production are very limited. However, a study on the milk composition of captive elk (*C. elaphus nelsoni*) reported: 19.8% dry matter, 6.2% protein, 7.5% fat, 4.1% lactose, and 1.1% ash during the first three months of lactation (58). Milk intake of the calf peaked at 21 days, but gradually declined during the following two months. The decline in milk intake preceded the start of significant dry-feed intake, which after 40 days became increasingly important in meeting the calf's require-

Table 11.6. Means, Ranges, and Coefficient of Variance of Nitrogen Distribution (g/100g) in Camel, Buffalo, and Ass Milk

Component	Camel n = 20	Buffalo n = 20	Ass n = 10
Total N			
Mean	500.0	740.5	282.8
Ranges	420.0–609.0	651.0–852.7	259.0–322.0
CV (%)	15.13	8.85	8.33
Casein-N			
Mean	320.2	566.2	
Ranges	217.0–448.0	441.0–691.7	
CV (%)	23.66	14.38	343.60
% in TN	64.0	76.6	189.0–245.0
Whey protein-N			100.3
Mean	84.3	69.0	86.1
Ranges	59.0–112.0	42.0–99.0	
CV (%)	20.9	27.1	
% in TN	16.9	9.3	
Proteose-peptone-N			
Mean	27.9	26.9	9.80
Ranges	14.0–49.0	19.0–35.0	7.0–14.0
CV (%)	37.4	22.1	39.1
% in TN	5.6	3.6	3.5
NPN			
Mean	67.4	77.1	29.4
Ranges	44.0–97.0	49.0–117.0	21.0–42.0
CV (%)	26.7	33.3	31.1
% in TN	13.5	10.5	10.4

Adapted from Taha and Kielwein (63).

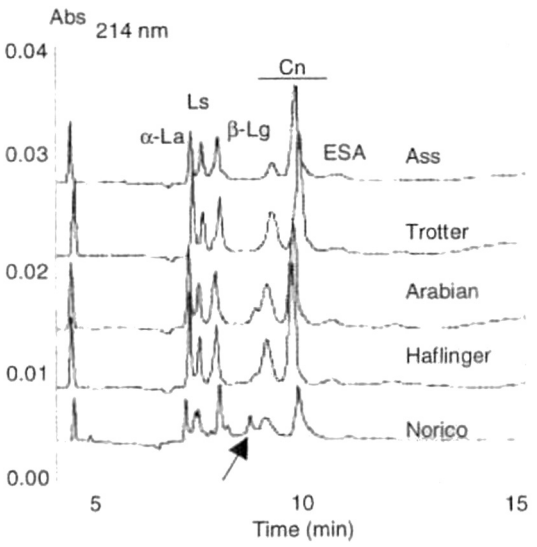

Figure 11.5. CE-SDS analysis of ass and whole mare's milk: differences between breeds and species. Adapted from Civardi et al. (15).

ments. Growth rates of hand-raised elk were lower than those of dam-raised elk (70). Evaporated milk fed ad libitum appeared to be an effective and practical approach for hand raising some wild ungulates.

The milk productivity of five domesticated elk females (*Alces alces*) was investigated at the Pechorollych State Nature Reserve, Russia, during 17 lactation periods for four years (68). It was found that the duration of lactation period in elk cows was on average 105 days, and the maximal daily milk production (3.4–7.6 L/elk cow) was observed on 20 d postpartum. Milk production was decreased by 50–60 days due to an excited behavior of females in their estrous activity (68).

Early development of cervids has been correlated with juvenile survival and lifetime reproductive success (61). The study revealed that male calves of free-ranging elk were born later and weighed more than females. Annual rates and duration of supplemental feeding had no measurable effect on birth weight of elk calves. The study also concluded that nutritional benefits of winter feeding on maternal condition entering late gestation might have improved milk yields of dams, thus producing weight gains through the first week of life that exceeded rates of gain previously reported for elk neonates (61).

3.7 Pinnipeds (Seal and Sea Lions)

Pinnipeds represent a group of mammals that are quite distinct, yet diverse in their physiology and lactation strategy (10, 47, 57). It was postulated that the marine mammal, the phocids, such as the Northern elephant seal, lactate for one to six 6 weeks, during which time they typically fast (19). On the other hand, otariids, such as the Antarctic fur seal, the California sea lion, and the Australian sea lion, have much longer lactation periods ranging from four months to two years, but they feed during that time (19).

The gross composition of pinniped milk differs from that of other species mammals. The milks of these marine mammals are rich in fat, as high as 60% in phocids and about 20–35% in otariids (19, 47). The protein content of pinniped milk is about 10%, which is the highest concentration among all mammalian species milks. However, there is only paucity of information available on specific nutrients including the amino acid composition of the milks of different species of pinnipeds. The amino acid compositions of only the Harp seal and Northern fur seal have been reported (5, 41).

In a comparative study of total amino acid concentration and amino acid pattern, such as the relative proportion of each amino acid (protein-bound plus free) to the total amino acids, in the milks of the Northern elelphant seal, Antarctic fur seal, California sea lion, and Australian sea lion, Davis et al. (19) found that total amino acid content was 10% (w/v) or greater and did not vary significantly among the species. The most abundant amino acids in the milks of all species were glutamate, proline, and leucine. Essential amino acids were 40%, branched-chain amino acids were 20%, and sulfur amino acids were 4% of the total milk amino acids in all species. Although the total amount of essential amino acids differed by only 9% among the four groups of pinnipeds, this difference was statistically significant ($P < 0.01$) (Table 11.7).

The same report showed that stage of lactation had little effect on milk amino acid pattern (Table 11.7) except in the Northern elephant seal, where there was a slight decrease in isoleucine (8%), methionine (10%), and histidine (14%) and a slight

increase in valine (4%) during the course of lactation ($P < 0.01$). The essential amino acids and methionine:cystine ratio were significantly different ($P < 0.01$) among the four pinniped species (Table 11.7). Comparison of milk from the pinniped species with that of 14 other mammalian species suggested that there was a commonality in milk amino acid pattern despite the wide variation in total amino acid concentration among the species (19).

Female Juan Fernandes fur seals (*Arctocephalus philippii*) undertake long foraging trips during lactation, resulting in intersuckling intervals that are among the longest ever recorded for a mammal (45). Milk of Juan Fernandes fur seals contained on average 55.1% dry matter, 41.4% fat, 11.9% protein, 1.2% sugar, 0.7% ash, 780 mg/kg calcium, and 840 mg/kg phosphorus (45). The fat and energy contents of the fur seals or sea lions (Family Otariidae) were the highest in the first month of lactation. The same report showed that energetic content of the fur seal was 17.95 kJ/g milk, and 74% of fatty acids were unsaturated.

3.8 Polar Bear

The compositions of polar and grizzly bear milk were studied using the milk obtained from two polar bears that were caught near Barrow, Alaska, and from one grizzly bear that was caught near Haines Junction, Yukon (18). The polar bear milk was creamy white and had a strong fishy odor, while the grizzly milk was pale yellow and had the consistency of thick cream and the odor of fresh bovine milk (18).

There was a slight decrease in total solids as the stage of lactation advanced. The milk was, however, collected from different animals, whereby the observed difference might be due to individual animal differences rather than to the stage of lactation difference. The total solids contents of the polar bears were substantially higher than that of the other species, ranging from 43 to 47%, and fat, solid-not-fat, and protein were extremely high compared to other species (Table 11.8). However, the lactose content was extremely low compared to cow milk but comparable to that of aquatic mammals (16, 40). The polar bear milk contained more fat than that of whale milk (40) and less fat than that of seal milk (16). The protein content of polar bear milk was about the same as that of whale milk and higher than that of seal milk (18).

The sum of palmitic, palmitoleic, stearic, and oleic acid contents of the two samples of polar bear milk fat consisted of more than 75% of the fatty acid

Table 11.7. Total Essential Amino Acids (EAA), Total Branched-Chain Amino Acids (BCAA), Total Sulfur Amino Acids (SAA), and the Methionine-to-Cystine Ratio in Pinniped Milk[a]

Pinniped species	EAA[b]	BCAA	SAA	Met:Cys[b]
	(mg Amino Acid/g total amino acid)			
Northern elephant seal				
Early lactation (3)[c]	423 ± 7	194 ± 2	40 ± 1	1.2 ± 0.1
Late lactation (3)	420 ± 2	194 ± 1	41 ± 2	0.9 ± 0.1
Antarctic fur seal				
Early lactation (5)	388 ± 18	188 ± 8	42 ± 4	3.1 ± 2.0
Mid-lactation (6)	394 ± 20	188 ± 10	41 ± 4	3.4 ± 1.7
California seal lion				
Late lactation (5)	418 ± 8	199 ± 3	41 ± 3	1.7 ± 0.2
Australian sea lion				
Late lactation (6)	387 ± 17	194 ± 8	39 ± 2	2.4 ± 0.4
Other mammal species[d]				
Mid lactation (61)	374 ± 443	175 ± 220	31 ± 51	0.8 ± 4.3

[a]All numbers are mean ± standard deviations.

[b]EAA and Met:Cys ratios differed among pinnipeds ($P < 0.01$).

[c]Number of animals is given in parentheses.

[d]Range of mean values from human, chimpanzee, gorilla, baboon, rhesus monkey, cow, goat, sheep, llama, pig, horse, elephant, and cat milks.

Adapted from Davis et al. (19).

Table 11.8. Gross Composition of Polar Bear Milk

	Sample 1[a]	Sample 2[b]	Sample 3[c]
Total solid, %	46.7	43.9	44.1
Water, % (by difference)	53.3	56.1	55.9
Fat, %	32.0	31.0	31.1
Solid-not-fat, % (by diff.)	14.7	12.9	13.0
Ash, %	1.30	0.97	1.17
Lactose, %	0.62	1.1	0.49
Protein, % (N × 6.38)	12.6	10.3	10.2
Specific gravity, 22° C	1.019	1.006	1.015

Adapted from Cook et al. (17).
1[a]: 16–17 months.
2[b]: 28–29 months.
3[c]: 16–17 months, previously measured.

content of the milk fat. The grizzly bear milk fat had a much lower content of palmitoleic acid and a higher level of linoleic acid than did that of polar bear milk (18). It also contained more than 4% arachidic acid, while polar bear milk fat had no detectable level of that fatty acid.

4 MILK YIELD OF MINOR SPECIES MAMMALS

For a normal lacation curve of most mammalian species, the milk yield starts at a high level immediately after parturition, reaches a peak at three to six weeks in the case of cow or goats, and then gradually declines toward the end of lactation. The musk ox milk also showed a similar general trend of lactation curve of cow or goat milk, where the highest milk yield was observed at three to four weeks of lactation (Figure 11.1). It is known that the milk fat and protein concentrations are inversely related to the milk yield. However, this relationship may not be consistent, and there are some variations in the trend of milk fat and protein concentrations among milks of minor species mammals. Colostrum has considerably higher levels of total solids, protein, immunoglobulins, and ash, and lower concentrations of lactose than milk obtained five days or later postpartum in most mammals, including the minor mammalian species (34, 50, 59).

Factors affecting the increases in milk yield of mammals are increased body weight, advancing age, increased plane of nutrition, moderate or cool environmental temperatures, and good body condition at parturition (59). Milk yield and composition of any mammals are influenced by many physiological and environmental factors, where a good example is colostrums and normal milk (34, 46, 59).

Factors influencing the decreases in milk yield for any mammalian species include: a decreased plane of nutrition, advancing lactation, short dry period, high environmental temperatures and humidity, diseases, feed intake, and so on (50, 59). Milk yield of musk ox gradually decreased after around six weeks postpartum and rapidly decreased at 80 days of postpartum (Figure 11.1). Other minor species including moose and caribou have similar trends of volume of milk production, with variations in the length of lactation.

5 CHEMICAL CHARACTERISTICS OF MILKS OF OTHER MINOR SPECIES

All mammals producing lactose in their milks contain α-lactalbumin to modify galactosyl transferase in the lactose synthase system (2). The minor mammals listed in the Table 11.1 contain negligible amounts of α_{s1}-casein but have predominant levels of β-casein, as does human milk. As one of the whey proteins, α-lactalbumin is a strong calcium-binding protein. Humankind has extended the use of milk beyond infancy as a nutrient source and consumed the milks of other mammals for socioeconomic reasons.

Both sodium and potassium are related to the level of lactose in goats and other ruminant species milks, which is due to the fact that an increase in osmotic pressure because of increased lactose content is balanced by a decrease in the levels of other milk components, particularly monovalent ions (44). Sodium

and potassium levels in milk vary coordinately during lactation. Both ions are distributed according to their passive electrochemical gradients across the apical membrane of the mammary epithelial cells (9, 53).

There is a commonality in milk amino acid pattern despite wide variation in total amino acid concentration among species when compared to the amino acid patterns of milks from minor species including marine mammals with those of 14 other mammalian species (19).

The milks of cows as well as nonbovine minor species contain high calcium and phosphate levels, which would be beneficial for bone growth and mineralization for infants and children and prevention of esteoporosis in the elderly. Although some species' milk, including goats, are hypoallergenic to humans, the consumption of nonbovine minor species milks and their products may have some difficulties for consumers, including low quality of the dairy products associated with technological problems (2).

6 PRODUCTS OF OTHER MINOR SPECIES' MILKS AND THEIR CHARACTERISTICS

There are little documented data available for the manufacturing technology, nutritional, and food quality characteristics of dairy products made from less domesticated other minor species including moose, elk, musk ox, alpaca, caribou, and ass. Cheese and fermented and other dairy products manufactured from these minor species would vary greatly in body, texture, and flavor mainly due to the compositional differences in fat and proteins, particularly the caseins.

Procedures used for milk preservation vary depending upon environmental limitations, manufacturing methods, and availability of the milk, especially for the low-producing, domesticated minor species mammals. Refrigeration and pasteurization are great constraints in third world countries, where methods have to be devised for milk production and consumption (2, 39).

The body and texture of fermented milk products are virtually dependent on both lipid and casein composition and types, where the α_{s1}-casein present in *Bos Taurus* (western cattle) and *Bos indicus* (Zebu, Indian cattle) causes a strong curd in cheese and yogurt (2). Almost all of the minor non-bovine mammalian species described in this chapter do not contain α_{s1}-casein but have predominantly β-casein, resembling human milk. The major protein of goat milk is β-casein, which is responsible for the formation of soft curd resulting in soft types of cheeses with high moisture. Similarly, soft body type cheeses would be produced from the milks of the other minor species.

For other types of fermented dairy products such as yogurt and kefir, the products made from these minor species' milks would contain nutritionally rich whey proteins high in cysteine and tryptophan (2, 39). These fermented products have some nutritional advantages over cheeses produced from the same milks because most cheeses lose whey protein during manufacturing processes. One of the whey proteins, α-lactalbumin, is a strong calcium-binding protein. Electrophoretic mobility of this protein in the absence of calcium revealed that α-lactalbumin migrates faster in an electric field upon chelation of calcium, because of the exposure of negative carboxylate groups when calcium is unbound (66).

Although the relative migration values of α-lactalbumin for the minor species milks are not known, the typical R_m values of proteins are: cow (1.14), horse (1.39), camel (dromedary, 1.21), goat (1.19), and sheep (1.17), respectively (2). These values suggest that the α-lactalbumin is different in amino acid sequence between species and may differ in the amount of calcium bound to the molecule even if they are functionally alike in all species' milks.

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12
Human Milk

Jane Morgan

1 INTRODUCTION

Milk is designed to be the first food for mammals. Although milk from different mammals may have similar qualitative nutritional characteristics, the quantities of nutrients differ considerably by species (29). Energy and macronutrient composition of milk from nine mammalian species including human is shown in Table 12.1. Quality and quantity of milk provision determine the rate of growth of the offspring. The macronutrient that differs most among the species is fat (Table 12.1) and this, in turn, determines to a great extent the overall energy content. Furthermore, protein content differs by as much as 10 times between species. Human and cow milk have the lowest concentrations of energy and fat. At the other end of the spectrum, milk designed for the infant blue whale has 10 times the amount of fat and six times the energy content of that of human milk. Rates of growth of the various mammals (Table 12.2) illustrate the consequences of these differences. The mean growth rate of the human infant during the milk feeding period (25 g/day) is dwarfed by that of the infant blue whale (86,000 g/day), but growth is dependent not only on milk composition but also on the volume consumed.

Human milk has been said to resemble a living tissue, such as blood, whereas the commonly used substitute for human milk, infant formula based on cow milk, is simply a nutrient medium (17). In fact, besides containing energy, macronutrients, and micronutrients, human milk contains a wide range of biologically active substances, including immunoglobulins (antibodies), hormones, growth factors, and at least 60 enzymes. The nutrient composition of human milk is, however, not uniform. It changes

Table 12.1. Average Energy and Nutrient Composition of Milk from Nine Mammals per 100g Milk (Widdowson 1970)

Mammal	Energy (kcal)	Protein (g)	Fat (g)	Carbohydrates (g)
Rat	134	9	9	3
Cat	159	11	11	3
Dog	134	8	9	4
Pig	129	6	9	5
Human	70	1	4	7
Cow	70	3	4	5
Elephant	121	5	9	4
Hippopotamus	205	7	18	2
Blue whale	426	12	40	1

Table 12.2. Birth Weight, Length of Lactation, Weight at Weaning, and Growth Rate of Nine Mammals (Widdowson 1970)

Mammal	Mean birth weight (g)	Length of lactation (days)	Weight at weaning (g)	Mean growth rate (g/day)
Mouse pup	2	15	9	0.47
Rat pup	5	21	40	1.7
Kitten	100	35	600	14
Dog pup	100	35	1,200	29
Piglet	1,500	56	18,000	295
Infant	3,500	180	8,000	25
Calf	35,000	60	70,000	580
Elephant calf	114,000	1,460	600,000	335
Blue whale calf	3,000,000	210	21,000,000	86,000

during the course of a feeding and during the course of lactation. The composition is therefore not as constant as the relatively constant maternal blood plasma from which the nutrients found in human milk are derived.

There is no doubt about the importance of the provision of human milk for the health and well-being of all infants (2). In 2001 the World Health Organisation (WHO) recommended that human milk feeding be exclusive for the first six months of infants' lives (31) and no other foods should be provided, including solid foods, infant formula, and water. To translate this recommendation into practice provides a challenge for all health professionals working to improve the health of all infants. Very few infants in the developed world are exclusively fed human milk for six months. In the U.K. in 2000, the rate based on a nationally representative sample was 2% (11). Furthermore, there are subgroups in the population for which this recommendation may not be advantageous. Low-birth-weight infants (born with a weight less than 2,500g) and preterm infants (born before 37 weeks of gestation) have specific nutritional needs that are probably not met by exclusive human milk feeding for even four months post-term (7).

2 CURRENT CONCEPTS

There is universal consensus that human milk is the best food for normal and healthy full term infants with healthy mothers who have appropriate nutritional stores. In the initial stages of lactation, the process can be viewed not only as a means of providing essential nutritional support to the relatively immature human infant but also as an important stage in the transition of the infant from one of total dependency on the mother to an independent existence. Colostrum, the first milk, is high in antibodies (secretory immunoglobulin A [sIgA]), vitamin A, and zinc. This changes over the course of about 10 days postpartum to mature human milk, which has an energy and nutrient composition designed to produce the growth rate of the human infant. The practice of feeding infants human milk is convenient but ironically is not acceptable outside the home in many economically developed societies. The cost to the family budget is relatively low, especially in well-nourished mothers who deposit fat during pregnancy for mobilization during lactation. The cost of eating extra food during lactation has been calculated to be less than that needed to purchase the "equivalent" infant formula. Other advantages, details of which are provided elsewhere in this chapter, include the presence of unique non-nutritional factors and anti-infective powers. By four weeks of age, most infants in the United States of America (U.S.A.), the United Kingdom (U.K.), and other developed societies have received some cow milk modified infant formula. In the U.K., by 10 weeks 64% of infants are wholly formula fed (11). It is proving difficult to improve the prevalence of human milk feeding in some countries such as the U.K. despite its promotion by widespread education and publicity.

As stated by the WHO recommendation, human milk feeding should be exclusive for the first six

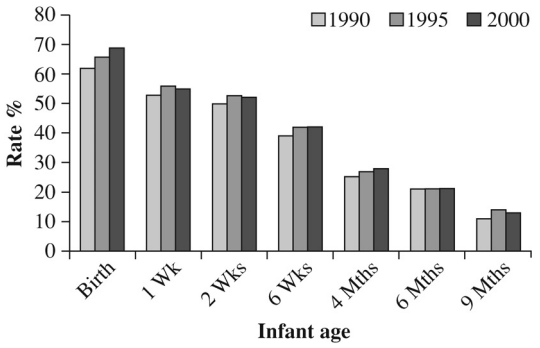

Figure 12.1. Human milk feeding rates from birth to nine months. Data for the United Kingdom (derived from references 9 and 11).

months of an infant's life. Prevalence of breast feeding rates in Europe and beyond are very variable; details have been reported by Michaelsen et al. (18). Lack of standardization in defining terms such as "exclusive breast feeding" limit the interpretation of the data. Nevertheless, prevalence data provide interesting insights into geographical differences. In the U.K., 25% of infants were breast fed at three months compared with more than 90% in Uzbekistan (18). In the U.K., the Department of Health (DoH) has published the results of six surveys documenting infant feeding practices since 1975. The recorded increase in human milk-feeding rates between 1975 and 1980 was partly attributed to the influence of the report "Present day practice in infant feeding" (3). However this pattern has not notably continued over the ensuing years, particularly after four months (Figure 12.1). Comparing human milk feeding rates in England and Wales with those in the United States, the rates were remarkably similar in the 1990s (11, 16). More recently, the percentage of infants initially receiving human milk was 69% in the U.K. (11) and 69.5% in the United States (23).

3 MATERNAL PHYSIOLOGICAL AND NUTRITIONAL CONSEQUENCES

The process of lactation requires functional and structural changes to occur in human breast development, known as mammogenesis. These changes occur mainly during pregnancy and are under the control of the hormones estrogen and progesterone. The later stages of mammogenesis are controlled by prolactin and placental lactogen. After parturition, with the removal of the placenta, estrogen levels fall with a concomitant increase in prolactin levels. Prolactin is essential for the successful process of lactation and this, with the suckling of the infant at the breast stimulating the process of lactation, or the production of milk. Section 4.2. describes the process in further detail. The increased level of prolactin is also associated with the delay in the return to ovulation, and reduced fertility rates may be further attenuated by maternal undernutrition.

Total weight gain during pregnancy varies considerably from woman to woman, and the variation is due to prepregnancy weight, socioeconomic circumstances, and activity levels. There are published recommendations for optimal weight gain in pregnancy based on a woman's prepregnancy weight (12). For a woman with a normal body mass index (BMI, weight [kg]/height [M^2), the recommended total gain is between 11.5 kg and 16 kg. There is considerable information about body composition changes during pregnancy. Specifically, fat (adipose tissue) deposition represents about 30% of weight gain and is accumulated most rapidly during the second trimester of pregnancy, with marked increases in the abdominal, subscapular, and thigh areas (8). Less has been published about changes in body composition during the lactation period. Certainly the fat stored during the middle part of pregnancy can be assumed to be mobilized to meet, in part, the increased needs of fetal growth in later gestation and also to meet the increasing demands for energy during lactation. Weight lost during lactation is primarily from fat stores. Thigh adipose tissue appears to be more readily mobilized than fat stores from the trunk during lactation, and an association has been observed between the duration of lactation and fat loss from the thigh region—the longer the lactation, the greater the losses (8).

However, significant weight loss does not necessarily occur during lactation in well-nourished women living in developed societies. It has been calculated that each cycle of pregnancy and lactation results in a gain of, on average, one kg in excess of that expected, taking into account the woman's age.

So, the conventional wisdom that breast feeding may help prevent the progressive weight gain reported by women with successive pregnancies has little basis in fact. Food intake increases during lactation, and the difference between energy expenditure (including the energy required for synthesis, as well as the content of human milk) and energy intake is, in some women, not enough to ensure weight loss (Table 12.3). In developed societies, women who exclusively breast feed their infants are reported to lose 0.6 to 0.8 kg/month (10), which is equivalent to 162 kcal/day–170 kcal/day. At six months, maternal weight stability is assumed.

3.1 Energy Needs

Table 12.3 provides details of energy expenditure, milk energy output, and estimated energy requirements from studies conducted in the U.K., Sweden, and the United States using the doubly labeled water technique (22). The major determinant of the extra energy needed during lactation is associated with the amount of milk produced and the energy cost of milk synthesis and the energy content of milk. Well-nourished women who are exclusively breast feeding produce on average 750 ml/day. If the energy content of milk is 67 kcal/100 ml (Table 12.4), approximately 500 kcal/day is secreted in the milk. There have been estimates of the cost of synthesizing human milk, and they range from 25 kcal/day to 125 kcal/day in the production of 750 ml of milk depending on estimates of the efficiency with which the milk is produced and secreted. Besides the cost of milk production, components including basal metabolic rates, the thermic response to feeding, and activity levels are used in the factorial approach to estimate total energy requirements during lactation. The U.S. dietary reference intakes (22) provide full details of energy requirements during lactation.

3.2 Protein Needs

Maternal protein requirements during lactation are also calculated using the factorial approach. The additional protein requirement is calculated from the amount of milk produced and its nitrogen content, together with estimates for the individual variation in milk production (30%) and an estimate of the efficiency of conversion of maternal dietary protein intake to milk protein (70%). For women who are wholly breast feeding, the extra increment associated with milk production is 9 g/day protein (8). The U.S. dietary reference intakes (22) provide full details of protein requirements during lactation.

3.3 Other Nutrient Needs

U.S. dietary reference intakes for a range of vitamins and minerals have been published and provide extensive information on this subject; for example, see (20) for the water-soluble vitamins. This publication provides specific recommendations for lactating women. The maternal requirement for dietary iron in lactation is well established (8). Exclusive breast feeding results in ammenorhea, so maternal iron needs are based on iron "losses" in human milk (0.027 mg/day), which are substantially less than average menstrual losses (0.7 mg/day). Therefore, iron secreted in human milk together with an esti-

Table 12.3. Energy Expenditure, Human Milk Energy Output, and Energy Requirements at Different Stages of Lactation from Data Derived from Studies Using Doubly Labeled Water Technique (Adapted from NAP 2002)

Country	Stage of lactation (month)	Total energy expenditure (kcal/day)	Activity energy expenditure (kcal/day)	Milk energy output (kcal/day)	Energy mobilized (kcal/day)	Energy requirements (kcal/day)
U.K.	1	2109	703	536	gained fat mass	2646
	2	2171	774	532		2702
	3	2138	793	530		2667
Sweden	2	2532	1123	502	72	2663
	6	2580	1123			
U.S.A.	3	2391	1061	483	155	2719

Table 12.4. Energy, Macronutrient, and Selected Micronutrient Content of Colostrum, Transitional, and Mature Human Milk, Infant Formula, and Cows' Milk (per 100 ml)

Nutrient	Colostrum	Transitional human milk (day 10)	Mature human milk	Cows' milk	Infant formula* (whey dominated)
Energy (kcal) (kJ)	56 (235)	67 (280)	67 (280)	66 (275)	67 (280)
Protein (g) PER (%)	2.0 (13)	1.5 (9)	1.3 (7)	3.3 (20)	1.5 (9)
Fat (g) FER (%)	2.6 (41)	3.7 (50)	4.2 (53)	3.8 (51)	3.6 (48)
Carbohydrate (g) CER (%)	6.6 (46)	6.9 (41)	7.0 (40)	4.8 (29)	7.2 (43)
Sodium (mg)	47	30	15	55	16
Calcium (mg)	28	25	35	120	59
Zinc (mg)	0.6	0.3	0.3	0.4	0.6
Iron (mg)	0.1	0.1	<0.1	0.06	0.8
Retinol (μg)	115	85	60	35	75
Vitamin D (μg)	N	N	0.01	0.08	1.0
Vitamin C (mg)	7	6	4	1.8	5.2
Folate (μg)	2	3	5	6	4
Thiamin(mg)	trace	0.01	0.02	0.04	0.04
Riboflavin (mg)	0.03	0.03	0.03	0.07	0.06
B_{12} (μg)	0.1	trace	trace	0.4	0.1

Data derived from various sources.
N: significant quantities but no reliable information.
*May contain nucleotides.
PER: protein energy ratio; FER: fat energy ratio; CER: carbohydrate energy ratio.

mate for basal iron losses for nonpregnant, nonlactating women (0.896 mg/day) lead to a theoretical median total iron need for absorption of 1.17 mg/day (21). Taking into account an assumption that 18% of iron is absorbed, the recommended dietary allowance (RDA) is set by determining the estimate of requirements at the 97.5 percentile; the USA-RDA for 14–18 years is 10 mg/day, 19–30 years is 9 mg/day and 31–50 years is 9 mg/day (21). Iron requirements during pregnancy represent a greater stress on maternal iron stores than lactation, unlike the situation for other nutrients. The low amount of iron in human milk (Table 12.4.) does not appear to be influenced by the mother's own iron status.

4 PHYSIOLOGY AND COMPOSITION

The human breast has been described as an exocrine gland, comprised of 15–29 segments of secretory, adipose, and connective tissue, alveoli, and ducts. The production of milk is stimulated by the continuous suckling of the infant. This action induces the production of prolactin, which itself increases milk production–lactogenesis. The production of oxytocin, which controls milk ejection, is also stimulated by the infant's suckling. The human mammary gland stores only small amounts of milk, unlike that of other mammals, so the "let down" reflex (the contraction of mammary glands and ejection of milk) is vitally important in the successful process of breast feeding. As levels of maternal progesterone fall postpartum, changes in both the composition and the quantity of milk occur. Drugs can influence lactation performance. Oxytocin as a nasal spray has been reported to have a positive effect on the let-down reflex, thus enhancing milk production. Further details of the hormonal control of lactation have been reported by Williams (30).

4.1 Milk Secretion Including Biochemistry

Human milk synthesis and secretion involves a number of pathways in the mammary gland epithelial cells, and secretion is under the control of the

hormone prolactin. Prolactin shows a circadian variation, which is reflected in milk production, in response to the demands of the infant and the ability of the mother to produce milk. There are four main secretory transcellular pathways involved in the process of human milk synthesis in the mammary epithelial cell (mammary alveolus). These are:

- Milk protein, lactose, calcium phosphate and citrate by exocytosis in Golgi-derived secretory vesicles.
- Milk fat (lipids) via the milk fat globule.
- Ions (sodium, potassium, chloride) and water secretion across the apical membrane.
- Immunoglobulins via pinocytosis-exocytosis (30).

There is in addition a paracellular pathway for plasma components, cells, sodium, and leucocytes.

Human milk proteins, α-lactalbumin and casein, are synthesised on the rough endoplasmic reticulum under the control of prolactin and secreted in the Golgi-derived secretory vesicles with lactose. The main immunoglobulin in human milk, sIgA, is synthesized by lymphocytes in the gland stroma and transferred across the cell in combination with a receptor via pinocytosis. Maternal food proteins (for example, cow milk proteins), which have resisted digestive proteolytic degradation, pass into milk via the paracellular pathways. These small amounts of maternally derived food proteins in human milk may be of importance in the development of immunological "tolerance" in the newborn human infant. The wide-ranging subject of food allergy prevention and food allergen avoidance in infancy has been well reviewed by Zeiger (32).

Fats may be derived from maternal plasma or synthesized within the mammary gland. As discussed in section 4.5, the fatty acid profile of human milk can reflect that of the maternal diet. Fatty acids with a carbon chain length under 16 may be synthesized from glucose in the mammary gland.

Lactose is synthesized from glucose and uridine diphosphate-galactose in the Golgi apparatus and is controlled by lactose synthetase. Lactose attracts water due to its property of exerting osmotic pressure, so the synthesis of lactose determines milk volume (30).

4.2 Composition and Production

Colostrum, the first milk produced, is high in certain protective factors, macrophages, lymphocytes, lactoferrin, lysozymes, and sIgA. The transitional phase is a period during which milk composition and volume stabilizes. At around 10 days postpartum the production of mature human milk is established. During the proceeding days, weeks, and months there are further changes in milk composition, for example in fat levels (Table 12.5) and in volume (Table 12.6), but these changes are relatively small. Although the mean values for volume are similar over time, there is a very wide individual variation around the mean, and the volume is influenced by the practice of complementary feeding (Table 12.6). The rate at which milk is transferred during the course of a feeding varies widely from mother to mother, thus the concept of an average time over which a single feeding takes place does not exist. Maternal factors (the milk supply and secretion rate) and infant needs (hunger, suckling pattern) are thought to influence milk flow. Present evidence suggests that milk intake is primarily driven by the infant, whose "demand" for milk regulates milk output.

Human milk does not have a constant composition. The first milk, colostrum, is low in volume and

Table 12.5. Average Fat Content in Human Milk at Different Stages of Lactation (Weaver and Prentice 2003)

	Lactation day				
	3	7	21	42	84
Total fat (g/100 ml)	2.0	2.9	3.5	3.2	4.8
Lipid class (%):					
Triacylglycerol	97.6	98.5	98.7	98.9	99.0
Cholesterol	1.3	0.7	0.5	0.5	0.4
Phospholipid	1.1	0.8	0.8	0.6	0.6

Table 12.6. Mean (Range) of Milk Output (g/d) from Women Living in Developed Societies (Adapted from Williams 1992)

	Stage of lactation		
Location	1 month	3 months	6 months
Sweden (exclusive milk feeding)	610 (416–839)	766 (497–1,029)	788 (510–1,123)
Australia (exclusive milk feeding)	1,187 (799–1,611)	No data given	1,128 (608–1,610)
U.K. (mixed feeding)	740 (480–1,059)	784 (280–1,114)	493 (135–906)
U.S.A. (mixed feeding)	569 (398–989)	523 (242–1,000)	436 (147–786)

high in certain proteins, especially sIgA, as well as vitamin A and the trace element, zinc. It is worthy of note that before the 1670s mothers were advised to discard colostrum, the implication being that the first milk was in some way harmful. This practice was reversed by the end of the 1700s, thereby ensuring that the newborn infant benefited from exposure to the important antibodies contained in colostrum. Over the first few days of lactation as the volume of milk secreted increases, its composition changes to "transitional" and then to 'mature' milk. Table 12.4 outlines the nutritional composition of colostrum and human milk together with that of a typical infant milk formula based on cow milk. Values for cow milk are provided for comparison. The data in Table 12.4 mask an important aspect of the composition of human milk—the wide variation in the concentration of energy, and macro- and micronutrients according to the time of day and the stage of feeding. With respect to the time of day, fat levels are higher in the morning feeding and toward the end of a feeding, and this phenomenon has been suggested to be associated with the infant's appetite control. However, there is now some doubt about this because the evidence for it is inconclusive. With respect to the stage of lactation, sIgA levels decline gradually with time, although levels of lactoferrin (an iron-binding protein) remain high beyond six months of lactation. The concentration of fat in human milk increases over the duration of lactation (Table 12.5). Daily milk output and the composition of milk also vary widely between different women.

There are reports that the milk of women whose infants are born preterm is higher in nitrogen and protein than the milk from mothers of term infants (15). In addition, the amounts of energy, sodium, and calcium have also been reported to be higher in milk produced after a preterm delivery. These observations have been interpreted as conferring a nutritional advantage in the maternal milk feeding of preterm infants, although Williams (30) has cautioned about the overinterpretation of these types of findings, which may be explained by a reduced volume output (1).

There are many protective factors in human milk, and these have been reviewed by Weaver and Prentice (26). Table 12.7 provides an outline of some of these factors and gives a brief overview of the function of each. It is worth noting that the "Bifidus factor" is not present in cow milk but is present in some commercial yogurts (Haenlein, personal communication).

4.3 Microorganisms

As shown in Table 12.7, human milk contains factors with antimicrobial properties such as the anti-*staphylococcus* factor, a lipid with an anti-*staphylococcus* action. However, human milk is not devoid of harmful pathogens. *Staphylococcus epidermidis* and other skin organisms have been reported to be the commonest microbes found in human milk samples donated to a milk bank. *Staph. Aureus* was found in 25% (5/21) of samples, and the source of the organism was speculated to be the suckling infant (27) In a small number of samples, enterobacteria were found. The low number of milk samples with fecal contamination was presumed to indicate a high level of personal hygiene. Storage by domestic refrigeration results in the growth of certain nonfermentation gram-negative bacteria, though storage at -18° C prevents growth. Milk may also be a vehicle for the transmission to the infant of viral infections derived from the mother, including the mumps virus, the human immunodeficiency virus (HIV), and the cytomegalo virus. Current policy for HIV-positive mothers living in the U.K., and those who are at high risk but not serologically tested, is to

Table 12.7. Protective Factors Present in Human Milk and Their Functions (Adapted from Weaver and Prentice 2003)

Anti-microbial activity factors:	
Anti-*staphylococcus* factor	Lipid with anti-*staphylococcus* action
Anti-*Giardia* factor	Lipid with anti-*Giardia* factor
Secretory immunoglobulin A	Protects intestinal epithelium from ingested microbial luminal antigens and viruses; may actively prime neonate's immune system
Lysosyme	Antibacterial enzyme lyses cell wall
Bifidus factor	N-acetyl-D-glucosamine containing oligosaccharide which stimulates beneficial lactic acid bacteria, e.g. *Bifidobacterium bifidus*, and *Lactobacillus* in the colon, creating a pH 5 environment, hostile to pathogens *E. coli* and *Shigella spp*
Macrophages	Engulf bacteria
Lymphocytes	Secrete immunoglobulins (B cells) and lymphokines (T cells)
Complement	Assists in bacterial lysis
Interferon	Anti-viral agent
Oligosaccharides	Inhibitors of bacterial adhesions to epithelium
Enzyme and enzyme-inhibitor activity factors:	
Protease inhibitors	Inhibit digestion of bioactive proteins in human milk
Bile salt	Stimulates lipase
Binding proteins factors:	
Lactoferrin	An iron binding protein, competes with intestinal bacteria for iron, reducing infection risk
B_{12} and folate binding proteins	Competes with bacteria for these vitamins, bacteriostatic, deprives bacteria of essential nutrients.

avoid breast feeding. For preterm infants for whom mothers' own milk is not available, banked donor milk can be used initially. But to reduce the risk of HIV and other contamination, screening and pasteurization to 62° C is to be undertaken (13). This level of heat treatment will not destroy the immune factors but will destroy live cells, heat labile vitamins, and bile-salt stimulated lipase.

Milk banks supply donor human milk to infants in neonatal intensive care units. Milk banks are involved in the collection of human milk from healthy, screened mothers who have a plentiful supply. The milk is tested and heat treated. Subsequently the donor milk is fed to infants who are ill or whose mothers cannot supply sufficient milk of their own to satisfy the nutritional needs of the infant. Information on the United Kingdom Association for Milk Banking can be found at http://www.ukamb.org, and details of milk banks throughout the United States, with information about nutritional uses, donors, and recipients, are found at www.hmbana.org.

4.4 Milk Protein

Human milk is a low-protein food, with the protein energy ratio of 13% for colostrum falling to 7% in mature human milk (Table 12.4). Human milk protein contains insoluble (casein) and soluble (whey) proteins in the ratio of 40% casein to 60% whey proteins, whereas the casein-to-whey ratio is 82% to 18% for whole cow milk. Whey proteins in human milk include α-lactalbumin, sIgA, lactoferrin, and lysozymes (6). Casein, the protein of the curd, is associated with phosphate, magnesium, and citrate ions, which are bound together as a calcium caseinate complex. Human milk casein forms smaller micelles with a looser structure than the casein of cow milk, and this structure facilitates specific enzymic action during digestion. Technological processes (for example, heat treatment) have been developed to change the structure of cow milk protein in the manufacture of infant formulae in order to enhance protein digestibility. About 25% of total

human milk nitrogen is non-protein nitrogen, of which 50% is urea, with small amounts of glucosamines, nucleotides, free amino acids, polyamines, and biologically active peptides. Taurine, a growth modulator, is one of the free amino acids present in human milk that is at lower concentration in whole cow milk. In recent years some cow milk infant formulae have been supplemented with taurine. A low-birth-weight formula available in the U.K. contains 5.5 mg/100 ml of taurine (13). Human milk contains relatively high levels of carnitine, an amino acid-like substance, which is involved in the oxidation of fatty acids. Infants can synthesize carnitine, but preterm infants and those undergoing catch-up growth may be unable to synthesize it at a sufficiently rapid rate to meet demand, and supplementation may be advisable. A low-birth-weight formula available in the U.K. contains 2.0 mg/100 ml of carnitine (13). Other growth modulators present in human milk include epidermal growth factor, insulin, and somatomedin-C.

4.5 Milk Fat

Human milk is a high-fat food, and the energy derived from fat (known as the fat-energy ratio) for mature human milk is 53% (Table 12.4). Human milk contains a high proportion of long-chain polyunsaturated fatty acids (PUFAs) in response to the needs of the developing brain and nervous tissue ex-utero. The fatty acid composition of human milk fat has been shown to partly reflect the fatty acid composition of the mother's diet, and with wide variation in milk fat composition appears to be tolerated by the infant without any ill effects. Table 12.8 provides data to demonstrate the influence that maternal diet exerts on the fatty acid composition of human milk.

Fat is important in the provision of energy as well as being the nutrient vehicle for fat-soluble vitamins and essential fatty acids. Although the amount of fat in human milk is not very different from that in cow milk, the types of fatty acids are very different. As stated, human milk contains long-chain polyunsaturated fatty acids (PUFAs). Human milk fat is high in unsaturated fatty acids, particularly the essential fatty acids linoleic (18:2n6) and α-linolenic (18:3n3). Arachidonic acid (20:4n6) is supplied in sufficient amounts to support the structure and function of neural and brain tissue in fetal life and in postnatal development (28). Long chain PUFAs have been claimed to be conditionally indispensable for the neonate, especially for the preterm baby. Preterm infants may have difficulty synthesizing long-chain PUFAs from their precursors in sufficient amounts. Linoleic and linolenic acid, which are both essential fatty acids, are present in preterm infant milk formula at around the levels of 0.5 g/100 ml and 0.1 g/100 ml, respectively. A systematic review (24) has concluded that n3 long-chain PUFA supplementation may give rise to rapid early visual maturation in preterm infants, but long-term benefits are still to be observed.

Fat absorption from human milk is more efficient than from cow milk–based formulae partly due to the presence of bile salt–stimulated human milk

Table 12.8. The Influence of Maternal Diet on the Fatty Acid Composition of Human Milk

	Subject A	Subject B
Energy intake of subject (kcal/d)	2,800	2510
Fat energy ratio in diet (%)	7	51
Fatty acid profile of human milk (g/100 g total fatty acids):		
12:0	17	6
14:0	13	7
16:0	18	24
16.1	1	2
18:0	6	7
18:1	40	40
18:2	1	11

lipase, although this is probably not of great significance except in premature infants, whose gastrointestinal enzymic function is poorly developed. Most modern cow milk infant formulae (but not goat milk formulae) contain fats in the form of vegetable oils, which are very different in their fatty acid structure from those in cow milk or human milk. Human milk has a high level of cholesterol (Table 12.5), although the explanation for this is not clear. In fact, relatively high serum concentrations of cholesterol are a feature of many mammals during the suckling period. The serum cholesterol concentration of an infant fed human milk is higher than that of one fed cow milk formulae, where the fat has been replaced with vegetable oils. Studies relating the fat profile of an infant's diet, or even the duration of human milk feeding, to later health consequences are scarce. There are problems with the interpretation of the findings as factors (for example, demography and environmental factors) other than that diet cannot be accounted for satisfactorily.

4.6 Milk Carbohydrates

Lactose accounts for 80% of the carbohydrates in human milk and for approximately 40% of its total energy. It is particularly suitable as the carbohydrate in milk because of its high solubility, promotion of protective intestinal flora (for example, *Bifidobacterium bifidus*) and the enhancement of calcium absorption. Other carbohydrates in milk include monosaccharides, oligosaccharides, and protein-bound carbohydrates (26). The mean concentration of lactose in human milk is surprisingly constant in different populations around the world. Between 1.5–3.5 months of lactation, the mean lactose concentration was reported to be 7.4 g/100 ml in underprivileged Ethiopian women; 7.6 g/100 ml in privileged Ethiopian women, and 7.3 g/100 ml in Swedish women (6).

4.7 Milk Micronutrients

Human milk is the complete food for healthy term infants up to the age of around 4–6 months, and its essential vitamins and minerals are efficiently absorbed and utilized. Levels of water-soluble vitamins are likely to be influenced by the mother's diet and her own vitamin status. This is true also, but to a lesser extent, for fat-soluble vitamins. There are concerns about the adequacy of the provision of certain vitamins after an infant is six months of age, if human milk is still the main food. Guidelines on the provision of supplements have been devised for the U.K. by the DoH (4). "Breast fed infants under six months do not need vitamin supplementation provided the mother has an adequate vitamin status during pregnancy. From the age of six months infants receiving breast milk as their main drink should be given supplements of vitamins A and D" (4). A DoH vitamin supplement of five drops daily contains 7 μg of vitamin D, 200 μg of vitamin A, and 20 mg of vitamin C. Vitamin K poses other issues. The human milk vitamin K content varies widely and may vary between 1 and 10 μg/L. Newborn infants have no colonic flora synthesising vitamin K; the infant's ability to absorb vitamin K is variable and plasma levels are low. About 2% of newborn infants show evidence of a hemorrhagic disease due to inadequate vitamin K–dependent coagulation factors. Hemorrhagic disease causes bleeding from the intestine and other sites. Oral vitamin K (1 mg) is now recommended for all healthy newborn infants in the U.K., with the addition of four oral doses being offered at two weekly intervals to infants fed human milk. Levels of vitamin K in cow milk are higher than in human milk and the content of a typical whey-type formula is 7 μg/100 ml, close to the upper limit in human milk. Hemorrhagic disease due to inadequate vitamin K almost never occurs in infants fed cow milk formula.

Only small amounts of vitamin D are found in human breast milk (Table 12.4), which indicates that a dietary source of this substance is teleologically unimportant. Infants have a store of vitamin D at birth, and there is an additional supply resulting from the action of sunlight (ultraviolet [UV] light) on 7-dehydrocholesterol in the skin, so infants should spend time exposed to sunlight outdoors. The amount of exposure to UV light will differ from infant to infant and the country in which the infant was born. The U.K. policy for vitamin D supplementation has previously been discussed.

There are only small amounts of iron in human milk (Table 12.4) but in healthy term infants this has little nutritional consequence in the initial months of life. A normal healthy fetus stores iron in its liver in the last trimester of pregnancy. Because of this, a full-term infant can maintain satisfactory hemoglobin levels without any other sources of iron for prob-

ably about the first six months of life. Breast milk is noticeably low in iron—76 μg/100 ml; however, because the iron is well absorbed (50–70%, compared with 10–30% from cow milk), and because an infant has stores, an extra dietary source is unnecessary until the stores are exhausted at around six months. Most of the iron in human milk is present in the fat globule membranes of the lipid fraction, and the remainder (30%) is found in lactoferrin. The iron content of human milk is not affected by maternal stores (see section 3.3). As discussed, lactoferrin is a nutrient-binding protein, which has a role in facilitating the absorption of nutrients (for example, iron) and thus competes with bacteria, inhibiting pathogen multiplication in the infant gut. After around six months of age, an exogenous or dietary iron source is needed. Infant milk formulae and many infant food products contain added iron, thus ensuring an appropriate dietary intake. In addition, food types such as red meat, prepared appropriately, can be included to provide a source of bio-available iron. Table 12.4 provides details of levels of other selected micronutrients in human milk including folate, thiamine, riboflavin, and vitamin B_{12}.

5 PRACTICES

Successful lactation is associated with an infant's being put to the breast as soon after birth as possible, with additional feeding at night and with frequent suckling initially and exclusivity of milk as the source of food. The output of milk and its energy and fat content increase over the first months of lactation as growth proceeds and appetites develop. Once breast feeding is established, the number of feedings may be reduced to six to eight over 24 hours, although infants vary widely in nutritional demands and mothers vary widely in the volume of milk they can produce. Exclusive human milk feeding with no other foods or drinks for six months of an infant's life may be the ideal for maintaining a high milk output as well as sustaining health advantages to the infant. In the 1980s, the "Baby friendly" initiative was established by the WHO for 10 steps to successful breast feeding (Table 12.9) (15).

However, the majority of women in developed countries are unable or unwilling to continue to breast feed for this length of time. Some women find the practice unrewarding. More than a third of first-time mothers in maternity units experience problems feeding their infants. Many of these problems (perceived milk insufficiency, painful breasts or nipples, and problems with suckling) can be addressed with lactational support. Women who need to return to work within six months of the birth of their child are less likely to feed initially, or they cease feeding sooner and introduce infant formula feeding sooner than those women who do not work. Convenience and economic considerations affect choice as many mothers need, or want, to work outside their homes. The use of infant formula may enable some to continue to lactate, but the introduction of infant formula together with solid foods invariably reduces milk output.

The reasons that mothers decide to feed infant formula from birth or to switch from human milk to infant milk formula are complex. The description of "younger, economically disadvantaged mothers" being less likely to feed their own milk than well-educated, economically advantaged mothers is borne

Table 12.9. Ten Steps to a Baby-Friendly Environment (WHO 1989) (Lawson 2003)

Step 1	Have a written breast-feeding policy that is routinely communicated to all health care staff.
Step 2	Train all health care staff in skills necessary to implement this policy.
Step 3	Inform all pregnant women about the benefits and management of breast feeding.
Step 4	Help mothers initiate breast feeding within half an hour of birth.
Step 5	Show mothers how to breast feed and how to maintain lactation even if they should be separated form their infants.
Step 6	Give newborn infants no food or drink other than breast milk, unless medically indicated.
Step 7	Practice rooming-in to allow mothers and infants to remain together 24 hr a day.
Step 8	Encourage breast feeding on demand.
Step 9	Give no artificial teats or pacifiers or soothers to breast-fed infants.
Step 10	Foster the establishment of breast-feeding support groups and refer mothers to them on discharge from hospital.

out by the findings of national surveys. The results have shown that factors that influence use of infant formula are surprisingly similar to the stereotypical mother who practices the early introduction of solid foods (5). For healthy infants aged between 6–12 months, human milk feeding can continue or cow milk infant formula or follow-on milk is recommended. Whole cow milk as a main drink is not recommended before 12 months of age. The reasons for this recommendation are twofold. There are reports that iron deficiency anaemia is more likely to develop, and there is a possibility of the development of an adverse immune response to cow milk protein in young infants. Semi-skim milk is not recommended before two years, and full skim milk is not usually recommended before five years of age, because of concerns regarding inadequate intakes of energy and nutrients, specifically fat-soluble vitamins and the essential fatty acids.

6 ALTERNATIVE PRODUCTS

The 1940s saw commercially prepared cow-milk-based term infant formula becoming increasingly popular, even though it is not possible to mimic exactly the nutritional and non-nutritional components of human milk. The composition of infant milk formulae has undergone important changes in the last decade. Table 12.4 outlines the average energy and nutrient content of a typical infant milk formula based on cow milk. Generally since the 1950s, butterfat from cow milk has been replaced with a suitable blend of oils from a vegetable source so that now all infant formulae contain blends based on vegetable oils. This has led to an increased intake of PUFAs in the formula-fed infant.

The protein content of cow-milk-based formula has also been decreased over the decades with reductions in the electrolytes (especially sodium) and phosphate. This is partly in response to concerns over the potential renal solute load (PRSL) of high-protein–, high-solute–containing feedings. Further details are given in section 8. In addition to the alteration in the amount of protein, the casein-to-whey ratio has been decreased from an 82:18 casein-to-whey to a 40:60 casein-to-whey ratio (see section 4.4). To maintain energy levels of modified formulae, the carbohydrate content is also adjusted by the addition of lactose or maltodextrins. Follow-on formulae, also based on cow milk, can be fed to infants over six months and will constitute the main milk drink in this case. Follow-on formulae can be considered as a complementary food and can enhance the mixed diet of an infant, where solid foods provided may be low in protein, energy, or micronutrients compared with the nutrient profile of infant formula or human milk. Follow-on formula is higher in protein, some micronutrients, and iron than term formula.

Formulae for low-birth-weight infants aim to meet the increased energy and nutrient needs of very low-birth-weight and preterm infants. There are two types of formula currently on the U.K. market. First, there are low-birth-weight formulae designed for the nutritional management of infants in special care baby units. After the infant has been discharged from the hospital he or she may still be growing rapidly and, in this case, post-discharge infant formulae, again based on cow milk, are available for the preterm infant who is not receiving human milk. Hypoallergenic formulae are manufactured for infants with a strong family history of atopy (allergy) and/or already diagnosed atopic disorders, and are either soy-protein–based or have partially hydrolyzed modified cow milk protein. The risk of developing an allergy to soy protein is no less than that of developing an allergy to cow milk protein. It is desirable, therefore, that parents seek dietetic advice before embarking on the modification of the infant's milk diet. Hydrolyzed cow milk protein formulae for infants with an atopic background (a known family history of food allergy) can be used as an alternative to soy-based products. It is also known that unmodified milk from sheep or goats fed to human infants can remedy cow milk allergy, although medical research beyond anecdotal reports in trade magazines is sparse or even controversial.

7 THE NEXT MILESTONE

Infant feeding is not simply the provision of human milk alone (19). In the transition period from a reliance solely on a milk-based diet to that of one based on cow milk and family foods, there is a period when an infant receives complementary foods or "weaning foods." The timing of the introduction of foods other than breast milk has been discussed earlier and is the subject of much debate. Further information on this milestone subject is contained in the review by Lanigan et al. (14). Infants initially re-

ceive solid foods, which have an appropriate profile in nutritional composition (high in energy, iron, and zinc) with an appropriate texture and taste, bearing in mind the physiological limitations of the young infant. Solid foods can be made in the home or manufactured and purchased. The preferred types of foods first to be introduced are discussed by Michaelsen et al. (18) and Sritharan and Morgan (25).

The final section of this chapter provides a overview of two relevant aspects of the physiology of the human infant.

8 INFANT PHYSIOLOGY

Young infants and in particular preterm infants cannot dilute or concentrate urine effectively. Knowledge of the relationship of the renal solute load and the renal concentrating ability to water balance is important in the development of guidelines for appropriate infant feeding practices. The PRSL refers to the solute load of dietary origin, protein, sodium, potassium, and chloride. PRSL = Na + K + P + Cl + protein intake (mg)/175, when the electrolyte intakes of sodium (Na), potassium (K), phosphorus (P), and chloride (Cl) are expressed in mosml/l (6). The PRSL for human milk is 93 mosml/l, that for a cow-milk-based formula is 135 mosml/l, and for whole cow milk is 308 mosml/l (6). The provision of whole cow's milk as a main drink is clearly unsuitable to young infants because of the danger of hypertonic dehydration.

Gastrointestinal enzymatic function is immature in early infancy. Digestion and absorption are promoted by many specific components in human milk, making human milk utilization more efficient than infant formula in the first months of life. The human milk casein-to-whey ratio (40% casein to 60% whey proteins) means that the more soluble (that is, digestible) whey proteins predominate and are more easily digested. In addition, human milk casein structure differs from that of cow milk casein (6), and this may influence digestibility. In the colon, urea can be utilized as a nitrogen source by bacteria and with organic acids to form amino acids, which can also be absorbed (6). Lactose is digested to glucose and galactose, which are readily absorbed. Lactose fermentation in the colon produces lactic acid and a low pH 5 (Table 12.7), which in turn provides an environment encouraging growth of nonpathogenic bacteria. Lactose also facilitates the absorption of calcium. Lipase in human milk helps in the digestion of fat (6). This is important because pancreatic lipase activity is low in early infancy. In addition, the relatively small fat droplets with their large surface area encourage enzymic activity and digestion of human milk fats. As far as iron, folic acid, vitamin B_{12}, and zinc are concerned, the presence of lactoferrin and other binding protein compounds facilitate their absorption (Table 12.7).

9 SUMMARY

Human milk is a unique food, tailored for the needs of the growing human infant. There is extensive knowledge of its nutritional and non-nutritional composition. The wide variation in the concentration of these components means that human milk cannot be easily copied or mimicked. Yet feeding modified cow milk formula, an alternative to human milk, is popular. The practice of feeding infants cow milk formula appears not to harm the health of the majority of infants for whom it is the sole food source between four and ten weeks of life and beyond. Human milk feeding practices vary across all cultures and all socioeconomic divides. The challenge in the future is to provide an environment in which all infants receive sufficient human milk over an appropriate length of time to enable them to grow and develop to their optimal potential.

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Figure 2.1. Sure-footed, fearless goats are climbing an 8 m-high board-trail to a feeding station, illustrating the ability of goats to climb tree limbs to feed on leaves. Here at the Westmoreland Berry Farm, Virginia, U.S.A., the goats attract visitors, who have fun feeding the goats small amounts of corn kernels hoisted up in a small bucket to the feeding station above. Photo Westmoreland Berry Farm, Oakgrove, VA; by permission.

Figure 2.2. Swiss Saanen goat. Photo G.F.W. Haenlein.

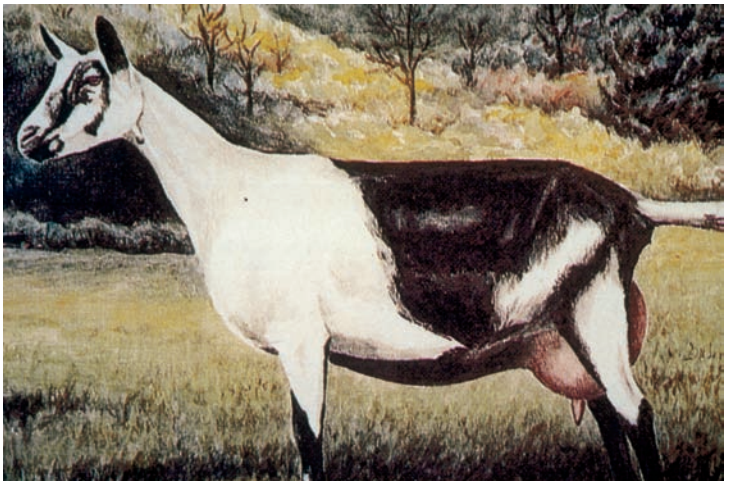

Figure 2.3. American Alpine goat. Photo American Dairy Goat Association.

Figure 2.4. American Oberhasli goat. Photo G.F.W. Haenlein.

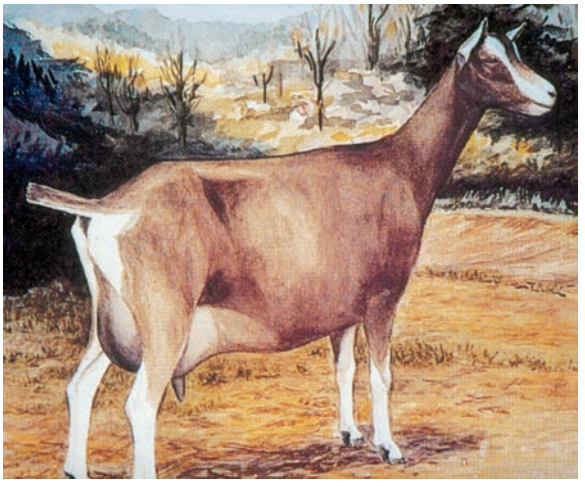

Figure 2.5. American Toggenburg goat; note the unique badger face. Photo American Dairy Goat Association, Spindale, NC.

Figure 2.6. American Nubian goat. Photo G.F.W. Haenlein.

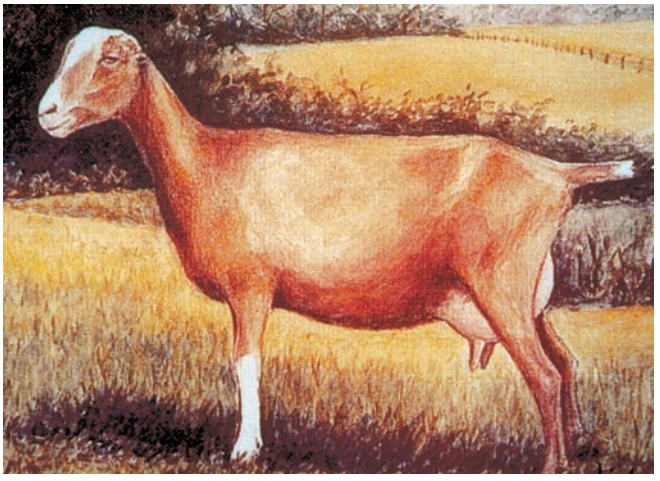

Figure 2.7. American LaMancha goat; note the unique vestigial "gopher" ear. Photo American Dairy Goat Association, Spindale, NC.

Figure 2.8. Spanish Murciana-Granadina goat. Photo Ministeró Agricultura Publ., 1980, Madrid, Spain.

Figure 2.9. Spanish Malagueña goat. Photo Ministeró Agricultura Publ., 1980, Madrid, Spain.

Figure 2.10. Spanish Canaria goat. Photo Ministeró Agricultura Publ., 1980, Madrid, Spain.

Figure 2.11. Spanish Guadarrama goat. Photo Ministeró Agricultura Publ., 1980, Madrid, Spain.

Figure 2.12. Italian Girgentana goat. Photo G.F.W. Haenlein.

Figure 2.13. Italian Garganica goat. Photo G.F.W. Haenlein.

Figure 2.14. Italian Maltese goat. Photo G.F.W. Haenlein.

Figure 2.15. Egyptian Damascus goat. Photo G.F.W. Haenlein.

Figure 2.16. Indian Jamnapari goat, one of the ancestors of the American Nubian goat; note the extremely long lop ears, Roman nose, and overshot lower jaw. Photo G.F.W. Haenlein.

Figure 2.20. Liquid goat milk products manufactured by Oak Knoll Dairy of Vermont, Vermont, U.S.A.

Figure 2.21. Examples of various commercial goat milk products marketed in the U.S., which include fluid milk, cheeses, yogurt, and powdered and evaporated goat milk products.

Figure 2.29. Different varieties of high-quality French soft goat milk cheeses. Source: Goat milk cheese plant, Poitiers, France.

Figure 3.1. A top-quality East Friesian dairy ewe in Switzerland. Photo: O. Mills, 2000, by permission, Shepherd Publishing Ltd. and Sheep Dairy News, Malvern, Worcestershire, U.K.

Figure 3.3. French Lacaune dairy ewe. Photo: UPRA, 1998, by permission, Shepherd Publishing Ltd. and Sheep Dairy News, Malvern, Worcestershire, U.K.

Figure 3.5. Spanish Manchega dairy ram. Photo: Ministerio de Agricultura Publ., 1980, Madrid, Spain.

Figure 3.6. Spanish Churra dairy ewe. Photo: Ministerio de Agricultura Publ., 1980, Madrid, Spain.

Figure 3.9. Typical hand milking of a transhumance flock of dairy sheep in Romania. Photo: G. F.W. Haenlein.

Figure 3.10. Typical transhumance pasturing of a dairy sheep flock accompanied by donkeys carrying household equipment for the shepherds in the mountains of Romania. Photo: G.F.W. Haenlein.

Figure 3.11. Typical rotary milking parlor for dairy sheep. Photo: F. Kervina et al., 1981, by permission, Alfa-Laval Co. Publ., Tumba, Sweden.

Figure 3.12. Rear view of the clean udders of Lacaune dairy ewes in a milking parlor. Photo: UPRA, 1998, by permission, Shepherd Publishing Ltd. and Sheep Dairy News, Malvern, Worcestershire, U.K.

Figure 6.1. Above: A herd of Bactrian camel (two-humped camel). Top right: Suckling of a Dromedary female camel (one-humped camel) by her calf before milking. Right: Hand milking of a Dromedary female camel.

Figure 7.2. A mechanical milk separator for cream separation. Photo provided by Yucai Zheng.