

Nutritional Value and Technological Suitability of Milk from Various Animal Species Used for Dairy Production

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Abstract: The analysis of nutritional value and selected traits of technological suitability of milk was performed on the basis of the available literature. This analysis concerned various animal species used for dairy purposes (cattle, buffalo, goats, sheep, camels, donkeys, and horses). It has been stated that a considerable diversity exists in the analyzed parameters and traits of milk, which results in various directions of milk utilization. Cow milk accounts for more than 80% of world milk production. It is the most universal raw material for processing, which is reflected in the broadest spectrum of manufactured products. Sheep and buffalo milk, regarding their high content of protein, including casein, and fat, make a very good raw material for processing, especially cheesemaking. Donkey and horse milk have the most comparable protein composition to human milk (low content of casein, lack of α_{s1} -casein fraction and β -lactoglobulin, and high content of lysozyme). Donkey milk is additionally characterized by a fatty acid profile distinctive from milk of other analyzed animal species. Camel milk also has valuable nutritional properties as it contains a high proportion of antibacterial substances and 30 times higher concentration of vitamin C in comparison to cow milk. The composition of goat milk allows using it as the raw material for dairy processing and also to some extent as a therapeutical product (low content or lack of α_{s1} -casein).

Introduction

The history of milk begins in the Neolithic Age, a time when humans started the transition from hunting and gathering to a more settled way of life. This, in turn, allowed for new possibilities of adapting resources to acquire food. The most important, together with agricultural development, was the domestication of animals, which meant constant access to their meat, fur, and of course milk. The first attempts to domesticate ruminants (goats, cows, and sheep) began 11,000 y ago in the Middle East. Throughout the centuries, milk became a desirable and valuable food source wherever livestock animals were bred.

Global Milk Production

Cattle are the most significant species in dairy production. At present, the number of animals bred for dairy purposes is numerous. Different regions around the world have adapted the particular species common to their area for the purpose of producing milk. In many regions of the world buffalo milk is often used. Camel milk is consumed in various countries that rear camel, such as

Kenya, Somalia, Ethiopia, and Pakistan. Latin America has a wide variety of ruminants to choose from including camelids and llamas. Moose milk is popular in Russia and Sweden, whereas in Mongolia horse milk is commonly consumed and yak milk is used in Tibet. Sápmi habitats have been using reindeer milk for hundreds of years. The latest nutritional discovery is donkey milk, which is exceptionally similar to human milk in terms of protein composition. This similarity has made donkey milk tremendously interesting for nutritionists, as it is thought to be less prone to cause allergy.

Currently, global milk production is dominated by 5 animal species: dairy cattle, buffalo, goats, sheep, and camels. According to FAO Statistical Databases (2010) for the year 2009, the total world milk production accounted for 696.6 million kg³ of which 83.3% (580.5 million kg³) was cow milk, 13% (90.3 million kg³) buffalo milk, 2.2% (15.1 million kg³) goat milk, 1.3% (9 million kg³) sheep milk, and 0.2% (1.6 million kg³) camel milk.

The major cow milk producers worldwide are The European Union (148.1 million kg³), The United States of America (85.9 million kg³), India (45.1 million kg³), and Russia (32.3 million kg³). The production of buffalo milk is concentrated in 2 countries. Nearly 92% of its worldwide production is in India (60.9 million kg³) and Pakistan (21 million kg³). The largest producers of goat milk in the world are India (26.3%) and Bangladesh (14.3%), and leaders among the European countries are France (3.8%) and Greece (3.3%). The world's major producer of sheep milk is China (12.2%). The leaders in Europe include Greece

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(8.7%), Turkey (8.2%), Romania (7.2%), and Italy (6.1%). Camel milk is almost exclusively produced in Somalia (54.4%), Ethiopia (11.9%), Mali (8.1%), Sudan (7.5%), and Saudi Arabia (5.6%).

Nutritional Value

Data displayed in Table 1 present substantial variability in the basic chemical composition of milk from various animal species. A meta-analysis of literature data (statistical group $n = 30$) was applied for the 5 species of greatest importance in world milk production. This analysis allowed showing average values of basic milk components (protein, fat, and lactose) and to some extent minimize the impact of factors altering the milk composition, such as breed, feeding system, stage of lactation, or time of year (Table 1). The energy value of milk from various animal species is closely related to the concentration of certain compounds in dry matter, especially the amount of fat. The highest energy value is characteristic of sheep milk—5932 kJ/kg (Park and others 2007), lower than cow milk—3169 to 3730 kJ/kg (Barłowska 2007), buffalo milk—3450 kJ/kg (Kanwal and others 2004), camel milk—3283 kJ/kg (Shamsia 2009), and goat milk—3018 kJ/kg (Park and others 2007). The lowest energy value is specific of donkey milk—1842 to 2051 kJ/kg (Guo and others 2007), horse milk—2080 to 2453 kJ/kg (Ofstedal and others 1983), and human milk—2407 kJ/kg (Shamsia 2009).

Milk proteins

The main component of milk, which has a major impact on its nutritional value and technological suitability, is protein. Milk proteins are a heterogeneous group of compounds that differ in composition and properties. They are divided into casein complexes and whey protein fractions. Casein is the most important protein in milk, while the proportion of whey proteins is relatively low. Guo and others (2007) reported that the content of whey proteins in human milk is in the range of 0.68 to 0.83 g/100 g; in cow milk 0.55 to 0.70; 0.49 to 0.80 in donkey milk, and 0.74 to 0.91 g/100 g in horse milk. Sheep milk is the richest in whey proteins—1.02 g/100 g (Dario and others 2008) and also contains the highest concentration of casein—4.18 g/100 g (Dario and others 2008), similarly to buffalo milk, which contains 4.0 g of casein in 100 g of milk (Polidori and others 1997; Zicarelli 2004). Almost half less of casein is in cow milk, 2.46 to 2.80 g/100 g (Zicarelli 2004; Guo and others 2007); goat milk—2.81 g/100 g (Leitner and others 2004); and camel milk—2.21 g/100 g (Khaskheli and others 2005). Human milk also contains casein; however, in small amounts—0.32 to 0.42 g/100 g (Guo and others 2007); therefore, the ratio between whey proteins and casein is very high, 2.08, as mentioned by Shamsia (2009). Donkey and horse milk are also characterized by a low content of casein fraction, respectively, 0.64 to 1.03 g/100 g and 0.94 to 1.2 g/100 g (Guo and others 2007).

Currently there are 4 main casein fractions distinguished: α_{s1} -, α_{s2} -, β -, and κ . Their proportion is diverse and polymorphism of these proteins was demonstrated in most of the animal species (Litwińczuk and others 2006; Barłowska 2007; Barłowska and others 2007). The first report of the polymorphic status of milk proteins was made by Aschaffenburg and Drewry (1955). Since that time many research centers have started exploring polymorphism of various milk proteins in the milk of most of the animals used for dairy purposes. These large-scale experiments have been aimed at the possibility of using genetic variants of milk proteins as markers of production traits, especially in various breeds of dairy cattle and goats.

The human casein does not contain the α_{s1} -fraction, which is the predominant factor causing milk protein allergies. However, it is rich in the β -fraction (Sood and others 1997). Conversely, casein in cow and buffalo milk is very abundant (38.4% and 30.2% of total casein, respectively) in the α_{s1} -fraction (Zicarelli 2004). Additionally, human milk does not contain β -lactoglobulin, the main whey protein in ruminant milk. Human milk is the most natural and perfectly composed food for human infants, but in cases when breast-feeding is not possible, cow milk is commonly used as a substitute for human milk (El-Agamy 2007). The lower casein and higher whey protein contents in human milk make it very nutritious for a newborn due to the resultant soft coagulum after milk ingestion, thus digestibility and absorption of soluble proteins are higher, while ingested cow milk gives a firm coagulum more difficult to digest (Malacarne and others 2002; Shamsia 2009). Moreover, this substitution can cause not only nutritional but also immunological problems, such as allergy to milk proteins (El-Agamy 2007). Milk protein allergy (MPA) is an allergic reaction to proteins commonly found in cow milk. It is caused by the immune system reacting to the milk proteins as they would present a threat to the body. An activated immune system reacts just as it would to a foreign virus or a toxin (Shabo and others 2005). In rare cases, such allergies can occur in breast-fed infants, and even in the fetus (Rudzki 2005). This is because trace amounts of β -lactoglobulin can appear in the pregnant woman's body fluids as well as in her milk. Such cases occur when a woman ingests cow milk (Sorva and others 1994). β -Lactoglobulin is resistant to gastric pepsin hydrolysis, therefore it passes through the intestinal membrane into the bloodstream in almost native form (Lara-Villoslada and others 2005). Several studies have demonstrated that the majority of children with cow milk protein allergy (CMPA) synthesize antibodies predominantly against α -casein and β -lactoglobulin (Lara-Villoslada and others 2005). Cow milk contains more than 20 proteins with allergic potential (El-Agamy 2007). Rudzki (2005) reported that β -lactoglobulin sensitizes up to 80% of patients with CMPA, while α_{s1} -casein about 60% of patients. Cow milk has a very high proportion of these 2 proteins. Bobe and others (2007) reported that in cow milk the casein content accounts for 86.01% of total protein, α_{s1} - for 31.42%, whey proteins for 14.12%, and β -lactoglobulin for 10.37%. In terms of infant nutrition, it is a rather unfavorable ratio between casein and whey proteins, therefore it is modified to obtain a proportion closer to 40:60, which may bring the composition of cow milk to that of human milk, and thus reduce the incidence of CMPA (Lara-Villoslada and others 2005). Some infants and children allergic to cow milk will have an allergic reaction after ingesting buffalo, goat, sheep, donkey, and horse milk proteins due to the presence of positive immunological cross-reaction with their counterparts in cow milk (El-Agamy and others 2009). However, it is considered that donkey, camel, and goat milk may be good substitutes of human milk. Donkey milk is the most similar to human milk in terms of composition of protein fraction (Tesse and others 2009), it has a low content of casein, and a relatively high (53.03 to 57.06% of total protein) content of whey protein (Guo and others 2007). Additionally, it is characterized by the lack of α_{s1} -casein and has a different structure of β -lactoglobulin. Equine β -lactoglobulin is without the free SH and in a monomeric form even at neutral pH, whereas in cow milk it is in a dimeric form at neutral pH and has a free SH (Sugai and others 1999). Donkey milk also contains large amounts of lysozyme (13.13 to 15.34% of total protein) in contrast to cow, sheep, and goat milk (Vincenzetti and others 2005). It is therefore a more abundant

Table 1–Basic chemical composition of milk from various animal species.

Species		Protein%	Fat%	Lactose%	References
Cattle (<i>Bos taurus</i>)	Mean <i>n</i> = 30	3.42	4.09	4.82	Auld and others (2000); Barłowska and Litwińczuk (2006); Barłowska; (2007); Calsamiglia and others (2007); Carroll and others (2006); Ceballos and others (2009); Chiofalo and others (2000); De Marchi and others (2007); Flowers and others (2008); Kay and others (2005); Kędzierska-Matysek and others (2011); Leiber and others (2006); McCarthy and others (2007); Ménard and others (2010); Schroeder and others (2003); Slačanac and others (2010); Stoop and others (2008); Tsenkova and others (2000)
	SD	0.35	0.46	0.21	
	Min	2.54	3.23	4.40	
	Max	4.19	5.34	5.33	
Buffalo (<i>Bubalus bubalis</i>)	Mean <i>n</i> = 30	4.38	7.73	4.79	Abo El-Nor and others (2007); Abou Donia and others (2010); Ahmad and others (2008); Bansal and others (2007); Bilal and others (2006); Bufano and others (2006); Chashnidel and others (2007); Devendra (1980); Enb and others (2009); Faruque and Hossain (2007); Han and others (2007); Kanwal and others (2004); Khan and others (2007); Ménard and others (2010); Osthoff and others (2009); Pandya and Khan (2006); Pece and others (2007, 2009); Peeva (2001); Tzankova (2001)
	SD	0.71	1.92	0.68	
	Min	3.44	4.90	2.95	
	Max	6.29	13.39	6.10	
Sheep (<i>Ovis aries</i>)	Mean <i>n</i> = 30	5.73	6.99	4.75	Ahmad and others (2008); Dario and others (2008); Giaccone and others (2005); Haenlein and Wendorff (2006); Jandal (1996); Jaramillo and others (2008); Kuchtik and others (2008); Martini and others (2008); Mikulec and others (2008); Molik and others (2008); Nudda and others (2002); Park and others (2007); Raynal-Ljutovac and others (2008); Recio and others (1997); Şahan and others (2005); Slačanac and others (2010); Tsiplakou and others (2008, 2009)
	SD	0.61	1.23	0.35	
	Min	3.35	4.10	3.70	
	Max	6.60	9.30	5.21	
Goat (<i>Capra hircus</i>)	Mean <i>n</i> = 30	3.26	4.07	4.51	Bernacka (2005, 2006); Ceballos and others (2009); Dámian and others (2008); Dønnem and others (2011); Jandal (1996); Jenness (1980); Kanwal and others (2004); Kondyli and others (2007); Konyali and others (2010); Kuchtik and Sedlackova (2003); Laudadio and Tufarelli; (2010); Luna and others (2008); Park (2006); Raynal-Ljutovac and others (2008); Riek and Gerken (2006); Savoini and others (2003); Sawaya and others (1984b); Slačanac and others (2010); Todaro and others (2005); Tsiplakou and others (2009); Vacca and others (2010)
	SD	0.46	0.76	0.26	
	Min	2.38	3.06	4.08	
	Max	4.43	6.02	5.09	
Camel (<i>Camelus</i>)	Mean <i>n</i> = 30	3.26	3.80	4.30	Abu Lehia (1987); Abu Lehia and others (1989); Al Haj and Al Kanhal (2010); Al-Dobaid (2009); Bakheit and others (2008); Eisa and Hassabo (2009); El-Agamy (2006); Elamin and Wilcox (1992); Farah and Rüegg (1989); Faye and others (2008); Gnan and Sheriha (1986); Guliye and others (2000); Hassan and others (1987); Kamal and others (2007); Khaskheli and others (2005); Knoess and others (1986); Konuspayeva and others (2009b); Mehaia and others (1995); Omer and Eltinay (2009); Sawaya and others (1984a); Shamsia (2009); Shuipe and others (2008); Wangoh and others (1998); Zeleke (2007)
	SD	0.80	1.11	0.78	
	Min	2.06	2.35	2.77	
	Max	5.23	6.67	5.85	
Llama (<i>Lama glama</i>)		4.20	4.70	5.90	Riek and Gerken (2006)
Alpaca (<i>Lama pacos</i>)		3.90	3.20	5.60	Riek and Gerken (2006)
Vicuna (<i>Vicugna vicugna</i>)		3.70	4.60	7.40	Riek and Gerken (2006)
Yak (<i>Bos grunniens</i>)		3.51	5.80	3.90	Sheng and others (2008)
Reindeer (<i>Rangifer tarandus</i>)		9.90	15.50	1.20	Gjostein (2004)
Zebra (<i>Equus burchelli</i>)		1.63	2.20	7.00	Oftedal and Jenness (1988)
Horse (<i>Equus caballus</i>)		1.90	1.30	6.90	Caroprese and others (2007); Oftedal and Jenness (1988);
		1.99	1.63	6.91	Riek and Gerken (2006)
		1.82	1.46	6.74	
		1.72	0.38	6.88	
Donkey (<i>Equus asinus</i>)		1.59	0.28	6.73	Chiavari and others (2005); Oftedal and Jenness (1988);
		1.74	1.82	5.87	Salimei and others (2004)

source of this enzyme than human milk is, with the participation of this enzyme accounting for 3.49% of total protein (Guo and others 2007). Lysozyme has bactericidal and bacteriostatic properties, which may help to protect children against intestinal infections (Chiavari and others 2005; Vincenzetti and others 2005). Camel milk may be another good substitute for human milk (Konuspayeva and others 2009a) as it does not contain β -lactoglobulin, a typical milk protein characteristic of ruminant milk (Laleye and others 2008). The camel is not a member of *Ruminantia*, even though it ruminates, it is classified as

Tylopoda (Shabo and others 2005). Another crucial anti-allergenic factor is that the functional components of camel milk include immunoglobulins similar to those in human milk, which are known to reduce children's allergic reactions and strengthen their future response to foods (Shabo and others 2005). El-Hatmi and others (2007) reported that camel milk contains higher amounts of antibacterial substances (for example, lysozyme, lactoferrin, and immunoglobulins) as compared to cow and buffalo milk. Goat milk is often considered to be less allergenic than cow milk. This opinion is not fully confirmed as their protein compositions are quite

similar. Goat milk is less prone to cause allergic reaction mainly due to lower participation of α s₁-casein (5% of the total casein), or total lack of this protein fraction occurring in individuals with mutations defining “zero” allele of α s₁-casein, namely, *CSN1S1* (Ramunno and others 2001). Lara-Villoslada and others (2005) explain further that the lower allergenicity of goat milk compared to cow milk is due to the fact that a lower share of α s₁-casein reduces the sensitivity to the other allergen protein, namely, β -lactoglobulin. In addition, the digestion of β -lactoglobulin (aforementioned as resistant to gastric pepsin hydrolysis), might be facilitated by the lower casein content.

Data concerning the concentration of amino acids in milk from various animal species (Table 2) clearly show that the best composition of exogenous amino acids can be found in the milk of goats and sheep. They fully cover the requirement for those amino acids. It is worth noting that in milk from buffalos, cows, and horses, cysteine is the limiting amino acid; furthermore, methionine is also a limiting amino acid, while in camel milk lysine is the limiting amino acid. Guo and others (2007) stated that donkey milk has a higher concentration of valine and lysine compared to cow, goat, sheep, buffalo, and horse milk. Kamal and others (2007) demonstrated that camel milk contains more methionine, valine, phenylalanine, arginine, and leucine than cow milk.

Milk lipids

Fat is the major substance defining milk's energetic value and makes a major contribution to the nutritional properties of milk, as well as to its technological suitability. Milk fat is synthesized in the milk cells of the udder. Lipids form inclusions, which gradually increase in size, and finally migrate to the upper part of cell from which they are shed as globules into the collecting lumen. Milk fat globules have an average diameter of less than 0.1 μ m to approximately 18 μ m (El-Zeini 2006) and consist of a triglyceride core surrounded by a natural biological membrane. The milk fat globules membrane (MFGM) contains the typical components of any biological membrane such as cholesterol, enzymes, glycoproteins, and glycolipids (Fauquant and others 2007). Mansson (2008) claims that lipids build 30% of the membrane and can be further

broken down into the following groups: phospholipids (25%), cerebrosides (3%), and cholesterol (2%). The remaining 70% of the membrane consists of proteins. The average diameter of milk fat globules varies depending on the animal species (Table 3). Fat globules with the biggest average diameter are found in buffalo milk (8.7 μ m), the smallest in camel (2.99 μ m) and goat milk (3.19 μ m). A comparison of the dispersion state of fat in cow and goat milk performed by Attaie and Richter (2000) resulted in the statement that the average diameter of milk fat globules in goat milk was 2.76 μ m (with a range of 0.73 to 8.58 μ m) and 3.51 μ m for cow milk (with a range of 0.92 to 15.75 μ m). Goat milk fat globules occupy a surface area of 21,778 cm²/mL, while in cow milk this area is 17,117 cm²/mL. About 90% of all fat globules in goat milk have a diameter of less than 5.21 μ m, while 90% of the globules in cow milk have a diameter of less than 6.42 μ m. A high state of dispersion of milk fat has a positive influence on the access that lipolytic enzymes have to small fat globules (SFGs). Therefore, milk from goats or camels is more digestible for humans (Tomotake and others 2006; D'Urso and others 2008).

Cholesterol is present in the milk fat globule membrane (MFGM) and it accounts for 95% of the sterols of milk fat (Parodi 2004). Briard and others (2003) proved that SFGs are characterized by a larger surface area of MFGM per fat unit. Therefore, a bigger share of SFGs is connected with a relatively higher concentration of cholesterol in milk. Data in Table 3 confirm this relationship to some extent. Camel milk, which has the highest state of dispersion of milk fat, contains the most (of the studied animals species) cholesterol (31.3 to 37.1 mg/100 g milk). In the case of buffalo milk, the situation is reversed, it contains the least cholesterol (6.5 mg/100 g milk).

Human milk has a very specific fatty acid profile, significantly different from ruminant milk (Table 4). It contains almost one-third less saturated fatty acids (SFAs) and 9 times more polyunsaturated fatty acids (PUFAs). Donkey milk is also characterized by a specific fatty acid profile. In fact, it contains several times more SFAs (C8:0, C10:0, and C12:0), twice less of C14:0 and C16:0 fatty acids. Furthermore, it contains very little stearic acid, C18:0 (1.12%), while in milk of other species it is approximately

Table 2—Amino acids profile of milk from various animal species.

	FAO/WHO reference for substantial amino acids	Amino acid concentration (g/100 g protein)								
Amino acid		Buffalo ^b	Sheep ^a	Donkey ^c	Yak ^e	Horse ^c	Cattle ^c	Camel ^d	Goat ^d	Human ^c
Aspartic acid (<i>Asp</i>)		n/a	n/a	8.9	7.8	10.4	7.8	6.9	7.4	8.3
Threonine (<i>Thr</i>)	4.0	5.714	4.2 to 4.4	3.6	4.6	4.3	4.5	4.1	5.7	4.6
Serine (<i>Ser</i>)		n/a	n/a	6.2	5.2	6.2	4.8	4.3	5.2	5.1
Glutamic acid (<i>Glu</i>)		n/a	n/a	22.8	18.4	20.1	23.2	18.1	19.3	17.8
Proline (<i>Pro</i>)		n/a	n/a	8.8	10.4	8.4	9.6	12.0	14.6	8.6
Cysteine (<i>Cys</i>)	3.5 (Cys + Met)	0.586	0.8 to 0.9	0.4	1.4	0.6	0.6	1.9	0.6	1.7
Glycine (<i>Gly</i>)		n/a	n/a	1.2	1.5	1.9	1.8	2.1	2.1	2.6
Alanine (<i>Ala</i>)		n/a	n/a	3.5	3.4	3.2	3.0	2.1	3.6	4.0
Valine (<i>Val</i>)	5.0	6.760	6.2 to 6.4	6.5	5.5	4.1	4.8	4.1	5.7	6.0
Methionine (<i>Met</i>)	3.5 (Met + Cys)	0.928	2.7	1.8	3.1	1.5	1.8	2.0	3.5	1.8
Isoleucine (<i>Ile</i>)	4.0	5.714	4.6	5.5	4.4	3.8	4.2	4.9	7.1	5.8
Leucine (<i>Leu</i>)	7.0	9.792	9.7 to 9.9	8.6	9.7	9.7	8.7	6.1	8.2	10.1
Tyrosine (<i>Tyr</i>)	6.0 (Tyr + Phe)	3.858	3.7 to 3.8	3.7	5.5	4.3	4.5	3.1	4.8	4.7
Phenylalanine (<i>Phe</i>)	6.0 (Phe + Tyr)	4.713	4.2 to 4.3	4.3	5.0	4.7	4.8	4.0	6.0	4.4
Histidine (<i>His</i>)		n/a	n/a	2.3	2.6	2.4	3.0	2.1	5.0	2.3
Lysine (<i>Lys</i>)	5.5	7.497	7.7 to 7.8	7.3	8.1	8.0	8.1	4.0	8.2	6.2
Arginine (<i>Arg</i>)		n/a	n/a	4.6	3.4	5.2	3.3	2.0	2.9	4.0
Tryptophan (<i>Try</i>)	1.0	n/a	n/a	n/a	n/a	1.2	1.5	n/a	n/a	1.8
Limiting aminoacid		Cysteine Methionine	–	Cysteine Methionine	Tyrosine Phenylalanine	Cysteine Methionine	Cysteine Methionine	Lysine	–	–

^aGerchev and others (2005); ^bDimitrov and others (2007); ^cGuo and others (2007); ^dKamal and others (2007); ^eSheng and others (2008).

Table 3—The average MFG diameter and the cholesterol concentration in milk from various animal species.

Average fat globule diameter (μm)	Buffalo	Sheep	Cattle	Camel	Goat
	%	%	%	%	%
0.1 to 1	—	—	—	19.94	25.40
1 to 2	—	15.69	19.01	—	26.86
2 to 4	23.78	39.59	49.40	60.69	21.02
4 to 6	21.67	40.33	19.61	14.16	4.53
6 to 8	11.45	3.28	3.59	5.20	13.04
8 to 10	10.78	0.73	5.09	—	6.34
10 to 12	13.00	0.37	0.15	—	2.89
12 to 14	—	—	—	—	—
14 to 16	—	—	3.14	—	—
16 to 18	20.34	—	—	—	—
Mean average diameter (μm)	8.70 ^b	3.78 ^b	3.95 ^b	2.99 ^b	3.19 ^b
Cholesterol concentration (mg/100 g of milk* or mg/100 cm ³ of milk**)	6.50* ^g or 8.89 to 10.24** ^e	14.23* ^d	25.60* ^a to 31.40* ^g	31.30* ^a to 37.10* ^f	16.90 to 18.09** ^c

^aGorban and Izzeldin (1999); ^bEl-Zeini (2006); ^cStrzałkowska and others (2006); ^dGabryszuk and others (2007); ^eTalpur and others (2007); ^fKonuspayeva and others (2008); ^gKhan and Iqbal (2009).

12%. The C18:1 (oleic) acid deserves special attention among the unsaturated fatty acids. In donkey milk the amount of oleic acid is 3 times smaller than in milk of other species. As already mentioned, donkey milk is very rich in PUFAs, C18:2 and C18:3, linoleic and linolenic. Camel milk is also unique concerning its fatty acid profile. It contains 6 to 8 times less of the short chain fatty acids compared to milk from cows, goats, sheep, and buffalo. Buffalo milk contains almost 3 times more C14:0 (myristic) acid and 2 times less C16:0 (palmitic) acid than cow, sheep, and goat milk. One characteristic of goat milk is a high concentration of short-chain fatty acids. Ceballos and others (2009) reported that goat milk fat in comparison to cow milk fat contains 54.6% more C6:0 acid, 69.9% C8:0, 80.2% C10:0, and 56.3% CLA and 75% less C4:0 acid. The short-chain fatty acids such as capric acid and caprylic acid, which are prominently present in goat milk, were found useful in therapies for patients suffering from malabsorption syndrome, metabolic disorders, problems with cholesterol, anemia, bone demineralization, and in infant malnutrition (Pop and others 2008). Characteristic of sheep milk is a higher concentration of butyric acid (C4:0) and conjugated linoleic acid (CLA) than cow and goat milk.

One of the specific features of ruminant milk is the presence of the aforementioned CLA, which has numerous functional properties. The most biologically active is the diene of configuration *cis*-9, *trans*-11 (octadecadienoic); it is claimed to inhibit the occurrence and development of cancer of the skin, breast, colon, and stomach (Parodi 1999), while its isomer *trans*-10, *cis*-12 is thought to prevent obesity (Bawa 2003; Wang and Jones 2004). Additionally, CLA reduces the levels of triglycerides, total cholesterol, including LDL, and thus improves the ratio of LDL/HDL in plasma, which is a crucial factor in the prevention of coronary heart disease and atherosclerosis (Gavino and others 2000; Tricon and others 2004). CLA also is said to inhibit the development of osteoporosis (Watkins and Seifert 2000), to improve the metabolism of lipids, to reduce the blood glucose level, and to stimulate the immune system (O'Shea and others 2004). CLA concentration depends mainly on the nutrition of the animals (Michalski and others 2005). Auldist and others (2002), Loor and others (2003), and Schroeder and others (2003) have demonstrated a significant increase of the CLA concentration in milk from cows grazing on pasture as compared to milk obtained from cows that were fed with Total Mixed Ration (TMR). A similar relationship was stated by Fedele and others (2001) with buffalo milk. Moreover, feed has an influence on the n-6/n-3 acid

ratio in milk. According to Haug and others (2007), milk fat from cows fed with nonfresh feedstuffs is characterized by a 4:1 n-6/n-3 acid ratio. This ratio decreases in summer when cows graze on pastures, reaching values near 2:1. Recently, an argumentative issue has arisen in reference to the ratio between n-6 and n-3 fatty acids. Haug and others (2007) also say that individuals living in the mesolithic era had n-6 and n-3 FA intake at a 1 to 4:1 ratio, while the diet of a modern European reaches a ratio of 10 to 14:1. Inuit and several Japanese populations still consume large amounts of n-3 fatty acids, and it can be observed that they are characterized by a lower risk of coronary diseases and some varieties of cancer.

Milk mineral components

Milk is an important source of mineral substances, especially calcium, phosphorus, sodium, potassium, chloride, iodine, magnesium, and small amounts of iron. The main mineral compounds of milk are calcium and phosphorus, which are substantial for bone growth and the proper development of newborns (Al-Wabel 2008). The high bioavailability of these minerals influences the unique nutritional value of milk. In a modern European diet, milk is the main source of calcium. Calcium bound to casein (both in organic and mineral form) exhibits significant availability during the milk digestion process (Gueguen and Pointillart 2000); thus, the bioavailability of this element is closely correlated with a higher concentration of casein (Gaucheron 2005). The highest concentration of this, and other mineral elements, is specific to sheep milk; whereas human and donkey milk contain the smallest amounts of those compounds (Table 5).

Iron concentration in milk is naturally low and influenced by the presence of lactoferrin and xanthine oxidase transferase (Al-Wabel 2008). Iron, zinc, and copper in ruminant milk are related mainly to the casein fraction, whereas in human milk they are connected to soluble proteins (Raynal-Ljutovac and others 2008).

Goat milk is characterized by the lowest concentration of iron, zinc, and copper. Camel milk is the richest in these minerals (Table 5). Despite the low iron concentration in goat milk, iron is more bioavailable in goat milk than it is in cow milk. The explanation for that is that goat milk contains a higher share of nucleotides which contribute to heightened absorption in the intestine (Raynal-Ljutovac and others 2008).

Milk vitamins

Milk is a valuable source of vitamins, both water-soluble and fat-soluble ones. Goat and sheep milk are characterized by higher

Table 4–Fatty acids profile of milk from various animal species (% of total fatty acids).

Fatty acid	Cattle ^d	Goat ^d	Sheep ^c	Buffalo ^c	Camel		Donkey ^a	Human ^{e,f}
					Bactrian ^b	Dromader ^b		
C4:0	3.84	1.27	4.06	3.90	0.54	0.34	0.60	0.60 ^f
C6:0	2.28	3.28	2.78	2.33	0.46	0.29	1.22	0.07 ^f
C8:0	1.69	3.68	3.13	2.41	0.53	0.27	12.80	0.21 ^f
C10:0	3.36	11.07	4.97	2.40	0.46	0.27	18.65	1.39 ^f to 1.04 ^e
C12:0	3.83	4.45	3.35	3.09	1.24	0.80	10.67	4.71 ^f to 6.48 ^e
C14:0	11.24	9.92	10.16	28.02	15.43	10.10	5.77	3.92 ^f to 7.44 ^e
C16:0	32.24	25.64	23.10	12.58	32.05	29.74	11.47	18.68 ^f to 22.24 ^e
C16:1	1.53	0.99	0.68	1.93	7.01	6.60	2.37	1.29 ^f to 2.50 ^e
C18:0	11.06	9.92	12.88	12.58	14.75	17.82	1.12	5.63 ^f to 6.45 ^e
C18:1	1.63 + 21.72	0.37 + 23.80	26.01	24.10	18.78	24.66	9.65	31.26 ^f to 32.78 ^e
C18:2	2.41	2.72	1.61	2.04	1.19	1.61	8.15	17.73 ^f to 16.29 ^e
C18:3	0.25	0.53	0.92	0.68	0.60	0.51	6.47	1.36 ^f to 0.60 ^e
C20:4	–	–	0.20	0.35	n/a	n/a	0.07	0.30 ^f to 0.51 ^e
C20:5	–	–	0.09	0.18	n/a	n/a	0.27	0.10 ^e
C22:6	–	–	0.08	0.12	n/a	n/a	0.30	0.19 ^e
CLA	0.45	0.68	0.67	0.49	n/a	n/a	n/a	n/a
SFA	71.24	70.42	65.17	65.86	69.90	64.86	67.6	44.30 ^e
MUFA	25.56	25.67	24.29	26.43	28.07	33.03	15.8	36.56 ^e
PUFA	3.20	4.08	2.45	2.67	1.79	2.12	16.60	19.10 ^e

^aSalimei and others (2004); ^bKonuspayeva and others (2008); ^cTalpur and others (2008); ^dCeballos and others (2009); ^eArsic and others (2009); ^fWan and others (2009).

vitamin A concentrations in comparison with cow milk (Park 2007). All of the β -carotene in milk from goats and sheep is converted into retinol, resulting in the white color of that milk. Goat milk is a good source of vitamin A, niacin, thiamin, riboflavin, and pantothenic acid. However, it contains 5 times less vitamin B₁₂ and folic acid than cow milk does (Table 6). The lack of these 2 vitamins in the human diet is thought to result in anemia (Jandal 1996; Park 2007; Raynal-Ljutovac and others 2008). Camel milk is a kind of exception because of its high concentration of vitamin C (Haddadin and others 2008). Camel milk contains 30 times more vitamin C than cow milk does, and 6 times more than human milk (Table 6). This is highly important in desert areas, where fruits and vegetables are scarce. Therefore, camel milk is often the only source of vitamin C in the diet of inhabitants of those regions.

Technical Suitability of Milk

The majority of milk produced in the world undergoes processing, during which a variety of technological procedures occur. It is not only mainly related to cow milk, but also sheep, buffalo, goat, and camel milk. The most universal is cow milk and technological suitability of milk from other species is very diverse. The concentration of protein, mainly including casein, determines the technological suitability of milk. Casein in milk binds to calcium phosphate in the form of colloidal particles, micelles. Micelles are characterized by different sizes in milk from different animal species (Bornaz and others 2009). Camel milk contains micelles with the largest diameter (380 nm), whereas the smallest micelles are found in cow (150 nm) and sheep milk (180 nm). Average size values are typical for goat milk (260 nm). Attia and others (2000) and Bornaz and others (2009) showed a negative correlation between the casein concentration and micelle size. The rennet clotting time of milk changes according to micelle size; it demonstrates optimal time values for small and medium sizes of micelles. Brulé and others (2000) reported that big micelles contain higher concentrations of calcium phosphate, whereas smaller micelles contain more κ -casein. Similar results were published by Bornaz and others (2009), stating that κ -casein share decreases with an increase of casein micelle diameter. Moatsou and others (2004) reported that a high concentration of protein, fat, and calcium per casein unit in sheep milk predestinates it as an excellent material for cheesemaking. According to Bornaz and others (2009) goat milk is char-

acterized by a longer hydrolysis time than cow milk (552 s and 372 s, respectively). Therefore, casein curd obtained from goat milk is weaker and more susceptible to tearing than curd from cow milk. This is the main reason for increased losses of cheese yield, compared to the amount of final product obtained from the same volume of cow milk (Park and others 2007). The least suitable material for cheese production is camel milk. Even though it is characterized by a very short hydrolysis time (12 s), it does not form a curd, but merely produces scattered flakes of casein. Therefore, camel milk meant to be used for cheese production (for example, Camelbert) has to be mixed with milk from other animal species. Moreover, the lactic fermentation process in camel milk does not lead to obtaining a desirable curd (Attia and others 2001). However, camel milk is more resistant against high-temperature treatments than cow milk (El-Agamy 2000). The level of ionic calcium in milk determines the concentration of colloidal calcium phosphate, which is a structural factor and influences the casein micelle size. Amenu and Deeth (2007) stated that salts and mineral substances play a significant role in the cheesemaking process. The proportion between calcium and nitrogen fraction also has a considerable impact in cheesemaking, as it influences the curd formation in the enzymatic coagulation. This proportion for milk with a short clotting time has a value of 0.23, while milk with a ratio of 0.20 has a long clotting time.

The heat coagulation time (also expressed as heat stability) is determined not only by the acidity of milk, but also by the concentration of whey proteins and calcium ions. The protective mutual relationship between whey proteins and casein occurs in milk characterized by a typical content of whey proteins (deviations may be caused by mastitis, an inflammation of the mammary gland). On the one hand, denaturated whey proteins undergo a microfloculation process on the surfaces of casein micelles (in order according to their heat resistance: serum albumin, β -lactoglobulin, and α -lactalbumin), that prevents them from further aggregation and dissolving from the solution. On the other hand, the interaction with casein hinders the calcium from accessing the micelles, which results in the increased colloidal stability. The extent of mentioned protective action of casein on the whey proteins becomes insufficient when the content of the latter is increased. The most resistant to the heat treatment is milk characterized by the molar ratio of β -lactoglobulin to κ -casein that equals 1 (Walstra and others 2006). In case of milk from small ruminants, there are numerous issues

Table 5—Concentration of minerals in milk from various animal species.

	Cattle ^e	Sheep ^g	Horse ^a	Buffalo ^f	Human ^e	Camel ^{b,h}	Goat ^e	Goat ^d	Donkey ^c
(mg/100 g)									
Calcium	122	195 to 200	132.7	112	33	114 ^h to 116 ^b	134	132	67.67
Phosphorus	119	124 to 158	88.4	99	43	87.4 ^b	121	97.7	48.7
Potassium	152	136 to 140	66.5	92	55	144 ^b to 156 ^h	181	152	49.72
Magnesium	12	18 to 21	10.2	8	4	10.5 to 12.3 ^b	16	15.8	3.73
Sodium	58	44 to 58	19.8	35	15	59 ^h	41	59.4	21.83
(μg/100 g)									
Zinc	530	520 to 747	270	410	380	530 ^h to 590 ^b	56	370	
Iron	80	72 to 122	37	161	200	230 ^b to 290 ^h	7	60	
Copper	60	40 to 68	64	35	60	140 ^b	5	80	
Manganese	20	5.3 to 9		27	70	80 ^b	3.2	6.53	
Iodine	2.1	10.4			7		2.2		
Selenium	0.96	3.1			1.52		1.33		

^aSchryver and others (1986); ^bMehaia and others (1995); ^cSalimei and others (2004); ^dKondyli and others (2007); ^ePark and others (2007); ^fPatiño and others (2007); ^gRaynal-Ljutovac and others (2008); ^hAl Haj and Al Kanhal (2010).

Table 6—Vitamin concentration in milk from various animal species.

Detail	in 100 g				in 100 mL
	Goat	Sheep	Cattle	Human	Camel
Vitamin A (IU), (*μg)	185	146	126	190	26.7*
Vitamin D (IU), (*μg)	2.3	1.18*	2	1.4	0.3*
Thiamin (mg)	0.068	0.08	0.045	0.017	0.048
Riboflavin (mg)	0.21	0.376	0.16	0.02	0.168
Niacin (mg)	0.27	0.416	0.08	0.17	0.77
Pantothenic acid (mg)	0.31	0.408	0.32	0.20	0.368
Vitamin B ₆ (mg)	0.046	0.08	0.042	0.011	0.55
Folic acid (μg)	1	5	5	5.5	87
Biotin (μg)	1.5	0.93	2	0.4	—
Vitamin B ₁₂ (μg)	0.065	0.712	0.357	0.03	85
Vitamin C (mg)	1.29	4.16	0.94	5	33
References	Park and others (2007)				Haddadin and others (2008)

concerning their heat instability. In goat milk, the main contributing factors are the high concentration of ionic calcium and the low micellar solvation. The amount of citrate is a considerable factor influencing the concentration of ionic calcium. Goat milk contains 40% less citrates than cow milk, 1037 mg/L and 1768 mg/L, respectively. In order to increase the colloidal stability of goat milk, the addition of citrate is often used before the heat treatment (Park 2006).

Fat in the milk of various animal species (as mentioned in the section “Milk lipids”) has a varying composition and state of dispersion. The dispersion state of milk fat has influence on the creaming rate and optical, rheological, and technological parameters of milk, such as its color, viscosity, conductance, separation rate, emulsion stability, and suitability for cheese and butter production.

One of the inherent properties of cow milk is the creaming rate of milk, which is determined by the dispersion of fat along with the concentration of agglutinins. If cow milk is left undisturbed for a given amount of time, most of the milk fat will rise to the surface. This happens not only because of the size of fat globules, but also because of the presence of a native protein (immunoglobulin M), which precipitates on the surface of cooling fat globules. The name of this protein, cryoglobulin, originates from this specific property. Big fat globules will migrate higher with increased speed; furthermore, while colliding with others, they will create aggregates. The whole process is catalyzed by cryoglobulin (Farah and Rüegg 1991; Fox 2003). Goat, sheep, and buffalo milk are characterized by a significantly slower creaming rate which is related to their lack of cryoglobulin (Attai and Richter 2000; Fox 2003). Farah and Rüegg (1991) found that despite the similar state of milk fat dispersion, camel milk when compared with cow milk

has a lower rate of creaming. It is also explained by an insufficient amount of agglutinins (such as cryoglobulin).

Additionally, the dispersion state of milk fat has a considerable impact on the technological processes in dairy production as it determines the texture, flavor, and physicochemical properties of cheese and butter. Superior quality parameters in the production of soft cheeses are obtained from milk with dominant share of SFGs. Michalski and others (2003, 2004) evaluated Camembert cheese made from three kinds of milk (containing fat globules with a diameter of 3 μm, 4 μm, and 5 μm). They stated diversity of behavior during technological and maturation processes. Smaller amounts of whey (as more water remained in the cheese) were obtained in cheese production from milk with SFGs, conversely to cheese from milk with large fat globules (LFGs). It is explained by the fact that SFGs are characterized by greater membrane surfaces (therefore, they bind more water), in contrast to LFGs. Soft cheeses made from milk with SFGs had a more desirable (softer) texture. A similar experiment was performed on Emmental (type of hard cheese). It has shown that better quality parameters are obtained with the use of milk with LFGs. They bind less water; thus, the obtained cheese was more dense and firm, and processes of proteolysis during maturation occurred more rapidly. In the case of butter production, it is preferable to use milk with dominant share of LFGs, as they contain two times less membrane material, which results in lower concentration of cholesterol in the final product. Butter produced from such fat is more yellow, with softer consistency (contains more unsaturated fatty acids) and greater spreadability. Additionally, membranes of LFGs are more easily destabilized, which contributes to a more rapid churning process. Butter made from milk with a dominant share of SFGs (containing more membrane fragments) is characterized by an increased

concentration of adsorbed water and protein. Excess content of protein and water in butter is undesirable as it increases the rancidification processes.

One of the distinct properties of goat milk is the specific odor. Le Quere and others (1998) reported that this “goaty” aroma is determined by the relatively high concentration of free fatty acids C6:0 to C10:0, hexanoic acid, octanoic acid, nanoic acid, and acids with branched chains (3-methylbutanoic, 4-methyloctanoic, 4-ethyloctanoic). Chilliard and others (1984) indicated that in goat milk lipoprotein lipase is distributed on the surface of fat globules (46%), in milk serum (46%), and 8% on the surface casein micelles. However, those proportions are significantly different in cow milk where 76% of the lipase is bound up with casein, 17% with serum, and only 6% with fat. Thus, goat milk is more susceptible to lipolytic processes and spontaneous lipolysis induced by the cooling of fresh milk. This property, together with a higher concentration of short-chain fatty acids, results in a so-called “goaty” aroma (Bihagi and Jalal 2010). According to numerous studies the origin of the specific goat odor is also related to the α s₁-casein genotype (*CSN1S1*). Cheese produced from goat milk with *AA* genotype has a weaker goaty smell than cheese obtained from the milk of goats with *FF* genotype. It has been emphasized that the milk from goats with genotype *FF CSN1S1* has a higher lipase activity compared to milk from goats with *AA* genotype (Vassal and others 1994; Delacroix-Buchet and others 1996; Pierre and others 1998a,b; Coulon and others 2004; Chilliard and others 2006; Pop and others 2008; Devold and others 2010; Vlaic and others 2010).

Conclusion

The most important animals in world milk production are cattle. Cow milk is the most universal raw material for processing, which results in the broadest spectrum of manufactured products. Therefore, knowledge about cow milk is the most comprehensive as this milk has a crucial significance in human nutrition. Other species of animals used for dairy purposes have regional meaning. However, it should be highlighted that in certain regions of world (with conditions precluding dairy utilization of cattle), milk obtained from these species is a valuable source of nutrients, providing the food source for inhabitants of these regions. Sheep and buffalo milk, regarding the high content of protein, including casein, and also fat, make a very good raw material for processing, especially cheesemaking. Donkey and horse milk have the most comparable protein composition with human milk (low content of casein, lack of α s₁-casein fraction and β -lactoglobulin, and high content of lysozyme). They are consumed predominantly in a nonprocessed form. Camel milk also has valuable nutritional properties as it contains a high proportion of antibacterial substances and 30 times higher concentration of vitamin C in comparison with cow milk. The composition of goat milk allows for a wide range of uses, such as consumption milk, and even to some extent as a therapeutical product (low content or lack of α s₁-casein) and most of all, as the raw material for dairy processing. The high dispersion state facilitates the digestion process of this milk and its products.

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