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IMPACT OF HOT ENVIRONMENT ON COLOSTRUM AND MILK COMPOSITION

U. BERNABUCCI ✍, L. BASIRICÒ AND P. MORERA

Dipartimento di Scienze e Tecnologie per l'Agricoltura, le Foreste, la Natura e l'Energia, Università degli Studi della Tuscia, Viterbo, Italy

Abstract

Under hot and warm environments productivity and reproduction efficiency of farm and wild animals are negatively affected. The negative effects of hot environments on animal health are responsible for the alteration of colostrum and milk production in term of quantity and quality. Colostrum and milk are nutrient-rich fluids secreted by the mammary gland of female mammals after giving birth and during growth and development of the young. Multiple factors influence the production and the composition of colostrum and milk, including species, breed, health status, feeding practices and environmental conditions. Colostrum and milk are not only a good source of macronutrients and micronutrients, but contains many biologically-active constituents. Colostrum and milk of various species differ widely in amounts and proportions of their principal constituents, especially comparing monogastric with ruminant animals because of the difference between their physiology and digestion. The interspecies variations in part reflect different adaptive strategies to environmental conditions and selective pressures of various species during the evolution. A limited number of studies documented the effects of hot condition on modification of colostrum and milk quality, in particular referred to nutrients and immunoglobulin composition, but no information are available on the effects of hot environment on nutraceutical properties and bioactive molecules content of colostrum and milk.

Key words: Colostrum, milk, hot environment, heat stress.

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✍ **Corresponding author**
Tel: +390761357439
Fax: +390761357434
E-mail:bernab@unitus.it

INTRODUCTION

Climate is changing. Earth's climate has warmed in the last century (0.74±0.18°C) with the 1990s and 2000s being the warmest on instrumental record (62). Furthermore, Earth's climate is predicted to continually change at rates unprecedented in recent human history (62). Current climate models indicate a 0.2°C increase/decade for the next two decades and predict the increase in global average surface temperature by 2100 may be between 1.8 and 4.0°C (62).

Under hot and warm environments productivity and reproduction efficiency of farm and wild animals are negatively affected (71, 113). The negative effects of heat stress will become more apparent in the future if climate change continues as most predicted and as the world's population and food supply continues to increase in, and migrate towards the tropical and subtropical regions, respectively (147).

Homeothermic animals (depending on their physiological state) have a thermoneutral zone where energy expenditure to maintain normal body temperature is minimal, constant and independent of environmental temperature (192). When environmental variables, such as ambient temperature, humidity, air movement and solar radiation combine to reach values that surpass the upper limit of the thermoneutral zone, animals enter a condition known as heat stress. Heat stress occurs when the core body temperature of a given species exceeds its range specified for normal activity resulting from a total heat load (internal production and environment) exceeding the capacity for heat dissipation. This prompts physiological and behavioural responses to reduce the strain. Behavioural and physiological responses are initiated to increase heat loss and reduce heat production in an attempt to maintain body temperature within the range of normality. These responses may be responsible for the alteration of colostrum and milk production in term of quantity and quality.

Objectives of this review are to focus and discuss colostrum and milk quality in different species and how heat stress impacts colostrum and milk composition.

COLOSTRUM COMPOSITION OF DIFFERENT SPECIES

Colostrum is a nutrient-rich fluid secreted by the mammary glands of female mammals after giving birth and during the first 24-48 h after birth, and it changes to mature milk subsequently. It is a complex biological fluid and its composition is similar to that of blood and differs significantly from milk. Colostrum does not have a typical composition profile across species (Tables 1 and 2). Multiple factors influence the production and the composition of colostrum, including the species, the breed, the health status of the mammal, feeding practices, and time collected post-parturition.

Colostrum is not only a good source of macronutrients such as proteins, carbohydrates, fat, and micronutrients including vitamins and minerals, but also contains many biologically active constituents. These include immunoglobulins (Ig), antimicrobial proteins, growth factors, plus anti-inflammatory, antioxidant and immune-enhancing components not present in milk or present in substantially lower concentrations. It plays an important role in the nutrition, protection and development of the newborn infant, and contributes to the immunological defense of the neonate (86, 133) by stimulating the immune system, or by providing passive protection, especially in the gastrointestinal tract. Many of its constituents come directly from the blood stream, for instance, Ig, somatotropin, prolactin, insulin and glucagons, others are locally produced in the udder from mammary epithelial cells and the stroma [fat, lactose, caseins, α-lactalbumin (α-La), β-lactoglobulin (β-Lg), etc.].

The colostrum composition varies with time after the birth most significantly within the 24 h after parturition. Its natural evolution is related to the immediate demands of the newborn and, since most species of mammals develop at different rates and have different nutritional requirements, the colostrum and follow-on milk of each species, have a different composition. Therefore, some colostrums are very similar and some are extremely different. Details of colostrum bioactive constituents (growth and immune factors) have been studied in only a few species such as cattle and humans, whereas the changes in proteins, fat and carbohydrate (lactose) concentrations have been determined in several species.

Bovine colostrum has received considerable attention since it contains many beneficial substances, and several scientific and clinical studies demonstrate its health benefits. Cow's colostrum contains higher levels of vitamins especially D-carotene, vitamins A, E, D, and B; it also contains more minerals (iron, magnesium and sodium salts) and less fat and carbohydrate than normal milk. It is above all characterized by a high content of total proteins (15.4–15.7%), the bulk of which is composed of α-La, β-Lg and especially IgG_1, IgG_2, IgM and IgA, peptides (lactoferrin (LFe), transferrin), hormones (insulin, prolactin, thyroid hormones, cortisol), growth factors, prostaglandins, enzymes and cytokines (43). The concentrations of most ingredients, especially those of Ig and growth factors, are the highest in the first colostrum portions immediately after calving, and thereafter are rapidly decreased (16, 17, 134, 139, 140). At the same time, the content of casein in colostrum is lower than that in milk (111, 117). It should be noted that Ig account for more than 50% of the total amount of colostrum proteins and contain almost all antibodies encountered in maternal blood (178). Transport of

Table 1. Nutrients composition of colostrum from different species.

		Colostrum nutrients				
Species		Protein	Fat	Lactose	Unit	Reference
Homo sapiens	Human	2.3	2.9	5.3	g/100 ml	72
Bos taurus	Cow	14.9	6.7	2.5	%	76
Bos grunniens	Yak	16.1	14.0	1.9	%	165
Bubalus bubalis	Water buffalo	18.75	5.44	2.7	%	3
Capra hircus	Goat	10.24	7.73	1.93	%	190
Ovis aries	Sheep	21.24	14.04	3.26	%	115
Camelus dromedarius	Dromedary	13	1.5	3.6	%	102
Camelus bactrianus	Bactrian camel	19.2	0.3	5.9	%	35
Lama glama	Llama	16.79	0.75	4.12	%	145
Equus caballus	Horse	48.9	24.9	49.5	g/l	153
Sus scrofa	Pig	10.6	5.8	3.4	%	124
Oryctolagus cuniculus	Rabbit	13.2	17.7	1.32	%	119
Rattus norvegicus	Rat	8.85	14.6	2.46	%	74
Felis catus	Cat	4.0	3.4	3.6	%	75
Balaena mysticetus	Bowhead whale	86.6	4.9	6.3	%	57
Loxodonta africana	African elephant	21.0	56.0	61.8	g/Kg	11

Values referred to 24h milking after parturition for all species.

Table 2. Immunoglobulin (Ig) content of colostrum from different species.

		Colostrum Ig levels				
Species		IgG	IgA	IgM	Unit	Reference
Homo sapiens	Human	0.43	17.35	1.59	mg/ml	170
Bos taurus	Cow	50.5	3.9	4.2	mg/ml	170
Bubalus bubalis	Water buffalo	54.0	3.22	5.22	mg/ml	28
Capra hircus	Goat	50-60	0.9-2.4	1.6-5.2	mg/ml	126
Ovis aries	Sheep	101.2	6.2	2.9	mg/ml	167
Camelus bactrianus	Bactrian camel	47.2			g/l	35
Equus caballus	Horse	200.0			mg/dl	77
Sus scrofa	Pig	21.5	1.8	1.1	mg/ml	137

Values referred to 24h milking after parturition for all species.

maternal Ig into colostrum occurs in all mammals probably to varying extensions, but the significance of the Ig in colostrum depends on the species. In some species (human, rabbit, etc.), the transfer of maternal Ig to the blood stream of the neonate occurs in uterus across the placental or yolk sac membrane. In other species (horse, swine and ruminants), transfer of maternal Ig to the neonate occurs exclusively via the colostrum. Both in uterus and colostral routes of transfer are operative in other species (rat, mice, dog, cat). The concentration and class of Ig in the colostrum of a species reflect the route and origin of the Ig. Immunoglobulins transferred in quantity in uterus or via the colostrum are mainly of the IgG class. Immunoglobulins locally produced by plasmacytes located adjacent to the secretory epithelium and in the mammary secretions are largely of the IgA and IgM classes.

In domestic species, there is a preferential transport of IgG into colostrum when compared with other Ig classes. The colostrum of sows contains mainly IgG and lesser quantities of IgA and IgM. When milk secretion commences, the serum-derived IgG is supplanted by IgA synthesized in the mammary gland as the predominant Ig (171). A similar pattern is observed in horse (79, 162). In the domestic ruminants, however, IgG remains the dominant form throughout lactation. Larson et al. (90) reported a ratio of 85-90% IgG, 7% IgM and 5% IgA in dairy cows. As reported for cows, the major Ig fraction in buffalo colostrum was found to be IgG. In buffalo colostrum, IgG, IgM and IgA occur in the ratio of 86%, 8% and 5%, respectively (28). Canine and feline colostrum also contain mainly IgG, with smaller amounts of IgA and IgM. Like other species, levels of all Ig fall when milk secretion begins, but in cats, as in ruminants, IgG remains the predominant type (136). In contrast, the predominant Ig in human colostrums is IgA of the secretory type. Immunoglobulins M and G occur in colostrum but only as minor components.

In addition to Ig, it is recognized that in humans many of the essential growth factors are transferred across the placenta. Therefore, human colostrum contains only trace amounts of these growth factors. In contrast, none of these factors are transferred across the placenta in the pregnant cow, so bovine colostrum is richer in growth factors as compared to human colostrum. The concentration and the nature of growth factors in colostrum varies widely among species and also according to the period of lactation. Although, there are many similarities in the composition of human and bovine colostrum, human colostrum has much higher concentrations of epidermal growth factor (EGF) than those of bovine equivalent (134), whereas the reverse is true for insulin-like growth factors I and II (IGF-I and IGF-II) and for all other growth factors that are at lower concentrations in human colostrum than bovine colostrum.

The most abundant and well characterized growth factors in bovine colostrum are IGF-I and IGF-II. Insulin-like growth factors stimulate cell growth as endocrine hormones via the blood and as paracrine and autocrine growth factors locally, both promote the muscle and body growth (142). Transforming growth factor-α and β (TGF-α and TGF-β) are other growth factors present in bovine colostrum, they are present in small quantity. The TGFs stimulate gastrointestinal growth and repair, inhibit acid secretion, stimulate mucosal restitution after injury and increase gastric mucin concentration. Both TGF-α and TGF-β are helpful in the repair and integrity of epithelium of gastrointestinal tract.

Bovine colostrum was found to contain higher concentrations of cytokines than mature milk, these variety of cytokines with immunomodulatory properties are: granulocyte-macrophage colony-stimulating factor (G-CSF), interleukin (IL) -1, -1β, -6, and -18, interferon-γ (IFN-γ) and tumor necrosis factor-α (TNF-α). The high levels of cytokines in colostrum are related to its ability to promote the immunomodulatory activity and neonatal immunity (53). The possible modulation of the immune system by immune components in the human colostrum has been reported. In human colostrum, the presence of IL-1a and IL-1b (109, 168), IL-6 (150), IFN-γ (18), TNF-α (148) and the anti-inflammatory cytokine IL-10 (42), has been reported. In addition, cytokine inhibitors, such as soluble forms of TNF-α receptor I and II, and IL-1ra, were also detected in human colostrum (21).

Other important immune factors present in cow and human colostrums are the prolin rich polypeptide (PRP) and the LFe (142). PRP has been shown to stimulate the thymus to regulate the immune system in the body. PRP stimulates the weakened immune system and also stabilizes hyperactive immune system due to autoimmune diseases and allergies in the body. Lactoferrin is an iron binding glycoprotein which facilitates iron absorption and also acts as antimicrobial agent. It promotes the growth of fibroblasts and intestinal epithelial cells and plays a role in gut immunity.

The existence and levels of the above bioactive compounds will vary greatly between colostrum specimens of different origins. Comparisons between cow colostrum composition and human one have been published (69, 133) and studies show that the growth factors and cytokines in cow colostrum are nearly identical to that of humans (43, 142). In contrast, limited data are available for biologically active molecules of colostrum from other mammals (goat, sheep, buffalo, camel, donkey and horse).

Despite the importance of nutrients in colostrum, published data describing colostrum chemical composition (protein, carbohydrate, fat, vitamins and minerals) of various species are extremely limited. The literature on comprehensive research of mammals colostrum composition date back to 20-30 yr ago; most recent researches investigating colostrum focus narrowly on IgG and ignores macronutrients and micronutrients concentrations. However, composition of nutrients in colostrum is important in satisfying the nutritional requirements of newborn mammals, that require fat and protein for energy and muscle development in the first days of life, as well as vitamins and many other nutrients that are concentrated in the first lacteal secretions (185).

Recently Kehoe et al. (76) reviewed the literature on bovine colostrum composition and reported the mean percentages of fat, protein, and lactose in cow colostrums that were 6.7, 14.9, and 2.5, respectively. Lactose concentration is reduced in colostrum and acts inversely of other constituents, such as solids, proteins, and ash, which are all found in high concentrations and decrease over time. Mean concentrations of fat-soluble vitamins, including retinol, tocopherol and β-carotene, were 4.9, 2.9, and 0.7 μg/g, respectively. Mean concentrations of water-soluble vitamins were 0.34, 0.90, 4.55, 0.60, 0.15, 0.21, and 0.04 μg/mL for niacin, thiamine, riboflavin, vitamin B12, pyridoxal, pyridoxamine, and pyridoxine, respectively. Mean concentrations (mg/kg) of selected minerals in colostrum were also determined (Ca 4.716; P 4.452; Mg 733; Na 1.058; K 2.845; Zn 38; Fe 5.3; Cu

0.3; S 2.595; and Mn 0.1). The analysis of fatty acids profile also showed that bovine colostrum was characterized by higher concentrations of unsaturated fatty acids in comparison to the later lactation phases, and had a low content of short-chain fatty acids (except for C4:0 acid) and a high content of C18:0 and C18:1 acids (111, 121).

The composition of bovine colostrum is quite different from the colostrum produced by humans. The differences between bovine and human colostrum reflect the different needs of the respective newborns. The most substantial difference is found in the protein content of these colostrums and in the lactose concentration. Human colostrum and milk contain the highest amount of lactose (milk sugar) of any species. The lactose provides about 40% of all of the calories available to the suckling infant. In addition bovine colostrum contain substantially more casein than is found in human colostrum. Human colostrum was also characterized by a lower percentage of saturated fatty acids including medium chain length acids, a higher percentage of monounsaturated, and a lower level of linoleic and linolenic acids, but a higher percentage of their long chain polyunsaturated derivatives (44). The mean concentrations (g/100mL) of fat, protein, and lactose in human colostrum were 2.9, 2.3, and 5.3, respectively. Mean concentrations of fat-soluble vitamins, including retinol, tocopherol and β-carotene, were 4.9, 2.9, and 0.7 μg/g, respectively. Mean concentrations of water-soluble vitamins were 0.75, 0.15, 0.25, 2.0, 0.15, 0.21, and 0.04 μg/mL for niacin, thiamine, riboflavin, vitamin B12, respectively. Mean concentrations (mg/mL) of selected minerals in colostrum were also determined (Ca 0.23; Na 0.48; K 0.74; and Zn 5.40; Fe 0.45 μg/mL) (72).

In the goat, Yang et al. (190) reported that the concentration of dry matter, fat, protein and mineral in colostrum was higher than those components in cow and human milk, and the concentrations of vitamin B1, B2 and C were also very high. The concentrations of fat, ash, lactose, and proteins at 3 h of lactation were 7.73%, 1.57%, 1.93%, and 10.24% respectively. Goat colostrum contained very high concentrations of Ca, P and Mg, and very low concentrations of Zn, Fe, Cd, As, Pb and Hg. Moreover, 25% of the fatty acids in goat colostrum were unsaturated compared to 40.8% for bovine milk fat and 60.8% for human milk fat and the ratios of saturated to unsaturated fatty acids were 3.03, 1.10 and 0.57, respectively, for goat, cow and human colostrum.

Another small ruminant is the ewe. The chemical composition of ewe colostrum was significantly changed in the content of fat and proteins in the first days after lambing (27). Mean percentages of fat, protein, and lactose in colostrum were 14.04, 21.24 and 3.26, respectively (115). The concentration of fat, protein and lactose of ewe colostrum was higher than those in cow, goat and human colostrum. The differences among cow, goat, and sheep in lactose content is small compared to other two constituents as fat and proteins. The analysis of fatty acids profile also showed that ewe colostrum is a product rich in saturated acids (82).

Colostrum from buffaloes does not differ from that of bovine. The average percentages of total solids, solids non-fat, total protein, casein, ash and chloride of colostrum at initiation of lactation, were reported as 28.52±0.33%, 23.08±0.315%, 18.75±0.30%, 5.06±0.31%, 1.64±0.04% and 0.198±0.13%, respectively (3). Fat and lactose contents of colostrum shortly after parturition were 5.44±0.21% and 2.70±0.08%, respectively. The content of iron and copper is markedly higher in the buffalo colostrum as compared to normal milk.

Colostrum of camel is yellowish white in color and has a lower viscosity than that of farm animals. It contains high levels of total solids including total proteins, especially the whey proteins and Ig. It also has high contents of ash and chlorides, but low levels of lactose which are similar to bovine colostrum. Most of the reports suggest that camel colostrum contains very low fat when compared to bovine colostrum (35, 102). Some differences between colostrum composition of Dromedary and Bactrian camels are also noted, with Bactrian colostrum being higher in lactose, protein, and ash content than that of Dromedaries. The mean percentages of fat, proteins, and lactose in Dromedary colostrum were 1.5, 13, and 3.6, respectively and in Bactrian camels were 0.3, 19.2 and 5.9. Casein, whey proteins, and non-protein nitrogen represent 34, 57, and 9% of total nitrogen, respectively, and these ratios are quite different from those of bovine colostrum. Generally, non-protein nitrogen is higher in camel colostrum than in that of cow, goat and human.

Camel and lamoid colostrums are similar in color and viscosity and in fat percentage. In llama colostrum mean percentages of fat, protein, and lactose were 0.75±0.25, 16.79±1.64 and 4.12±0.46, respectively (145). As expected for colostral milk, average protein concentration reached the highest value of the 3 constituents, whereas fat had the lowest. Lactose concentration in the colostrum was lower than in milk.

Equine colostrum has common characteristics with bovine and human colostrum. The mare colostrum fat acid concentration is roughly one third compared with the cow's one, and the relation between unsaturated and saturated acid is 1.32 against 0.45. Serum proteins are 50% of total proteins, there is also a high concentration of lysozyme. The content (g/L) of protein, fat, lactose of mare's colostrums, at 6 h after parturition, were 48.9, 24.9 and 49.5, respectively (153). The Ca/P ratio is 1.7, quite close to physiological absorption level. Lactose concentration, very similar to human milk, has a specific feeding role (34, 131).

Colostrum of the sow has high total solids and protein content but a comparatively low concentration of carbohydrate (lactose) and fat (9). The transition from colostrum to milk during the first 2-3 days of lactation is characterized by a sharp decline in total solids and protein and a simultaneous increase in the concentrations of lactose and fat. Proteins, lactose and fat contribute approximately 18, 22 and 60%, respectively, of the total energy content of sow's colostrum. In sow colostrum mean percentages of fat, proteins, and lactose were 5.8, 10.6 and 3.4, respectively (124). In contrast to many other species, the ash content (salts and minerals) is lower in sow colostrum.

In other domestic species as rabbit, colostrum has a high total solids content, the major part consisting of about equal quantities of proteins and fat, with lactose present as a minor component. The mean percentages of fat, proteins, and lactose in rabbit colostrum were 17.7, 13.2, and 1.32, respectively (119). The levels of proteins and fat were about four times those in cow's milk, whereas lactose was present at only about one-quarter of its concentration in cow's milk. The contents of biotin, folic acid, nicotinic acid, thiamine were higher in the colostrum sample than in the milk from the 4th day onwards. On the other hand, the trends for vitamin A and vitamin B, with high levels in the colostrum and the gradually decreasing levels as the lactation proceeds, are similar to the trends of these vitamins in bovine colostrum.

Several studies on the composition of mouse and rat milk have been reported, but little information is available on the changes in the composition of colostrum. In most of the studies reported, only one constituent was determined. In a study on chemical composition and mineral content of rat colostrum, Keen et al. (74) reported the mean percentages of fat, proteins, and lactose that were 14.6±1.07, 8.85±0.24, and 2.46±0.14, respectively. Mean concentrations (μg/mL) of selected minerals in colostrum were also reported and were 8.65±0.53, 9.20±0.59, 13.77±0.47, 0.33±0.03, 792±37 and 174±6 for iron, copper, zinc, manganese, calcium and magnesium, respectively. The iron and copper concentration of rat colostrums is considerably higher than that found in human milk which normally ranges from 0.2 to 0.5 μg/ml, and in colostrum from most dairy animals ranging between 0.2 and 0.3 μg/ml.

In conclusion, differences and similarities in the nutrients (proteins, fats, lactose, vitamins and minerals) and non-nutrients (biologically active substances) of colostrum in the mammal species examined in this review reflect different species-specific strategies for neonatal immunity (immunoglobulins, humoral and cellular) and specific nutritional requirements of newborn mammals.

MILK QUALITY OF DIFFERENT SPECIES

Milk is a white or yellowish liquid secreted by the mammary gland consisting of an emulsion of fat globules and a suspension of casein micelles (casein, calcium, phosphorous), all suspended in an aqueous phase which contains solubilized lactose, whey proteins, and some minerals. Leukocytes in milk are part of the suspended phase.

Lipids in milk serve as an energy source, act as a solvent for the fat-soluble vitamins and supply essential fatty acids. Milk fat globules range in size from 0.1 to 15 μm and have a density of about 0.92 g/ml. A thin membrane covers these fat globules and helps to stabilize the fat globules in an emulsion within the aqueous environment of the milk. The major lipids in milk fat are triglycerides, which are composed of three fatty acids covalently bound to a glycerol molecule by ester bonds. The remained of the lipid fraction (~2% of the total in human and cow's milk) is phospholipids, diglycerides and cholesterol.

The major milk proteins are caseins (α -, β -, and k-casein), β-Lg (~50% of whey proteins) and α-La (~25% of whey protein). In milk of most mammalian species, there are 3-4 caseins; the different caseins are distinct molecules but are similar in structure. Casein is composed of several similar proteins, which form a multi-molecular granular structure called 'casein micelle'. The micellar structure of milk casein is an important part in the mode of milk digestion in the stomach and the basis of many of the milk products industries such as cheese. In addition to casein molecules, the casein micelles contain water and salts.

Lactose, a disaccharide composed of D-glucose and D-galactose, is the major milk carbohydrate in most species. Lactose is the least variable component of milk. The species that have very little lactose in milk, often have another sugar (e.g. cangaroo has a trisaccaride) as the major osmole. The least variability of lactose in milk depends on the close relationship between lactose synthesis and the amount of water drawn into the milk. In addition to lactose, milk contains other carbohydrates in small amounts, including glucose, galactose and oligosaccharides.

Milk contains all the major vitamins. The fat-soluble vitamins A, D, E, and K are found mainly in the milk fat. The B vitamins are found in the aqueous phase of milk. All the 22 minerals considered essential to the human diet are present in milk. However, the major minerals in milk are calcium and phosphorous which are associated with casein micelles.

Milk is a nutritious food containing numerous essential nutrients for the metabolism, growth, development and well-being of the young mammal. Milk supplies energy, amino acids, vitamins, and minerals to the suckling during an important part of life (67). Some of these constituents are synthesized in the mammary gland (milk fat, lactose, caseins, α-La and β-Lg) while others enter milk by specific transport mechanisms. In addition to the nutritional components, milk is also a remarkable source of bioactive compounds that may have beneficial non-nutritional functions (60, 103). These include a wide range of specific and non-specific antimicrobial factors, cytokines and anti-inflammatory substances, hormones, growth modulators, and digestive enzymes many of which have multiple activities (163).

Milks of various mammalian species differ widely in amounts and proportions of their principal constituents, especially comparing monogastric with ruminant animals because of the difference between their physiology and digestion. Factors such as the type of proteins, the proportion of proteins, fat, and sugar, the levels of various vitamins and minerals and the size of the butterfat globules, are among those than may vary. The interspecies variations in part reflect different adaptive strategies and selective pressures of various species during the evolution of the mammals (65, 67).

In literature, analyses are available for milks of nearly 200 of the more than 4000 species of extant mammals (65). Summaries of the differences compiled by Jenness (67) indicate that water content of milk can range from about 90% (in kangaroo) to 34.6% (in fur seal), while fat content, the most variable component of milk in both their concentration and chemical composition, ranges from almost 1% (in donkey) to more than 50% (in fur seal). Aquatic mammals typically have high milk fat percentage. Milk proteins vary considerably among species but not so much as milk fat. Proteins range from approximately 1% (in human) to about 14% (in whale). Generally milk protein percentage is positively correlated with milk fat percentage. Lactose ranges from trace (in kangaroo) to 7.4% (in donkey). Often, lactose concentration is negatively correlated with both fat and protein concentrations. Minerals (as ash) in milk range from almost 0 to 2%. Other differences in milk among species are also known for vitamins, enzymes and other components. Some workers have stressed the different nutritive requirements of the young belonging to different species, corresponding to different growth pattern, as a possible major selective pressure in determining the composition of milk (11). As a rule, mammals that nurse frequently produce a milk less rich of nutrients and watery. Human milk is noticeably thinner and sweeter than cow's milk (66). Many milk components like proteins have genetic variants. Caseins consist of α-, β- and k- types with about 27 genetic variants from A to E for each. The whey proteins (α-La and β-Lg) also have about 11 different genetic variants. This gives milk proteins considerable variation between animal species, which can be exploited for processing and human nutrition. The extent to which this divergence in milk components has been affected by the nutritive requirements of the young, by the dietary sources of the lactating female, and by several other genetic and environmental factors has not been completely clarified.

The following is a brief overview on milk obtained from different species, including the human.

Human (*Homo sapiens)* milk (HM) is a complex fluid rich in all the nutrients needed by the newborn baby during the first weeks of life (54, 57, 130) and also contains non-nutritional bioactive components that promote infant health, growth, and development (45, 80, 92, 99). Human milk is always alkaline, the pH ranges from 6.4 to 7.6. It contains on average, 87.1% water, 4.5% fat, 1.1% proteins, 7.1% lactose, 0.2% minerals (as ash), and supplies 72 kcal/100 g of energy (67). Race, age, parity, or diet do not greatly affect HM composition. Human milk fat, in addition in providing about 50% of all calories, is an essential nutrient for the brain development and a vehicle for absorption of fat-soluble vitamins. Fat content does not vary consistently during lactation but exhibits large diurnal variations and increases during the course of each nursing. Triacylglycerol constitutes more than 98% of the total fat in breast milk, while 0.1% are phospholipids and 0.3-0.4% is cholesterol (70). Palmitic acid (C16:0) and oleic acid (C18:1) are the most abundant fatty acids in breast milk triglycerides, with comparatively high proportions of the essential fatty acids: linoleic acid (C18:2 ω6) and linolenic acid (C18:3 ω3). Moderately high proportions of other long-chain polyunsaturated fatty acids, such as arachidonic acid (C20: 4 ω6) and docosahexaenoic acid (C22:6 ω3), are also present (68). Fatty acid composition varies somewhat with the composition of diet. Phospholipids (about 75 mg/100 ml) include phosphatidyl ethanolamine, phosphatidyl choline, phosphatidyl serine, phosphatidyl inositol, and sphingomyelin. Human milk is richer in lecithin than cow's milk, but the latter contains more phosphorous than HM because of its higher casein content.

Human milk proteins provide infants with essential amino acids and nitrogen necessary for growth of lean body mass and protein synthesis. Of the total nitrogen-containing compounds in HM, proteins account for approximately 75% that is the lowest content of protein in milk of any mammals (116). On the other hand the proportion of non-protein nitrogen in HM (about 25%) is higher than any other species (55). Two types of proteins are present: caseins (~40%) and whey proteins (~60%) (66). The principal human casein is homologous to bovine β-casein. It supplies nutrients for the infant but also is an important source of metabolically bioactive peptides. Major whey proteins are α-La, LFe, secretory IgA, lysozyme (Lyz), and serum albumin (66, 92). Some of these are bioactive components that may have beneficial non-nutritional functions. For instance, LFe is a glycoprotein that transports and promotes the absorption of iron in the gut, shows antibacterial activity to a wide range of organisms, and acts as a nutritional protein, producing amino acids for absorption on digestion. Secretory IgA, the principal immunoglobulin of breast milk, also works to protect the infant from respiratory viruses, bacteria attacks and intestinal parasites (135). Bifidus factor encourages the growth of lactobacillus which helps to prevent the growth of other harmful intestinal bacteria. Other Ig, including IgG and IgM, in breast milk also help in protecting against bacterial and viral infections. Lysozyme is an enzyme that protects the infant against *E. Coli* and *Salmonella* spp. It also promotes the growth of healthy intestinal flora and has anti-inflammatory functions. Lipase and amylase are other enzymes that helps in digestion and creates a healthy environment in infants' intestine. Non-protein nitrogen substances content in breast milk include: urea (about 50%), nucleotides, peptides, and a large number of free amino acids. Human infant is unable to synthesize adequate amounts of taurine, a neurotransmitter or neuromodulator in the brain and retina, that is in relatively high concentrations in HM.

Human milk contains the highest concentrations of the disaccharide lactose of any species studied to date. It accounts for approximately 40% of the total energy provided by breast milk, regulates the water content of milk and helps to control intestinal flora because of its ability to promote growth of certain strains of lactobacilli. In addition to lactose, breast milk contains significant quantities of oligosaccharides, representing about 10% of total milk carbohydrates. Recent observations suggest that either the oligosaccharides or their digestive products have a potent antibacterial role.

The mineral content of HM varies between 0.19% and 0.34 % and includes among macro minerals: Na, K, Ca, Mg, P, and Cl. Iron, Cu, and Zn contents vary considerably. Other elements are present in trace.

The amount and types of vitamins in breast milk are directly related to the mother's vitamin intake. Human milk contains a higher concentration of vitamin A, vitamin D, folic acid and vitamin C. All other vitamins, except K, are present in nutritionally significant concentrations. Leukocytes are living cells that are also found in breast milk. They help fight infection.

Many domestic animals are kept to produce milk for human consumption. Milk from cow, goat, sheep (ewe), water buffalo, camel, horse (mare) and donkey are of particular interest in human nutrition. These animals form the basis of commercial milk production in various parts of the world. The various species produce significantly different quantities of milk. Even within the same species there are wide variations in production, largely depending on: domestic purpose, breed and genetic quality, environmental conditions, physiological conditions, level of management.

Bovine (*Bos taurus*) milk (BM) is the major mammalian milk that is consumed by humans as a food commodity. In the last decades in the western societies, the consumption of cow's milk has decreased partly due to claimed negative health effects, sometimes unjustified, attributed to the high content of saturated fatty acids assumed to contribute to heart diseases, weight gain and obesity (58, 61)

Bovine milk composition is distinct qualitatively and quantitatively from that of HM due to their diet and the presence of a rumen. As a rule, BM contains significantly lower amounts of lactose than HM, however has significantly more proteins than HM. There is little difference in the fat content between cow and HM considering fats in total, while there are significantly differences considering the types of fats. Bovine milk has a pH ranging from 6.5 to 6.8, making it slightly acidic, on the contrary of alkaline HM. It contains, on average, 87.3 % water, 3.2% protein, 3.9% fat, and 4.6% lactose, 0.7% minerals, and supplies 66 kcal/100 g of energy (67). Milk composition changes markedly depending on breed, age, nutrition, stage of lactation, energy balance, environmental conditions and health status of the udder. Of the total lipid fraction in cow's milk, triacylglycerols account for about 95%, diacylglycerol for about 2%, phospholipids for about 1%, cholesterol for 0.5% and free fatty acids (FFA) for less than 0.5% (69). Fat content and fatty acid composition are the most modifiable of the main components in milk because of feeding, breed, stage of lactation, season and geographical location. Triacylglycerols are composed approximately of 65% saturated (SAFA), 30% monounsaturated (MUFA), and 5% polyunsaturated fatty acids (PUFA). Some of the SAFA, as myristic (C14:0) and palmitic (C16:0) acid, are associated with high blood cholesterol, coronary heart diseases weight gain, and obesity. In contrast to this, SAFA such as butyric (C4:0), caprylic (C8:0), capric (C10:0) and lauric (C12:0), are beneficial to humans in many ways (cancer prevention, antiviral and antibacterial functions). Bovine milk is rich in oleic acid (C18:1 ω9), the MUFA more concentrated in milk (about 0.8% whole milk) and it has a very high oleic acid/PUFA ratio. Several studies have shown that diets with high MUFA/PUFA ratio are favourable for human health giving better protection against cardiovascular diseases than diets rich in PUFA (30, 114). The main PUFA are linoleic (C18:2 ω6) and α-linolenic (C18:3 ω3) acids. The ratio between ω6 and ω3 fatty acids in BM fat is near 1-2:1. Thus, milk from cow can be an important source of ω3 fatty acids with positive effects on health reducing the risk of cardiovascular diseases and cancer. Bovine milk is the main source of the conjugated linoleic acid (C18:2 9c,11t-CLA), about 0.6% of the fat fraction. In experimental animals CLA has been shown to have anticarcinogenic effects (49). Bovine milk contains a small percentage of phospholipids and glycosphingolipids, about 1% of total milk lipids. Glycosphingolipids are an important components of milk fat globule membranes (MFGM) and display beneficial health properties for human because of their functional roles in a large number of reactions. Some of them have been implicated in the defence of newborns against pathogens. Gangliosides are one of these components mainly found in nerve tissues, and they have been demonstrated to play important roles in neonatal brain development, receptor functions and allergies. Cholesterol is a normal constituent in cow's milk, although in little amount. Because cholesterol occurs in the fat globule membrane, its concentration in dairy foods is related to the fat content. Cholesterol in the body is the precursor of some hormones and Vitamin D.

Of the total nitrogen-containing compounds in cow's milk, about 78% are caseins, 20% whey proteins and 2% non-protein nitrogen. Milk proteins have a high biological value, containing all essential amino acids, in the same proportion of human proteins. They also provide substrates for protein synthesis, serve as substrates for gluconeogenesis and several of these have biological properties ranging from antimicrobial and antihypertensive ones to those facilitating absorption of nutrients, as well as acting as growth factors, hormones, enzymes, antibodies and immune stimulants. The main casein present in cow's milk is the α_S-casein. Caseins biological functions are to carry calcium and phosphate and to form a clot in the stomach for efficient digestion. Whey proteins are a source of amino acids and possess anti-inflammatory or anti-cancer properties. Among the major milk whey proteins, the β-Lg is the main whey protein present in bovine milk. The second one most represented is α-La. The ratio between β-Lg and α-La occurs in BM approximately at a 3:1 (58). In BM the principle Ig are IgG and IgA. The following minor proteins with protective properties are also present in BM: LFe, lactoperoxidase, enzymes, protein compounds of MFGM, proteosopeptone compounds, and glycomacropeptides. All BM caseins and main whey proteins show genetic polymorphism that can affect milk composition and some parameters of milk processing. Fresh cow's milk is a good source of glutathione that acts as an antioxidant. Although, whey proteins are responsible for some milk allergies, the major allergens in milk are the caseins. Among the amino-acid content of non-protein nitrogen, the concentration of taurine is low in bovine milk respect to the concentration in HM.

The level of lactose in BM is significantly lower than that in HM. Lactose before to be absorbed must be cleaved in the small intestine by the enzyme. The production of this enzyme declines significantly after weaning in all mammals. Consequently, many humans become unable to digest lactose properly as they mature. Lactose intolerance is a natural process and there is no reliable way to prevent or reverse it.

Bovine milk provides appreciable source of minerals and vitamins (58). Their content in cow's milk is much higher than in HM but certain vitamins and minerals that are necessary for human development, may be lacking in cow's milk. The mineral selenium and the vitamins E and A are the most important antioxidants in BM. Cow milk is a good source of calcium, phosphorus, magnesium, potassium, selenium, and trace-element such as zinc and iodine. Cow milk contains small amounts of copper, iron, manganese, and sodium and is not considered a major source of these minerals in the diet. Vitamins have many roles in the body, including metabolism co-factors, oxygen transport and antioxidants. They help the body use carbohydrates, protein, and fat. Among water soluble vitamins, BM is a good source of thiamin (vitamin B1), riboflavin (vitamin B2) and vitamin B12 while has small amounts of niacin (vitamin B3), pantothenic acid (vitamin B5), pyridoxine (vitamin B6), vitamin C, and folate. Among fat soluble vitamins BM is rich in vitamins A and D. Their content in dairy products depends on the fat content of the product. Cow milk contains small amounts of vitamins E and K and is not considered a major source of these vitamins in the diet.

There are a large number of enzymes in cow's milk and the functions of many are not well-defined. The major lipase in milk is lipoprotein lipase, associated with the casein micelle. The major protease in milk is plasmin. Alkaline phosphatase is inactivated by heat and it is used as indicator of proper pasteurization. Lactoperoxidase has antibacterial properties in milk like Lyz, although, the amount of Lyz in cow's milk is very small. Cow's milk, however, is not suitable for infants. It lacks some of the key immunological components that are required by the human infant and the foreign proteins may trigger allergic reactions in some babies.

Goat (*Capra hircus*) (GM) and sheep (*Ovis aries*) milks (SM) and dairy products provide an alternative to BM. Goat and sheep milk is white in colour compared with

BM, which is yellowish because of the presence of carotene (149). Goat milk has a stronger flavour than SM and BM due to the liberation of short-chain fatty acids during rough handling (6, 50). Goat milk pH is alkaline in nature, which is very useful for people with acidity problems (63). Sheep milk contains higher levels of fat (7.2%), proteins (4.6%), lactose (4.8%), ash (0.9%) and energy (102 kcal) as compared with GM (fat: 4.5%, proteins: 3.2%, lactose: 4.3%, ash: 0.8% and energy: 70 kcal). These differences make the rennet coagulation time for SM shorter and the curd firmer owing to the differences in the caseins (47). In SM, solids in average are 18%, while in goat and cow are 13.3% and 12.7%, respectively. The peculiar character of the fat globules of GM and SM is that they are smaller in size when compared to that of BM (approximately 83% are less than 3.5 μm). Mehaia (100) reported average fat globule sizes in this decreasing order: BM > SM > GM. The higher amount of these small fat globules in GM and SM is responsible for the better digestibility and for a more efficient lipid metabolism of these milks compared with BM (123). Moreover, unlike BM and SM, GM lacks the agglutinins (51, 64). As a result, the fat globules in GM do not cluster together, making them easier to digest. Triacylglycerols constitute the highest group (nearly 98%) of SM and GM lipids, including a large number of esterified fatty acids. Simple lipids (diacylglycerols, monoacylglycerols, cholesterol esters), complex lipids (phospholipids) and liposoluble compounds (sterols, cholesterol esters, hydrocarbons) are also present (52, 125). The most significant difference between GM and SM and milk from other species is the high presence of short- and medium-chain fatty acids such as caproic (C6:0), caprylic (C8:0), capric (C10:0), lauric (C12:0) acid (64). All these lipids are easier for intestinal enzymes to digest and also have unique beneficial effects in various medical problems, especially for cardiovascular diseases. The phospholipid profile is similar to that of the plasma membrane, which may confirm a common origin. This fraction accounts for roughly 0.8% of total lipids depending on the species, type of feed and season.

Casein micelle of GM and SM have similar characteristics, while both differ from the small cow casein micelles. Physico-chemical characteristics of caprine micelles (more calcium, inorganic phosphorus, and non-centrifugal casein, casein are less solvated and heat stable, and lose ß-casein more readily than bovine casein micelles) (64, 143) makes these proteins more easily and rapidly digestible with several advantages to infants and children with gastro intestinal disorders. Goat milk may also have advantages when it comes to allergies. In contrast to BM, GM contains only trace of an allergenic casein protein (α_{s1}-casein); this peculiarity is used to detect BM in goats milk/products as a way of quality control. β-casein is the dominant casein component in goat milk (64). Proportions of k-casein isolated and characterized from goat and sheep milk, are higher in goat than in sheep and cow milk (2, 144, 193). The most represented whey proteins in goat and sheep milk are β–Lg and α-La. Immunoglobulins, LFe, ferritin, proteose peptone, calmodulin (calcium binding protein), prolactin and folate-binding protein are also present in significant amount. Goat and sheep caseino-macropeptide has been well characterized in these species. Non-protein nitrogen contents of goat, sheep and human milks are higher than in BM. Among free amino acids, representing 10-20% of the NPN in milk, taurine and carnitine are important because of their physiological functions in the newborn. Among the bioactive peptides in GM and SM, the angiotensin convertin enzyme inhibitory peptide and antihypertensive peptides have received special attention due their beneficial effect in the treatment of hypertension.

The level of lactose in GM is usually slightly lower than that in SM and BM milk which a small advantage in lactose-intolerant people (64).

Lipase activity has been found in the milk of both goats and sheep (24, 63), but little or no Lyz activity has been found (24, 25). Xanthine oxidase has been reported in sheep and goat milk (20, 106), and it has also been reported to contain more rhodanase than BM (1). One study reported that raw GM contains less alkaline phosphatase than raw BM (104).

Mineral content of GM (about 0.8%) is slightly lower than that of SM (about 0.90%) but macro minerals concentrations of goat and sheep milk are much higher than those of HM. Among trace minerals, levels of Fe and Se are significantly lower in GM and SM milk than in HM, whereas goat and sheep milk have greater Zn and iodine contents than human; the last case is very important for human nutrition, since iodine and thyroid hormones are involved in the metabolic rate of physiological body functions (181). When compared to BM, goat milk provides more Ca, P, K, Mg and Cl, and less Na and S (23, 51, 127). The levels of Ca, P, Mg, Zn, Fe, and Cu are higher in sheep than in BM, while the opposite appears to be the case for K, Na, and Mn. In general, mineral contents may not fluctuate much, but they are affected by breed, diet, individual animal, stage of lactation, and status of udder health (127)

The vitamin content of GM and SM is similar to that of BM and HM. Goat milk supplies adequate amounts of vitamin A, and niacin, and excesses of thiamine, riboflavin and pantothenic acid for a human infant, while is deficient in vitamins C, folic acid and Vitamin B12 which cause "goat milk anemia" (64, 122). Several cases of anaemia attributed to goat milk diets were reported to have been cured by the patients being given folic acid (64). Vitamin contents in SM are mostly higher than in cow and goat milk, except for carotene, however, research data on vitamins in sheep milk are sparse.

Water Buffalo (*Bubalus bubalis*) milk (WBM) is the second most produced milk in the world, and of primary nutritional importance to the human diet in various parts of the world (101). Buffalo milk is one of the richest milks from a compositional point of view. It contains all the nutrients in higher proportions than BM. (65, 179). The biggest difference between WBM and BM is with respect to fat. The WBM contains more fat than BM, it averages between 6.9 to 8.5% (15% under favourable conditions) while in cattle milk fat content ranges between 3 to 5 % (5, 183). Higher total fat in WBM also provides for its high nutritive and energetic value (100 kcal/100 g). The proportion of saturated/unsaturated fatty acids is higher: 77:23. Some authors reported changes in the fatty acid composition of WBM as a function of the breed (175), the stage of lactation (174), and animal diet (129). The content of phospholipids and cholesterol is lower than cow, sheep and goat milks. BM and WBM contain the same types of casein, although in slightly different proportions. The more abundant caseins in buffalo milk are the β-casein and α_{s1}-casein, followed by α_{s2}-casein and k-casein. High proportion of β-casein in

WBM makes it easier to prepare humanized milk.

Due to high peroxidise activity, buffalo milk can be preserved naturally for a longer period. Buffalo milk lacks or only contains traces of β-carotene, this makes buffalo milk very white in colour compared with BM. Buffalo milk is significantly higher in Ca, P and iron than BM; wile is lower in K and Na than BM.

Camel *(Camelus dromedarius)* milk (CM) and milk products are gaining in acceptance and importance worldwide since they are important components of the human diet in many parts of the world (155).

Unique to camels is the ability to thrive under extreme weather conditions and still produce milk of high nutritional value. Data concerning the composition of milk vary greatly. Stage of lactation, age, number of calving, feed and water quantity and quality, affect significantly CM composition. Camel milk is generally opaque-white. It has a sweet taste, but sometimes can also be salty (138, 188). At times the milk tastes watery. The type of feed and the availability of drinking water cause the changes in taste (37). Camel milk has a pH between 6.5-6.7 (159), similar to the pH of SM. Camel milk contains on average, 86.5% water, 4.0% fat, 3.6% protein, 5.0% lactose, 0.8% ash, and supplies 70 kcal/100 g of energy.

The most important factors influencing water content of CM are the hydration status of the animals as well as the type of forage eaten. The water content of CM may fluctuate from 84% to 90% (78). When animals have free access to the water the content of water in milk is 86%, but when water is restricted the water content of milk increases to 91%. Thus, it would appear that the lactating camel loses water to the milk in times of drought. This could be a natural adaptation in order to provide not only nutrients, but necessary fluid to the dehydrated calf. Adaptation to warm environment causes also secretion of a profuse watery sweat caused by secretion of endogenous anti-diuretic hormone, that allows the loss of water into the milk. Water availability and water content of fodder also affect fat content of CM. The percentage of milk fat of camels ranges from 2.6% to 5.5% (191). When water milk content increases in thirsty camels, fat content decreases, from 4.3% to 1.1% (188, 189). The milk fat is also different from that of other animals. The fat globules are very small 1.2-4.2 µm in diameter. Triacylglycerols account for 96% of the total lipids in CM. The prevalent saturated fatty acids are the long-chained fatty acids C16:0 (34.9%) C14:0 (14.5%) and C18:0 (9.7%); the same as compared to BM, WBM and SM fat but relatively higher as compared to HM fat. Short chain fatty acids (C4 -C12) are present in very small amount in camel milk fat, less compared to BM, WBM and SM fat, but higher than in HM fat (46, 160). The ratio of saturated/unsaturated acid (66.1% of saturated fatty acids and 30.5% of unsaturated fatty acids) is more favourable in CM compared with that of BM or other mammalians. All of these parameters gave a nutritional advantage to camel's milk, although it has high content of cholesterol (37.1 mg/100 g) (81). The prevalent phospholipids in CM are choline, phospholipids, sphingomyelin, phosphatidyl choline.

Camel milk is a rich source of proteins with potential antimicrobial and protective activities. Camel milk provides an alternative for those allergic to BM or for individuals who are diabetic. The proportions and kind of proteins are different respect to cow, goat and sheep. but the overall amino acid composition of the mixture of proteins is similar in all four. Camel milk proteins contain satisfactory balance of essential amino acids. Camel milk is characterized by higher level of Ig but lower in both LyZ and LFe than HM (160). Milk from the dehydrated camel has a severely decreased protein percentage (188, 189). Again, this demonstrates the direct effect of drinking water on the composition of milk. Camel milk shows higher levels of Na, K, Zn, Fe, Cu, Mn, niacin and vitamin C and relatively lower levels of thiamin, riboflavin, folacin, vitamin B12, pantothenic acid, vitamin A, lysine and tryptophan than those of BM (155). Equine (*Equus caballus*) milk (EM) composition have taken considerable interest in recent years as a substitute of BM for human consumption because it resembles HM in many respects (95, 182). The characteristics of EM of interest in human nutrition, include an exceptionally high concentration of polyunsaturated fatty acids, low cholesterol content, high lactose and low protein contents (169), as well as high levels of vitamins A, B and C. Moreover, EM is highly digestible, rich in essential nutrients and possesses an optimum whey protein/casein ratio, making it suitable in paediatric dietetics. Equine milk is thought to have also immuno-stimulating ability because of its exceptionally high contents in LFe, Lyz and ω-3 fatty acids (36). Chemical composition and constituents of EM have been studied thoroughly (32, 95, 128, 169). Equine milk contains on average 88.8% water, 2.1% protein, 1.2% fat, and 6.4% lactose 0.4% minerals, and supplies 48 kcal/100 g of energy. Breed, individuality of animals, stage of lactation, frequency of milking, maternal age, health and type of feed may affect the gross composition of EM. Fat content is lower in EM compared to HM and BM. Distribution of di- and triglycerides in mare's and women' milk is similar. The proportion of PUFA with an intermediate and high number of carbon atoms, in mare and HM is remarkably higher than in BM (95). Protein content in EM is higher than in HM and lower than in BM (40). Equine milk contains 1.3% total casein, 0.8% whey proteins and 0.03% non-protein nitrogen (105). Casein amount is higher than whey protein but in comparison to BM, EM contains less casein and more whey proteins as in HM. From the major whey proteins in equine milk predominate the α-La and the Ig (10). IgA is the major immunoglobulin in EM and HM, while, as reported before, in BM IgG is the predominant immunoglobulin. The principal anti-microbial agent in EM are Lyz and LFe, while in BM are Ig (7, 95). Among all casein fractions identified in equine milk, β-casein is a major structural component of the casein micelle, like human, with minor α_{s1}-casein (185). Non-protein-nitrogen constitutes 10-15% of the total nitrogen in mature EM which is intermediate between the values for HM and ruminant milk. Doreau and Martin-Rosset (33) reported that peptides derived from equine β-casein may have a positive effect on human health. Among all free amino acid content of EM, glutamine, glutamate, glycine, alanine and serine are the most abundant, like in bovine and HM. The content of taurine is present in higher amount in EM in comparison to BM, however, it is more less than HM. Equine milk is very digestible (73, 180). Ash content in EM ranges from 0.3-0.5% and among macro elements are present Ca, P, Mg, K and Na. Equine milk contains the same amounts of vitamins A, D and K as bovine milk, while vitamin C content is slightly higher.

Donkey (*Equus africanus asinus*) milk (DM), along with EM, is considered more similar to HM than to other mammalian milk. It is very nourishing because it contains more lactose and less fat than ruminant milk (48). The same authors reported that donkey milk contained 9.53% total solids, 1.57% protein, 1.16% fat, 6.33% lactose, and 0.4% ash on average, which is more similar to EM and HM than to the milk of other mammals. For this reason, DM was used for a long time during the twentieth century to rise infants as a substitute to breast milk. Donkey milk contains low fat (0.38% of milk), and is characterized by high levels of linoleic (average 8.15 g/100 g of total fatty acids) and linolenic acid (average 6.32 g/100 g of total fatty acids) (26). Donkey milk is poor in proteins, in average it contains 1.72% of total proteins (151), and it is characterized by a low caseins (47.3% of total proteins) and high whey proteins (35-50% of total proteins) rich in β-Lg (3.5-4.0 mg/ml) and Lyz (0.8-1.3 mg/ml). The percentage of essential amino acid in donkey milk proteins is higher than those of equine and bovine milk. The percentages of 8 essential amino acids in protein of DM were 38.2%, higher than those of mare and cow milk. Serine (6.2%), glutamic acid (22.8%), arginine (4.6%) and valine(6.5%) showed the higher levels in DM, while cysteine (0.4%) has the low level. The ash content of DM (0.39%) shows high levels of Ca and P.

Year of lactation, stage of lactation, breed and milking time did not influence the gross composition of the milk, except for fat and protein contents (152). Donkey milk displays a unique nutritional characteristics and could be used as a new dietetic food and breast or BM substitute for children (110).

HOT ENVIRONMENT AND COLOSTRUM COMPOSITION

Although the role of colostrum as indispensable nourishment for newborn mammals has been established (91), the influence of high ambient temperatures (HAT) on colostrum production has not been examined in depth. Only few studies have been undertaken on the seasonal variation of colostral Ig of cows. Kruse (84) observed no changes in colostral Ig because of season, and Shearer et al. (161) found higher concentrations of Ig in colostrum during summer months. Previous researchers (93) have also reported that sows under heat stress during late pregnancy produced colostrum with less IgG. Morin et al. (108) reported a significant month of calving effect on colostral specific gravity values, with highest values occurring in autumn and lowest values in summer. More recently, Westra and Wahyudi (187) indicated a tendency to lower IgG colostrum concentration in hot climate, and suggested to elevate IgG colostrum concentration to provide adequate passive immunity and at the same time preventing calves mortalities during hot weather.

Although plasma Ig is lower (31) and the mortality rate is higher (98) for calves born during summer, knowledge about the Ig content of colostrum produced under HAT conditions is limited. The influence of HAT on the nutritional and immunological values of colostrum have been studied in our laboratory (111).

Content and quality of colostrum proteins are significantly affected by HAT conditions (Table 3). Heat-stressed cows had lower mean percentages of total protein. Colostrum of heat stressed cows contained lower percentages of colostral casein, lactalbumin, and reduced concentrations of IgG and IgA, but did not reduce the percentage of lactoglobulin or the concentration of IgM. About 90% of total plasma Ig in the bovine consists of IgG (176), and content of IgG in colostrum depends on the amount transferred from the blood stream across the mammary barrier by a specific transport mechanism (90). Consequently, the smaller prepartum decline of plasma Ig and the lower content of colostral IgG (Table 3) of cows in the HAT group, indicated that heat stress impaired the transfer of IgG from the blood stream to the udder. Conversely, colostral IgA depends on the amount synthesized from the immune cells in the udder (177). Therefore, our data indicated that heat stress impairs the immune reactivity of the mammary gland plasmacytes that produce IgA. Reduced amount of Ig in colostrums produced by heat-stressed subject may impair passive transfer of Ig from colostrum to the newborn, since the passive transfer is associated with the mass of Ig ingested (83, 172) and the efficiency of the absorption (31, 173).

Under HAT conditions, percentages of colostral fat are decreased (111). Colostrum produced from heifers under HAT conditions also had changes in fatty acid compositions. Greater proportions of long-chain FA were observed

Table 3. Protein fractions in colostrum from heifers exposed to thermal comfort (TC) or high air temperatures (HAT). Adapted from Nardone et al. (111).

	Time after calving									Mean of four milkings		
	1 h		12 h		24 h		36 h					
	TC	HAT	TC	HAT	TC	HAT	TC	HAT	SEM	TC	HAT	SEM
Casein, %	5.3	4.3	3.5	1.1	1.6	1.4	1.9	1.7	0.8	3.5^a	2.3^b	0.5
α-Lactalbumin, %	0.9	0.9	0.6	0.4	0.4	0.2	0.5	0.4	0.1	0.7^a	0.5^b	0.1
β-Lactoglobulin, %	1.4	1.2	1.0	0.8	0.7	0.3	0.8	0.5	0.2	1.2	0.8	0.1
IgG, mg/dl	7925^a	6400^b	5100	4615	3357	2437	1586	1260	473	4496^a	3677^b	230
IgM, mg/dl	733	755	525	406	270	273	191	208	74	420	412	36
IgA, mg/dl	400^c	210^d	238	150	131	107	94	77	37	216^c	136^d	19

a,b Means within row and time after calving with no common superscript letters differ ($P<0.05$).
c,d Means within row and time after calving with no common superscript letters differ ($P<0.01$).

Table 4. Fatty acid (%) profile of colostrum from heifers exposed to thermal comfort (TC) or high air temperatures (HAT). Adapted from Nardone et al. (111).

	Time after calving											
Fatty acid	1 h		12 h		24 h		36 h			Mean of four milkings		
	TC	HAT	TC	HAT	TC	HAT	TC	HAT	SEM	TC	HAT	SEM
C4:0	4.3^{d}	8.0^{c}	5.1	6.5	9.7	8.9	7.9	6.7	0.7	7.1	7.5	0.4
C6:0	1.9^{b}	2.9^{a}	2.6	2.9	4.1^{a}	3.4^{b}	3.4^{a}	2.9^{b}	0.3	3.0	3.0	0.2
C8:0	1.0^{b}	1.5^{a}	1.4	1.4	2.1	1.7	1.8	1.4	0.2	1.6	1.5	0.1
C10:0	2.4	2.5	3.1	2.7	4.0^{a}	3.2^{b}	3.8	2.9	0.3	3.3^{a}	2.8^{b}	0.2
C10:1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.02	0.2	0.2	0.03
C12:0	4.2	3.8	4.7^{c}	3.7^{d}	4.5	3.7	4.6^{a}	3.7^{b}	0.3	4.5^{c}	3.7^{d}	0.1
C14:0	19.0^{c}	14.7^{d}	18.7^{c}	14.4^{d}	15.4^{a}	13.1^{b}	15.8^{a}	13.7^{b}	0.8	17.2^{e}	14.0^{f}	0.4
C14:1	0.5^{b}	0.8^{a}	0.5	0.6	0.5	0.6	0.6	0.6	0.1	0.6	0.6	0.09
C15:0	1.8	2.0	1.7	1.9	1.6	1.8	1.8	2.0	0.1	1.7	1.9	0.1
C16:0	36.1^{e}	30.2^{f}	34.6^{c}	30.9^{d}	32.3^{a}	30.0^{b}	32.1^{e}	30.5^{f}	0.7	33.8^{e}	30.4^{f}	0.4
C16:1	2.4	1.9	2.1	2.1	1.8	2.0	1.7^{b}	2.2^{a}	0.2	2.0	2.0	0.1
C17:0	1.3	1.6	1.2^{b}	1.6^{a}	1.2	1.5	1.3^{d}	1.6^{c}	0.1	1.3^{f}	1.6^{e}	0.1
C18:0	6.7^{d}	8.7^{c}	6.3^{d}	8.8^{c}	6.6^{d}	8.5^{c}	7.4^{d}	9.3^{c}	0.5	6.7^{f}	8.8^{e}	0.2
C18:1	15.2^{b}	18.0^{a}	14.2^{d}	18.9^{c}	13.9^{d}	18.8^{c}	15.3^{f}	19.5^{e}	1.3	14.7^{f}	18.8^{e}	0.6
C18:2	2.2	2.3	1.9^{d}	2.4^{c}	1.6	2.0	1.8^{b}	2.1^{a}	0.2	1.9^{b}	2.2^{a}	0.1
C18:3	0.6	0.7	0.5	0.7	0.5	0.6	0.5	0.6	0.1	0.5^{b}	0.6^{a}	0.08
C20:0	0.2	0.3	0.2^{d}	0.3^{c}	0.2	0.2	0.2^{b}	0.3^{a}	0.02	0.2^{d}	0.3^{c}	0.02

a,b Means within row and time after calving with no common superscript letters differ ($P<0.05$).
c,d Means within row and time after calving with no common superscript letters differ ($P<0.01$).
e,f Means within row and time after calving with no common superscript letters differ ($P<0.001$).

in cows exposed to hot conditions (Table 4). The calculation of the mean amount (grams per liter) of short-, medium-, and long-chain FA of colostrum produced for the four milkings showed that colostrum of heifers under HAT conditions had a remarkably lower content of short- and medium-chain FA (20.2 vs. 33.5 g/L), but the quantity of long-chain FA was only slightly depressed (11.0 vs. 12.7 g/L). A higher proportion of long-chain FA was found by other researchers and in our research also in milk (see next paragraph).

Also, lactose content was depressed in colostrums produced by a heat stressed dairy cow (111). Knowledge of the mechanisms of lactose synthesis (85) suggests that the lower availability of plasma glucose (13, 111) and colostral α-lactalbumin (Table 3) are a possible cause of the lower percentage of lactose in colostrum of cows under HAT conditions.

Energy value of colostrum was lower for heifers under HAT conditions (111) particularly at 12 h after calving (-38%). The nutritional value of colostrum is highly variable (29). However, health or performance of newborn calves fed colostrum with different nutritional values has not been examined in depth (29). The nutritional value of colostrum clearly has been a crucial factor for the thermoregulation of calves born in a cold environment (29).

Colostrum produced by cows under hot conditions have higher pH and lower titratable acidity (°SH) (111). Foley and Otterby (38) reported that HAT made storage of colostrum difficult. Our results on acidity of colostrum from heifers under HAT conditions suggested that, in addition to a direct effect of HAT during storage, the difficult preservation of colostrum in a hot environment might also depend on characteristics of fresh colostrum produced under HAT conditions.

A lack of knowledge regarding the nutritional significance of colostrum produced under hot environment and the lack of information on the effects of hot environment on other nutraceutical characteristics of colostrum suggest further investigations.

HOT ENVIRONMENT AND MILK COMPOSITION

Milk yield is strongly reduced in animals exposed to warm/hot environment (13, 19, 89, 113, 141, 186). Exposure of dairy cows to HAT determines also significant modification of milk quality (12, 15; 22, 107, 164). Results on the effects of HAT on milk fat percentages are conflicting (4, 88, 112). Milk from heat stressed cows presents lower percentages of protein, and lactose, higher pH, and lower titratable acidity (12, 15). Milk from summer cows presents also an impairment of rheological behaviour during cheese manufacturing and cheese yield (22). In a study it was reported that in Israeli Holstein dairy cows average milk protein production was reduced by 0.01 kg/°C (8). Milk yielded under HAT also has lower calcium, phosphorous and magnesium, and higher pH, chloride, freezing point and plasmin activity (12, 87, 97, 164).

In sheep, Sevi et al. (157) reported that declines of milk yield due to the exposure to solar radiation causes also a decline of fat yields. The lactose concentration of goats' milk decreased after 4 d of exposure to severe hot (154). In sheep it has been also reported that the exposure to solar radiation has detrimental effects on the hygienic quality of milk consisting of high number of pathogens and polymorphonuclear leukocytes (157).

A limited number of studies documented that HAT can also affect fatty acids composition and protein fractions of milk from dairy cows or sheep. These aspects are of interest because of the strict relationships between fatty acids and protein compositions and technological and/or nutritional properties of milk.

In 1965 Bianca (15) reported lower content of short-chain fatty acids and higher content of C16 and C18 in milk from heat stressed cows. Gallacier et al. (41) and Palmquist et al. (121) observed lower proportions of short-chain and higher proportions of long-chains fatty acids during warm months. Piva et al. (132) found an increase of unsaturated fatty acids in milk yielded during summer months. None of these authors attributed changes of milk fatty acids to a direct effect of heat stress, and suggested that they had to be attributed to the higher dietary intake of fat or to the lower forage intake which usually occur during summer (41, 121), or to a more massive utilisation of body reserves (132).

In a study carried out in climate chambers (146) it was also observed that milk from heat stressed dairy cows had low proportions of short (C4-C10) and medium-chain (C12-C16) fatty acids, and high proportions of long-chain (C17-C18) fatty acids. In the same study heat stressed cows also yielded 25% less milk with a lower percentage of fat than their counterparts kept in thermal comfort. As a consequence of the different fatty acids composition of milk and of the different fat and milk yield, the daily production of milk fatty acids in cows exposed to HAT was lower with regard to short and medium-chain fatty acids and nearly the same with regard to long-chain fatty acids (Figure 1). Therefore, this results indicated that the higher proportion of long-chain fatty acids observed in milk from heat stressed cows had to be attributed to the reduced synthesis of short- and medium-chain fatty acids in the mammary gland cells rather than to a higher incorporation of long-chain fatty acids. It was hypothesised that the energy deficit status that characterizes heat stress conditions might be the cause for the lower synthesis of short and medium-chain fatty acids synthesized into the mammary gland (165). Moreover, it was also suggested that the higher availability of long-chain fatty acids coming from lipomobilization would not hesitate in their higher incorporation into milk because these fatty acids might be utilized as energy sources by the mammary gland cells (166). All this would authorize to indicate that fat intake, changes in the pattern of feeding and/or lipid mobilisation would not represent the only factors affecting milk fatty acids changes in summer milk. In contrast, a study referred to dairy sheep (158) documented that the exposure to solar radiation was responsible for a worsening of the nutritional properties of milk associated with changes of the fatty acids profile and consisting of a reduced proportions of MUFA and PUFA and increased proportions of the C12-C16, which are known to exert hypercolesterolaemic effects in humans.

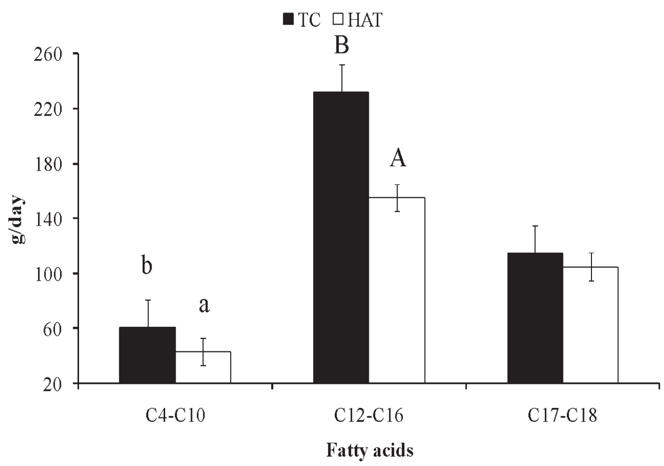

Figure 1. Milk short-chain (C4-C10), medium (C12-C16) and long-chain (C17-C18) fatty acids composition (g/day) in Holstein cows exposed to thermal comfort (TC) or to high ambient temperatures (HAT). Values are least square means ± SE. Adapted from Ronchi et al. (146).

a,b Means within fatty acids category with no common superscript letters differ (P < 0.05).

A,B Means within fatty acids category with no common superscript letters differ (P < 0.01).

The effects of heat stress on milk protein fractions have not been described extensively, and such lack of knowledge is surprising in the light of severe alterations of the cheesemaking properties of milk, reduction of cheese yield and alteration of cheese quality occurring in summer months around the world (96, 120, 157, 183).

Some authors reported a reduction of casein content in milk from summer cows (59, 94). In a field study (14) we found that, compared to milk yielded from spring cows, summer milk had lower contents of crude proteins and caseins, lower casein number, and higher milk serum proteins. Among caseins, the k-casein fraction did not differ between summer and spring cows. Conversely, milk from summer cows had lower of α_s- and β-caseins. In practice, results from this study indicated that the reduction of milk proteins observed in summer was due to the reduction in the casein content, which was in turn caused by a reduction in α_s- and β-casein. The α_s- and β-casein represent approximately 90% of total caseins, contain a high numbers of phosphate groups (156), and their phosphorylation needs the presence of the -phosphate of ATP. This phosphorylation is significantly impaired under energy deficit conditions (94), so that it has been hypothesised that the lower content of α_s- and β-casein in summer milk might be at least partially due to the reduction in energy and protein availability consequent to heat stress (13, 88, 111). These changes and higher milk plasmin activity (164) might also explain the documented summer-related losses in cheese yield and alteration of cheesemaking properties (96, 120, 183). Moreover, α_s- and β-casein, rich in phosphate groups, are the two acidic components of the casein micelles (156). Thus, the lower contents of α_s- and β-casein of milk yielded during the summer might also explain the higher milk pH and the lower milk titratable acidity commonly recorded during hot summer months (12). Finally, the lower α_s- and β-casein contents might explain the lower milk phosphorous content observed by others (39, 87) in milk yielded from cows exposed to HAT.

In the same study, we did not find seasonal variations of α-lactalbumin and β-lactoglobulin concentrations, even if serum proteins increased. Before our study, Hermansen et al. (59) had already reported a higher content of whey proteins in milk produced in the late summer with indications that their result was not related to proteolysis. Since our result was not concomitant with mammary gland health problems, we hypothesized, according to Mackle et al. (94), that it might be dependent on milk concentration due to decline of milk volume.

CONCLUSIONS

This paper pointed out differences in colostrum and milk composition among species and that most of the literature referred to composition of bovine and human colostrum, in contrast few information are available for colostrum from other farm animals, particularly for bioactive molecules composition. Milk from the most mammalian species differ widely in amounts and proportions of their principal constituents, especially comparing monogastric with ruminant animals because of the difference between their physiology and digestion. Factors such as the type of proteins, the proportion of proteins, fat, and sugar, the levels of various vitamins and minerals, are among those than may vary.

The knowledge of differences in composition and functional properties among different colostrum and milk from various species (cow, goat, buffalo, sheep, donkey, camel, mare and human) will increase knowledge on the beneficial effects of colostrum and milk proteins for human nutrition as well as their potential in disease prevention and/or treatment.

Quality of colostrum and milk produced from heat stressed dairy ruminants authorizes to indicate that colostrum and milk produced and consumed during hot seasons is not equivalent to those yielded and consumed in other periods of the year. These is true if we referred to nutrients and immunoglobulin compositions. In contrast, no information are available on the effects of hot environment on nutraceutical characteristics and bioactive molecules content of colostrum and milk.

Further studies are encouraged to verify the effects of heat stress on other crucial aspects of the colostrum and milk composition in farm animals and also in humans. Finally, also of interest would seem further epidemiological studies assessing the value of colostrum and milk in farm animals and humans to ascertain differences due to different climatic conditions.

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