

Science of Camel and Yak Milks: Human Nutrition and Health Perspectives

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ABSTRACT

Camels and yaks milks are rich in numerous bioactive substances that function beyond their nutritive value. Camel milk is more similar to goat milk and contains less short-chain fatty acids than cow, sheep and buffalo milks, and about 3 times greater vitamin-C than cow milk. 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. Camel milk helps treat liver problems, lowers bilirubin output, lightens vitamin inadequacy and nutrient deficiency, and boosts immunity. Camel milk reduces allergies caused by cow dairy products. Camel milk has low milk fat made mainly from polyunsaturated fatty acids. It lacks β -lactoglobulin and is rich in immunoglobulins, compatible with human milk. Yak milk has 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. Yak milk fat is richer in polyunsaturated fatty acids, protein, casein and fat than cow milk. Yak milk casein is used to produce antihypertensive peptides with capacities for producing value-added functional foods and proteins. Continual systematic education of milk science especially for non-cow species will be an obligation for health implications to be optimally perceived by human populations worldwide.

Keywords: Camel, Education, Health, Immunity, Milk, Nutrition, Yak

1. Introduction

Asia, Europe and North America produce most of the world milk products (**Figure 1**) [1]. The most of milk produced is from cattle except for Asia where cattle and buffalo are the key milk producers (**Figure 1**). The science of non-cow milks has, however, not been broadly, scientifically, and systematically appreciated by the public. The greatest dairy food consumption occurs in Western Europe, Scandinavians, Australia, and Canada (**Table 1**). These highlight the inevitability of further education and research data dissemination in both above and other world regions on human health implications of milk, especially from non-cow species.

Milk secretion results from pregastric fermentation of plant cells that generate volatile fatty acids (VFA) and microbial mass [2,3]. As such, milk is considered the most natural and efficient functional food. Such a global nutritional fame is because milk is produced from most abundant, least digestible matters in the nature (e.g., cellulose), and also because it encompasses numerous bioactives that function beyond their nutritive value. No

food can replace milk for neonatal development of brain, nervous, immune, and skeletal systems, which is an evolutionary testimony for its irreplaceable roles in creation of upcoming higher quality generations [3]. Lactating women on milk secret breast milk enriched with β -lactoglobulin and ovalbumin [4]. Livestock milk may be enriched with vitamin-E for greater nutritional value [5]. Milk from immunized ruminants has reduced hypercholesterolemia [6]. Conjugated linoleic acid (CLA) of mainly CLA cis9, trans11 (75% - 90%) and CLA trans10, cis12 have implications as anti-carcinogenic, anti-atherogenic, anti-inflammatory, and anti-lipogenic agents [7,8]. As such, ruminant research has attempted to manipulate nutritional programs to enrich milk with CLA [7]. Milk immunoglobulins act against Enterotoxigenic Escherichia coli [9]. Dairy consumption has also reduced metabolic syndromes [10]. Whey proteins are insulinotropic and medium chain fatty acids improve insulin action and fat metabolism. Medium and short chain fatty acids in milk specifically butyric acid, publically considered likely unhealthy, can improve intestinal fat and nitrogen assimilation and insulin sensitivity [11,12].

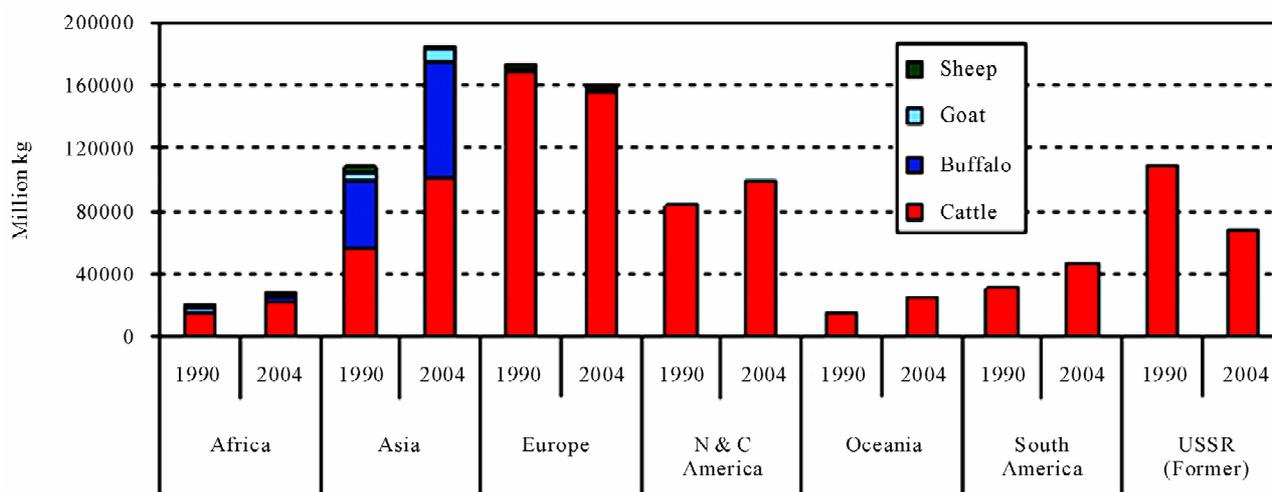


Figure 1. Total and proportional world ruminant milk production.

Table 1. Highest per capita dairy products consumers.

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 2. Average milk composition per 1 kg of milk.

Component	Cow	Camel	Yak	Breast
Fat, g	40	45	65	40
Protein, g	34	35	51	19
Lactose, g	48	44	44	65
Minerals, g	7	7	8	2
Solids-non-fat, g	90	86	104	73
Total solids, g	133	128	169	121
Cholesterol, mg	140	370	220	200
Calcium, g	1.20	1.43	1.31	3.20
Phosphorus, g	0.93	1.16	1.06	1.4
Saturated FA, g	24	24	39	18
Monounsaturated FA, g	11	14	22	16
Polyunsaturated FA, g	1	5	4	5

FA = fatty acids.

Given the versatile raising environment, evolution, genetics, and feeding management, milk composition differs vastly among livestock (**Table 2**). Protein and calcium supplies from animal foods including dairy products vary considerably among countries. Average intake in many regions is well below minimum daily requirements of about 70 g protein and 800 mg calcium [13]. Camel milk is produced very economically by animals living in the toughest environments. Camel milk is three times richer in vitamin C than cow milk. In some countries including Iran, Russia, Kazakhstan and India, camel milk is prescribed for early and effective recovery from a variety of disorders. Its vitamin C, iron, unsaturated fatty acids and B-family vitamins boost immunity. Nonetheless, the public awareness of non-cow dairy foods nutritional and health perspectives is highly insufficient. The limited global insight reflects the much

less available research data and more importantly the less emphasized education, compared to cow dairy foods. Therefore, a primary objective is to delineate exclusive nutritional and technological properties of camel and yak milks in providing healthy foods for humans in the new era. A second primary objective is to help optimize milk science education worldwide with an emphasis on camel and yak dairy foods.

2. Camel Milk for Nutrition and Health

Camel milk has on average 11.7% total solids, 3.0% protein, 3.6% fat, 0.8% ash, 4.4% lactose, and a pH of 6.5. The levels of Na, K, Zn, Fe, Cu, Mn, niacin and vita-

min-C are greater and that of thiamin, riboflavin, folacin, vitamin B12, pantothenic acid, vitamin-A, lysine and tryptophan are relatively lower compared to cow milk. Milk fat has a molar% of 26.7 palmitic acid, 25.5 oleic acid, 11.4 myristic acid, and 11.0 palmitoleic acid. Camel milk is more similar to goats' milk and contains less short-chain FA 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 ANRC-Casein. Camel milk contains substantially less vitamins-A (0.10 vs 0.27 mg/L) and B2 (0.57 vs 1.56 mg/L), similar vitamin-E content (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 [14].

Camel is known as the gold goal pseudo-ruminant of the 21st century in arid regions and drylands. In Kazakhstan, 37% of the total milk is produced by camel, with sheep, yak and cows producing 30%, 23% and 10%, respectively. Camel milk production varies from 3.5 up to 40 L per day under intensive management. Lactation lasts between 9 - 18 months, with peak yield occurring during the first 2 - 3 months postpartum. In another study, the range of major contents of camel milk were: 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 [15].

The camel milk is receiving more recognition as a global product in optimizing human health. The FAO predicts the 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 camel dairy products are 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. Although somewhat saltier than cow milk, camel milk represents a cost-effective husbandry under toughest conditions. Camel milk is 3 times richer in vitamin-C than cow milk. In many regions of Iran, Russia, Kazakhstan and India, camel milk has traditionally been prescribed as a food treatment for multiple diseases recovery [16-18]. Oral camel milk administration has proved protective against cadmium induced toxicity in rats [19]. Camel milk is also known for its rich iron, unsaturated fatty acids and B-vitamins.

A main challenge in camel milk processing is its incompatibility with the Ultra High Temperature (UHT) exposure, which is to preserve milk. Also, most camel producers have a nomad nature. An additional challenge is that camels are reputedly stubborn animals. Unlike

cows and other docile ruminants storing all their milk in udders, camels store their milk further up the body. Besides all, camel milk production might be considered an inferior-technology business, such that a scanty 5 L daily secretion is regarded a decent yield. Even under extensive production, improved feeding, husbandry and veterinary services should enable daily yields of up to 40 L. There seems to be at least 17 million camels (*Camelus dromedarius*) in the world including 12 million in Africa and 5 million in Asia [1]. Milk production varies between 1500 and 15,000 kg during a lactation of 9 and 18 months [20].

Camel milk has 21 different amino acids [20]. One kg of camel milk supplies 100% of daily human requirements for calcium and phosphorus, 57.6% for potassium, 40% for iron, copper, zinc and magnesium, and 24% for sodium [21]. Saturated acids comprise about 61% of milk FA, including palmitin (27%), stearin (14.7%), myristic acid (12.4%), with kapron and capric acid being only 0.8% [22]. Thus, 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 [21]. 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. Processing 100 kg of camel milk in temperatures between 50°C - 55°C can yield 9 - 10 kg of sour cream with 66% of fat. Processing the same amount of camel milk in temperatures between 45°C - 55°C can generate 12 - 14 kg of sour cream with 35% - 40% of fat [23]. One kg of curds is derived from 6 L of camel milk, one kg of dried curd is produced from 9.1 L of milk, one kg of melted butter with 98% of fat is made from 15 L of milk with 5.66% of fat, one kg of sour cream with 76.8% of fat is made from 13.5 L of milk with 5.66% of fat. Fermented camel milk is made of pure starter culture. It must be stirred 5000 - 6000 times by electrical beaters every 3 h. Fermentation starts at temperatures of 20°C - 25°C for the first 24 h. After that it should be cooled down to 18°C - 20°C. Fermentation will be complete after 6 h. The fermented milk can be kept for 60 days in dark bottle at a temperature of 40°C - 50°C and becomes ready for consumption. Carbonated fermented milk can be preserved up to 90 days.

A major use of camel milk is in allergy caused by various foods, especially ruminant-made foods of mainly cow milk and milk products. Such allergies may cause anaphylactic reactions. These include 1) immediate reaction within 45 min of drinking cow milk that leads to

urticaria, angioedema and likely true anaphylactic reactions; 2) medium reactions occurring 45 min to 20 h that manifests with pallor, vomiting and diarrhea; and 3) long-term reactions happening > 20 h with mixed reactions in the skin and respiratory and gastrointestinal tracts. Camel is a non-ruminant, despite ruminating, or so called Tylopode. Camel milk is exclusive by its rather low milk fat of about 2% that is made mainly from polyunsaturated FA. These FA tend to be fully homogenized and form smooth white milk. In addition, camel milk proteins are the most determining constituents in preventing/curing food-born allergies. This is because camel milk lacks β -lactoglobulin [24] and possesses a different β -casein (Beg, 1986) than cow milk. These proteins make cow milk allergenic. Moreover, camel milk contains many immunoglobulins, being compatible with human counterparts. Camel milk is also rich in vitamin-C, calcium and iron, thus boosting immune function. Camel milk was recently shown to cure allergies in children of 8-mon to 10-yr old [17].

In several regions of Iran, Pakistan and India, camel milk has long been used therapeutically against dropsy, Jaundice, spleen and liver complexities, tuberculosis, asthma, anemia, and piles [25]. Camel milk is healthier when it is drunk as a cool drink [26]. The milk also apparently has slimming properties [27]. The belief by the Bedouin of the Sinai Peninsula exists that any internal disease can be cured by drinking camel milk through driving from the body all the bacteria. Such milk properties must additionally be attributed to what camel eats. Milk from camel consuming straw might not exhibit the favorable health effects. By the rule of thumb considerations, generally camel milk nutritional value would be considered the lowest following milk from ewe, goat and cow. However, 4 - 5 kg of camel milk and milk products are sufficient to meet energy, lipids, proteins and calcium requirements of a man.

Following immediate use, the left-over camel milk is curdled and soured. The casein prepared from this milk product is called "industrial casein" [28]. It is not very firm for human intake, and is rather used for glue and gums making. The industrial casein from cow milk is however rich in proteins. The whey proteins of camel milk are richer in nitrogen compared to cow milk [28]. The high proteins and amino acid proportions of camel milk casein make camel milk an appropriate food supplement for humans. The unfavorable odor and taste, however, could affect its popularity. Thus, it is recommended to purify the camel industrial casein to maintain its competitive status in the human health markets.

3. Yak Milk for Nutrition and Health

The yak is a bovine subfamily classified as *Bos grun-*

niens. Yak is able to survive in extremely cold and hypo-oxygen environments at as low as -40°C and atmospheric pressure of 550 hPa. The estimated total world yak population is approximately 14.2 million [29]. 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 that comprises > 90% of all planet yaks [30]. Per lactation yak milk yield of 147 - 487 kg has been reported [30]. Yak dairy products milk in such high-altitude regions are popular foods. Yak milk has about 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. Nepal has initiated to make "yak cheese production" a commercial enterprise. Yak cheese contains 47% butterfat on a dry matter basis [31,32]. As such, yak milk is often used for making cheese, named as "chhurpi" in Tibetan and Nepali languages, and byaslag in Mongolia. Yak milk butter is used to make "butter tea" that is consumed by Tibetans. It is also used in lamps and made into butter sculptures during religious festivities. Although not widely available in North America, yak dairy products and particularly yak cheese are becoming more accessible in some dairy stores. Yak cheese contains about 4 times more CLA than Canadian cheddar, which shows its potential role in preventing cancer, heart disease, and metabolic disorders such as diabetes. 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 additional advantages, making yak milk very suitable for cheese making. Milk fat of yak at very high altitudes is richer in PUFA, namely CLA. As such, the resulting cheese and dairy products will have value-added nutraceutical functions.

Yak milk casein has been hydrolyzed to generate antihypertensive peptides, such as YQKFPQY (α 2-CN; f89-95), LPQNIPPL (β -CN; f70-77), SKVLPVPQK (β -CN; f168-176), LPYPYY (κ -CN; f56-61) and FLPYPYY (κ -CN; f55-61), and two novel ACE-inhibiting peptides [33,34]. These peptides are multifunctional bioactives with potential use for producing value-added functional foods and proteins [34]. Compared to cow milk fat, n-3 PUFA in yak milk fat is extremely higher (e.g., 3.2 times) [35]. The n-3 PUFA to n-6 PUFA ratio in yak cheese was 0.87, but only 0.20 in cow cheese. Based on the minimum healthy set ratio of >0.25 [36], yak cheese is considered a highly healthy food for humans. Greater CLA cis-9, trans-11 relative to cow cheese suggests more anticarcinogenic effects of yak cheese and dairy products.

The amounts of CLA cis-9, trans-11 and CLA trans-11-C18:1 in yak cheese have been found to be respectively 4.2 and 4.6 times greater than that in cow cheese [33]. Research data indicate that considerable amount of CLA cis-9, trans-11 originates directly from the rumen. To supply adequate amount of CLA cis-9, trans-11, inclusion of 100 g yak cheese in daily human diets should suffice [33].

The milk yield of yak and its hybrid, “khainag”, is 300 and 470 kg, respectively. The larger diameter of fat globule (5 to 6 μm) eases butter separation in yak milk, thus being suitable for milk cream making. Due to high carotene content, its butter is yellowish and quite delicious. Along with high proteins, yak milk has high acidity. Saturated and unsaturated FA comprise respectively 22% and 55.2% of total fat, with greater content of low molecular weight volatile acids, compared to cow milk [37]. Mongolians produce from yak milk butter as well as fermented and protein products. Butter products include milk membrane (orom), and yellow and white butter. The fermented products include yoghurt and koumiss (airag). Wet and dried curds (aaruul) are among protein products. Yak milk has greater contents of total proteins (4.6% - 5.8%), total casein (4.0%) and individual caseins than cow milk. The higher β -casein (45%) and the lower α -s-casein (40%) along with somewhat higher κ -casein (15%) make yak milk a favorable food for infants as traditionally consumed by Tibetan nomads [37]. Yak milk's whey proteins, β -lactoglobulin and serum albumin compositions are rather similar to homologous cow whey proteins. Nonetheless, more research is needed to figure out how to optimize yak milk utilization in humans of extreme climatic environments.

China may be the largest producer of naturally fermented yak milk called “kurut”. Kurut is an important food for people of Qinghai [38]. Kurut includes products produced by natural fermentation of yak milk in a specially treated big jar for at least 7 - 8 days at 10°C - 15°C. These conditions generate 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 to the people of Qinghai [39]. Kurut is rich in casein, immunoglobulins, serum albumin, β -lactoglobulin, α -lactalbumin, and two unknown fractions [40,41]. Kurut contains greater numbers of lactic acid bacteria and yeast than other traditional fermented milks (lactic acid bacteria counts of $9.18 \pm 0.851 \log \text{cfu/ml}$; yeast counts of $8.33 \pm 0.624 \log \text{cfu/ml}$) [40].

4. Conclusions and Implications

Milk is the most functional natural liquid because it 1) is

produced from the most abundant, least digestible nutrients and 2) generously hosts numerous bioactives that function beyond calculated nutritional values. Camel milk contains less short-chain FA than cow, sheep and buffalo milks, and has about 3 times greater vitamin-C than cow milk. One kg 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. Camel milk has long been used to treat liver problems, lower bilirubin output, reduce vitamin inadequacy and nutrient deficiency, and boost immunity. Camel milk reduces food allergies caused by cow milk and milk products. Camel milk has low milk fat content with increased PUFA proportions. Camel milk lacks β -lactoglobulin and is rich in immunoglobulins, thus being compatible with human milk. Yak milk has greater solids, protein and fat, and is richer in PUFA and casein than cow milk. Yak cheese has about 4 times more CLA than Canadian cheddar. Yak milk casein has been hydrolyzed to produce antihypertensive peptides with multiple bioactive functions and capacities for producing value-added functional foods and proteins. More research is needed to further characterize biophysical and biochemical properties of camel and yak milks as functional substitutes for cow milk and other animal products. Persistent education and data dissemination will be a commitment for such milk natural health implications to be optimally perceived by science and public communities worldwide.

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