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Review

Recent advances on camel milk: Nutritional and health benefits and processing implications—A review

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Abstract: Camels are important dairy animals and are better milk producers in arid and desert environments than other livestock kept in the same environment. They not only survive but also produce more milk for longer periods than other animals, such as cattle. Camel milk has unique properties and a number of advantages as compared to milk from other species. This paper reviews recent developments on camel (*Camelus dromedarius*) milk, its nutritional and health benefits. It also addresses the peculiar characteristics of camel milk and its implications on processing and development of camel dairy products. Camel milk has superior nutritional quality and purported medicinal properties against a range of human illnesses including antidiabetic, anti-autistic, anti-microbial, antihypertensive, anticarcinogenic, anticholesterolemic, antioxidant, anti-inflammatory, hypoallergenic, hepatoprotective and immune boosting effects. The claimed therapeutic property of camel milk is attributed to its possession of various bioactive compounds as well as generation of bioactive peptides from intact proteins during digestion and/or fermentation of the milk. Although available reports mainly based on *in vitro* studies and animal models indicate the therapeutic potential of camel milk, the clinical effectiveness and value of camel milk as a therapeutic agent has not been conclusively confirmed. Camel milk differs markedly from bovine milk in terms of structural and functional properties of the milk components, and composition of individual proteins and its colloidal structures. These differences present challenges for processing camel milk into products.

Keywords: camel milk; chemical composition; medicinal properties; nutritional value; peculiar characteristics

1. Introduction

Camels are kept by pastoralists in subsistence production systems mainly for their milk production. They are well known for maintaining milk production during drought conditions. Camels are very reliable milk producers during dry seasons and drought years when milk from cattle, sheep, and goats is scarce [1,2]. In drought-stricken areas of the world, where continuous drought decimates cattle, sheep and goat populations, only the camel survives and continues to produce milk. They produce more milk for longer periods during drought than any other domestic animal adapted to arid habitats, and this is of great importance to pastoralists as camel milk may contribute up to 50% of their food intake [1,3,4]. Field [5] estimated that the volume of milk produced by camels is six times that produced by indigenous cattle found in the dry lands. On the other hand, Cossins [6] reported that a camel can produce five times more milk for human consumption than a cow, and equivalent numbers of camels produce 2.7 times the protein while consuming only 1.3 times the dry matter required by cattle. A recent report by Kamal-Eldin *et al*. [7] indicated that camel requires about 2 kg of dry matter feed to produce 1 L of milk compared to 9.1 kg of feed needed by the cow.

The current estimated camel population in the world is 35 million, of which one million are Bactrian (two-humped) camels and the remaining are dromedary (one-humped) camels [2]. Approximately 86% of the dromedary camels are found in Africa, with the largest population in East and Central Africa (Somalia, Chad, Sudan, Ethiopia and Kenya) [2]. Africa is the major producer of camel milk in the world and it accounts for 90% of the global fresh whole camel milk production [8]. Camel milk has an important role in food security and rural economy of arid zones of north and east Africa, Central Asia, and the Indian subcontinent. Camel milk consumption is increasing among the urban population throughout these regions, including the Middle East. Nowadays, the demand for camel milk has increased in Africa, and it is being sold and consumed in big cities and towns where camels are not found [9]. In addition, interest is growing in camel milk among specific consumer groups in North America and Europe due to its potential medical benefits [2,7,10–12].

Milk production is one of the most important roles of camels in arid and semi-arid regions of Africa and Asia. Camel milk has an important role in food security and rural economy of arid zones of North and East Africa, Central Asia, and the Indian subcontinent. Camel milk is the main component of human diets, especially in hot regions and arid countries where they are found [13]. Desert dwellers and nomads mainly live on camel milk for days or months in the extreme hot climate without any significant loss of health. Camel milk often contributes about half of the nutrient intake of some pastoral communities in Africa [1,3,14] and milk production is the primary reason for keeping camels in most pastoral areas [9,15].

Camel milk has unique properties and it offers superior nutritional value and has medicinal properties as compared to milk of other mammals [8]. Both fresh and fermented camel milk have been used by nomadic pastoralists for the treatment of multiple diseases [7,8,16,17]. Components of camel milk differ considerably from milk of ruminant animals such as cows, sheep and goats. It has unique characteristics that makes it behave differently during processing and product development.

This paper reports the milk production potential of the one-humped camel, the peculiar characteristics of the milk, and its implications on processing and development of camel dairy products. It also highlights recent developments on camel milk, and its nutritional and health benefits.

2. Camel milk production

It is difficult to estimate the daily milk yield of a camel under pastoral conditions, owing to the inconsistency of milking frequency. Milk yield and composition are affected by species, breed, age, stage of lactation, parity, season of calving, feeding, health of the animal, reproductive status (estrus, gestation), management conditions (milking frequency, the presence of the calf, and method of milking: hand or machine milking), heat stress and availability of water [1,2,4,18–21]. Heat stress reduces camel milk yield. Severe water deprivation during heat stress was found to reduce the milk yield in camels, and the reduction was generally proportional to the severity of dehydration [4].

Individual total milk production of camels varies from 1000 to 12,000 L during 8–18 months lactation period with great differences among geographical regions (Africa vs. Asia) [20]. For example, milk yield of the Maghrebi female camels under favorable conditions increases up to 6–12 L/day, whereas the yield under traditional extensive conditions averages 2.0 L/day [22]. In a large-scale camel dairy farm that was established in Dubai, the average daily milk production, the mean length of lactation, and the mean total milk production per lactation of 174 one-humped camels were reported to be 6.0 ± 0.12 kg, 586 ± 11.0 days and 3314 ± 98.5 kg, respectively [23]. Jemmali *et al*. [24] reported an average daily milk production of about 6.72 ± 2.46 L and a mean total milk production of 2642 ± 523 L for 390 days of lactation with a range between 972 and 3538 L for camels (Neggas) from Tunisia. On the other hand, Bekele *et al*. [18] reported a mean daily milk offtake of camels kept under pastoral management in eastern Ethiopia to be 4.14 ± 0.04 kg/day. These researchers also showed that the lactation length of camels ranged from 224 to 567 days with a mean of 353 ± 14 days and the average lactation milk offtake was 1422 ± 74 kg.

Reports also indicate that one-humped camels in the Punjab district of Pakistan can produce up to 30 kg day^{-1} of milk immediately after calving with an average of 17.4 kg day^{-1} over a 10-month period, which translates to a total milk yield of 5300 kg per 305 days [2,19]. Al-Majahim camels (camel breed in Saudi Arabia known for milk production) from Saudi Arabia were reported to produce up to 18 L day^{-1} of milk under intensive systems [2,19]. On the other hand, the milk production of Somali camels on pasture during the rainy season has been estimated at an average of 10 L day^{-1} during the lactation period [2,19].

The lactation curve of camels is influenced by age, parity, level of production, and month of calving [25]. A study by Nagy and Juhasz [20] revealed that the distinct peak milk production was observed in camels during the 4^{th} month after parturition (mean daily maximum 8.9 ± 0.04 kg), then mean production declined gradually, reaching 50% of the maximum by the 16^{th} month postpartum (4.3 ± 0.06 kg). Abdalla *et al*. [26] stated that in camels, optimal milk production capacity was obtained between the fifth and sixth parities, which is later than in dairy cows, whose maximum milk yield is usually observed at the third parity.

The length of lactation of camels can vary from 9 to 18 months [1]. This depends mainly on the husbandry practices, which are determined largely by the need for milk, more being required in the dry months than in the wet months when other sources of food are available. In general, both udder halves are milked at the same time by two herdsmen, but before milking, the calf is allowed to suckle until the milk starts to flow and then the camel is milked [1,15]. Without this stimulation, it is difficult, if not impossible, to milk the dam. If the calf dies, the dam dries up if milking is not stimulated. Often it is sufficient for the dam to see the skin of her calf for milk secretion to be stimulated [1,15].

3. Physical properties of camel milk

Camel milk is generally opaque white [27,28]. The white color of camel milk is attributed to the lower β-carotene content of camel milk [2,29–31]. It has a sweet and sharp taste, but sometimes it can be salty [2,17,27,28]. The taste generally depends on the type of fodder and availability of drinking water [27]. The pH of camel's milk ranges from 6.2 to 6.5 [1,17] and the density ranges from 1.026 to 1.035 [1] with an average value of 1.029 [17,28,32,33]. Both density and pH are lower than those of cow's milk [1]. The lower pH of camel milk could be attributed to the high vitamin C content of the milk [34]. Compared to cow's milk, camel's milk sours very slowly and can be kept longer without refrigeration [1]. The viscosity of camel milk at 20 ℃ is 1.72 mPa s, whereas the viscosity of bovine milk at the same dry matter content and under the same conditions is 2.04 mPa s [35]. The freezing point of one-humped camel milk is between −0.57 ℃ and −0.61 ℃ [31], which is lower than cow milk (−0.51 ℃ to −0.56 ℃). Moreover, camel milk has a high alcohol stability number (32.3) versus 20.8, 10.3, 12.5, and 14.1 for cow, buffalo, goat, and sheep milk, respectively [36]. The buffering capacity of skim camel milk was reported to be lower than that of bovine milk. The highest buffering capacity reported for skim camel milk was at pH 4.95, whereas bovine skim milk exhibited higher buffering capacity at pH 5.65 [32]. Camel milk has a calorific value of 665 versus 701 kcal/L for cow milk [33]. The acidity of camel milk was reported to be 0.144% lactic acid while its electrical conductivity was reported to be 6.08 millimhos [28].

4. Composition of camel milk

Literature data have shown wide ranges of difference in camel milk composition. Meta-analysis of literature data on gross composition of camel milk (one-humped and Bactrian) gave mean values (in g/100 mL) of 3.82 ± 1.08 for fat content, 3.35 ± 0.62 for total protein, 4.46 ± 1.03 for lactose, 12.47 ± 1.53 for total solids, and 0.79 ± 0.09 for ash [37]. The same study reported a mean value (in g/100 mL) of 4.14 ± 0.80 for fat content, 3.33 ± 0.52 for total protein, 12.69 ± 1.11 for total solids, 4.18 ± 0.72 for lactose and 0.76 ± 0.09 for ash for milk of East African one-humped camels [37].

The components of camel milk are considerably different from those of other ruminants [1,38]. There are greater variations in the constituents of camel milk than in cow milk. The main difference between cow and camel milk lies in the different physicochemical characteristics of the individual components [1]. The composition of camel milk in comparison to bovine and human milk is given in Table 1. Camel milk has higher ash content as compared to both bovine and human milk whereas the lactose content of human milk is much higher than that of camel and bovine milk (Table 1). On the other hand, the protein, fat and total solids content of bovine milk is higher than that of camel milk.

Table 1. Gross composition (average and range*) of camel milk in comparison to bovine and human milk.

Proximate composition (g/100 g milk)	Camel	Bovine	Human
Water	89.0 (88.7–89.4)	88.1(87.7–89.2)	87.8 (87.1–89.3)
Total protein	3.1 (2.4–4.2)	3.2 (3.1–3.3)	1.2 (0.9–1.9)
Total fat	3.2 (2.0–6.0)	3.8 (3.3–5.4)	3.5 (2.1–4.0)
Lactose	4.3 (3.5–4.9)	5.1 (4.9–5.6)	6.4 (6.3–7.0)
Ash	0.8 (0.69–0.9)	0.72 (0.7–0.8)	0.2 (0.2–0.3)
Total solids	11.0 (10.6–11.3)	11.9 (10.8–12.3)	12.2 (10.7–12.9)
References	[39,40]	[28,39,41]	[28,40,42]

*Values in parenthesis are ranges.

The importance of camel milk in human nutrition lies in the fact that it is very similar to human milk just like mare and donkey milk [8,31,43]. The casein profile of camel milk is similar to human milk especially its ß-casein content [8]. Camel milk is reported to be the most appropriate substitute for cow milk, mainly because of the high proportion of ß-casein, low proportion of α-casein, deficiency in β-lactoglobulin, and similarity of the immunoglobulins to those found in human milk [33,43]. Variation in camel milk composition is attributed to several factors including seasonal variation, variation in water intake, quality of feed, analytical procedures for measurement, milking interval, stage of lactation, breed and climate [10,40,44].

4.1. Water

The water content of camel milk may fluctuate from 84% to 90% [27,38]. Variation in water content of camel milk is also observed in numerous research findings and is attributed to variation in animal feed, availability and consumption of water [10]. When camels have free access to water the content of water in milk is 86%, but when water is restricted, the water content of milk increases to 91% [38]. Thus, it would appear that the lactating camel loses water to the milk in times of drought, i.e., camels produce diluted milk in hot weather when water is scarce [1,38]. This could be a natural adaptation to provide not only nutrients but necessary fluid to the dehydrated calf [45].

4.2. Total solids

The dry matter in milk consists of fat, lactose, proteins and ash. Stage of lactation and season have a significant influence on the daily production of milk. Camel milk consists of an average total solids content of 15.06% of which, protein accounts for (4.9%), milk fat (5.60%), lactose (5.85%), mineral substances (0.99%) [46]. Khaskheli *et al*. [47] reported total solids content for camel milk ranging from 7.76 to 12.13%, whereas Dowelmadina *et al*. [48] reported the value 11.9 ± 1.5% for total solids content of camel milk produced in Sudan. On the other hand, Makgoeng *et al*. [49] reported a total solids content of 12.2 ± 0.75% for milk collected from camels kept at Tsabong in south-western Botswana. An inverse relationship was found between total solids in camel milk and water intake by camels [50].

4.3. Fat

The fat content of camel milk varies between 2.9 and 5.4% [1] and the average size of the fat globules of camel milk is less than that of cow milk [8,28,30,51,52]. The small size of the camel milk fat globule accounts for its high-fat digestibility [8,28,31] but leads to difficulties in obtaining butter and results in lower butter yield [30]. The main differences in physical properties of cow and camel milk fat are indicated in Table 2.

Table 2. Differences in physical properties between camel and cow milk fat.

Properties	Camel milk	Cow milk	References
Creaming property	On standing, camel milk creams less rapidly and less completely than cow milk and no skimmable cream can be obtained even after standing for several days.	Cow milk creams easily.	[1,52]
	Camel milk shows little tendency to cream up due to deficiency of the protein agglutinin.		[30,53]
Fat globule size	It has a small fat globule size and a thicker fat globular membrane. These properties make it difficult to produce butter from camel milk.	Cow milk has bigger fat globules and butter can readily be made from cow milk.	[30,53]
Churning temperature	Butter can be obtained from camel milk only at a high churning temperature of 20–25 °C.	Churning temperature of cow milk ranges between 8 and 12 °C.	[1]
Melting range of butter	The melting range of camel milk butter ranges from 41–42 °C and is on average 8 °C higher than the corresponding value for cow milk butter.	The melting range of cow milk butter ranges from 31.50–34.80.	[1,30]

The high melting range of camel milk fat may be attributed to its high content of unsaturated long-chain fatty acids, low content of short-chain fatty acids [8] and very high levels of higher molecular weight triacylglycerols (TAGs, C48–C52) in camel milk [30]. The high melting range of camel milk fat makes it difficult to churn the cream at the temperatures (8–12 °C) used for cow milk churning [30]. As a result, more force is needed to separate the fat globule membrane from the camel milk fat and to allow for the globules to adhere to each other [30].

The fatty acid profile and cholesterol content of camel milk in comparison to bovine and human milk are reported in Table 3. Compared to cow milk fat, camel milk fat contains less short-chain (C4–C8) fatty acids [28,30,39,54]. It was reported that camel milk contains 6–8 times less short chain fatty acids compared to milk from cows, goats, sheep and buffaloes [52]. Camel milk fat contains higher proportions of long-chain monounsaturated fatty acids as compared to bovine, mare and goat milk fat [30,54]. In dromedary camel milk, the monounsaturated fatty acid (MUFA) content was high, with an average value of 73 g/100 g of total fatty acids [39].

Camel milk has high unsaturated fatty acids, low saturated and short chain fatty acids and low contents of carotene than bovine milk fat [30,55,56]. Fat obtained from one-humped camel milk is rich in long-chain fatty acids compared to fat obtained from bovine milk [8,36]. The ratio of saturated and unsaturated fatty acids is also in favor of camel milk in terms of unsaturated fatty acids in comparison to other dairy animals [37]. Findings showed higher content (43%) of unsaturated fatty acids in one-humped camel milk. Similarly, higher percentage of saturated fatty acids (69.9%) in bovine milk was reported when compared with camel milk (67.7%) [37]. The unsaturated fatty acids of camel milk were detected as arachidonic acid (0.4%–5%), palmitoleic (7.3%), and oleic acid (25%). However, polyunsaturated fatty acids are present in relatively small amounts, such as linoleic (4.1%–4.6%) and linolenic acid (0.6%–0.9%) [57]. Stearic acid, myristic acid, capric acid, and palmitic acid are found in camel milk as major saturated fatty acids [57].

Fatty acid composition of camel milk fat was found to vary due to genetic differences within the species [58]. Dowelmadina *et al*. [59] reported that the breed of camel had significant effect on omega-3 fatty acid composition of camel milk fat.

Table 3. Fatty acid profile (% of total fatty acids) and cholesterol content of camel milk in comparison to bovine and human milk.

Fatty acids	Camel	Bovine	Human
SFA (%)	47.0–69.9	55.7–72.8	39.4–45.0
MUFA (%)	28.1–31.1	22.7–30.3	33.2–45.1
PUFA (%)	1.8–11.1	2.4–6.3	8.1–19.1
ω6/ω3	n.d.	2.1–3.7	7.4–8.1
Cholesterol (mg/100 mL milk)	31.3–37.1	13.1–31.4	14.0–20.0

Source: [28,40,52]; n.d. = not detected; SFA = saturated fatty acids; MUFA = monounsaturated fatty acids; PUFA = polyunsaturated fatty acids.

The literature reports contradicting values about the cholesterol content of camel milk in comparison to milk of other mammals. Some reports (Table 3) indicate that the cholesterol content of camel milk is higher than bovine and human milk. However, some researchers claim that camel milk has lower cholesterol content especially when compared to bovine milk. Faye [60] reported that the average cholesterol content in camel milk was lower (5.64 ± 3.18 mg/100 g) than in cow milk (8.51 ± 9.07 mg/100 g) but the difference was not significant. Fat content in camel milk (2.69 ± 0.98 g/100 g) was significantly lower ($p < 0.001$) compared to cow milk (4.52 ± 3.36 g/100 g) [60]. Camel (225 ± 125 mg/100 g fat) and cow (211 ± 142.4 mg/100 g fat) milk maintained almost similar cholesterol/fat ratios [60]. Recent reports also confirmed the lower amounts of cholesterol in camel milk as compared to that of cow milk [30,31,61].

4.4. Proteins

Camel milk comprises of 2.15%–4.90% total protein with an average of 3.1 ± 0.5% and the proteins are divided into two main fractions: casein and whey protein [37]. As discussed earlier, variation in camel milk composition is mainly attributed to variation in seasonal conditions and camel breeds [10].

Protein fractions and amino acid composition of camel milk in comparison to bovine and human milk are indicated in Table 4. Camel milk contains 1.63%–2.76% of casein, which is the major share (52%–87%) of total protein [44]. Comparison of camel milk with bovine milk proteins shows pronounced differences in the quantitative distribution of casein and whey proteins. β-Casein is found in higher concentration (65% of total casein) than in bovine milk (39% of total casein) whereas κ-casein, which is about 13% of total caseins, in bovine milk amounts to only 3.5% of the casein fraction of camel milk [1,28]. The α_{s1}-casein and α_{s2}-casein contents of camel milk were reported to be 21% and 9.5%, respectively [62].

Table 4. Protein fractions (g/liter) and amino acid concentrations (g/100 g protein) of camel milk in comparison to bovine and human milk.

Protein fraction	Camel	Bovine	Human
Total caseins	22.1–26.0	24.6–28	2.4–4.2
Total whey proteins	5.9–8.1	5.5–7.0	6.2–8.3
Caseins/whey proteins ratio	73.2:76.2	82:18	29.7:33.7
α S1-Casein	4.9–5.7	8.0–10.7	0.77
α S2-Casein	2.1–2.5	2.8–3.4	Absent
β-casein	14.4–16.9	8.6–9.3	3.87
κ-casein	0.8–0.9	2.3–3.3	0.14
β-Lactoglobulin	Absent	3.2–3.3	Absent
α-Lactalbumin	0.8–3.5	1.2–1.3	1.9–3.4
Amino acids			
Aspartic acid	6.9	7.8	8.3
Threonine	4.1	4.5	4.6
Serine	4.3	4.8	5.1
Glutamic acid	18.1	23.2	17.8
Proline	12.0	9.6	8.6
Cysteine	1.9	0.6	1.7
Glycine	2.1	1.8	2.6
Alanine	2.1	3.0	4.0
Valine	4.1	4.8	6.0
Methionine	2.0	1.8	1.8
Isoleucine	4.9	4.2	5.8
Leucine	6.1	8.7	10.1
Tyrosine	3.1	4.5	4.7
Phenylalanine	4.0	4.8	4.4
Histidine	2.1	3.0	2.3
Lysine	4.0	8.1	6.2
Arginine	2.0	3.3	4.0
Tryptophan	n.d.	1.5	1.8
Limiting amino acid	Lysine	Cysteine and Methionine	-

Source: [28,40,52]; n.d. = not detected.

Camel milk does not coagulate easily and as a result it is difficult to make fermented dairy products such as cheese and yoghurt from camel milk. The difficulty of product making from camel milk is attributed to the unique structural and functional properties of the milk proteins especially of the low amounts of kappa casein which causes destruction of casein network during cutting and loss of dry matter of cheese to the whey [63].

Camel milk casein differs from cow milk casein in terms of micellar size distribution in that there is a greater number of large micelles in camel milk than cow milk [1,31]. Most casein particles in cow milk have a diameter of 40–160 nm. In camel milk, casein particles range in diameter from 20 to more than 300 nm [1]. The low proportion of k-casein in camel milk correlates to its large casein micelle size and its poor acid and enzyme-induced coagulation compared to bovine milk [7]. The composition and structure of the casein micelles are believed to influence their destabilization and coagulation by enzymes during digestion by rennet/chymosin in the stomach and during cheese-making [7]. The chymosin cleavage site of the k-casein of camel milk (Phe97-Ile98) is different from that of bovine milk (Phe105-Met106) and it contains two additional proline residues at positions 95 and 105 [7,64].

The second largest component of camel milk proteins are whey proteins that account for 20%–25% [7,28,47] of total proteins and the whey proteins range between 0.63 and 0.80 g/100 g of milk [31,47]. Immunoglobulins, lactoferrin, lactophorin, lactoperoxidase, lysozyme, peptidoglycan recognition proteins, serum albumin, and α-lactalbumin are major whey proteins found in camel milk [7,8,28,62]. Comparison of camel milk whey proteins with bovine milk whey proteins showed different composition, where β-lactoglobulin is the main component in bovine milk and α-lactalbumin is the main component in camel milk [7,8,31,65]. β-lactoglobulin, the main whey protein of bovine milk, is not found in camel milk [1,8,28,31]. Lack of β-lactoglobulin in camel milk results in a thin consistency and weak gel structure in yoghurt made from camel milk [7,64]. The denaturation of β-lactoglobulin and its association with k-casein at around 80°C is a key reaction in the formation of firm yoghurt gels from bovine milk [7]. Similar whey protein composition is found in human milk [66].

Salami *et al*. [67] demonstrated higher degree of digestibility (hydrolysis) of camel milk with both trypsin and chymotrypsin enzymes and antioxidant activity of camel α-lactalbumin. Camel milk α-lactalbumin contains higher concentration of antioxidant amino acid residues, therefore possessing greater antioxidant activity than that of bovine α-lactalbumin [67].

Camel milk is more similar to human milk because it contains higher concentration of β-casein [8,52]. The abundance of ß-casein in camel milk is considered to be one of the major reasons for easy digestibility of camel milk to human infants since ß-casein is less resistant to peptide hydrolysis than αs-casein [8]. Because of its easy digestibility and quick absorption than milk from other dairy animals, camel milk is also considered as a substitute for mother's milk for human infants when it is not possible for mothers to feed their babies [52].

The presence of a different β-casein than cow milk and absence of β-lactoglobulin in camel milk are responsible for prevention of food-borne allergies [8,31,68]. Moreover, immunoglobulins present in camel milk are compatible with human counterparts. Shabo *et al*. [69] found that camel milk helps in treating allergies in children from 8 months to 10 years old. Lack of β-lactoglobulin, one of the major allergenic compounds in cow's milk, suggests that camel milk can be used in infant formula [28].

Due to its high protein and amino acid content, camel milk can serve as a most suitable supplementary food for humans. The amino acid profile of camel milk (Table 4) shows that it contains most of the essential amino acids required in human nutrition. The amino acids cysteine and methionine are reported to be limiting amino acids in the milk of buffalos, cows, and horses; however, the limiting amino acid in camel milk is lysine [52]. Camel milk contains more methionine, valine, phenylalanine, arginine, and leucine than cow milk [52].

Genetic factors are reported to influence camel milk composition traits. A report by Nowier and

Ramadan [70] indicated the association between β-casein gene polymorphism and camel milk composition traits. They reported that β-casein gene polymorphism had a significant effect on acidity and protein percentage in Maghrebi camel milk. A recent report by Letaief *et al*. [71] indicated genetic variability in three casein variants (αs1-casein, β-casein and κ-casein) in Tunisian, Sudanese and Nigerian camel populations and suggested that these variabilities are key determinants to differences in milk production and composition among camel breeds. αs1-casein polymorphism affects the milk lipids and protein compositions; thus, it has a strong impact on the nutritional quality and technological properties of milk [72]. Two genetic variants of αs1-casein have been described in one-humped camel milk [72].

4.5. Lactose

The lactose content of camel milk ranges from 4.8 to 5.8% and is slightly higher than the lactose content of cow milk [1]. It seems that the lactose content of camel milk is relatively constant throughout lactation. Studies on the effect of drought on the composition of camel milk found that the lactose content was low at birth being around 2.8% but within 24 h it was increased to 3.8% [1,8]. A further increase up to 5% of lactose was observed as long as drinking water is available [1,8]. Dehydration of the animals led to a decline in milk lactose content to as low as 2.6% [1].

Large variation in amount of lactose may be attributed to the nature of feed that animals consume in deserts [47]. The most preferable diet of camels includes *Salsola*, *Atriplex*, and *Acacia* plants to meet salt requirements of their body [73], therefore the taste of camel milk is defined as salty, sweet, or sometimes bitter.

One of the problems associated with consumption of raw cow milk is the inability to digest the milk sugar lactose by lactose intolerant people. Although camel milk contains comparable amounts of lactose like cow milk, lactose intolerant people can consume camel milk with little signs of illness [7,31,74–76] and camel milk is more easily metabolized as compared to cow milk [7,75]. The explanation suggested for tolerance of lactose-intolerant individuals to camel milk was that camel milk produces less casomorphins than cow's milk, which would provoke less intestinal motility and would cause lactose to become more exposed to the action of lactase [8,75].

4.6. Minerals

The mineral content of camel milk in comparison to bovine and human milk is reported in Table 5. The total mineral content of one-humped camels varies from 0.60% to 0.90% with an average of 0.79 ± 0.07% [37], which is usually termed as total ash. Among several contributing factors for variations in mineral content [10], differences in breed of the animal showed wide variation in the mineral content of one-humped camel milk [77]. Each 100 g of camel milk provides calcium (Ca) (114–116 mg), phosphorus (P) (87.4 mg), potassium (K) (144–156 mg), sodium (Na) (59 mg), magnesium (Mg) (10.5–12.3 mg), iron (Fe) (230–290 µg), zinc (Zn) (530–590 µg), manganese (Mn) (80 µg), and copper (Cu) (140 µg) [10,47,52]. Khaskheli *et al*. [47] found 0.20–0.28 g of chloride contents per 100 g of camel milk with mean value of 0.26 ± 0.01 g/100 g. Sawaya *et al*. [78] reported that Fe, Cu, Na, K, and Mn are considerably higher in camel milk than bovine milk. Similarly, Muthukumaran *et al*. [31] reported significantly higher contents of Cu, Fe, Na and K in camel milk than bovine milk. Barlowska *et al*. [52] also reported that iron, zinc and copper contents of camel milk are higher than goat, cow and human milk. A recent report by Konuspayeva *et al*. [79] indicated the relative richness of camel milk in K, Na, Cl, Fe and Zn. The presence of higher Na and K content in camel milk is attributed to the consumption by camels of forages rich in salt and this is responsible for the salty taste of camel milk [31,73]. It was also reported that dehydrated camels produce milk with high-chloride content [27,45]. Barłowska *et al*. [52] reported similar content of phosphorus, magnesium, and calcium in camel milk to that of bovine milk.

Table 5. Mineral contents of camel milk in comparison to bovine and human milk.

Minerals	Camel	Bovine	Human
Macrominerals (mg/100 g)			
Calcium	114–116	122.0	33.0
Phosphorus	87.4	119.0	43.0
Potassium	144–156	152.0	55.0
Magnesium	10.5–12.3	12.0	4.0
Sodium	59.0	58.0	15.0
Microminerals (µg/100 g)			
Zinc	530–590	530.0	380.0
Iron	230–290	80.0	200.0
Copper	140.0	60.0	60.0
Manganese	80.0	20.0	70.0
Iodine	n.d.	2.1	7.0
Selenium	n.d.	0.96	1.52

Source: [28,52]; n.d. = not detected.

The iron concentration in camel milk is six times higher compared with bovine milk [8]. Iron in camel milk is present as a major component of the iron-binding protein, lactoferrin [80]. Iron is a component of blood and plays an essential role in electron transport reactions, DNA synthesis, oxygen transport, gene regulation and is component of various storage proteins [31,81]. Mg, Zn, and Mn act as cofactors and are required for activation of various metabolizing enzymes [82]. Mn, Zn, and Cu possess extensive antioxidant property and protect body cells from oxidative stress–induced cellular damage [82]. It was reported that two cups (500 mL) of dromedary camel milk can supply 70–90% of the recommended daily nutrient intake of zinc and 192% of the recommended daily nutrient intake of magnesium [39]. The higher contents of zinc [27] in camel milk plays a key role in secretory activity of insulin from islet of ß-cells and the interaction of insulin to its receptors [83]. Na, K, Ca, and Mg in camel milk play an essential role in maintaining blood volume and blood pressure [84].

4.7. Vitamins

The vitamin content of camel milk in comparison to bovine and human milk is indicated in Table 6. Camel milk is enriched with both water-soluble as well as fat-soluble vitamins, such as vitamin B complex, C, D, A, and E [85]. When compared with cow milk, camel milk showed similar content of vitamin E (0.56 mg/L compared with 0.60 mg/L from cow milk). However, the contents of other vitamins are comparatively less, such as vitamin B12, pantothenic acid, vitamin A (0.10 mg/L) than 0.27 mg/L, B2 (0.57 mg/L) than 1.56 mg/L of cow milk, respectively [85]. Faye *et al*. [86] reported that camel milk is rich in vitamin C and to a lesser extent in niacin (vitamin B3) and vitamin D, the concentrations of other vitamins are not different from milk of other species. Vitamin D3 content in camel milk was reported to be eight times higher than that in bovine milk [31].

Table 6. Vitamin contents of camel milk in comparison to bovine and human milk.

Vitamins	Camel	Bovine	Human
Vitamin A (µg/100 g)	26.7	126	190
Vitamin D (µg/100 g)	0.3	2.0	1.4
Thiamine (B_1) (mg/100 g)	0.05	0.05	0.02
Riboflavin (B_2) (mg/100 g)	0.17	0.16	0.02
Niacin (B_3) (mg/100 g)	0.77	0.08	0.17
Pantothenic acid (B_5) (mg/100 g)	0.37	0.32	0.20
Pyridoxine (B_6) (mg/100 g)	0.55	0.04	0.01
Biotin (B_7) (µ g/100 g)	n.d.	2	0.4
Folic acid (B_9) (µg/100 g)	87	5	5.5
Cobalamin (B_{12}) (µ g/100 g)	85	0.36	0.03
Vitamin C (mg/100 g)	33	0.94	5.0

Source: [28, 52]; n.d. = not detected.

The vitamin C content of camel milk is higher than that of bovine milk [27,85]. Vitamin C serves as an antioxidant [27]. It helps in iron absorption and is involved in wound healing. Stahl *et al*. [87], Muthukumaran *et al*. [31] and Ho *et al*. [8] reported three- to fivefold higher vitamin C content (37.4 mg/L) in camel milk in comparison to cow milk (11.0 mg/L). Therefore, camel milk could be an alternate means of vitamin C especially in arid zones where fruits and green vegetables that contain vitamin C (ascorbic acid) are scarce [27,78]. It was reported that two cups (500 mL) of dromedary camel milk can supply the recommended daily nutrient intake of vitamin C [39].

Camel milk is highly nutritious and consumption of one liter camel milk daily could fulfill 100% body requirements of electrolytes and minerals [88]. A quarter of liter (250 mL) of camel milk provides about 10.5% of vitamin C, vitamin B1, and vitamin B6, as well as 8.25% of vitamin B2, 15.5% of vitamin B12, and 5.25% of vitamin A of the recommended daily intake [44].

5. Medicinal properties of camel milk

Camel milk contains important bioactive components that can be used in disease prevention and treatment [44]. Camel milk has been claimed to have health benefits and therapeutic values against a number of human illnesses. Some of the most common purported therapeutic uses of camel milk include its antidiabetic [27,31,89], anti-microbial [31,90], antihypertensive [27,31,91], anticarcinogenic [27,31,92,93], anticholesterolemic [17,31] effects and as an immune booster [33]. The scientific rationale for the use of camel milk as a natural health product comes primarily from its purported antioxidant, immunomodulating, anti-inflammatory, insulin-like, and anti-apoptotic attributes [94]. These properties were largely determined through *in vitro* studies and therefore only provide hypothetical mechanisms of benefit.

The clinical effectiveness and value of camel milk as a therapeutic agent is currently unclear. Although studies in animal and human populations exist, they are mostly small in nature and are often poorly designed trials [94]. The purported therapeutic roles of camel milk reported in the literature based mainly on *in vitro* studies and trials using animal models and the limited *in vivo* and clinical studies using human subjects are discussed below.

5.1. Animal trials/In vitro studies

5.1.1. Neuroprotective effects

Camel milk can be used for the treatment of neurological disorders. A study conducted in animal (rat) model showed that camel milk exhibits anti-Parkinson's activity. Camel milk-treated animals showed highly significant anti-Parkinson's effect when compared with the control and standard therapy groups. Histopathology of the brain showed mild degenerative changes with preserved architecture in camel milk-treated group than the control and standard therapy groups [95].

Another study conducted by the authors indicated antiseizure and neuroprotective activity of camel milk in strychnine-induced animal model of seizures and compared with diazepam [96]. Antiseizure activity was observed as delay in seizure onset, decrease in total duration of convulsions, and mortality rate in camel milk-treated mice when compared with distilled water-treated mice. Histopathology of the brain showed significant preservation of hippocampal neurons in camel milk–treated animals as observed with relatively normal and healthy neuron and mild neuronal damage as compared to animals treated with strychnine alone [96]. Thus, camel milk can be used in seizure disorders as an alternative medicine to prevent drug-related toxicities and drug resistance.

5.1.2. Antioxidant activity

Camel milk-derived peptides possess antioxidant properties and thus can be used in disease prevention. Most of the therapeutic value of camel milk such as anticancer, hepatoprotection, and use in autism treatment is due to its antioxidant activity [44]. Recently, Jrad *et al*. [97] demonstrated generation of antioxidative peptides from camel milk caseins and free radical scavenging activity of camel casein after *in vitro* hydrolysis by pepsin and pancreatin. Milk-derived peptides are inactive within their parent proteins but become active and released after enzyme hydrolysis. Free radical scavenging, metal ion chelation properties of these peptides, as well as the ability to inhibit lipid peroxidation are attributed to their activation by enzyme hydrolysis [98].

5.1.3. Anticancer activity

Camel milk also exhibits anticancer activity. A recent study showed that camel milk peptides (NV-13 and KQ-15) can be used to treat diseases associated with oxidative stress [99]. A study conducted by Korashy *et al*. [100] explored anticancer activity of camel milk and concluded that camel milk inhibited both human hepatoma and breast cancer cell survival and proliferation through the activation of both the extrinsic and intrinsic apoptotic pathways. Studies also indicated that camel milk lactoferrin was able to inhibit about 50% of colon cancer cells along with significant reductions in the amount of DNA damage [31,93], significant reduction in proliferation, viability as well as migration of colorectal cancer HCT 116 [31,101] and reduction in breast cancer MCF-7 through activation of autophagy [31,101].

5.1.4. Hepatoprotective effect

Camel milk possesses hepatoprotective effect due to its antioxidant activity [44]. Camel milk was reported to show protective effects against drug induced hepatotoxicity due to its antioxidant activity [44]. The higher antioxidant activity of camel milk is attributed to its chelating effects on toxicants and due to a high content of antioxidant amino acids [102]. Histopathological evaluation of liver tissues also showed protective effect of camel milk in preventing alcohol-associated cellular damage when compared with those who were not treated with camel milk [103]. Ming *et al*. [104] reported that camel milk can improve alcoholic liver injury in mice by regulating inflammatory factors and immune system disruptions. Camel milk not only prevents alcohol-induced colonic dysfunction and lipid accumulation, but also regulates oxidative stress and inflammatory cytokine production to protect against chronic alcoholic liver disease in mouse [104].

5.1.5. Effect on autoimmune disorders

Camel milk can be used as an alternate therapy in treating autoimmune disorders which can affect brain tissues and the gut. The basis for this role of camel milk is the presence of immunoglobulins, such as IgG, IgM, IgA, and IgD that have been detected in camel sera and camel milk [44]. Immunoglobulins present in camel milk are significantly smaller and only one-tenth the size of human antibodies [8,105]. Size of antibodies is a main drawback in the development of immunotherapy because larger antibodies fail to reach their target sites easily [44]. These small immunoglobulins from camelids thus form natural nanobodies, providing a new drug delivery system for the treatment of autoimmune and neurodegenerative disorders [106]. Because of their small size, simple structure and high affinity toward specific antigens camel milk antibodies can easily penetrate dense tissues, reach the active site, and interact with the specific antigen [105]. Camel IgG shows a complete neutralising activity against tetanus toxin and is recognized as a better inhibitor of enzyme antigens [8].

5.1.6. Anti-inflammatory effect

A recent report by He *et al*. [107] showed that camel milk can modulate the gut microbiota and has anti-inflammatory effects in mice with colitis induced using dextran sodium sulfate, i.e., camel milk can be used to prevent colonic inflammation. Camel milk inhibits the inflammatory response by suppressing the overexpression of inflammatory cytokines in the colon [107]. It effectively regulated intestinal microbiota in mice with colitis by increasing the gut microbiota diversity, increasing the abundance of beneficial bacteria, and reducing the number of harmful bacteria [107]. This study showed that camel milk can ameliorate dextran sodium sulfate–induced colitis through regulating the intestinal microbiota, maintaining intestinal barrier function, and inhibiting proinflammatory cytokines [107]. Dharmisthaben *et al*. [108] reported that peptides generated during fermentation of camel milk by lactic acid bacteria (*Lactobacillus plantarum* KGL3A) exhibited antioxidant and anti-inflammatory activities. These lower molecular weight peptides decreased the production of proinflammatory cytokines by the lipopolysaccharide treated murine macrophages.

5.1.7. Antimicrobial activity

Camel milk was reported to remain stable for a longer time at room temperature when compared with milk from other animals [32]. While bovine milk took 3 h to turn sour (to reach a pH of 5.7) at 30 °C, camel milk took 8 h to reach a pH of 5.8 at the same temperature [32]. The longer shelf life and protective (antimicrobial) effect of camel milk is attributed to the high contents of antimicrobial agents such as lysozyme, lactoperoxidase, lactoferrin, immunoglobulin, and bacteriocins in the milk [76,83,90]. Camel milk exhibits antibacterial and antiviral activity against disease-causing microorganisms including *Escherichia coli*, *Salmonella*, *Staphylococcus*, *Bacillus*, *Listeria monocytogenes* and rotavirus [8,90,109]. The antibacterial activity of camel milk helps in controlling diseases that are caused by bacterial infections, such as tuberculosis and Crohn's disease [8]. Regular consumption of camel milk resulted in faster clinical and radiological improvement in patients with multiple drug-resistant tuberculosis [110]. Conesa *et al*. [111] identified that anti-viral and antibacterial properties of camel milk are due to the presence of higher quantities of lactoferrin in camel milk than in cow milk. The mean lactoferrin concentration in raw milk of the one-humped camel was reported to be 0.209 ± 0.131 mg/mL [112] and 0.220 mg/mL [113]. On the other hand, the lactoferrin content of cow milk reported in the literature ranges from 0.0767 ± 0.022 mg/mL [114] to 0.140 mg/mL [113].

Camel milk supplementation of patients with hepatitis C was found to be effective in improving liver function and blood parameters [115]. Reports indicated that camel lactoferrin inhibits the activity of hepatitis C virus [31,102] and it has a higher antiviral activity against hepatitis C virus than human, sheep and bovine lactoferrin [102]. Camel milk was also found to strengthen the cellular immune response and promoted the recovery of chronic hepatitis B patients by inhibiting replication of the viral DNA [44]. Antifungal and antiparasitic activities in camel milk have also been reported [8].

5.1.8. Antihypertensive activity

Bioactive peptides with various biological roles including antihypertensive activities have been reported to be found in camel milk [8,42]. Many diseases such as Alzheimer, diabetes, atherosclerosis, rheumatoid arthritis, and cancer result from uncontrolled oxidative stresses by excess of free radicals and other reactive oxygen species present in cellular organism [42]. Thus, bioactive peptides derived from milk proteins used as an antioxidant play significant role by preventing the formation of radicals or by scavenging the radicals [116].

Camel milk is reported to be a rich source of proteins with potential antimicrobial, antioxidative, and angiotensin-I-converting enzyme (ACE) inhibitory activities [117]. Casein peptides derived from camel milk showed higher antioxidant and ACE-inhibitory activities after enzymatic digestion [118]. Most ACE-inhibitory and opioid peptide fractions of the fermented milk mainly contained β-CN derived peptides as precursor molecules [42]. The relatively higher content of β-CN in camel milk may be advantageous from this point of view. Relatively higher digestibility, antimicrobial activity, and antioxidant activity from camel milk α-lactalbumin and whey protein was reported [119]. Moslehishad *et al*. [120] reported that higher ACE-inhibitory and antioxidant activity was observed in cultured camel milk than bovine milk as a result of structural differences and the presence of higher proline content in camel milk caseins. Homayouni-Tabrizi *et al*. [99] identified two novel antioxidant peptides from camel milk proteins using digestive proteases. It was reported that presence of ACE-inhibitory peptides in fermented milk along with high-calcium content may reduce blood pressure [121].

In conclusion, bioactive peptides released after enzymatic hydrolysis of camel milk are responsible for their increased ACE-inhibitory and radical-scavenging activity, and thus can be used to lower blood pressure in hypertensive individuals.

A recent study also confirmed that camel milk derived bioactive peptides (CM-BAPs), which can be obtained using enzymatic hydrolysis to form hydrolysates or through fermentation process, have more significant bioactive properties in comparison to camel milk intact proteins [122]. A report by Redha *et al*. [122] also confirmed that camel milk derived bioactive peptides have significantly higher bioactive properties than camel milk intact proteins. CM-BAPs have been reported to have antioxidant, anti-diabetic, anti-obesity, antihypertensive, antibacterial, antibiofilm, anticancer, anti-inflammatory, anti-haemolytic, and anti-hyperpigmentation activities [122].

5.1.9. Hypocholesterolemic effect

Hypercholesterolemia and obesity are major growing concerns that are associated with various life-threatening conditions such as cardiovascular disorders, hypertension and cancer [31]. Camel milk has got an excellent anti-cholesterolemic effect, which can reduce cardiac diseases [30]. Bioactive peptides derived from fermented camel milk were reported to have a positive effect on lowering plasma cholesterol level [17,33]. Presence of orotic acid in camel milk may partly be responsible for the hypocholesterolemic effect of camel milk since orotic acid is known to decrease cholesterol level in humans [17,33]. A study conducted to determine the effects of fermented camel milk (garris) and gariss containing *Bifidobacterium* on plasma and liver cholesterol levels in rats resulted in a decrease in plasma low-density lipoprotein (LDL) and plasma triglyceride in rats fed on garris and garris fermented with *Bifidobacterium* [17,123]. Reduction of the cholesterol level is attributed to the interaction of bioactive peptides with cholesterol, which further reduces the cholesterol levels after consuming fermented camel milk products [31].

5.1.10. Antiallergenic effect

Infants who are allergic to bovine milk proteins suffer a severe immune response when they ingest nonhuman milk in particular bovine milk [42]. Bovine milk is frequently used to supplement or substitute human milk for children. Unfortunately, hypersensitivity to bovine milk proteins is a major source of food allergy, which affects primarily infants. The majority of children suffering from bovine milk protein allergy synthesize antibodies primarily against the beta-lactoglobulin (β-LG) and alpha-casein (α_{s1}-CN) [42].

In vitro and *in vivo* experiments showed that camel milk is hypoallergenic and a promising substitute for children who are allergic to bovine milk [27,31,42,65]. Variations in the amino acid compositions between bovine milk and human milk are reported to be the problems in feeding bovine milk-based infant formulation. Human milk casein pattern revealed the dominance of β-CN and αs_1-CN is found in small proportion. Kappeler *et al*. [113] reported high β-CN, lower αs_1-CN, and absence of β-LG from camel milk. Thus, this tendency indicates the similarity between camel and human milk. El-Agamy *et al*. [66] also indicated that camel milk could be an alternate source of protein for children who are unable to take cow milk.

5.1.11. Autism treatment

Camel milk has been reported to have potential therapeutic effects in patients suffering from autism [31,124]. Autism is a severe neurodevelopmental disorder that is characterized by impairment in verbal and nonverbal communication, imagination, reciprocal social interaction, and evidence of developmental delay within the first three years of life [124]. To date there is no known effective and approved intervention method for autism. Recent reports indicated behavioral benefits of camel milk in autistic children and suggested camel milk as a promising therapeutic intervention in autistic syndrome disorder [31,125]. Children with autism showed great improvement in their behavior after camel milk administration [105]. Children suffering from autism who consumed camel milk showed reduced autism symptoms and improved motor skills, language, cognition, joint coordination, and skin health [126].

5.1.12. Antidiabetic effect

Camel milk has traditionally been used for controlling and managing diabetes in Asia and the Middle East. Yagil *et al*. [127] reported that the nomadic Bedouin people have traditionally been drinking camel milk for the purpose of treating diabetes mellitus.

Camel milk could be effective in controlling diabetes-related complications such as hypercholesterolemia, impaired kidney and liver functions, etc. [31,128]. Reports indicated antihyperglycemic, anti-hyperlipidemic, antioxidant properties of camel milk protein hydrolysates [129] and antithrombotic (anticoagulant) actions of whole camel milk [130] in an animal model system (streptozotocin-induced diabetic rats) suggesting the potential benefits of camel milk for diabetes management. The antidiabetic activity of camel milk is attributed to various factors. One of the possible mechanisms could be that camel milk possesses insulin-like protein, which binds with insulin receptors and stimulates insulin to interact with its receptors [31,102,131]. According to Ayoub *et al*. [132], one of the factors responsible for the antidiabetic effect of camel milk is the higher content of insulin (52 U/L) and insulin-like protein (3 times bovine milk) contained in camel milk. It was also reported that camel whey protein and their pepsin generated hydrolysates were able to have a positive impact on activation of human insulin receptors (hIR) and its signaling pathways leading to a greater glucose uptake in cell line model [31,130,133]. A recent study conducted to investigate the functional action of lactoferrin (LF) purified from camel milk on insulin receptors (IR) and its pharmacology and signaling in hepatocarcinoma (HepG2) and human embryonic kidney (HEK293) cells revealed the bioactivity of LF toward IR function (activation of insulin receptors), indicating it as a potential bioactive protein behind the antidiabetic properties of camel milk [134,135]. Moreover, the regeneration of pancreatic β-cells that further promotes synthesis and secretion of insulin via the pancreatic β-cells is enhanced through consumption of camel milk [31,83].

Easy absorption of camel milk into blood circulation could also be another reason for its antidiabetic property. Since camel milk does not coagulate at gastric pH, it immediately passes through the stomach along with its specific insulin and reaches the duodenum for its quick absorption. It has been found that insulin in camel milk is encapsulated in lipid vesicles to form nanoparticles, which protect insulin from proteolytic degradation and serve as a vehicle to transport it into blood circulation by overcoming mucosal barriers in stomach [7,83,136].

5.2. Human trials

As compared to *in vitro* studies and trials involving animal models, there are only few research reports that involved human trials/clinical studies aimed at investigating the efficacy of camel milk for the treatment of human illnesses. These studies focused mainly on diabetes, autism and allergies. There are limited studies involving human trials that assessed the effects of camel milk on the prevention and treatment of type 1 and type 2 diabetes [89,137–143]. An epidemiological study conducted in North-West Rajasthan Province of India showed zero prevalence of diabetes in a traditionally camel milk–consuming Raica community as compared to 3%–4% prevalence of diabetes in other communities living in the same environment, having the same lifestyle, but who were not drinking camel milk [144]. Regular consumption of camel milk by diabetic people resulted in a substantial reduction in the mean dose of insulin needed to obtain glycemic control and improve fasting blood sugar and glycosylated hemoglobin (HbA1c) [137]. Clinical trials showed 30%–35% reduction in doses of daily insulin in patients of type 1 diabetes receiving camel milk [145]. A recent review by AlKurd *et al*. [146] that involved meta-analysis of randomized controlled trials to summarize the effect of camel milk intake on glucose homeostasis parameters in patients with type 1 and type 2 diabetes also confirmed that long-term consumption of camel milk by patients with diabetes could be a useful adjuvant therapy alongside classical medications, especially in lowering the required insulin dose and HbA1c. Unlike the animal studies, human trials have not shown a benefit in improved lipid levels, and liver function was not assessed in these studies [94].

A randomized clinical trial aimed at investigating the possible therapeutic effects of camel milk on behavioral characteristics as an interventional strategy in autistic children (65) demonstrated that camel milk could be very promising therapeutic intervention in autism spectrum disorder [147]. Similarly, a meta-analysis of randomized controlled trials conducted to determine the potential of camel milk as a therapeutic intervention to treat autism-spectrum disorder (ASD) revealed that patients treated with raw or boiled camel milk had lower Childhood Autism Responsiveness Scale scores, indicating that camel milk may reduce neuroinflammation or autoimmunological responses associated with ASDs [148].

In general, the limited studies involving human trials on the use of camel milk for treatment of autism in children demonstrated significant improvements in the clinical measurement of autism spectrum disorder [149,150]. However, these trials were conducted for shorter period (two weeks) and may not necessarily reflect long-term effects. Thus, longer and large-scale randomized clinical trials are required to verify the potential benefits of camel milk for the treatment of autism.

A study conducted by Shabo *et al*. [69] on children with severe food allergies including milk revealed that children supplemented with camel milk showed complete recovery from allergy symptoms within four days of the experiment. They suggested that the results should be validated by large-scale clinical trials. A cross-over clinical trial conducted to evaluate the safety of camel milk intake on patients who are allergic to cow milk protein demonstrated that camel milk is safe and tolerable in patients above one year of age with cow milk protein allergy and can be considered as a good alternative due to its better flavor and lower cost than other formulas [151].

In summary, camel milk has traditionally been used to treat some human aliments in the Middle East, Africa and Asia [94]. A number of reports claim the therapeutic properties of camel milk based on *in vitro* studies or trials using animal models. However, most of the claims have not yet been verified using *in vivo* and clinical studies on human beings. Although the results of the *in vitro* studies show the potential of camel milk for treatment of human illnesses, the results of such studies should be cautiously interpreted, and it is not appropriate to make generalized conclusions until the purported therapeutic claims are verified by clinical trials involving human subjects.

6. Conclusions

In recent years, interest on camel milk and milk products is increasing in the world owing to the superior nutritional value and purported medicinal properties of the milk against a range of human illnesses. Although the gross composition of camel milk is similar to bovine milk and milk from other domestic animals, it has unique inherent characteristics that makes it behave differently during processing and product development.

The special properties of camel milk include: high iron and vitamin C content; suitability for lactose intolerant people; long shelf life; large amounts of insulin/insulin-like protein; therapeutic properties; high digestibility; higher nutritional value than bovine milk; possession of little or no allergy effects due to the lack of β-lactoglobulin; great biological values due to its significant amount of bioactive peptides; and its hypoglycemic effect and subsequent use in diabetes management and control.

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Conflict of interest

The author declares no conflict of interest.

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