

## Equidae, Camel, and Yak Milks as Functional Foods: A Review

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### Abstract

Milk is considered the most nutritious natural fluid. Milk from livestock provides a nearly ideal food for humans of all ages. Thus, effective education is a foremost policy in enabling the public to become adequately cognizant of the health implications of milk especially from less-known species. The objective is to describe nutritional and health implications of milk produced by camel, equidae, and yak. Camel milk has about 11.7% total solids, 3.5% protein, 4.5% fat, 0.8% ash, and 4.4% lactose. Camel milk has greater Na, K, Zn, Fe, Cu, Mn, niacin and vitamin-C, and relatively lower thiamin, riboflavin, folate, vitamin B<sub>12</sub>, pantothenic acid, vitamin-A, lysine and tryptophan than cow milk. Camel milk is more similar to goat milk and contains less short-chain fatty acids than cow and buffalo milks. An emphasis is being increasingly placed on jenny and mare milks as nearly optimal substitutes for human and cow milks. Jenny and mare milks are very similar with low fat (1.1-1.3%), total solids (8-10%) and protein (1.5-1.8%), and high lactose (6-7%). Jenny milk protein is asonably high in lactose,  $\beta$ -lactoglobulins, and peptide-bound and essential amino acids. Equidae milk immunoglobulins inhibit Enterotoxigenic *Escherichia coli*, has high quality proteins and very low fat and cholesterol. Equidae milk can alleviate allergies in very young infants and the elderly. Yak milk contains 16.9-17.7% solids, 4.9-5.3% protein, 5.5-7.2% fat, 4.5-5.0% lactose, and 0.8-0.9% minerals. Colloidal and soluble calcium and phosphorus make yak milk highly suitable for cheese making. Yak milk fat obtained at very high altitudes is richer in polyunsaturated fatty acids and conjugated linoleic fatty acids. As a result, yak cheese and dairy products have value-added nutraceutical functions. With the important nutritional and health implications of equidae, camel and yak milks highlighted, systematic education must persistently continue to enable sufficient and efficient use of such non-cow milks by humans worldwide.

**Keywords:** Camel; Education; Equidae; Health; Human; Immunity; Milk; Yak

### Introduction

The average intake of dairy products from livestock in many regions is much below minimum daily requirements of about 70 g protein and 800 mg calcium [1]. The yield and composition of livestock milk vary by breed and genetic differences. Milk products' nutritional, physical and chemical properties affect human digestion capacity and health [2]. Asia, Europe and North America are the major milk and meat producers. The highest per capita intake of dairy products belongs to Western Europe, Scandinavia as well as Australia and Canada (Table 1). This highlights the importance of systematic and timely education in other world regions on human nutrition and health implications of livestock milk. Milk of equidae (horses and jennys), camel and yak has unique nutritional properties that can supply humans worldwide with a viable substitute for cow milk (Table 2). Camel milk is similar to human milk in total fats, total solids, and monounsaturated and polyunsaturated fatty acids content (Table 2). Jenny (i.e., female donkey) and mare (i.e., female horse) milks have very low fat and cholesterol contents, and are considered most similar to human milk in protein and lactose contents. Camel and equidae milk have received research and commercial interests for optimal infant, adult, and elderly nutrition [3]. A main objective of this review article is to provide a specialized delineation of equidae, camel, and yak milks for optimal public health and nutrition. A universal ultimate objective is to help optimize livestock milk science education and dissemination, especially from less-known species.

### Milk for humans: Revisited medical and health perspectives

Milk synthesis involves pregastric and hindgut fermentation of plant cell-walls and cell-contents into volatile fatty acids, ammonia, peptides and microbial mass, which are main substrates for milk secretion [4,5]. Milk contains essential amino acids, specialized

casein and peptides, lactalbumins and immunoglobulins, nucleosides, nucleotides, unsaturated and conjugated linoleic acids, sphingomyelins, fat soluble vitamins and minerals that function beyond their nutritional value [6-8]. As an evolutionary testimony, neonatal development of brain network, nervous and immune systems, and body skeleton entirely or mostly rely on milk [5]. Milk consumption is not related to gastrointestinal- related immune malfunctions [9], and enriches

Country	Milk (liters)	Cheese (kg)	Butter (kg)
Finland	184	19.1	5.3
Sweden	146	18.5	1.0
Ireland	130	10.5	2.9
Netherlands	123	20.4	3.3
Norway	117	16.0	4.3
Spain	119	9.6	1.0
Switzerland	113	22.2	5.6
Britain	111	12.2	3.7
Australia	106	11.7	3.7
Canada	95	12.2	3.3

**Table 1:** Highest per capita dairy products consumers (2006)(47).

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Received September 09, 2011; Accepted December 03, 2011; Published December 05, 2011

Citation: Nikkhah A (2011) Equidae, Camel, and Yak Milks as Functional Foods: A Review. J Nutr Food Sci 1:116. doi:10.4172/2155-9600.1000116

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Component	Camel	Jenny	Mare	Yak	Human	Cow
Fat, g	4.5	1.1	1.3	6.5	4.0	4.0
Protein, g	3.5	1.7	2.1	5.1	1.9	3.4
Lactose, g	4.4	6.6	6.4	4.4	6.5	4.8
Minerals, g	0.7	0.4	0.4	0.8	0.2	0.7
Solids-non-fat, g	8.6	9.2	9.3	10.4	7.3	9.0
Total solids, g	12.8	10.2	10.5	16.9	12.1	13.3
Cholesterol, mg	37	2.2	4.5	22.0	20	14
Calcium, mg	143	68	89	131	32	120
Phosphorus, mg	116	50	56	106	14	93
Saturated FA, g	2.4	0.4	0.4	3.9	1.8	2.4
Monounsaturated FA, g	1.4	0.2	0.3	2.2	1.6	1.1
Polyunsaturated FA, g	0.5	0.4	0.5	0.4	0.5	0.1

FA = fatty acids

**Table 2:** Average composition per 100 g of milk of cow, human, yak equidae, and camel (1,6,8,25,33,42,66,68,78).

breast milk  $\beta$ -lactoglobulin and ovalbumin [10]. Milk strengthens body frame structure and bone health [11,12]. Recent biotechnologies have enabled enriching milk with vitamin-E. Also, milk from immunized cows have been produced to lower blood cholesterol [13, 14]. These suggest opportunities to design and produce value-added functional foods from milk [15]. Conjugated linoleic acid (CLA) isomers, mainly CLA<sub>cis9,trans11</sub> (75-90%) and CLA<sub>trans10,cis12</sub>, may have anti-carcinogenic, immune-boosting, and anti-lipogenic effects [16,17,18]. Milk immunoglobulins remove *Enterotoxigenic Escherichia coli* [19]. Recent evidence suggests that dairy consumption can alleviate metabolic syndromes [20,21]. Improved folate function by milk intake can reduce homocysteinemia and heart failure [22]. Timely education fueled by research findings will enable the public to recognize a pseudo-science that might dismiss milk as simply a source of saturated/animal fat. Milk fat is not similar to non-milk animal fats because saturated milk fats are escorted by functional bioactive substances [3,21]. Shorter-chain fatty acids including butyric acid, generally considered unhealthy, have been shown to improve nutrient assimilation and insulin function [22]. However, in very early stages of neonatal development, cow milk may not be an optimum food for infants. Neonatal cow milk intake may be linked to insulin-dependent diabetes [23,24]. Thus, suitable substitutes for cow milk need to be ensured.

### Camel milk

Camel milk has approximately 11.7% total solids, 3.5% protein, 4.5% fat, 0.8% ash, 4.4% lactose, 0.13% acidity and a pH of 6.5 [25,33]. Comparing cow milk, camel milk has greater Na, K, Zn, Fe, Cu, Mn, niacin and vitamin-C, and relatively lower thiamin, riboflavin, folate, vitamin B<sub>12</sub>, pantothenic acid, vitamin-A, lysine and tryptophan [33]. The range of major contents of camel milk are as follows: fat 2.9-5.5%, protein 2.5-4.5%, lactose 2.9-5.8%, ash 0.35-0.95%, water 86.3-88.5%, and SNF 8.9-14.3%, with a mean specific gravity of 1.03 [26]. Camel milk is also known for its rich iron [26,28], unsaturated fatty acids, and B-vitamins contents [26,29]. It is more similar to goat milk and contains less short-chain fatty acids than cow, sheep and buffalo milks. *In vitro* protein digestibility and protein efficiency ratio values were 81.4% and 2.69, respectively, based on 90.0% and 2.50 for casein. Camel milk has low total fat content, made mainly from polyunsaturated FA. Camel milk contained substantially less vitamins-A (0.10 vs. 0.27 mg/L) and B<sub>2</sub> (0.57 vs. 1.56 mg/L), similar vitamin-E (0.56 vs. 0.60 mg/L), and about 3 times greater vitamin-C (37.4 vs. 11.0 mg/L) than cow milk, respectively [25]. Camel daily milk production varies from 3.5 up to 40 L under intensive management. Lactation lasts between 9-18 months,

with peak yield occurring in the first 2-3 month of lactation. In regions such as Kazakhstan, 37% of the total milk comes from camel; with sheep, yak, and cows supplying 30%, 23% and 10%, respectively.

Camel milk has 21 different amino acids [31]. One kg of camel milk meets 100% of daily human requirements for calcium and phosphorus, 57.6% for potassium, 40% for iron, copper, zinc and magnesium, and 24% for sodium [32]. Saturated acids comprise about 61% of milk FA, including palmitic (27%), stearic (14.7%), myristic acid (12.4%), with kapron and capric acid being only 0.8% [33]. Camel milk fat is made of 39% unsaturated FA. Camel milk can help treat some liver problems, lower bilirubin output, lighten vitamin inadequacy and nutrient deficiency, and augment immunity [32]. Fermented camel milk contains some minor amount of alcohol, and 12.4% of dry matter including 4.8% fat, 3.6% protein, 0.12 mg/kg carotene and 56 mg/kg vitamin-C. One kg of fermented milk has 766 kcal energy. From each 3 L of fermented milk, 1 kg of curd is produced, almost half of the curd yield in sheep, goat and cow milk [32,33,34].

Camel milk is receiving more recognition as a global healthy food. The Food and Agriculture Organization of the United Nations (FAO) predicts that camel dairy products will appear on European supermarket shelves. However, logistic challenges in manufacturing and processing must be overcome. Despite the increasing demands from Sahara to Mongolia, the annual 5.4 million tones of camel dairy products are still greatly inadequate. Sector and local investments must escalate to meet demands and create profitable markets both in the Middle East and the Western world. There are about 300 million potential customers in the Middle East and millions more in Africa, Europe and the Americas for camel dairy products. In many regions of Iran, Russia, Kazakhstan and India, camel milk is traditionally prescribed as a cure for disease recovery [27,28,29]. Oral camel milk administration is protective against cadmium-induced toxicity in rats as a model for humans [30].

A main challenge in camel milk processing is its incompatibility with the Ultra High Temperature (UHT) exposure needed to make milk long-lasting [31,33]. Another challenge stems from the camel producers' mainly nomad nature. Camels are reputedly stubborn. Moreover, unlike cows and other docile ruminants that store all their milk in udders, camels store their milk further up the body [33]. With extensive production and improved feeding and veterinary services, daily milk yields reach up to 40 L. There are at least 17 million camels (*Camelus dromedarius*) worldwide including approximately 12 million in Africa and 5 million in Asia. Milk production varies between 1500 and 15000 kg during a lactation cycle of between 9 and 18 months [31].

A major use of camel milk is in allergy caused by various foods, especially ruminant-made foods including cow milk products. Such allergies may cause anaphylactic reactions [35,36]. Camel milk was recently shown to cure allergies in children of 8-mon to 10-yr old [28]. In addition, camel milk proteins are the most important constituents in preventing/curing food-born allergies. This is because camel milk lacks  $\beta$ -lactoglobulin [35] and has different  $\beta$ -casein [36] than that of cow milk. These proteins make cow milk allergenic. Moreover, camel milk contains many immunoglobulins, being compatible with human counterparts.

In Iran, Pakistan and India, camel milk has long been used therapeutically against dropsy, jaundice, spleen and liver complexities, tuberculosis, asthma, anemia, and piles [37]. Camel milk has slimming properties and is healthier when drunk cool [38,39]. A belief by the

Bedouin of the Sinai Peninsula exists that any internal disease can be cured by drinking camel milk that drives from the body all the bacteria. Following immediate use, the left-over camel milk is curdled and soured. The casein prepared from this milk product is called 'industrial casein' [40]. It is not very firm for human intake, and is rather used for glue and gums making. The high proteins and amino acid proportions of casein make camel milk an appropriate food supplement. The unfavorable odor and taste, however, could affect its popularity. It is recommendable to purify the camel industrial casein for a more favorable competitive status in human health markets [40].

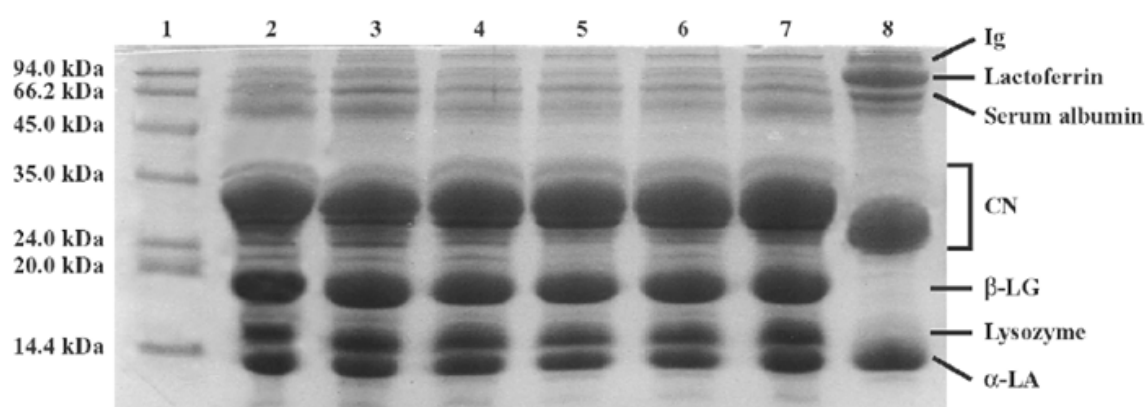
### Jenny milk

Due to similarity to human milk, milk of jenny (i.e., female donkey) receives growing attention, particularly in Europe [41]. Limited knowledge exists on chemistry and nutritional properties of jenny milk, comparing mare milk. Based on available data, jenny milk is very similar to mare milk with low total solids (8-10%) and protein (1.5-1.8%) and high lactose (6-7%). Jenny milk fat varies within 0.28-1.82% [42,43]. Jenny milk protein is low in casein (47.3%) and whey protein (36.9%), but it is reasonably high in lactose and  $\beta$ -lactoglobulins (30%) [44]. It has high levels of peptide-bound and essential AA. Comparing cow, buffalo, goat, ewe, camel, and mare milks, jenny milk is richest in valine and lysine. Jenny milk's special peptides stimulate intestinal functional recovery by growth and protective factors [41]. Thus, jenny milk may be an alternative for infants with cow milk intolerance. Jenny milk has been fed safely to cure food intolerance [41]. Jenny milk, if suitably modified, could be fed to infants to avoid cow milk allergies [45]. Moreover, jenny milk may favor osteogenesis, arteriosclerosis therapy, coronary heart disease, and cholesterolemia [46]. However, because of limited donkey production, milk use for human consumption in realistic scales has been doubtful. China with about 8 million heads has the highest donkey population worldwide [3]. Other major countries include Pakistan and Ethiopia [47]. China has attempted to improve jenny milk production through advancing donkey breeding facilities, such that an annual jenny milk yield of 40,000 metric tons has been obtained [3,48]. As such, jenny milk has been processed to help meet nutritional demands of certain groups of people. This has increased income from donkey enterprises.

Human milk protein content is lower than cow, buffalo, yak, camel, goat, sheep, and reindeer milks. However, it is more similar to jenny and mare milks [49]. The casein to total protein ratio is also lower in human milk, because it has more whey-soluble proteins than milk of cow, buffalo, and sheep. Thus, it is again similar to jenny and mare milks [49]. Given jenny milk's unique nutrient profile and economic potential, it could be a commercial substitute in infant nutritional programs [50]. Human milk must develop a soft curd during the infant gut assimilation. Such a soft curd is formed partly due to the low soluble calcium in human milk. As such, in many regions infants have been safely fed milk of jenny, mare, goat and camel rather than milk of cow [49,51]. Cow and buffalo milks make harder curds that are more favorable for cheese making. Whilst human milk is ideal for infant nutrition, before 6-8 month of infant age, cow milk should be diluted with water to ensure safer outcomes. After about one year of age, when feeding cow milk to infants is more appropriate, diluting cow milk may not be necessary.

A recent study on Jiangyue donkey breed in Northwest China showed that jenny milk contained approximately 9.5% total solids, 1.6% protein, 1.2% fat, 6.3% lactose, and 0.4% ash, being similar to mare and human milks [3]. Milk pH and density were constant throughout lactation. However, milk protein and ash decreased through lactation while milk fat had high variability. Whey protein, casein, and amino acids contents varied less. Jenny milk was rich in  $\beta$ -lactoglobulin and lysozyme. The % of 8 essential AA in jenny milk protein was 38% or higher than that of mare and cow milks [3]. Jenny milk protein contained greater serine (6.2% vs. 4.8% and 5.1%), glutamic acid (22.8% vs. 23% and 17.8%), arginine (4.6% vs. 3.3% and 4%), and valine (6.5% vs. 4.8% and 6%) and lower cystine (0.4% vs. 0.6% and 1.7%) than cow and human milks, respectively [3]. Jenny milk proteins mainly include  $\alpha$ S1- and  $\beta$ -caseins, lysozyme,  $\alpha$ -lactalbumin,  $\beta$ -lactoglobulin (Figure 1) [52]. The average  $\beta$ -lactoglobulin and  $\alpha$ -lactalbumin contents were 3.75 and 1.8 mg/ml, respectively. Overall, jenny milk is characterized by low casein and high lysozyme content (1.0 mg/ml), compared with other milks (Figure 1) [52].

The active components of jenny milk may increase Interleukin-2 (IL-2), Interferon- $\gamma$  (IFN- $\gamma$ ), Interleukin-6 (IL-6), tumor necrosis factor



**Figure 1:** Sodium dodecyl sulfate-PAGE of jenny and human milk proteins. Lane 1 is protein marker; lanes 2, 3, 4, 5, 6, and 7 are jenny milk samples for 15, 30, 60, 90, 120, and 150 days postpartum, respectively; lane 8 is a human milk sample for 60 days postpartum. Reasonable levels of casein,  $\beta$ -lactoglobulin, lysozyme and  $\alpha$ -lactalbumin, and lower levels of immunoglobulins, lactoferrin and serum albumin characterize jenny milk vs. human milk (3,44,52). The SDS-PAGE was under reducing conditions (3), using a Mini-Protean 3 gel electrophoresis apparatus with a 4% acrylamide stacking gel and a 16% separating gel. A mark protein ladder, with proteins of 14.4 to 94 kDa, was used as a molecular weight standard. A human milk sample (at d 60 postpartum) was obtained from a healthy donor. Current was applied at a constant voltage of 80 V until samples entered the separating gel, and voltage was increased to 120 V. Gels were stained with 0.1% Coomassie Brilliant Blue R-250 in 10% acetic acid and 40% methanol, and destained overnight in 10% acetic acid and 10% methanol with 2 buffer changes (3,89).

$\alpha$  (TNF- $\alpha$ ) and Interleukin 1 $\beta$  (IL-1 $\beta$ ) secretion [53]. Such specialized milk protein fractions with high lysozyme suppress tumor proliferation *in vitro* and can indirectly destroy tumors by activating lymphocytes and macrophages [53]. As a result, jenny milk is considered a nutraceutical in replacing human and bovine cow milks under allergic, atopic, and inflammatory conditions. The two milks modulate immune function to release nitric oxide (NO) and IL-8, which are potent anti-atherogenic vasodilators [54,55]. Fermented jenny milk is capable of modulating the immune system in the elderly [55]. Jenny milk and colostrum induce NO release and CD25 and CD69 expression on human peripheral blood mononuclear cells [56]. Jenny milk, but not colostrums, was able to induce release of interleukins (IL) (IL-12, IL-1 $\beta$  and IL-10) and TNF- $\alpha$ . The NO release and immune responses indicate the potential capacity of jenny milk in preventing atherosclerosis and immune depression.

Protein fractions are very similar for jenny and human milks [57,58]. This justifies their hypoallergenic properties and suitability for infant nutrition [59] and cosmetic preparations [60,61]. The high lactose of jenny milk facilitates making fermented products and drinks [62]. Such properties would place even greater emphasis on the significance of jenny milk as a healthy food for humans [63,64]. Furthermore, jenny's raw milk has low bacterial counts (about  $4 \times 10^4$  CFU/mL), which is due to its high lysozyme content [65]. Jenny milk could also be used to make commercial supplements in brewery and probiotic beverage industries [62,65].

### Mare milk

Mare milk protein content is higher than human milk and lower than cow milk. Casein in mare milk is also intermediate relative to human and cow milks. However, fat content is lower in mare milk than in human and cow milks (Table 2) [66]. Mare and human milks are similar in milk fat diglycerides and triglycerides distribution. The proportion of polyunsaturated FA (PUFA) is higher in mare and human milks than in cow milk (Table 2). For its structural and functional properties, mare milk is more suitable than cow milk for human and infant nutrition [66]. From 25 children of 19-72 months age with IgE-mediated cow milk allergy, all exhibited strong positive skin test responses to cow milk, whereas only 2 had positive skin test responses to mare milk. All children had positive response to oral food challenge of cow milk, but only one showed such a response to mare milk [67]. These data suggest that mare milk may be a suitable substitute for cow milk in cases of severe IgE-mediated cow milk allergy.

The ranges of mare milk total solids and fat contents were respectively 24.25–26.28% and 2.85–2.93% on the first day, 12.15–12.78% and 2.05–2.17% on days 2 to 5, and 10.37–10.61% and 1.04–1.32% on days 8 to 45 of lactation [68]. Milk levels of octanoic, decanoic, dodecanoic, myristic and palmitoleic acids increased through lactation, whereas that of stearic, oleic, linoleic and linolenic acids decreased. Mare to cow milk ratios of octanoic, decanoic, dodecanoic, linoleic, linolenic, stearic, myristic and palmitic acids were approximately 9.6, 3.1, 2.1, 4.4, 224, 0.2, 0.6 and 0.5, respectively. Mare colostrum contents of vitamins-A, D<sub>3</sub>, K<sub>3</sub> and C were respectively 0.88, 0.0054, 0.043, 23.8 mg kg<sup>-1</sup>, which were 1.4–2.6 times their levels in mare milk (i.e., 0.34, 0.0032, 0.029, 17.2 mg kg<sup>-1</sup>) [68]. Vitamin-E content was similar between colostrum and milk (1.342 and 1.128 mg kg<sup>-1</sup>, respectively), being also similar to cow milk [68].

Total protein, whey protein, casein and non-protein nitrogen (NPN) were respectively, 16.41%, 13.46%, 2.95% and 0.052% in mare

colostrum. They were respectively 4.13%, 2.11%, 2.02% and 0.043% in milk during 2-5 days postpartum, and 2.31%, 1.11%, 1.20% and 0.031% in milk during 8-45 days postpartum [69]. Milk ratios of true protein and whey protein to total protein decreased whilst casein and NPN increased from foaling through 45 days in milk. Colostral and milk AA decreased over the first 45 days of lactation. Milk threonine, valine, cystine, tyrosine, and lysine decreased, but glutamic acid and proline increased with time after parturition [69]. Mare milk's biological value was highest (132.3) just after parturition, due to high threonine and lysine contents. It, however, decreased to 119.7 at 5-d postpartum and to 107.9 at 45-d postpartum [69]. Mare milk has a greater biological value than bovine cow milk. Calcium was lowest just after foaling (747.7 mg/kg) and was highest at day 5 postpartum (953.7 mg/kg) [69]. Colostrum and milk contained (mg/kg), respectively, 928.6 and 517.2 potassium, 320.0 and 166.6 sodium, 747.7 and 822.9 calcium, 741.7 and 498.8 phosphorus, 139.7 and 65.87 magnesium, 2.95 and 1.99 zinc, 0.996 and 1.209 iron, 0.606 and 0.249 copper, and, 0.0447 and 0.0544 manganese [69].

Rumen FA biohydrogenation results in very low PUFA levels in cow milk. Feeding vegetable oils to increase milk PUFA yield dilutes such a response [70,71]. Mare milk contains higher  $\alpha$ -linolenic acid (ALA) and linoleic acid (LA) (i.e., essential fatty acids, EFA) that are precursors of  $\omega$ -3 and  $\omega$ -6 PUFA, respectively [71,72].  $\alpha$ -linolenic (C<sub>18:3n-3</sub>) and eicosapentaenoic (C<sub>20:5 n-3</sub>, EPA) acids generate 1) prostaglandins such as PGI with vasodilatory effects, 2) thromboxanes such as TXA with vasoconstrictive effects, and 3) docosahexaenoic acid (C<sub>22:6n-3</sub>, DHA). Linoleic acid (C<sub>18:2 n-6</sub>) generates other prostaglandins (PGI<sub>2</sub>) and thromboxanes [72, 73]. Mare milk is rich in EFA, especially linoleic acid, which benefits human health because it cannot be produced by humans. The linoleic acid to  $\alpha$ -linolenic acid ratio in mare milk is 1.3 to 2, being suitable for infant nutrition. Liver can transform them to EPA, DHA and arachidonic acid. These PUFA increase endothelial nitric oxide synthesis, inhibit proinflammatory cytokine production, lower blood cholesterol, help prevent atherosclerosis, and reduce coronary heart diseases [74,75,76].

### Yak milk

The yak is a bovine subfamily classified as *Bos grunniens*. Yak survives in extremely cold and hypo-oxygen environments of as low as -40°C and atmospheric pressure of 550 hPa. Total world yak population is approximately 14.2 million [77]. Domestic yaks graze throughout highlands of the Hindu Kush and Karakoram in Afghanistan and Pakistan, the Himalayas in India, Nepal and Bhutan, the Tibetan Plateau and Tian Shan Mountains of Northern China, Western and Northern Mongolia, and also some areas of Russia and other independent states. China has the largest number of yaks in the world with approximately 13 million or > 90% of all planet yaks [78]. Yak milk yield of 147-487 kg per lactation has been reported [78]. Yak milk and dairy products are popular foods in high-altitude regions. Yak milk contains 16.9-17.7% solids, 4.9-5.3% protein, 5.5-7.2% fat, 4.5-5.0% lactose, and 0.8-0.9% minerals [78]. An example of variations in yak milk yield and fat content through first and second lactations is illustrated in Figure 2. Yak milk contains much lower fat in summer than in winter, which is in part due to the greater summer milk yield. While milk yield is not very different between the first and second lactation, milk fat is much higher during the second than first lactation (Figure 2). Yak cheese contains 47% butterfat on a dry matter basis [79,80]. Yak milk is often used for cheese-making, known as "chhurpi" in Tibetan and Nepali languages, and byaslag in Mongolian. Yak milk butter is used

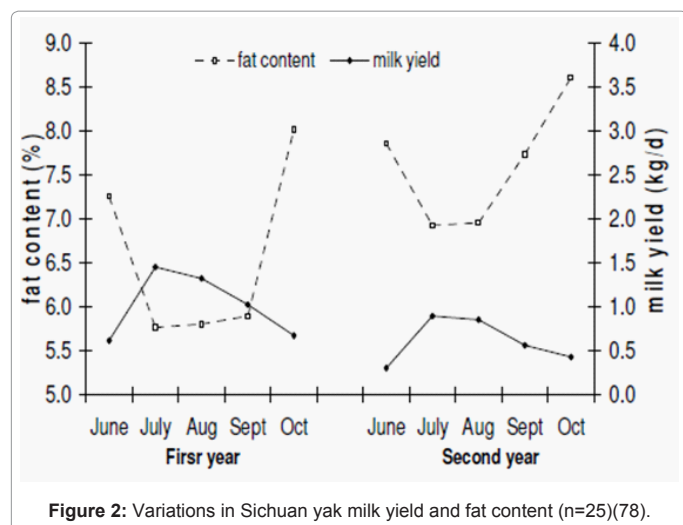


Figure 2: Variations in Sichuan yak milk yield and fat content (n=25)(78).

to make 'butter tea' that is consumed by Tibetans. Although not widely available in regions such as North America, yak dairy products and particularly yak cheese are becoming more accessible in dairy markets. Yak cheese contains about 4 times more CLA than Canadian cheddar, with increased human health implications [79,80]. Yak milk is rich in protein, casein and fat compared to cow milk (Table 2). High contents of colloidal and soluble calcium and phosphorus are other advantages, being highly suitable for cheese-making. Milk fat of yak at very high altitudes is richer in PUFA and CLA.

Yak milk casein has been hydrolyzed to produce antihypertensive peptides, such as YQKFPQY ( $\alpha$ s2-CN; f89–95), LPQNIPL ( $\beta$ -CN; f70–77), SKVLPVPQK ( $\beta$ -CN; f168–176), LPYPYY ( $\kappa$ -CN; f56–61) and FLPYPYY ( $\kappa$ -CN; f55–61), and two novel ACE-inhibiting peptides [81,82]. These peptides are multifunctional bioactives with potential use for value-added functional foods and proteins production [81]. Compared to cow milk fat, n-3 PUFA in yak milk fat is much higher (e.g., 3.2 times) [83]. The n-3 PUFA/n-6 PUFA ratio in yak cheese was 0.87, but only 0.20 in cow cheese. Based on the bottom-line healthy n-3 PUFA/n-6 PUFA ratio of > 0.25 [84], yak cheese would be a very healthy food. Greater CLA<sub>cis-9,trans-11</sub> content relative to cow cheese implies more anticarcinogenic effects for yak cheese and dairy products. The amounts of CLA<sub>cis-9,trans-11</sub> and CLA<sub>trans-11-C18:1</sub> in yak cheese are respectively 4.2 and 4.6 times greater than that in cow cheese [83]. To supply enough CLA<sub>cis-9,trans-11</sub> inclusion of 100 g yak cheese in daily human diets would suffice [83]. The larger diameter of fat globule (5 to 6  $\mu$ m) eases butter separation in yak milk, suitable for cream-making. Saturated and unsaturated FAs comprise respectively 22% and 55.2% of total fat [85]. Yak milk has greater total proteins (4.6–5.8%), total casein (4.0%) and individual caseins than cow milk. The higher  $\beta$ -casein (45%), the lower  $\alpha$ -s-casein (40%), and relatively higher  $\kappa$ -casein (15%) make yak milk appropriate for infants [85].

China is the largest producer of a naturally-fermented yak milk known as "kurut". Kurut is an important food for people of Qinghai [86]. Kurut refers to a group of products produced by natural fermentation of yak milk in a specially-treated big jar for 7–8 days at 10–15°C. These conditions are necessary to produce enough acid, alcohol and flavor. A common property of kurut is the presence of alcohol and lactic acid. Kurut is almost known in all regions of Qinghai as an indigenous fermented milk product with economic and nutritional importance [87]. Kurut is rich in casein, immunoglobulins, serum

albumin,  $\beta$ -lactoglobulin, and  $\alpha$ -lactalbumin [88]. Kurut contains greater numbers of lactic acid bacteria and yeast than other traditional fermented milks (lactic acid bacteria counts of  $9.18 \pm 0.851$  log cfu/ml; yeast counts of  $8.33 \pm 0.624$  log cfu/ml)[88].

## Conclusions and Implications

As the most nutritious natural fluid, milk contains numerous bioactives that function beyond their nutritional value. This review article delineated the comparative nutritional and health characteristics of milk produced by equidae, camel, jenny, and mare for human nutrition and health. Qualitative and quantitative significance of dairy products from above species to postmodern human health and nutrition were highlighted. Emerging technologies in optimal processing of dairy products to improve their functional values were briefly discussed. An ultimate goal will be to minimize allergies and boost immunity, particularly in infants, patients, and the elderly. Thorough, persistent, and timely education and research insight dissemination will be among the ongoing obligations for the natural health properties of milk, especially from less-known species, to be optimally appreciated by human populations worldwide.

## Acknowledgements

Environment receives the highest admirations for its endless opportunities and capacities for improvements. The Ministry of Science, Research and Technology, and University of Zanjan, Iran, are acknowledged for supporting the author's programs of optimizing science education in the new millennium.

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