2.2 Goat Milk – Chemistry and Nutrition

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1 Introduction

As the longest domesticated animal in history, goats have been the provider of milk and dairy products to human beings for their subsistence as well as a healthy and nutritious diet. Although goats produce approximately 2% of the world's total annual milk supply (FAO, 2004; Park and Haenlein, 2010), their contributions to the nutritional and economic wellbeing of mankind is highly important in many parts of the world, notably in the Mediterranean countries and in the Middle East (Kosikowski, 1977; Juàrez and Ramos, 1986; Park, 1994a, 1994b; Park and Haenlein, 2007). More people drink the milk of goats than milk of any other single species on a worldwide basis (Haenlein and Caccese, 1984; Park, 1991, 1992a,1994b, 1994). 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 (Rosenblum and Rosenblum, 1952; Walker, 1965; Devendra and Burns, 1970; Haenlein and Caccese, 1984; Park, 1991, 1994a, 1994b; Park and Chukwu, 1988). Because of the limited availability of cow milk, goat milk and its products are important daily food sources of protein, phosphate, and calcium in developing countries (Haenlein and Caccese, 1984; Park, 1991).

Interest in dairy goats and goat milk products is a part of the recent trend in health food demand and consumption in developed countries as well as a renewed interest in goat milk as a substitute for those who suffer from allergies or intolerance against cow milk (Walker, 1965; Van der Horst, 1976; Taitz and Armitage, 1984; Chandan, Attaie, and Shahani, 1992; Park, 1990, 1994a, 1994b; Tziboula-Clarke, 2003). In recent years, goat milk products such as cheeses, yogurts, and ice creams also gained increasing popularity among certain ethnic groups, health food lovers, connoisseurs, customers, and private goat farmers in the US (Park, 1990; McGhee, Jones, and Park, 2015).

On the other hand, unlike the cow milk industry, large-scale industrialization of the dairy goat production in many countries is limited due to the relatively low level of milk production, which is approximately 50 kg per doe per lactation annually (Loewenstein *et al.*, 1980; Juàrez and Ramos, 1986; FAO, 1997; Park *et al.*, 2007). However, the average 50 kg milk production per doe per lactation (FAO, 1997) is very low and may have included all non-dairy breed goats in the population statistics, especially from developing countries. Most dairy goat breeds are very improved, and produce as much as an average 900 kg/doe/lactation in France and their goat milk production is very well industrialized (Muňoz and Tejon, 1980; Haenlein, 2006). The American Dairy Goat Association reported that average milk yields of Saanen, Alpine, Oberhasli, and Toggenburg breeds in the US ranged from 1024 to 1185 kg per doe per lactation (Park and Haenlein, 2010). The average annual goat milk yield per doe in Switzerland also exceeded 1000 kg. The major nutrient composition, flavor, and appearance of goat milk resemble cow milk, but goat milk has its unique chemical, biochemical, physical, and nutritional characteristics compared to cow and other species milk.

Handbook of Milk of Non-Bovine Mammals, Second Edition.
Edited by Young W. Park, George F.W. Haenlein, and William L. Wendorff.

2 Nutritional and Chemical Composition of Goat Milk

2.1 Basic Nutrient Composition

Although there are certain species-specific differences in composition of milk, the basic nutrient composition of goat milk is similar to that of cow milk. Like in the case of cow milk, the composition of goat milk varies with diet, breed, animals within breed, parity, environmental conditions, feeding and management conditions, season, locality, and stage of lactation (Schmidt, 1971; Underwood, 1977; Park and Haenlein, 2007). 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 2.11), 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 of milking cows (Figure 2.17), and the same phenomena would occur in goat milk. 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, and then increase towards the end of lactation. This causes an inverse relationship between the yield of milk and percentage composition of these components (Schmidt, 1971).

Goat milk contains slightly less total casein, but higher non-protein nitrogen than the cow counterpart (Table 2.11). 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 (3 to 4 times) greater levels of the two components than human milk, which is species-specific and directly related to the 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 (Haenlein and Caccese, 1984; Jenness, 1980; Posati and Orr, 1976). The prominent difference is in the proportion of energy derived from lactose and protein. Fat, protein, and lactose in goat and cow milks account for approximately 50, 25, 25% of the energy, whereas human milk contributes 55, 7, and 38% (Jenness, 1980).

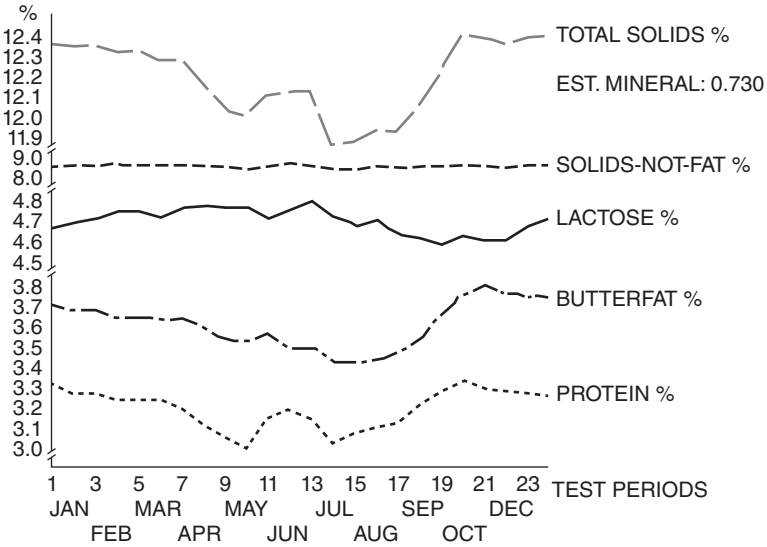

Figure 2.17 Composition of all Ontario milk 1972. *Source:* Adapted from Irvine (1974).

Table 2.11 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

Source: Data from Posati and Orr (1976), Jenness (1980), and Haenlein and Caccese (1984).

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 physicochemical structure and composition of milk fats. The average size of goat milk fat globules is about 3.5 micrometers (μm) as compared to 4.5 μm for cow milk fat (Fahmi, Sirry, and Safwat, 1956; Haenlein and Caccese, 1984; Stark, 1988). 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 2.12). 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 (Haenlein and Caccese, 1984; Chandan, Attaie, and Shahini, 1992). 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 temperatures (Jenness, 1980; Morand-Fehr and Sauvant, 1980; Haenlein and Caccese, 1984; Kehagias *et al.*, 1986; Chandan, Attaie, and Shahini, 1992).

Goat milk contains 97–99% of free lipids and 1–3% bound lipids of total milk fat (Table 2.13). The ratio of bound to free lipids is comparable to that for cow milk (Cerbulis, Parks, and Farrell,

Table 2.12 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	0 .2
10.5	0.2	1.4	1.7	–
12.0	–	.1	2.0	0.1
13.5	–	–	0.4	–
15.0	–	–	0.3	–
16.5	–	–	–	–
18.5	–	–	0.1	–
Average	3.49	4.55	5.92	3.30

Source: Adapted from Fahmi *et al.* (1956).

Table 2.13 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

Source: Cerbulis *et al.* (1982). Reproduced with permission of Elsevier.

1982). Fractional compositions of free lipids of goat milk are similar to those of cow 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, while the opposite trend was found for bound lipids of both goat and cow milks (Table 2.14). Polar lipids make up approximately 1.6% of the total lipids (Cerbulis *et al.*, 1984). Of the polar lipid fraction, glycolipids make up 16% in goat milk as compared to the 6% in cow milk (Morrison, Jack, and Smith, 1965). 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 2.15). 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 (Patton, Long, and Sokka, 1980). 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 2.16; Jenness and Patton, 1976; Jenness, 1980; Juàrez and Ramos, 1986; Jensen *et al.*, 1990; Haenlein, 1992). Goat milk has almost twice higher amounts of caproic (C6:0), caprylic (C8:0), and capric (C10:0) acids than cow milk, which are highly correlated to "goaty" flavor (Haenlein and Caccese, 1984; Jenness, 1980; Juàrez and Ramos, 1986). The higher

Table 2.14 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

Source: Cerbulis *et al.* (1982). Reproduced with permission of Elsevier.

Table 2.15 Distribution of phospholipid subclasses in goat, cow, and human milks.

Phospholipid fraction	Total phospholipids (%)		
	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

Source: Data from Cerbulis *et al.* (1982) and Renner *et al.* (1989).

levels of these short-chain acids may be attributable to the differences in polymerization of the acetate produced by the rumen bacteria in goats (Tziboula-Clarke, 2003). Human milk contains an especially negligible amount of short-chain fatty acids (Jensen *et al.*, 1990).

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 versus 1.16) (Iverson and Sheppard, 1989). 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

Table 2.16 Fatty acid composition of total lipid and cholesterol esters of goat, cow, and human milks.

Fatty acid	Total lipid (g/100 g fat)			Cholesterol esters (g/100 g CE)	
	Goat	Cow	Human[e]	Goat[f]	Cow[e]
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]Jenness (1980).
[b]Gonc, Schmid, and Renner (1979).
[c]Juàrez and Ramos (1986).
[d]Martinez-Castro, Juarez, and Martin-Alvarez (1979).
[e]Jensen *et al.* (1990).
[f]Keenan and Patton (1970).
CE: cholesterol esters, which is less than 4% of total cholesterol, Tr: trace.

cheese has been used in the dairy industry (Palo and Simkova, 1981; Iverson and Sheppard, 1989). The remarkably high concentrations of C16:0 and C18:1 (oleic) acids in goat and cow milk fats are not species specific; rather they are common to most mammals (Table 2.16).

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 *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 (Alonso *et al.*, 1999). Numerous BCFA (all having more than 11 carbon) were identified and quantified (Massart-Leen *et al.*, 1981), and over 20 volatile BCFA were identifed in caprine cheese (Ha and Lindsay, 1991). Iso and anteiso acids predominated in the BCFA of goat milk, in proportions similar to those of cow milk (Juàrez and Ramos, 1986). Goat milk fat has a range of other monomethyl-branched components, mostly with methyl-substitution on carbons 4 and 6, but they are virtually absent from cow milk, with only a trace amount of 6-methyl-hexadecanoate detected (Massart-Leen *et al.*, 1981).

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 (Cerbulis, Flanagan, and Farrell, 1985). 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 (Jensen, 1973; Jenness, 1980). Both goat and cow milk fat contain adequate amounts of essential fatty acids for human infants.

Goat milk has much higher glycerol ethers than cow milk, which appears to be important for the nutrition of the nursing newborn (Haenlein and Caccese, 1984). Goat milk also contains lower levels of orotic acid than cow milk, which has a significant effect on the prevention of fatty liver syndrome (Jenness, 1980; Haenlein and Caccese, 1984).

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 (Parodi, 1994; Belury, 1995; Lawless *et al.*, 1998), antiatherogenic activity (Lee *et al.*, 1994; Lawless *et al.*, 1998), the ability to reduce the catabolic effects of immune stimulation (Cook *et al.*, 1993; Lawless *et al.*, 1998), the ability to enhance growth promotion (Chin *et al.*, 1994; Lawless *et al.*, 1998), and the ability to reduce body fat (Pariza *et al.*, 1996; Lawless *et al.*, 1998). CLA is a mixture of positional and geometric isomers of linoleic acid (C18:2) that contain conjugated unsaturated double bonds (Dhiman *et al.*, 1999). 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 (Chin *et al.*, 1992; Dhiman *et al.*, 1999).

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 non-treated control group (Mir *et al.*, 1999). 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. Since cows fed on only pasture produced milk fat with a higher CLA content than did cows receiving less feed from pasture (Dhiman *et al.*, 1999), it is expected that dairy goats would produce a 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 (Lawless *et al.*, 1998). 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 (Fehr and Le Jaouen, 1976). 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 (Juàrez and Ramos, 1986), where an 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 μeq/ml compared with cow milk (3.0 μeq/ml) and buffalo milk (3.4 μeq/ml) (Agnihotri and Prasad, 1993). 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 (Agnihotri and Prasad, 1993).

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) (Bakke, Steine, and Eggum, 1977). However, other factors may be involved in that flavor because samples with the same free fatty acid contents showed sometimes quite different flavors (Juàrez and Ramos, 1986).

The amount of FFA accumulated during ripening of dairy products would be an overall measure of lipolysis, and is quite variable depending on the type of products, lactic and secondary starters, rennet type used, ripening time, and manufacturing methods and other factors (Nouira *et al.*, 2011). The FFA concentrations of reduced-fat and full-fat goat milk cheeses were investigated (Nouira *et al.*, 2011) and as well the FFA levels of Turkish commercial yogurt products were reported (Table 2.17; Güler and Park, 2011).

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 (Ha and Lindsay, 1991). Table 2.18 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 goat contained significant amounts of both 4-methyloctanoic and 4-ethyloctanoic acids, which contributed mutton-like and goat-like flavors, respectively (Ha and Lindsay, 1991). 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 (Woo, Kollodge, and Lindsay, 1984).

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 cow cheese (Ha and Lindsay, 1991). Concentrations of 4-methyloctanoic acid in goat Cheddar cheese increased significantly from day 1 to 12 week aging period (Attaie and Richter, 1996). 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 (Ha and Lindsay, 1991; Attaie and Richter, 1996). The threshold concentration of 4-ethyloctanoic acid for goaty aroma was 1.8 ppb (Boelens, Haring, and de Reijke, 1983) and 6.0 ppb (Brennand, Ha, and Lindsay, 1989) in diluted citric acid solution at pH 2.0. FFA content increased during storage at 4 ^{o}C, where the FFAs initially consisted of short-chain acids but increased C16:0 and C18:0 after 10 days (Bas, Morand-Fehr, and Rouzeau, 1978).

Lipolysis in goat milk increases during storage at room temperature for 4 and 12 h (Singh and Gupta, 1985). Goat milk had a significant correlation between spontaneous lipolysis and lipoprotein lipase activity, while no correlation was found in cow milk (Bojörke and Castberg, 1976; Chilliard *et al.*, 1984). Goat milk has a 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 (Jin and Park, 1995).

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 (Posati and Orr, 1976), 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

Table 2.17 Profiles of mean concentrations (μg 100/g of yoghurt) of free fatty acids and benzoic acid in 10 brands of Turkish commercial set-type yoghurts.[1]

Free fatty acids	Brands										*P*
	AK	AS	DN	DS	IC	PN	SK	ST	TV	YR	
Ethanoic (C_2)	12.4±4.0^{ab}	23.8±8.1^{bc}	5.3±2.7^{a}	5.4±4.0^{a}	15.1±7.2^{ab}	3.3±2.8^{a}	8.5±5.3^{ab}	12.1±11.6^{ab}	13.9±2.3^{ab}	34.6±23.7^{c}	**
Butanoic (C_4)	6.3±3.8^{c}	9.1±6.1^{cd}	5.4±5.0^{b}	12.1±5.4^{e}	3.6±2.2^{ab}	4.5±2.1^{d}	8.6±9.3^{cd}	14.7±10.3^{f}	1.3±0.6^{a}	9.8±3.2^{cd}	***
Hexanoic (C_6)	9.2±5.3^{bc}	10.2±3.2^{cd}	3.9±3.2^{a}	16.2±12.2^{e}	9.5±7.4^{b}	5.9±2.9^{a}	9.0±11.2^{bc}	14.4±11.5^{e}	5.1±0.7^{a}	14.3±6.4^{d}	***
Octanoic (C_8)	2.2±0.4^{a}	2.1±0.4^{a}	4.5±2.0^{f}	3.4±6.1^{g}	6.4±5.0^{cd}	3.4±0.8^{ab}	4.6±2.9^{bc}	7.6±4.2^{e}	3.2±1.0^{ab}	5.8±1.3	***
Total (C_2-C_8)	30.1±13.6	45.3±17.7	19.1±13.0	37.4±27.9	34.6 ±22.0	17.1 ±8.7	30.7±28.7	48.9±37.7	23.59±4.74	64.6±34.7	
Decanoic (C_{10})	4.4±1.5^{a}	3.8±0.9^{bc}	10.4±4.1^{f}	6.4±5.2^{g}	8.4±3.6^{d}	5.9±0.9^{bc}	6.9±3.2^{cd}	11.2±5.2^{f}	6.9±2.6^{d}	8.8±3.2^{e}	***
Dodecanoic (C_{12})	7.2±2.6^{a}	10.1±5.4^{bc}	15.7±4.8^{e}	10.4±17.2^{f}	10.7±4.0^{bc}	13.2±3.1^{e}	9.7±2.7^{bc}	11.6±4.3^{d}	8.8±3.8^{c}	8.9±1.1^{b}	***
Tetradecanoic (C_{14})	35.7±12.3	34.7±15.5	48.8±14.1	38.4±17.1	48.1±8.6	36.0±9.8	37.7±5.2	39.5±10.5	39.8±12.1	32.3±7.9	NS
Total (C_{10}-C_{14})	47.3±16.4	48.7±21.8	74.9±23.1	55.2±39.5	67.2±16.2	55.2±13.9	54.3±11.3	62.4±20.1	55.6±18.6	50.0±12.1	
Pentadecanoic (C_{15})	3.0±0.7^{b}	3.3±1.5^{b}	6.2±3.6^{c}	1.6±1.9^{a}	5.8±1.7^{c}	3.6±1.7^{b}	2.4±1.8^{a}	ns	2.53±1.81^{b}	2.9±1.1^{b}	**
Hexadecanoic (C_{16})	186.5±53.5	158.2±68.1	209.2±60.7	170.5±81.0	217.9±33.2	183.9±41.3	200.3±3.4	198.7±21.1	227.9±25.3	153.3±51.5	NS
9-Hexadecenoic ($C_{16:1}$)	ns	ns	2.9±1.9^{c}	0.2±0.1^{a}	3.5±1.9^{c}	2.9±2.7^{c}	4.5±4.3^{d}	1.7±1.2^{b}	7.3±4.5^{e}	ns	*
Heptadecanoic (C_{17})	4.4±1.8^{c}	ns	2.6±0.4^{b}	ns	6.1±1.7^{d}	3.1±2.3^{b}	1.9±1.0^{a}	1.8±0.5^{a}	4.7±0.8^{c}	6.8±3.2^{d}	**
Octadecanoic (C_{18})	120.5±40.2^{bc}	88.6±40.9^{ab}	98.8±26.6^{abc}	78.5±42.6^{a}	111.9±29.8^{ab}	75.3±16.6	141.2±31.0^{c}	144.5±44.1^{bc}	131.4±35.0^{bc}	75.5±28.1^{ab}	*
9-Octadecenoic ($C_{18:1}$)	88.6±48.1	59.8±31.4	73.1±26.0	56.9±16.2	80.7±31.7	111.8±27.0	64.9±7.4	43.0±19.0	99.3±18.0	40.2±25.5	NS
Total (C_{15}- $C_{18:1}$)	405.9±146.9	309.8±142.1	392.8±119.4	307.7±141.8	425.8±100.0	380.6±1.9	415.1±49.4	388.5±86.5	473.1±85.5	278.6±109.5	
Benzoic acid	9.08±0.2^{e}	4.37±0.3^{a}	4.84±0.37^{ab}	7.2±0.3^{cd}	7.00±0.82^{c}	5.53±0.41^{b}	7.37±0.48^{cd}	7.94±0.35^{d}	10.92±0.76^{f}	7.37±0.48^{cd}	**

*Each observation is mean ± standard deviation of four yoghurt samples.
$^{a.b.c}$Means with a different superscript within the same row were significantly different between yoghurt brands.
P: significance level; ns: non-significant; $^{*}P < 0.05$, $^{**}P < 0.01$, and $^{***}P < 0.001$.
Source: Guler and Park (2011).

Table 2.18 Concentrations (μg/g cheese) of volatile free fatty acids (VFFA) and volatile total fatty acids (VTFA) in cheeses from goat and sheep milks.

		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	–[a]	–	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[b]	0.03	0.01	–	0.45	0.06	0.65
14.	An *ethylhepanoic*[b]	0.03	0.02	–	0.83	–	–
15.	An ethylheptenoic[b]	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[b]	–	–	–	–	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[b]	–	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

[a] Not detected.
[b] Tentative identification.
Source: Ha and Lindsay (1991). Reproduced with permission of Elsevier.

cholesterol is implicated with coronary heart disease. However, cholesterol in goat milk is usually in the range of 10–20 mg/100 ml milk (Jenness, 1980). 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 (Jenness, 1980; Chandan, Attaie, and Shahani, 1992). Fatty acid composition of cholesterol esters (Table 2.16) reveals that goat cholesterol esters have greater palmitic and oleic acid fractions than cow counterparts (Jenness, 1980; Juàrez and Ramos, 1986).

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 (Arora, Bindal, and Jain, 1976). Most of this milk lipid fraction (91%) is cholesterol, which is about 420 mg/100 g fat (Arora, Bindal, and Jain, 1976). Significant variation in cholesterol content was observed among different breeds, and most of the cholesterol in goat milk is in the free state, with only a small fraction in the ester form, 52 mg/100 g fat (Arora, Bindal, and Jain, 1976). Cholesterol esters of cow milk fat represent about one-tenth of the sterol content in cow milk (Keenan and Patton, 1970). On the average, 66% of the free

and 42% of the esterified cholesterol were associated with goat milk fat globules (Keenan and Patton, 1970).

2.3 Carbohydrates

The major carbohydrate of goat milk is lactose, which is about 0.2–0.5% less than that of cow milk (Posati and Orr, 1976; Chandan, Attaie, and Shahani, 1992). 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 a higher content of fat and a lower content of lactose than goat milk (Haenlein and Caccese, 1984). Cow milk contains minor levels of monosaccharides and oligosaccharides, while their presence in goat milk is not known (Chandan, Attaie, and Shahani, 1992).

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) (Haenlein and Caccese, 1984; Carles, 1986; Mikkelsen, Hojrup, and Knudsen, 1987). These proteins were named after their corresponding proteins of cow milk due to their homologous nature in composition and properties (Whitney *et al.*, 1976). The casein composition in goat milk is influenced by genetic polymorphism on the casein loci (Tziboula-Clarke, 2003).

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 2.19). 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 (Chandan, Parry, and Shahani, 1968; Remeuf and Lenoir, 1986). However, goat milk showed considerable variations in its α_{s1}-casein content ranging from 2.7 g/l to only 0.12 g/l (Mora-Gutierrez, Kumosinski, and Farrell, 1991). Expression of α_{s1}-casein may be genetically regulated in certain breeds such as French-Alpine. β-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 2.20).

The percent composition of different protein fractions in goat and cow milks are summarized in Table 2.20. 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 (Jenness, 1980). 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 (Storry *et al.*, 1983).

β-Lactoglobulins (β-Lg) in goat milk have 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 (Jenness, 1980). 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 (Jenness, 1980). The α-lactalbumins play an important role in milk biochemistry, since 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

(a) α_s-Caseins. Among cow milk proteins, the α_s-caseins have one major component, α_{s1}-casein, and several minor components (Whitney *et al.*, 1976), where the α_s-caseins possess the fastest electrophoretic mobility and are precipitated in 0.4 M $CaCl_2$ at pH 7.0 and 4 °C

Table 2.19 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/100 ml)	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
Non-protein 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/100 ml)	25	10–35	4–40
Ribonuclease (μg/100 ml)	425	1000–2000	10–20
Xanthine oxidase (μl O_2/h/ml)	19–113	120	

Source: Data from Chandan *et al.* (1968), Jenness (1980), Remeuf and Lenoir (1986), and Renner *et al.* (1989).

(Whitney *et al.*, 1976). 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 (Parkash and Jenness, 1968). 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 (Brignon *et al.*, 1977). There is one major difference between α_{s2}- and α_{s1}-casein, which is a disulfide linkage in the former while complete lack of disulfide or thiol in the latter (Jenness, 1980).

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 (Tziboula-Clarke, 2003). These alleles are

Table 2.20 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
αLactalbumin	0.06–0.11	0.08–0.12	0.12
Serum albumin	0.01–0.11	0.02–0.04	0.04

Source: Study 1: Storry *et al.* (1983). Study 2: Jenness (1980).

distributed among seven different classes of protein variants (α_{s1}-casein A-G) and are associated with four levels of α_{s1}-casein expression ranging from 0 (null allele α_{s1}-Cn^0) to 3.5 g/l per copy of each A, B, or C (strong) alleles (Tziboula-Clarke, 2003). The allele E (medium) is related to an intermediate content (1.1 g/l per allele), and those F and G (weak) are associated with low contents of α_{s1}-casein (0.5 g/l per allele) (Tziboula-Clarke, 2003).

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 (Marchalonis and Weltman, 1971). 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 (Jenness, 1980; Pelissier and Manchon, 1976).

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 the α_{s1}-casein band in gel electrophoresis (Aschaffenburg and Dance, 1968; Pierre and Portmann, 1970; Jenness, 1980). However, a further report (Mora-Gutierrez, Kumosinski, and Farrell, 1991) showed that goat milk can contain considerably variable levels of α_{s1}-casein ranging 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.

(b) β-Caseins. As shown in Tables 2.19 and 2.20, the β-caseins are the major components (54.8%) of total goat milk casein (Jenness, 1980; Storry *et al.*, 1983; Remeuf and Lenoir, 1986; Renner, Schaafsma, and Scott, 1989). The β-casein has more numerous genetic variants than the other caseins and their differentiation by gel electrophoresis is more complicated (Whitney *et al.*, 1976). β-Caseins appear in decreasing mobilities in alkaline gel electrophoresis (9% cyanogum, 3.5 M urea) in the following order: $A^1 = A^2 = A^3 > B = B_z > D, E > C$ (Kiddy, 1975). 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 (Whitney *et al.*, 1976). 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 (Whitney *et al.*, 1976; Jenness, 1980).

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 (Voglino, 1972) but not compared with the D variant, and their relative mobilities in alkaline gel have not been defined (Whitney *et al.*, 1976).

(c) 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 β-A^2 → γ-A^2). This indicates that γ-casein variants consist of the residues 29 → 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 (Groves *et al.*, 1972; Whitney *et al.*, 1976).

It was also theoretically shown that cleavage of β-casein A^2 at Lys_{105} and Lys_{107} yields the two C-terminal fragments that are identical to the TS-A^2 and R-caseins, whereas fragmentation of β-casein B yields segments identical to the S- and TS-B caseins (Whitney *et al.*,

1976). The fragment of β-casein from 106 to 209 is termed γ_2-casein, while that of β-casein from 108 to 209 is termed γ_3-casein (Whitney *et al.*, 1976).

(d) κ-Caseins. The κ-casein is the only component of the goat milk caseins from which the entire sequence of amino acids have been determined (Dayoff, 1979). The sequence of goat 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. Like the bovine homolog, goat κ-casein has Phe in position 105 and Met in 106 (Jenness, 1980). 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) (Jenness, 1980).

The κ-caseins occur in the form of a mixture of polymers held together by intermolecular disulfide bonds (Swaisgood and Brunner, 1963). 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 (Mackinlay, Hill, and Wake, 1966; Whitney *et al.*, 1976). 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 vary from zero to possibly five carbohydrate chains (Rose *et al.*, 1970).

(e) 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 (Whitney *et al.*, 1976; Jenness, 1980). Since β-lactoblobulins and α-lactalbumins are generally in significant quantities in whey proteins, only these two proteins are further discussed here.

(e1) β-lactoglobulins. Goat β-lactoglobulin (β-Lg), like its bovine homologs, consists of a polypeptide chain of 162 amino acid residues and differs from bovine β-Lg B at six positions including both terminal residues (Jenness, 1980). 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 (Cauvin, Liberatori, and Conti, 1976; Jenness, 1980). 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 the microcomplement fixation technique (Alexander and Pace, 1973; Jenness, 1980).

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 (Philliops, Jenness, and Kallan, 1968; McKenzie, Ralston, and Shaw, 1972). 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 (Jenness, 1980).

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 (Juàrez and Ramos, 1986).

(e2) 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 (MacGillivray, Brew, and Barnes, 1979). 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 (MacGillivray, Brew, and

Barnes, 1979). 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 (Jenness, 1980).

Since goat α-La has immunological cross-reactivity with other α-La's, it is distinguishable from bovine α-La by the microcomplement fixation technique or by absorption of antibodies by columns of matrix-bound α-La (Prieels *et al.*, 1975). 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 (Jenness, 1980).

α-Lactalbumin is present in all milks that contain lactose since it is required for biosynthesis of lactose at meaningful rates (Ebner and Schanbacher, 1974). 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 (Ebner and Schanbacher, 1974). 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 non-reducing *N*-acetyl-glucosamine residue on a glycoprotein because the transfer of galactose to glucose is slow, while in the presence of α-La the transfer is rapid and glucose becomes an effective substrate (Ebner and Schanbacher, 1974; Whitney *et al.*, 1976).

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 (Bhattacharya *et al.*, 1963). The major component of α-lactalbumin possesses four disulfide bonds and the isolation of an α-lactalbumin with from 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 (Brown *et al.*, 1969).

(e3) 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 a molecular weight of 66 267 and is a rod-shaped protein containing one cysteine and 17 cystine residues, and is partially unfolded at low (<4) and high (>8) pH values (Van Camp and Huyghebaert, 1996). Both BSAs in milk whey and bovine blood serum are identical, except for heterogenous behavior in electrophoretic properties at pH 4.0 (Whitney *et al.*, 1976).

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 (Whitney *et al.*, 1976). The N-terminal and C-terminal amino acid residues of BSA are aspartic acid and alanine, respectively.

(e4) 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 2.19). Goat milk contains the IgG's in greatest concentrations than in other ruminants. Goat milk contains similar ranges of immunoglobulins to those of cow and sheep milk and colostrums (Table 2.19). Radioimmunoassays showed that mature goat milk contained 30 to 80 μg of IgA, 10 to 40 μg of IgM, and 100 to 400 μg of IgG/ml,

while goat colostrum contained much more than regular milk, having 0.9 to 2.4 mg of IgA, 1.6 to 5.2 mg of IgM, and 50 to 64 mg of IgG/ml (Pashud and Mach, 1970).

Certain aspects of structure have to be considered for the nomenclature of immunoglobulins (Butler, 1969; Whitney *et al.*, 1976). The immunoglobulins are unique among the milk proteins (Whitney *et al.*, 1976) in: (i) the molecular genetics of their synthesis, (ii) their heterogeneity, and (iii) their synthesis. Immunoglobulin nomenclature is mainly based on immunochemical criteria including cross-reactivity with reference proteins, typically from humans. Since the World Health Organization introduced the first nomenclature for human immunoglobulins (Ceppelini *et al.*, 1964), 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 pre-colostral secretions (Mach and Pahud, 1971). Most bovine IgG1 possesses a lower isoelectic distribution and greater net acidity than IgG2; thereby the former migrates more anodally during electrophoresis at alkaline pH (Butler, 1969; Mach and Pahud, 1971; Duncan *et al.*, 1972). Bovine immunoglobulin IgG2 exists in less amount than IgG1, while both are external excretions (Mach and Pahud, 1971; Duncan *et al.*, 1972). 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 (Mach and Pahud, 1971; Duncan *et al.*, 1972).

In comparison to immunoglobulins of different species, it was confirmed that antigenic homology exists between bovine IgM and its human counterpart (Mehta, Reichlin, and Tomase, 1972). The bovine immunoglobulin IgM has been recognized in other species milk that has similar physical, chemical, and biological characteristics of bovine IgM (Butler, 1969).

Bovine immunoglobulin IgA is homologous in other species and their homologies to human counterparts are also confirmed (Kenyon, Anderson, and Jenness, 1962; Mach and Pahud, 1971; Duncan *et al.*, 1972). 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 (Butler, 1969; Whitney *et al.*, 1976).

2.4.3 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 versus cow) within a casein fraction (Table 2.21). The α-caseins contain greater aspartate, lysine, and tyrosine than β-casein, while the latter has higher leucine, proline, and valine than the former. The α-La contains significantly greater aspartate than 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.* (1994) reported that there were commonalities in the overall amino acid pattern of the milks of all species tested (Table 2.22). 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 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 2.23). Total amino acid contents in goat and other non-primate milks were substantially greater than those in human and primate milks, as

Table 2.21 Comparison of amino acid composition of isolated proteins of goat milk with those of cow milk (g/100 g protein).

	α-Casein[a]		β-Casein		κ-*Cn*[b]	γ-*Cn*[c]	β-Lg[d]		α-Lactalbumin	
Amino acid	**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: β-lactoglobulin.
[e] Jenness (1980).
[f] Webb and Johnson (1965) unit for goat milk data were converted from residue/mole to g/100 g protein.

previously shown (Table 2.23). Other commonalities in all species milks were essential amino acids (EAA) 40%, branched-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 2.23). Goat, cow, and human milks have a satisfactory balance of EAA equalling or exceeding the FAO-WHO requirements for each amino acid to human infants (Jenness, 1980).

2.4.4 Bioactive Peptides of Goat Milk Proteins

Functionalities of Bioactive Peptides in Milk and Dairy Products

Biologically and physiologically active peptides are produced from several food proteins during digestion in the gut and fermentation of foods by lactic acid bacteria (Korhonen and Pihlanto, 2007). As bioactive peptides are liberated, they exhibit various functional and physiological effects in the body such as gastrointestinal, cardiovascular, endocrine, immune, and nervous systems. Examples of these functionalities of the peptides include antihypertensive, antimicrobial, antioxidative, antithrombotic, opioid, hypocholesterolemic, antiappetizing, and immunomodulatory activities (FitzGerald and Meisel, 2003; Korhonen and Pihlanto, 2003; Park, 2009). Many milk protein-derived peptides exhibit more than one functionality, including peptides from the sequence 60–70 of β-casein, which has immunostimulatory, opioid, and ACE-inhibitory activities (Korhonen and Pihlanto, 2007). The bioactive peptides derived from various dietary proteins have been reviewed by many researchers (Clare, Catignani, and Swaisgood, 2003; FitzGerald and Meisel, 2003; Pellegrini, 2003; Pihlanto and Korhonen, 2003; Li *et al.*, 2004).

Table 2.22 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∀15	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∀10
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

*Values are means ± SD of each amino acid (in mg) divided by the total amino acids (in g, excluding tryptophan).
Source: Adapted from Davis *et al.* (1994).

ACE-Inhibitory Peptides Derived from Caprine Milk Caseins

Bovine and caprine milk proteins are composed of 80% casein (CN) fractions. Research *in vitro* and on animal models indicates that peptides derived from CN are not only nutrients but also a source of low molecular weight peptides having various biological activities. These peptides are generated and become active after digestion by proteolytic enzymes or during the fermentation and maturation processes of cheese and yoghurt (Korhonen and Pihlanto, 2007). Antihypertensive and immuno-stimulating peptides can be generated from caprine β-CN as well as bovine β-CN (Geerlings *et al*., 2006; Silva, Pihlanto, and Malcata, 2006).

Quite a few peptide fragments and sequences of bioactive peptides derived from caprine milk and its cheese proteins on the basis of different bioactivities have been found, which are listed in Table 2.24. Although bioactive peptides from goat milk have not been studied as much as those from bovine milk, at least two main functional bioactivities of caprine milk and its cheese products have been reported, including ACE-inhibitory and antimicrobial active compounds (Table 2.24). For casein fractions, α-, β-, and κ-CN have been reported as sources of bioactive components of goat milk proteins.

The hydrolysis of goat milk caseins has been shown to produce ACE-inhibitory peptides (Lee *et al.*, 2005). The peptic hydrolysate from goat casein was found to be the most active and several ACE-inhibitory peptides have been isolated from the hydrolysate (Table 2.24). Sodium caseinates prepared from cow, sheep, goat, pig, buffalo, and human milk were hydrolyzed by a partially purified proteinase of *Lb. helveticus* PR4 (Minervini *et al.*, 2003). Among the produced peptides, the caprine β-CN f58-65 and α_{s2}-CN f182-187 were also found to have ACE-inhibitory peptides (Table 2.24).

The ACE-inhibitory effect of goat protein hydrolysate (GP-hyd) diet in spontaneously hypertensive rats (SHR) were graphically demonstrated (Geerlings *et al.*, 2006). The systolic blood

Table 2.23 Total essential amino acids (EAA) and total branched-chain amino acids (BCAA) in primate and non-primate 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
Non-primate				
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 versus Non-primates ($P < 0.001$) and in humans and great apes versus lower primates ($P < 0.001$).

Source: Adapted from Davis *et al.* (1994).

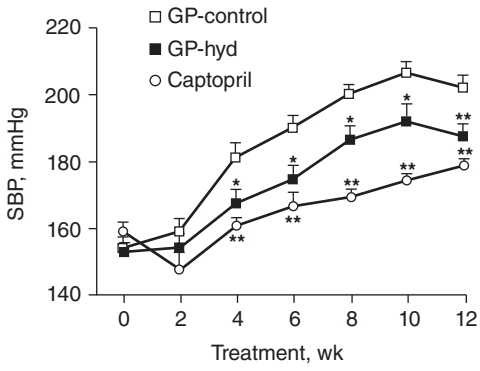

Figure 2.18 Systolic blood pressure (SBP) measured by tail-cuff plethysmography in spontaneously hypertensive rats (SHR) fed a diet containing goat protein(GP-control), an ad libitum diet containing goat protein hydrolysate (GP-hyd) diet, and a diet containing goat protein and captopril for 12 weeks. $^{*}P < 0.05$ and $^{**}P < 0.01$. *Source*: Adapted from Geerlings *et al.* (2006). Reproduced with permission of Elsevier.

pressure (SBP) of the goat protein (GP) control group showed a gradual increase from weaning that reached maximal values at 10 weeks of life (Figure 2.18). On the other hand, a long-term GP-hyd diet feeding partly prevented the increase in SBP in SHR, and this effect reached statistical significance after 4 weeks of treatment (Figure 2.18). Three new ACE- inhibitory peptides such as TGPIPN, SLPQ and SQPK were also isolated by the researchers, as shown in Table 2.24.

ACE-inhibitory and antioxidant active peptides in water-soluble extracts were obtained from raw and sterilized ovine and caprine cheese-like systems coagulated with enzymes of the plant *Cynara cardunculus* (Silva, Pihlanto, and Malcata, 2006). The peptides Tyr–Gln–Glu–Pro,

Table 2.24 Peptide fragment and sequence of bioactive peptides derived from goat milk and its cheese proteins.

Peptide fragment	Sequence	References
ACE inhibitory peptides		
Caprine α_{s1}-CN f(143-146)	AYFY	Lee *et al.* (2005a)
Caprine α_{s2}-CN f(4-8)	HPIKH	Minervini *et al.* (2003)
Caprine α_{s2}-CN f(174-179)	KFAWPQ	Quiros *et al.* (2005)
Caprine and ovine α_{s2}-CN f(203-208)	PYVRYL	Quiros *et al.* (2005) Lopez-Exposito *et al.* (2006)
Caprine β-CN f(58-65)	LVYPFPGP	Minervini *et al.* (2003)
Caprine β-CN f(78-83)	TGPIPN	Greerlings *et al.* (2006)
Caprine β-CN f(84-87)	SLPQ	Greerlings *et al.* (2006)
Caprine β-CN f(181-184)	SQPK	Greerlings *et al.* (2006)
Caprine β-Lg f(46-53)	LKPTPEGD	Hernandez-Ledesma *et al.* (2002)
Caprine β-Lg f(58-61)	LQKW	Hernandez-Ledesma *et al.* (2002)
Caprine β-Lg f(103-105)	LLF	Hernandez-Ledesma *et al.* (2002)
Caprine β-Lg f(122-125)	LVRT	Hernandez-Ledesma *et al.* (2002)
Caprine and ovine β-CN f(47-51)	DKIHP	Gomez-Ruiz *et al.* (2005, 2006)
Caprine κ-CN f(59-61)	PYY	Lee *et al.* (2005a)
Caprine and ovine κ-CN f(106-111)	MAIPPK	Manso and Lopez-Fandino (2003)
Antimicrobial/antibacterial peptides		
Caprine α_{s1}-CN f(24-30) (cheese)	VVAPFPE	Rizzello *et al.* (2005)
Caprine β-CN f(60-68) (cheese)	YPFTGPIPN	Rizzello *et al.* (2005)
Caprine β-CN f(183-187) (cheese)	MPIQA	Rizzello *et al.* (2005)
Caprine and ovine LF f(17-41)	ATKCFQWQRNM-RKVRGPPVSCIKRD	Vorland *et al.* (1998)
Caprine and ovine LF f(14-42)	QPEATKCFQWQRN-MRKVRGPPVSCIKRDS	Recio and Visser (2000)

Source: Adapted and reorganized from Park *et al.* (2007). Reproduced with permission of John Wiley & Sons.

Val–Pro–Lys–Val–Lys, and Tyr–Gln–Glu–Pro–Val–Leu–Gly–Pro–* from β-CN, as well as Arg–Pro–Lys and Arg–Pro–Lys–His–Pro–Ile–Lys–His–* from α_{s1}-CN exhibited ACE-inhibitory activity. The only peptides released upon cleavage of the peptide bond Leu190–Tyr191 of caprine or ovine β-CN, and corresponding to the β-CN sequence Tyr–Gln–Glu–Pro–*, were found to have antioxidant activity.

One Spanish goat milk cheese and Cabrales, Idiazabal, Roncal, Manchego, and Mahon sheep milk cheeses were found to have the ACE-inhibitory peptides that were virtually concentrated in the 1 kDa permeate. Most of these peptides including the peptide DKIHP [β-CN f(47–51)] were derived from α_{s2}- and β-CN (Gomez-Ruiz *et al.*, 2005, 2006).

ACE-Inhibitory Peptides Derived from Caprine Milk Whey

The hydrolysates of whey protein mainly β-lactoglobulin from goat and sheep milk have shown to have ACE-inhibitory activity (Hernandez-Ledesma *et al.*, 2002). Higher ACE-inhibitory activities were observed from the caprine and ovine β-Lg hydrolysates obtained with enzymes of microbial origin than those hydrolysates prepared with digestive enzymes. Four new ACE-inhibitory peptides were identified from the hydrolysate of caprine β-Lg prepared with termolisin (Table 2.24). These peptides were identified as β-Lg fragments f(46–53), f(58–61), f(103–105), and f(122–125), and their IC_{50} values ranged from 34.7 to 2470 μM. The peptide LLF was included within the sequence of opioid peptide β-lactorphin (YLLF).

Bovine, caprine, and ovine κ-CMP and their tryptic hydrolysates have moderate ACE inhibitory activity, which was increased considerably after digestion under simulated gastrointestinal conditions (Manso and López-Fandiño, 2003). Active peptides from CMP were produced via proteolysis with trypsin, that were identified as MAIPPK and MAIPPKK peptides, corresponding to κ-CN fragments f(106–111) and f(106–112), respectively (Table 2.24).

Antimicrobial Peptides Derived from Caprine Caseins

Antimicrobial peptide precursors in milk proteins can promote the organism's natural defenses against invading pathogens, whereby food proteins may be considered as components of nutritional immunity (Pellegrini, 2003). The total antibacterial effect in milk is generally expected to be greater than the sum of the individual contributions of immunoglobulin and non-immunoglobulin defense proteins such as lactoferrin (LF), lactoperoxidase, lysozyme, and peptides (Park *et al.*, 2007). This may account for the synergistic effect of naturally occurring proteins and peptides in addition to peptides generated from inactive protein precursors (Gobbetti, Minervini, and Rizzello, 2004).

Caprine milk caseins can be a source of antimicrobial peptides. Four antibacterial peptides have been identified from a pepsin hydrolysate of ovine α_{s2}-CN, which correspond to α_{s2}-CN fragments f(165–170), f(165–181), f(184–208), and f(203–208) (Lopez-Exposito and Recio, 2006). The fragments f(165–181) and f(184–208) are homologous to those previously identified in the bovine protein, where the fragment f(165–181) was shown to have the strongest activity against all bacteria tested (Recio and Visser, 1999). The peptide corresponding to ovine α_{s2}-CN f(203–208) has multifunctional peptides, since it exhibited not only antimicrobial activity but also potent antihypertensive and antioxidant activity (Recio *et al.*, 2005). The caprine proteins would have similar activities to these peptides, because the amino acid sequence of these peptides is the same in both caprine and ovine proteins (Park *et al.*, 2007).

Antimicrobial Peptides Derived from Caprine Milk Whey

Lactoferrin (LF) is the major iron-binding whey protein in milk. LF concentration in mammary gland of many species including human, mares, and goats increases markedly during clinical infection. Peptides derived from LF have antibacterial activities that have drawn much attention during the past few decades (Park *et al.*, 2007). The enzymatic release of antibacterial peptides

has more potent activity than the precursor LF. The antibacterial domains of bovine LF f(17–41) and human LF f(1–47) as bovine and human lactoferricin (LFcin), respectively, were purified and identified (Bellamy *et al.*, 1992).

A chemical synthesis of fragment f(17–41) of caprine LF was performed in caprine and ovine milk LF studies, and an antibacterial activity was observed that had a lesser extent than the bovine counterpart (Vorland *et al.*, 1998). Antibacterial hydrolysates were produced from the hydrolysis of caprine and ovine LF by pepsin. These hydrolyzed peptides were homologous to LFcin, corresponding to fragment f(14–42), which was identified in the caprine LF hydrolysate. The caprine LFcin had a lower antibacterial activity than bovine LFcin against *Escherichia coli* but comparable activity against *Micrococcus flavus* (Table 2.24). The ovine LF was hydrolyzed by the action of pepsin and ovine LF hydrolysate activity from the corresponding region to the LFcin was found within the sequence of LF (Recio and Visser, 2000).

Antithrombotic Peptides Derived from Caprine Milk Proteins

Antithrombotic agents including antithrombotic peptides derived from milk proteins would be important for their application in human health. Coronary heart diseases, such as blood clotting thrombosis, are among the leading causes of mortality of adult humans in industrialized countries (Park *et al.*, 2007). In blood coagulation, fibrinogen plays an important role, particularly because it binds to specific glycoprotein receptors located on the surface of the platelets, which allows them to clump.

Two very active sequences of antithrombotic peptides were found that have an inhibitory activity of human platelet aggregation induced by thrombin and collagen after hydrolysis of ovine κ-CMP with trypsin (Qian *et al.*, 1995). In addition, bovine, ovine, and caprine κ-CMP and their hydrolysates with trypsin acted as inhibitors of human platelet aggregation (Manso *et al.*, 2002). Bovine κ-CN derived peptide, casoplatelin, affected platelet function and inhibited both the aggregation of ADP-activated platelets and the binding of human fibrinogen γ-chain to its receptor region on the platelets surface (Jolles *et al.*, 1986). A smaller κ-CN fragment f(106–110), casopiastrin, exhibited platelet aggregation but did not affect fibrinogen binding to the platelet receptor, and was synthesized by trypsin hydrolysis (Jolles *et al.*, 1986; Mazoyer *et al.*, 1992). However, no report is available for the caprine κ-CN peptides.

Other Bioactive Peptides Derived from Caprine Milk

Because of the great homology among the sequences of bovine, ovine, and caprine milk proteins, bioactive peptides such as opioid, mineral binding, antioxidant, and anticarcinogenic peptides released from bovine proteins can also be found within goat and sheep proteins (Park *et al.*, 2007). A number of peptides with opioid activity isolated from hydrolysates of bovine milk proteins and probably caprine milk proteins can modulate social behavior, increase analgesic behavior, prolong gastrointestinal transient time by inhibiting intestinal peristalsis motility, exert antisecretory action, modulate amino acid transport, cause proliferation of apoptosis in different carcinoma cell lines, and stimulate endocrine responses such as the secretion of insulin and somatostatin (Clare and Swaisgood, 2000; Mader *et al.*, 2005).

Casein phosphopeptides (CPP) in milk can form soluble organophosphate salts and may function as carriers for different minerals, especially calcium in the intestine (Sato, Naguchi, and Naito, 1986). Calcium-binding CPP from ruminant milk may have anticariogenic effects by inhibiting caries lesions through recalcification of the dental enamel, along with competition from dental plaque-forming bacteria for calcium (Reynolds, 1987).

2.4.5 Non-protein Nitrogen (NPN) and Minor Proteins of Goat Milk

Goat and human milk contain much higher NPN levels than those in cow milk (Park, 1991; Table 2.19). As compared with cow milk, goat milk has a 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 (Juàrez and Ramos, 1986). Similar but a little higher (78.3%) casein content was reported in pygmy goats (Jenness, 1980). 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 (Rowland, 1937; Jenness and Patton, 1976). 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 (Park, 1991, 1992).

With regard to minor proteins, lactoferrin, transferrin, and prolactin contents of goat milk are comparable to those of cow milk (Table 2.19). Human milk contains more than 2 mg of lactoferrin/ml, which amounts to 10–100-fold higher than goat milk. Goat and cow milks 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 milks were 44 $\pm$ 5 (SE) and 50 $\pm$ l, respectively (Malven, 1977).

Goat milk has higher levels of folate-binding protein than cow milk, causing actual folate content being lower in the former than the latter (Table 2.19; Chandan *et al.*, 1992; Ford *et al.*, 1972; Renner *et al.*, 1989). Goat milk contains about 12 μg/ml of folate-binding protein, which is a glycoprotein with about 22% carbohydrate (Ford *et al.*, 1972; Rubinoff, Schreiber, and Wakman, 1977), and binds 9.2 μg of folic acid/mg of protein (Jenness, 1980).

Goat milk also contains immunoglobulins IgGs, IgA, and IgM as NPN. Goat milk has similar ranges of immunoglobulins to those of cow and sheep milks and colostrums (Table 2.19). As occur in minor whey proteins, caprine milk also has proteose-peptones as 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 (Rowland, 1937).

2.5 Polyamines and Nucleotides

2.5.1 Polyamines

Interest in the naturally occurring polyamines in the diet and their roles in cellular metabolisms has been greatly increased for the past 2–3 decades. The main polyamines include putrescine, spermidine, and spermine. These compounds are flexible polycations, fully charged under physiological pH conditions, essential for cell growth and proliferation, and exhibit various roles in cellular metabolism (Bardocz, 1995; Bardocz and White, 1999; Loser, 2000; Eliassen *et al.*, 2002; Gugliucci, 2004; Kalac and Krausova, 2005; Larque, Molina, and Zamora, 2007).

Many reports (Buts *et al.*, 1993; Motyl *et al.*, 1995; Poloszaj, Ryniewicz, and Motyl, 1997; Galitsopoulou, Michaelidou, and Polychroniaddou, 2007) have been available on polyamine concentrations of ruminant species milk (bovine, caprine, ovine) compared with those of human milk as shown in Table 2.25. Considerable quantitative interspecies and interbreed variations were reported in the polyamine pattern in mammalian milk. As the milking time advances, considerable changes occurred in polyamine concentrations, which may be attributed to the changes in the needs of the animals with age. Mature caprine milk has substantially higher polyamine contents especially in spermidine and putrescine than those in bovine and ovine milk. Human milk contains even much lower contents than bovine and ovine milks (Table 2.25; Buts *et al.*, 1993; Poloszaj, Ryniewicz, and Motyl, 1997).

Polyamins are involved in DNA, RNA, and protein synthesis and there is evidence to suggest they are intimately engaged in the control of cell growth. However, the most important function

Table 2.25 Average major polyamine (putrescine, spermidine, and spermine) concentrations in milk of various species (μmol/l).

Time post-partum	Putrescine	Spermidine	Spermine	References
Human				
2–4 days	0.60	2.90	1.20	Dunchen and Thorell (1999)
7 days	0.24	2.20	3.13	Buts *et al.* (1993)
7 days	0.33	2.24	2.76	Pollack, Koldovsky, and Nishioka (1992)
7 days	1.29	7.11	6.63	Romain *et al.* (1992)
16 days	0.77	4.54	3.76	Dorhout *et al.* (1996)
Mature milk	0.40	2.70	1.00	
Caprine				
1–3 days	0.40	3.57	2.27	
4–5 days	0.15	3.00	2.40	Galitsopoulou, Michaelidou, and Polychroniaddou (2007)
15 days	0.01	1.04	0.81	
Mature milk	6.00	39.67	3.18	Poloszaj, Ryniewicz, and Motyl (1997)
Mature milk	5.12	26.00	3.80	Poloszaj, Ryniewicz, and Motyl (1997)
Bovine				
Mature milk	–	4.7	4.00	Motyl *et al.* (1995)
Matuer milk	1	1–3	1–3	Bardocz *et al.* (1993)
Ovine				
1–3 days	0.50	1.61	2.05	
4-5 days	0.53	2.02	1.88	Galitsopoulou, Michaelidou, and Polychroniaddou (2007)
15 days	0.40	2.05	2.39	

Source: Adapted from Michaelidou (2008). Reproduced with permission of Elsevier.

of polyamines is to mediate the actions of all known hormones and growth factors, suggesting that every cell in our body requires polyamines for its proper function (Bardocz *et al.*, 1999). In addition, the importance of polyamines in cell function is reflected in a strict regulatory control of their intracellular levels.

Polyamine requirements that cannot be met by biosynthesis have to be provided by exogenous polyamines consumed from the food (Michaelidou, 2008). Dietary polyamine intake spares the organism the cost of de novo synthesis or salvage and may optimize tissue function (Jeevanandam *et al.*, 1997). This indicates that the importance of dietary polyamines depends on the physiological and pathological state of the individual. During periods of rapid growth, polyamine requirements are higher in both animals and human. Organs such as the gastrointestinal tract, pancreas, and spleen with a high cell turnover rate are especially dependent on dietary polyamines (Michaelidou, 2008).

Since gut maturation is sustained by dietary polyamines, it has been suggested that polyamine supplementation may be beneficial in formula-fed infants. Absorption of cow milk allergen may be decreased by dietary polyamines and also may reduce the risk of food allergy (Dorhout and Muskiet, 1999). Moreover, polyamines may be important for the fidelity of the enhanced DNA transcription and RNA translation that occurs in response to infection and during tissue repair, gut growth after surgery, and in gut barrier functions (Grimble and Grimble, 1998). In addition, dietary polyamines could be important in aging because cell proliferation slows down with age and ornithine decarboxylase activity also decreases (Nishimura, Shiina, and Kashwagi, 2006). On the contrary, there are certain situations where low dietary polyamines may be beneficial,

such as in certain tumor treatments (Gugliucci, 2004; Larque, Molina, and Zamora, 2007). Thus, the effect of polyamines on health may vary among people, in terms of its direction and magnitude.

2.5.2 Nucleotides

Nucleotides and nucleobases are the preferred forms for absorption in the intestine, and are suggested to be the acting components of dietary and/or supplemented nucleic acid-related compounds in the gut (Michaelidou, 2008). Nucleotides, nucleosides, and nucleobases belong to the non-protein nitrogen (NPN) fraction in milk. These minor compounds display species-specific patterns in the milk of different species and have a specific physiological impact in the early life of different mammals (Table 2.26). Schlimme, Martin, and Meisel (2000) made

Table 2.26 Average nucleotide[1] concentration in milk of various species (μmol/l).

Time post-partum	CMP	UMP	GMP	AMP	References
Human					
2 days	55.1	17.7	3.3	33.4	
15 days	26.4	7.0	–	26.0	Gil and Sanchez-Medina (1982)
Mature milk	18.3	9.3	–	15.1	
Mature milk	66.0	11.0	1.5	5.7	Thorell, Sjoberg, and Hernell (1996)
2 days	55.1	17.7	3.3	33.4	Boza (1998)
15 days	26.4	7.0	–	26.0	
Colostrum	23.0	6.8	1.0	1.4	Duchen and Thorell (1999)
Mature milk	61.5	6.4	1.0	1.9	
Bovine					
1–2 days	36.8	394.9	–	53.8	
5 days	30.2	28.7	8.3	31.5	Gil and Sanchez-Medina (1981)
15 days	49.0	–	–	29.1	
Mature milk	2.9	–	1.8	–	Tiemeyer, Stohrer, and Giesecke (1984)
Mature milk	26.6	Traces	Traces	Traces	Ferreira *et al.* (2001)
Ovine					
1–2 days	362.0	925.6	39.6	286.8	
3 days	104.3	1451.5	–	146.3	Gil and Sanchez-Medina (1981)
15 days	71.7	200.7	–	118.7	
Mature milk	48.6	110.7	Traces	54.1	Ferreira *et al.* (2001)
1–3 days	28.3	378.4	9.3	17.2	
4–5 days	31.4	300.9	9.7	16.3	Plakantara, Polychroniadou, and Michaelidou (2007)
15 days	21.6	250.3	4.1	18.3	
Caprine					
1–2 days	39.4	558.6	–	23.1	
5 days	80.7	123.7	–	110.0	Gil and Sanchez-Medina (1981)
15 days	22.8	160.8	9.9	27.9	
Mature milk	72.5	227.2	Traces	85.6	Ferreira et al. (2001)
1–3 days	20.2	292.0	8.8	20.3	
4–5 days	15.9	269.2	8.7	11.1	Plakantara, Polychroniadou, and Michaelidou (2007)
15 days	8.7	145.4	6.6	5.5	

[a] [1]UMP, uridyl-5′-monophosphate; CMP, cytidyl-5′-monophosphate; GMP, guanosyl-5′-monophosphate; AMP, adenosyl-5′-monophosphate.

Source: Michaelidou (2008). Reproduced with permission of Elsevier.

a detailed review on the compositional, trophochemical, biochemical, and technochemical aspects of nucleosides and nucleotides in bovine milk and colostrum.

Because of the bio- and trophochemical properties of dietary nucleosides and nucleotides, the European Commission has permitted the supplementation of specific ribonucleotide salts in the manufacture of infant and follow-on formulas. Increased interest in the role of nucleotides in infant nutrition has resulted in many scholarly publications on this research (Hamosh, 1997; Bohles, Gebhardt, and Beeg, 1998; Cosgrove, 1998; Michaelidou *et al.*, 1998; Carver, 1999; Gil and Rueda, 2002; Yu, 2002; Aggett *et al.*, 2003; Alles, Scholtens, and Bindels, 2004).

The significance of various actions of nucleotides, especially to pre-term and gestational age infants, have long been recognized, where this premise also could be applied to different clinical situations. Effectiveness in human cell model systems implies that modified nucleosides may inhibit cell proliferation and activate apoptosis (Michaelidou, 2008). Food-derived inducers of apoptosis may be significant as exogenous anticarcinogens in the control of malignant cell proliferation, where the intestinal tract could be the primary target site for a possible selective apoptotic stimulant against malignant cells (Schlimme, Martin, and Meisel, 2000).

Dietary nucleotides further influence biosynthetic processes and modulate gene expression, at least on those genes involved in nucleotide metabolism (Sanchez-Pozo and Gil, 2002). Supplementation of nucleosides and nucleotide is beneficial to the functions of the system and the brain, but effects on the gut appear to depend on the type of damage (Yamamoto *et al.*, 1997). Caprine and ovine milks could be of interest in this regard.

2.6 Enzymes

Distribution of enzymes in goat milk is quite different from that in cow milk (Table 2.18; Chilliard *et al.*, 1984; Chandan *et al.*, 1992). The ribonuclease level in cow milk is much greater than in goat milk, where this enzyme is identical to bovine pancreatic ribonuclease (Juàrez and Ramos, 1986). Lysozyme concentrations of goat and cow milks are comparable (Table 2.27)as the characteristics of lysozyme content in artiodactyls' milks are in the low range (Parkash and Jenness, 1968). 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 (Chandan *et al.*, 1968).

Alkaline phosphotase content in goat milk ranged from 11 to 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 (Juàrez and Ramos, 1986). 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

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 (μeq FFA/h/ml)[a]	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 (μeq FFA/h/ml)[a]	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.

Source: Adapted from Chilliard *et al.* (1984). Reproduced with permission of Elsevier.

cow milks (Kuzuya, Kanamaru, and Tanahashi, 1984). Caprine AP (molecular weight 43 000) contained 297 residues and bovine AP (molecular weightt 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 (Kuzuya, Kanamaru, and Tanahashi, 1984).

Xanthine oxidase activity of goat milk is less than 10% of that of cow milk (Chandan *et al.*, 1992). Caprine xanthine oxidase contains higher amounts of aspartic acid, glutamic acid, proline, and glycine and lower amounts of serine than bovine xanthine oxidase (Zikakis, Dressel, and Silver, 1983). 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 (Juàrez and Ramos, 1986). Xanthine oxidase has also 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 the development of atherosclerosis in humans (Juàrez and Ramos, 1986). 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 does not appear to be attributed to the lack of molybdenum (Jenness, 1980).

Goat milk contains less lipase than cow milk (Chilliard *et al.*, 1984; Haenlein and Caccese, 1984). 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 cow counterparts (Table 2.27).

Goat milk has in average of 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) (Jenness, 1980). 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, which transfers sialic acid from cytidine monophosphate-sialic acid to lactose or *N*-acetyllactosamine (Jenness, 1980).

2.7 Minerals

Goat milk contains about 134 mg of Ca and 121 mg of P/100 g (Table 2.28). Human milk contains only one-fourth to one-sixth of these minerals. Although the macromineral 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 (Park and Chukwu, 1988). In underdeveloped countries, where meat consumption is low, goat milk is an important daily food souce of animal protein, phosphate, and calcium due to lack of availability of cow milk (Haenlein and Caccese, 1984; Park, 1991, 1992). Goat milk has higher calcium, phosphorus, potassium, magnesium, and chlorine, and lower sodium and sulfur contents than cow milk (Table 2.28; Chandan *et al.*, 1968; Haenlein and Caccese, 1984; Park and Chukwu, 1988, 1989).

There is a close inverse relationship between lactose content and the molar sum of sodium and potassium contents of goat or other species milks (Konar *et al.*, 1971; Park and Chukwu, 1988). Chloride is positively correlated with potassium and negatively with lactose, but sodium

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 (IU)	185	126	190
Vitamin D (IU)	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

Source: Data from Posati and Orr (1976), Park and Chukwu (1988, 1989), Jenness (1980), Haenlein and Caccese (1984), and Debski, Picciano, and Milner (1987).

is not significantly correlated with K, Cl, and lactose. The major minerals in goat milk during the first 7 weeks of lactation showed substantial fluctuations (Maraval and Vignon, 1982). The macrominerals 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 the stage of lactation, while citrate concentration in goat milk decreased during lactation. Cow milk has a more stable citrate level during lactation (Konar et *al.*, 1971). 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 (Maraval and Vignon, 1982). Citrate is a kind of harbinger of lactogenesis in goats (Peaker and Linzell, 1975), where its level in mammary secretion increases sharply from virtually nil to the normal 150–200 mg/100 ml on the day of parturition (Peaker and Linzell, 1975). The total carbon dioxide and carbonate in freshly drawn goat milk was 3.4 mM, and of this CO_2, 1.9 mmoles/liter was in the form of bicarbonate ion (Linzell and Peaker, 1971).

Concentrations of trace minerals are affected by diet, breed, animals, and stages of lactation (Park and Chukwu, 1989). 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 versus 1.69 mg/l) and Zn (7.9 versus 11.9 mg/l) (Park and Chukwu, 1989). A positive correlation was observed between levels of Co and P, K, Na, Ca, Al, and Mg in Norwegian bulk goat milk (Brendehaug and Abrahamsen, 1987).

Zinc content is the greatest among the trace minerals, and Zn in goat and cow milks are greater than in human milk (Park and Chukwu, 1989). Iron contents of goat and cow milks are significantly lower than in human milk (Table 2.28). On the other hand, goat and cow milks 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 (Underwood, 1977).

Goat and human milks contain higher concentrations of selenium than cow milk (Table 2.28). 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 milks. Goat milk total peroxidase activity (associated with glutathione peroxidase) was 65% as opposed to 29% for human and 27% for cow milk (Debski, Picciano, and Milner, 1987).

Goat and cow milks have an average of 12.4 and 25.9 μg/l of Mo, respectively (Hart, Owen, and Proudfoot, 1967). The supplementation of 1.1 mg of Mo/day in a goat's diet produced 12 μg/l of Mo in milk, while 13.0 mg of Mo/day elevated Mo in milk to approximately 70 μg/l. It was also reported that goat, cow, and human milks contained 2.6, 1.1–2.2, and 0.42 mg/l of borate, respectively (Jenness, 1980).

2.8 Vitamins

Goat milk has higher amounts 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; Ford *et al.*, 1972; Parkash and Jenness, 1968). 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 (Jenness, 1980). Vitamin B levels in goat and cow milks are a result of rumen synthesis, and are somewhat independent of diet (Haenlein and Caccese, 1984; Mann, 1988).

Goat milk, however, has a significant drawback in deficiencies of folic acid and vitamin B_{12} as compared to cow milk (Collins, 1962; Davidson and Townley, 1977; Haenlein and Caccese, 1984; Jenness, 1980; Park, Mahoney, and Hendricks, 1986). Cow milk has 5 times more folate and vitamin B_{12} than goat milk, where folate is necessary for the synthesis of hemoglobin (Collins, 1962; Davidson and Townley, 1977). Vitamin B_{12} deficiency has been reportedly implicated in "goat milk anemia," which is a megaloblastic anemia in infants (Parkash and Jenness, 1968). 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, where these vitamins must be supplemented from other food sources (McClenathan and Walker, 1982).

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 (Lavigne *et al.*, 1989). 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 (Lavigne *et al.*, 1989).

3 Physicochemical Characteristics of Goat Milk

3.1 Physicochemical 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

Table 2.29 Comparison of physicochemical characteristics and micelle structure of goat milk with those of cow milk.

Characteristics	Goat milk	Cow milk
Physicochemical 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, Lakshmanan, and Rao (1985).
[b] Remeuf and Lenoir (1986).

cow milk, indicating that goat milk fat contains higher unsaturated fatty acids than the cow counterpart. The saponification value is higher and the refractive index is slightly 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 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 (Tziboula-Clarke, 2003).

Some interesting differences are found in the Reichert Meissl value and the Polenske value between goat and cow milks (Table 2.29). Goat milk has a 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 (Remeuf and Lenoir, 1986), where these variations are attributed to individual factors such as animal, lactation period, and sample differences (Parkash and Jenness, 1968; Loewenstein *et al.*, 1980).

The relative proportions of the major components of goat casein are very much different from those of cow milk (Remeuf and Lenoir, 1986). Goat milk is less in α_s-casein and often contains much more α_{s2}-casein than α_{s1}-casein. Nevertheless, the latter is present in highly variable amounts depending on the individual goats (Mora-Gutierrez *et al.*, 1991). 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 lose β-casein more readily than bovine micelles (Jenness, 1980). Non-centrifugal casein and the average diameter of micelles of goat milk are significantly greater than those of cow milk (Remeuf and Lenoir, 1986). 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 2.29; Soods, Gaind, and Dewan, 1979; Remeuf and Lenoir, 1986).

Goat milk contains more soluble casein than cow milk. At 20 °C, goat and cow milk have 10 and 1% soluble casein, while 25 and 10% at 5 °C, respectively (Juàrez and Ramos, 1986). Low storage temperatures have a marked influence on the micellar system. Cooling leads to a partial solubilization of colloidal calcium phosphate and of β-casein (O'Connor and Fox, 1973). These modifications are responsible for an alteration of cheese-making properties of milk, especially a decrease in cheese yield. Caprine β-casein is more soluble on cooling than its bovine homolog (O'Connor and Fox, 1973).

Low casein content and probably other characteristics such 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. A high ionic calcium content and low micellular solvation in caprine milk may contribute to heat instability (Remeuf, 1992).

3.3 Relationship between Physicochemical Properties and Rennetability

The renneting time and the maximum firmness of the gel are found on a scale of 1 to 4 and the setting speed on a scale of 1 to 9 (Remeuf and Lenoir, 1986). 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 (Storry *et al.*, 1983). 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 (Parkash and Jenness, 1968; Remeuf and Lenoir, 1986). 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 mainly influenced by the pH value of the milk (Remeuf and Lenoir, 1986).

The casein concentration of the milk has a strong effect on rheological properties of the rennet gel, its setting speed, and its maximum firmness (Remeuf and Lenoir, 1986). 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 (Storry *et al.*, 1983). There are also significant correlations between the levels of colloidal Ca and inorganic phosphorus and the firmness of the gel or its setting speed (Storry *et al.*, 1983).

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 (1953) fed one-half of them 0.946 liter of goat milk and the other half 0.946 liter of cow milk daily for 5 months. She observed that children in the goat milk group surpassed those on cow milk in weight gain, statue, skeletal mineralization, bone density, blood plasma vitamin A, calcium, thiamine, riboflavin, niacin, and hemoglobin concentrations. Statistical differences were minimal for blood hemoglobin and various other biochemical and structural measurements between the two groups.

Most milks, including human milk, are deficient in iron contents (Table 2.28 and Figure 2.19). In an iron bioavailability study of goat and cow milks using anemic rats, Park, Mahoney, and

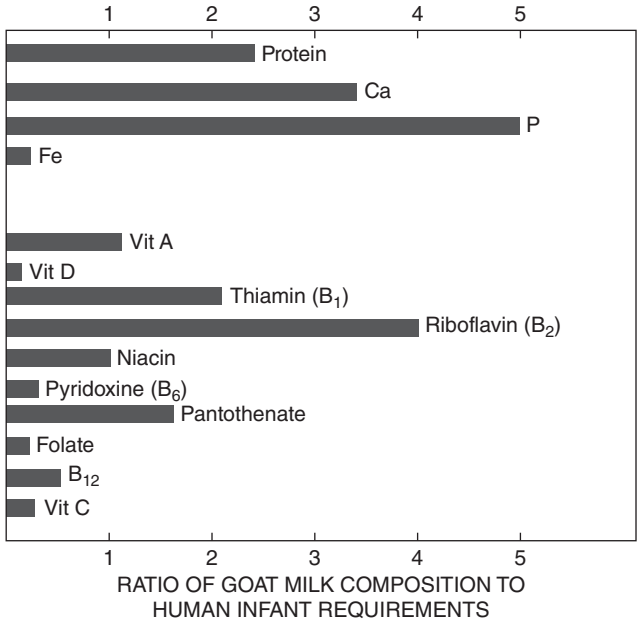

Figure 2.19 Nutrients in goat milk in relation to requirements of human infants. *Source:* Adapted from Jenness (1980). Reproduced with permission of Elsevier.

Hendricks (1986) 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 2.20). Goat milk has been blamed

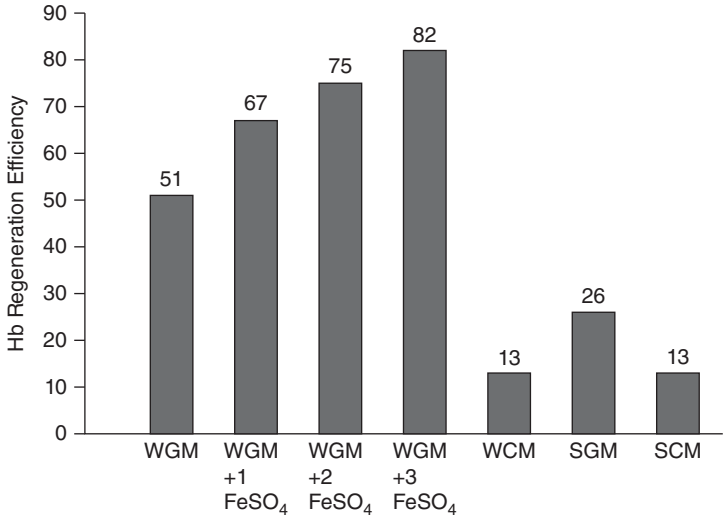

Figure 2.20 Hemoglobin regeneration efficiencies (HRE) of whole goat milk (WGM) diet, hole goat milk diet supplemented with 50, 100, or 200 ppm ferrous sulfate, whole cow milk (WCM) diet, skim goat milk diet, or skim cow milk diet fed to anemic growing rats for 10 days. HRE for WGM is significantly greater than that for WCM ($P < 0.01$) and SGM is greater than the SCM group ($P < 0.05$). *Source:* Adapted from Park, Mahoney, and Hendricks (1986). Reproduced with permission of Elsevier.

for the development of "goat milk anemia" due to the deficiency of folic acid in the milk (György, 1934; Collins, 1962; Nicol and Davis, 1967; Davidson and Townley, 1977; Park, Mahoney, and Hendricks, 1986). "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 (György, 1934). 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 the protein level and to be fortified with lactose and certain vitamins before feeding to babies, especially under 6 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 (Babayan, 1981; Haenlein, 1992). 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 (Chandan *et al.*, 1968; Jenness, 1980; Park, 1994b), (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 (Greenberger and Skillman, 1969; Kalser, 1971), and (iii) they also have been therapeutically used for treatment of various cases of malabsorption in patients suffering from steatorrhea, chyluria, hyperlipoproteinemia, and, in the case of intestinal resection, coronary bypass, childhood epilepsy, premature infant feeding, cystic fibrosis, and gallstones (Niv, Levy, and Greenstein, 1963; Greenberger and Skillman, 1969; Tantibhedhyangkul and Hashim, 1975; Mann, 1977; Jailkhani and De, 1979; Deeth and Tamime, 1981; Haenlein, 1992; Park, 1994b).

Fat in human milk is absorbed more readily by infants than fat from cow milk (Fomon, 1974). This is probably due to the difference in arrangement of fatty acids in the triglycerides (Jenness, 1980). 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 (Fomon, 1974; Jenness, 1980). If palmitic acid is located in the 2-position, the digestive and absorptive processes are shown to be greatly enhanced. 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 (Chandan *et al.*, 1968; Devendra and Burns, 1970; Haenlein and Caccese, 1984; Park, 1994b) 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 (Devendra and Burns, 1970; Park, 1994b).

Goat milk is reported to have greater buffering capacity, which would be beneficial for treatment of stomach ulcers (Devendra and Burns, 1970; Haenlein and Caccese, 1984; Park, 1991; Park, 1992a, 1994a). Nubian goat milk contained significantly higher levels of major buffering entities, such as proteins, non-protein N, and phosphate (P_2O_5) than cow milk (Holstein and Jersey; Park, 1991, 1992a), 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 (Rosenblum and Rosenblum, 1952; Walker, 1965; Taitz and Armitage, 1984; Park, 1994b), 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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