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REVIEW ARTICLE

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A Review on Composition, Derived Dairy Product and Therapeutic Value of Dromedary Camel Milk Aleme Asresie and Mulugojjam Adugna

College of Agriculture and Environmental Sciences, Department of Animal Sciences, Adigrat University, Adigrat, Ethiopia

*College of Natural and Computational Sciences, Department of Biology, Debretabor University, Debretabor, Ethiopia

ABSTRACT

A comprehensive review on dromedary camel milk composition, derived dairy product and therapeutic value in comparison with bovine milk, the factors affecting camel milk composition, and overview of composition, properties, nutritional value, dairy product and therapeutic value and functionality is reviewed. The values of camel milk composition from 1997 to 2013 are reviewed. Differences between camel and bovine milk composition lead to some difficulties in manufacturing derived dairy product. Problems associated with derived dairy product produced from camel milk, and factors reported to improve camel milk coagulation, are highlighted. Fresh and fermented camel milk products were found to provide various potential health benefits including Angiotension I-converting enzyme-inhibitory activity, hypocholesterolaemic effect, hypoglycaemic effect, antimicrobial and hypoallergenicity effects. The proposed mechanisms behind each health benefit are discussed. Keywords: Camel Milk, Therapeutic Value, Angiotension I-converting enzyme-inhibitory activity, hypocholesterolaemic effect, hypoglycaemic effect, antimicrobial and hypoallergenicity effects.

INTRODUCTION

According to the recent statistics by the Food and Agriculture Organization (FAO), the total population of camels in the world is estimated to be about 20 million, with Somalia having the largest herd worldwide (FAO, 2008). Camels live in the vast pastoral areas in Africa and Asia and divided into two different species belonging to the genus *Camelus*. Dromedary camels (*Camelus dromedarius*, one humped) that mainly live in the desert areas (arid), and Bactrian camel (*Camelus bactrianus*, two-humped) which prefer living in the cooler areas. The Bactrian species is domesticated in the East to the Northern China and in the West to Asia Minor and Southern Russia, including Mongolia and Kazakhstan (Farah, 1996; Yagil, 1982). On the other hand, the dromedary species widely occurs in the Middle East, North and East Africa, South West Asia and Australia. The Australian camels are mostly imported from Arabia; it is estimated that up to 20,000 camels were brought to the Australian arid between 1880 and 1907 (Northern Territory Government, 2007). The total population of the dromedary species (domestic) worldwide is estimated to be about 15 million head (Mukasa- Mugerwa, 1981) and will be the subject of this review. Camels are considered to be a good source of milk and meat, and are used for other purposes such as transportation and sport racing.

Camel milk has an important role in human nutrition in the hot regions and arid countries. This milk contains all the essential nutrients found in bovine milk (El-Agamy, Abou-Shloue, & Abdel- Kader, 1998; Karue, 1998). Camel milk is popular in Saudi Arabia and consumed as fresh and soured milk (Abu-Taraboush, Al-Dagal, & Al-Royli, 1998). Fresh and fermented camel milks have been used in different regions in the

world including India, Russia and Sudan as a treatment for a series of diseases such as dropsy, jaundice, tuberculosis, asthma and leishmaniasis or kala-azar (Abdelgadir, Ahmed, & Dirar, 1998; Shalash, 1984). Recently, camel milk was also reported to have other potential therapeutic properties, such as anti-carcinogenic (Magjeed, 2005), anti-diabetic (Agrawal, Budania, Sharma, Gupta, & Kochar, 2007a), and anti-hypertensive (Quan, Tsuda, & Miyamoto, 2008), and has been recommended to be consumed by children who are allergic to bovine milk (El-Agamy, Nawar, Shamsia, Awad, & Haenlein, 2009).

Moreover, camel urine was also reported to be used as a treatment for diarrhoea (Al-Attas, 2008).

Camel milk has not been given as much attention in research compared with bovine milk. Most of the research conducted on camels in the past was mainly focused on their anatomical and physiological features (Farah & Farah-Riesen, 1985). However, the recent studies have mainly concentrated on the compositional, characteristics and functionality of camel milk. Several reviews have been published on camel milk (e.g, Farah, 1993). This review covers the available information from 1997 to 2013 with emphasis on dromedary camel milk composition. The aim of this paper is to review the currently available information on dromedary camel milk composition, derived dairy product, and therapeutic value and functionality.

Dromedary camel milk composition

Milk is a complete food for newborn mammals during the early stages of rapid development (Shah, 2000). Camel milk composition has been studied in different parts of the world including Saudi Arabia (Elamin & Wilcox, 1992; Haddadin *et al.*,

2008; Mehaia *et al.*, 1995; Ohri & Joshi, 1961; Omer & Eltinay, 2009; Sawaya *et al.*, 1984; Shuiep, El Zubeir, El Owni, & Musa, 2008). Literature data have shown wide ranges of variation in camel milk composition (Konuspayeva, Faye, and Loiseau, 2009) conducted a Meta analysis study and given the means of camel milk composition (Bactrian and Dromedary) for the period between 1905 and 2006. The mean values of total solids (11.9%) of dromedary milk is slightly lower than that reported (Gassem & Abu-Tarboush, 2000; Mehaia *et al.*, 1995) in bovine milk (12.33%). Moreover, the main components are relatively close to that of bovine milk. According to the available references, the mean values of dromedary milk composition in Saudi Arabia are as follows: protein 2.9-0.5, fat 3.1-1.1, lactose 4.46-0.18, ash 0.78-0.04 and total solids 11.3-1.2 (El-Agamy, Abou-Shloue, & Abdel- Kader, 1998; Karue, 1998).

Camel milk composition was found to be less stable than other species such as bovine milk. However, variations observed in camel milk composition could be attributed to several factors such as analytical measurement procedures, geographical locations, feeding conditions and samples being taken from different breeds, in addition to other factors including stage of lactation, age, and calving number (Khaskheli *et al.*, 2005). Geographical origin and seasonal variations were found to be the most effective factors in camel milk composition. (Konuspayeva *et al.* 2009) have studied the effect of geographical origin on camel milk composition and shown that the milk composition from camels living in East Africa have higher fat content than the milk from camels living in Africa and Western Asia. Variation in camel milk composition

was also observed for camels from the same species (dromedary) but domesticated in different parts of the world (Mehaia *et al.*, 1995). Seasonal variations were also found to play a role in camel milk composition even for camels from the same species (dromedary) and regions (Bakheit, Bahr-Lindström, Zaidi, & Jornvall, 2008; Haddadin *et al.*, 2008; Shuiep *et al.*, 2008).

An inverse relationship was found between total solids in camel milk and water intake by camels. In one study, all components except lactose reached their maxima in mid-winter and were lowest in summer. For example, total solids were 13.9% in December and January, and 10.2% in August due to availability of drinking water (Haddadin *et al.*, 2008). In another study, the fat content of camel milk was reported to decrease from 4.3 to 1.1 percent due to the increase in water content of milk produced by thirsty camels (Yagil & Etzion, 1980). The increase observed in water content could be attributed to the decrease in total solids produced by the thirsty camels (Konuspayeva *et al.*, 2009).

Proteins

Total protein content of dromedary camel milk ranges from 2.15 to 4.90% (Konuspayeva *et al.*, 2009); Variation in camel milk composition was discussed earlier. Moreover, camel breeds and seasonal conditions were found, in particular, to play a role in camel milk protein content. Protein content (casein and whey proteins) was found to be similar for camel milk of the same breed, such as Majaheim (Elamin & Wilcox, 1992; Sawaya *et al.*, 1984), but varied for other breeds. Majaheim milk was reported to have higher protein content when compared with other dromedary breeds such as Wadah and Hamra (Mehaia *et al.*, 1995). Protein

content was also reported to vary according to season for the same breed; protein content was found to be lowest (2.48%) in August and highest (2.9%) in December and January (Haddadin *et al.*, 2008). Camel milk protein can be classified into two main components as described in the following sections.

Caseins

Casein (CN) is the major protein in camel milk. Dromedary camel milk has about 1.63-2.76% casein equal to about 52-87% of the total proteins (Farag & Kabary, 1992; Khaskheli *et al.*, 2005; Mehaia *et al.*, 1995). The beta-CN is the main camel milk casein followed by alfa S₁-CN, and constitutes about 65% and 21% of total casein, respectively (Kappeler, Farah, & Puhan, 2003) compared with 36% and 38% in bovine milk, respectively (Davies & Law, 1980).

Camel milk is similar to human milk in that it contains a high percentage of beta-CN; this high percentage could reflect its higher digestibility rate and lower incidence of allergy in the gut of infants, as beta-CN is more sensitive to peptic hydrolysis than alfa S-CN (Abou- Soliman, 2005; El Agamy *et al.*, 2009). Only 3.47% of the total casein corresponds to k-casein in camel milk (Kappeler *et al.*, 2003) compared with 13% in bovine milk (Davies & Law, 1980). Moreover, other researchers reported that k-CN possibly escaped detection or was obscured by other casein components due to its low concentration (Farah & Atkins, 1992). Furthermore, no bands were detected for k-CN after electrophoresis (Farah & Farah-Riesen, 1985). The amino acid sequence of dromedary casein was studied by (Kappeler, Farah, and Puhan, 1998). The number of amino acid residues in the four caseins sequences was: alfa s₁-

CN, 207; alfa s₂-CN, 178; beta-CN, 217; k-CN, 162. This study reported that the casein structure of dromedary camel milk is similar to that of bovine milk, and only few pronounced differences were noticed. These differences were highly noticeable in the primary structure of alfa s₁-CN, whereas similarities were observed in the secondary structure of casein when both compared with bovine casein structure. The amino acid composition of dromedary milk was reported to be similar to that of bovine milk; only glycine and cystine were found to be significantly lower in dromedary milk casein (Farah & Ruegg, 1989).

Camel milk k-CN was found to have a different site for hydrolysis by chymosin compared with bovine milk k-CN. Chymosin is known to hydrolyze bovine milk k-CN at the Phe105-Met106 bond, whereas its hydrolysis site on camel milk k-CN is Phe97-Ile98 (Kappeler *et al.*, 1998). Moreover, camel milk k-CN was reported to contain an extra proline residue in its sequence (Pro95). This additional proline residue is expected to play an important role in the stability of camel milk k-CN sequence compared with bovine milk k-CN sequence (Kappeler *et al.*, 1998). However, bovine rennet has been reported to coagulate camel milk less readily than camel rennet (Wangoh, Farah, & Puhan, 1993). Coagulation of camel milk through the action of both rennets was attributed to the pepsin content in the rennet preparation used (Wangoh *et al.*, 1993). Higher pepsin content in rennet results in a faster coagulation time. Other properties of camel milk proteins (casein and whey proteins) were also found to be significantly different from bovine milk proteins include lower electrophoretic mobility (Farah, 1986; Farah & Farah-Riesen, 1985) and higher molecular size (Farah, 1996). Compared with bovine

milk, camel milk exhibited a lower degree of hydrolysis after reaction with pancreatic enzymes (Salami *et al.*, 2008).

Whey proteins

Whey proteins are the second main component of camel milk proteins and constitute 20-25% of the total proteins. The Dromedary camel milk whey protein content ranges between 0.63 and 0.80% of the milk (Farah & Kabary, 1992; Khaskheli *et al.*, 2005; Mehaia *et al.*, 1995). In general, the composition of camel milk whey proteins is different to that of bovine milk whey, where camel milk is deficient in beta-lactoglobulin, as also observed for human milk (El-Agamy *et al.*, 2009). In bovine milk whey proteins, beta-lactoglobulin is the main component (50%) and alpha-lactalbumin is the second (25%), whereas in camel milk whey, beta-lactoglobulin is deficient (El Agamy, 2000; Farah, 1986; Farah & Atkins, 1992; Kappeler *et al.*, 2003; Laleye *et al.*, 2008; Merin *et al.*, 2001) and alpha-lactalbumin is the main component.

Camel milk alpha-lactalbumin was reported to have a molecular mass of 14.6 kDa and to comprise 123 residues, which is similar to bovine, human and goat milk alpha-lactalbumin (Beg, 1986; Beg, Bahr-Lindström, Zaidi, & Jörnvall, 1985). Moreover, large differences were found in the amino acid sequence of alpha-lactalbumin of camel milk compared with other species, including bovine and goat. Camel milk whey contains other main components such as serum albumin, lactoferrin, immune globulins and peptidoglycan recognition protein (Farah, 1993; Kappeler, Heuberger, Farah, & Puhan, 2004; Merin *et al.*, 2001). Lactoferrin from different milk sources are known to retain iron at pH lower than 3-4 (Mazurier & Spik, 1980); in contrast, lactoferrin in camel milk was found to lose

iron from its N lobe at pH 3-4 and from its C-lobe at pH 6-7 (Khan *et al.*, 2001). The whey released from camel milk after coagulation is known to have a white colour (El-Zubeir & Jabreel, 2008) compared with the greenish whey from bovine milk cheese manufacture. This is reported to be due to light scattering from the increased concentration of small particles of caseins and fat globules in camel milk whey (Mohamed & Larsson-Raznikiewicz, 1990), or may be because of the low concentration of riboflavin (Farah, 1993; Webb, Johnson, & Alford, 1974). Some properties of camel milk whey proteins were found to be different from those of whey proteins of the milk of other animals. It has been reported that heat stability of camel milk was affected by the protein content; camel milk shows poor stability at high temperatures of up to 140°C compared with bovine milk due to the absence or deficiency of beta-lactoglobulin and k-CN in camel milk (Al-Saleh, 1996; Farah & Atkins, 1992). The addition of either urea or formaldehyde does not improve the heat stability of camel milk (Metwalli, Ibrahim, & Hassanein, 2000); however, camel milk whey has been shown to be more heat stable than bovine or buffalo whey (Al-Saleh, 1996; El-Agamy, 2000; Wernery, 2006). The denaturation of camel milk was reported to be lower (32-35%) than that reported for bovine whey proteins (70-75%) at 80°C for 30 min (Al-Saleh, 1996). The emulsion foaming properties of camel milk whey proteins were studied by (Laleye *et al.*, 2008). Most of the droplets (88%) in the emulsion formed from camel whey have a diameter of greater than 2 μm at pH 5. In contrast, 80% of droplets formed from bovine whey at the same pH have a diameter of less than 2 μm and only 1.5% of the droplets have larger diameter than 3

mm. Bovine milk whey yields a higher foam volume than camel milk whey. Whey protein aggregation by heat treatment was found to increase in camel milk whey at pH lower than 5 because of the high content of Alfa-lactalbumin, leading to the conclusion that camel whey protein is more sensitive to acidity than bovine whey protein (Laleye *et al.*, 2008).

The enzymatic digestibility and antioxidant activity of camel lactalbumin were studied recently by (Salami *et al.*, 2009). Camel lactalbumin has shown higher degrees of hydrolysis (digestibility) with both trypsin and chymotrypsin enzyme than bovine alfa-lactalbumin, but both proteins shown similar sensitivity to pepsin enzyme. The antioxidant activity of camel alfa-lactalbumin was greater than that of bovine a-lactalbumin because it contains higher antioxidant amino acids residues, in addition to the differences in conformational features of both proteins.

Fats

The fat content of Dromedary camel milk is between 1.2 and 6.4% (Konuspayeva *et al.*, 2009). A strong positive correlation was found between fat and protein contents (Haddadin *et al.*, 2008). Fat content of camel milk was reported to decrease from 4.3 to 1.1 percent in milk produced by thirsty camels (Yagil & Etzion, 1980). Compared with bovine milk, Dromedary camel milk fat (Majaheim and Najdi breeds) contains smaller amounts of short chain fatty acids (Abu-Lehia, 1989) and a lower content of carotene (Stahl, Sallmann, Duehlmeier, & Wernery, 2006). This lower carotene content could explain the whiter colour of camel milk fat (Abu-Lehia, 1989). Higher contents of long chain fatty acids were also reported for Dromedary camel milk fat compared with bovine milk fat

(Konuspayeva, Lemarie, Faye, Loiseau, & Montet, 2008). Similarly, the mean values of unsaturated fatty acid content (43%) were higher in Dromedary camel milk, especially the essential fatty acids (Abu-Lehia, 1989; Haddadin *et al.*, 2008; Sawaya *et al.*, 1984).

Human milk fat contains a higher content of unsaturated fatty acids compared with bovine (Bracco, Hidalgo, & Bohren, 1971) and camel milk fat. It has been reported (Konuspayeva *et al.*, 2008) that the percentage of saturated acids is higher in bovine milk fat (69.9%) than in camel milk fat (67.7%). The average of cholesterol content of camel milk fat ($34.5 \text{ mg}100 \text{ g}^{-1}$) was found to be higher ($25.63 \text{ mg} 100 \text{ g}^{-1}$) than that reported for bovine milk fat (Gorban & Izzeldin, 1999; Konuspayeva *et al.*, 2008). Nevertheless, it was also found to be lower than that reported for some bovine milk (Haddadin *et al.*, 2008). The melting point and solidification temperature of camel milk fat were studied and discussed by (Abu-Lehia 1989) and (Ruegg and Farah 1991). These two properties were found to be higher in camel milk fat ($41.9-0.9^{\circ}\text{C}$ and $30.5-2.2^{\circ}\text{C}$ respectively), compared with bovine milk fat ($32.6-1.5^{\circ}\text{C}$ and $22.8-1.6^{\circ}\text{C}$ respectively), probably because camel milk fat contains a lower amount of short chain fatty acids ($\text{C}_4\text{-C}_{12}$) and a higher amount of long chain fatty acids ($\text{C}_{14}\text{-C}_{22}$) compared with bovine milk fat (Abu-Lehia, 1989; Haddadin *et al.*, 2008; Rüeegg & Farah, 1991) in addition to the differences in isomeric properties of oleic acid (Fjaervoll, 1970).

Lactose

The lactose content of Dromedary camel milk varies from 2.40 to 5.80% (Konuspayeva *et al.*, 2009). The wide variation of lactose content could be due to

the type of plants eaten in the deserts (Khaskheli *et al.*, 2005). Camels usually prefer halophilic plants such as *Atriplex*, *Salosa* and *Acacia* to meet their physiological requirements of salts (Yagil, 1982). Other times as bitter. It has been reported that the lactose content is the only component that almost remains almost unchanged over a season (Haddadin *et al.*, 2008) and under hydrated or dehydrated conditions (Yagil & Etzion, 1980). Lactose content was only found to change slightly for camel milk of some Dromedary breeds in different part of the world (Elamin & Wilcox, 1992; Haddadin *et al.*, 2008; Mehaia *et al.*, 1995; Sawaya *et al.*, 1984).

Mineral content

The total content of minerals is usually expressed as total ash; this amount varies from 0.60 to 0.90% in Dromedary camel milk (Konuspayeva *et al.*, 2009). Variations in mineral content were attributed to breed differences, feeding, analytical procedures (Mehaia *et al.*, 1995) and water intake (Haddadin *et al.*, 2008). The major mineral content of Dromedary camel milk was also found to vary between breeds, such as Majaheim, Najdi, Wadah and Hamra (Elamin & Wilcox, 1992; Mehaia *et al.*, 1995; Sawaya *et al.*, 1984).

Camel milk is a rich source of chloride (Khaskheli *et al.*, 2005) due to the forage eaten by camels, such as *Atriplex* and *Acacia*, which usually contains a high salt content (Yagil, 1982). The reduction in major milk components and increase in chloride content of milk from dehydrated camels might be another cause for the salty taste in camel milk (Yagil & Etzion, 1980). The minerals Na, K, Fe, Cu and Mn in Dromedary camel milk were substantially higher than that reported for bovine milk (Mehaia *et al.*, 1995; Sawaya *et al.*, 1984).

Fe was reported to play an essential role in a number of biological systems, including oxygen transport and storage as well as DNA synthesis (Al-Attas, 2008; Miller, 1996). Mn was shown to play a key role in cellular metabolism, where the presence of this element is important for the function of a number of enzymes (Al-Attas, 2008), including enzymes for cell protection from free radical damage (Combs, Clark, & Turnbull, 1997). Furthermore, the content of Ca, P and Mg of Dromedary camel milk were close to bovine milk (Sawaya *et al.*, 1984).

Vitamins

Dromedary camel milk was reported to contain various vitamins, such as vitamin C, A, E, D and B group (Farah, Rettenmaier, & Atkins, 1992; Haddadin *et al.*, 2008; Sawaya *et al.*, 1984; Stahl *et al.*, 2006). Camel milk is known to be a rich source of vitamin C; the vitamin content was reported to be three times (Farah *et al.*, 1992) to five times (Stahl *et al.*, 2006) higher than that in bovine milk. Hence, raw and fermented camel milk could be a good source of vitamin C for the people living in the desert area where vegetables and fruits are not available (Sawaya *et al.*, 1984). The mean of vitamin C content in Dromedary camel milk is 34.16 mg L⁻¹ (Farah *et al.*, 1992; Haddadin *et al.*, 2008; Sawaya *et al.*, 1984). Compared with bovine milk, the niacin (B₃) content was reported to be higher in camel milk (Haddadin *et al.*, 2008; Sawaya *et al.*, 1984). The content of vitamin A and riboflavin (B₂) in Dromedary camel milk was reported to be lower than that of bovine milk (Farah *et al.*, 1992; Sawaya *et al.*, 1984; Stahl *et al.*, 2006). The mean concentrations of pantothenic acid, folic acid and B₁₂ in camel milk from Jordan were reported to be much higher than that reported for bovine milk

(Haddadin *et al.*, 2008). These results are in contrast to that reported by (Sawaya *et al.*, 1984) from Najdi camel milk; this may be due to differences in camel breed and analytical procedures. However, the concentrations of thiamin (B₁) and pyridoxine (B₆) in Dromedary camel milk were comparable to those for bovine milk (Haddadin *et al.*, 2008; Sawaya *et al.*, 1984), whereas the concentration of vitamin E was very close to that of bovine milk (Farah *et al.*, 1992). According to the (USDA, 2009), Dromedary camel milk (250mL) provide an adult with about 15.5% of cobalamin (B₁₂), 8.25% of riboflavin (B₂), 5.25% of vitamin A and 10.5% of ascorbic acid (C), thiamin (B₁) and pyridoxine (B₆) of the Recommended Daily Intake (RDI). By comparison, bovine milk (250mL) provide an adult with about 43.5% of cobalamin (B₁₂), 36% of riboflavin (B₂), 11.5% of pyridoxine (B₆), 3.5% of ascorbic acid (C) and 9% of vitamin A and thiamin (B₁) of the RDI.

Dromedary camel milk derived dairy products

It has been reported that camel milk is only suitable for drinking (Yagil *et al.*, 1984). However various products produced from Dromedary camel milk include soft cheese (El-Zubeir & Jabreel, 2008; Inayat, Arain, Khaskheli, & Malik, 2003; Mehaia, 1993), fermented milk (Elayan, Sulieman, & Saleh, 2008; Farah, Streiff, & Bachmann, 1990), yoghurt (Hashim, Khalil, & Habib, 2008), ice cream (Abu-Lehia, Al-Mohiezea, & El-Behry, 1989) and butter (Asresie *et al.*, 2013; Farah, Streiff, & Bachmann, 1989; Rüegg & Farah, 1991). Yoghurt produced from camel milk (with no additives) was reported to have a thin, flow able and very soft texture (Hashim *et al.*, 2008). The addition of both 0.75% sodium alginate and 0.075% calcium chloride to camel milk was reported to

produce acceptable firmness and body similar to that for yoghurt produced from bovine milk (Hashim *et al.*, 2008).

Ice cream was reported to be produced successfully from camel milk using a mixture of 12% fat, 11% milk solids not fat (MSNF) and 37% total solids (Abu-Lehia *et al.*, 1989). The overrun of camel milk ice cream was found to significantly depend on the fat and MSNF levels in the mixture (Abu-Lehia *et al.*, 1989). For example the increase in fat and MSNF content in the mixture leads to an increase in viscosity. These camel milk products were made at laboratory scale, but some are usually produced at a larger scale in the pastoral areas during the peak season of milk production or when milk production is above that required for human and young calf use. These products are still not well developed enough to reach a commercial scale, and there is also a need to examine consumer acceptability of these products. There have been a number of attempts to produce cheese from camel milk, but most of these trials were unsuccessful and yielded contradictory results. The problems associated with production of cheese include:

1. Long coagulation time. Camel milk exhibits a two to three fold longer rennet coagulation time compared with bovine milk (Farah & Bachmann, 1987). This was attributed to the differences in the size of casein particles (Farah & Rüegg, 1989) that is mainly related to the availability of k CN (Farah & Atkins, 1992; Farah & Rüegg, 1989). Camel milk coagulum was reported to contain a greater number of large casein micelles than bovine milk coagulum (Farah & Rüegg, 1989). Such an increase in the number of large casein micelles is due to the reduced k-CN content (Eksterend,

Larsson, & Perlmann, 1980), consequently prolonging the coagulation time.

2. Weak curd. This is likely due to the low total solids content of the coagulum, especially casein (El-Zubeir & Jabreel, 2008; Mehaia, 2006; Ramet, 2001). Other reasons could be due to the small size of the camel fat globules (2.99mm) compared with that (3.78mm) of bovine fat globules (El-Zeini, 2006; Farah, 1993; Knoess, Makjdun, Rafiq, & Hafeez, 1986), or may be due to low elasticity and high fragility of the cheese gel texture (Ramet, 2001). Camel milk casein contains a higher number of large micelles (200-500nm) than bovine milk (220-300nm); this results in formation of a less firm coagulum during cheese processing (Farah & Rüegg, 1989).

3. Rennet action. The coagulum obtained from camel milk by bovine rennet action showed a fragile and heterogeneous structure (Farah & Bachmann, 1987; Farah & Rüegg, 1989).

4. Cheese yield. Soft white cheese made from camel milk by conventional processes was reported to give up to a 12% yield, which is 50% lower than for soft cheese produced from bovine milk (El-Zubeir & Jabreel, 2008; Mehaia, 1993). A lower yield of 5% was reported for hard cheese produced from camel milk (Mohamed & Larsson-Raznikiewicz, 1990). Soft white cheese made from camel milk using an ultra filtration process reported a higher yield of up to 20% due to increased recovery of proteins, fat, and other milk solids (Mehaia, 2006). Several factors have been reported to improve camel milk coagulation, including the addition of calcium chloride (El-Zubeir & Jabreel, 2008; Mehaia, 1993). Using camel gastric enzyme extracts (Siboukeur, Mati, & Hesses, 2005) and rennet instead of bovine rennet resulted in improved camel milk coagulation. This

could be attributed to the pepsin content in the rennet preparation used. Higher pepsin content in rennet results in a faster coagulation time (Wangoh *et al.*, 1993).

The addition of yoghurt culture or other lactic acid bacteria with rennet to camel milk was reported to facilitate camel milk coagulation by increasing the lactic acid content and improving curd firmness (Gassem & Abu-Tarboush, 2000; Mehaia, 1993), whereas the addition of yoghurt culture or other lactic acid bacteria alone to camel milk did not coagulate the milk (Gassem & Abu-Tarboush, 2000). Other studies reported that decreasing pH to 5.6 and increasing temperature to up to 42°C resulted in a reduction in camel milk coagulation time (Farah & Bachmann, 1987; Mehaia, Abou EL-Kheir, & Hablas, 1988; Siboukeur *et al.*, 2005).

The mechanism behind the reduction of camel milk coagulation time when lowering the pH could be due to the enhancement of the charge neutralization process and conformation changes occurring in the secondary phase of coagulation (Mehaia & Cheryan, 1983), whereas, increasing the temperature increases the rate of aggregation of the micelles and the formation of a gel network through the hydrophobic interactions (Kowalchuk & Olson, 1977). Increasing the concentration of rennet up to 70 times was also reported to accelerate camel milk coagulation (Ramet, 1989). The need for high rennet concentration to coagulate camel milk could be due to the presence of specific protease inhibitors in camel milk and/or a particular casein micelle structure limiting access of the protease to the k-CN substrate, however, these hypotheses need to be confirmed (Ramet, 2001).

Therapeutic value and functionality of dromedary camel milk

For a long time, milk was considered to only provide nutritional components such as essential amino acids (Hambræus, 1992). In the last decades, several studies have shown that milk is an important nutritional and functional source and could provide particular health benefits due to the presence of bioactive substances in milk. Fresh and fermented Dromedary camel milk have been acknowledged for a long time in different parts of the world to provide a potential treatment for a series of diseases such as dropsy, jaundice, tuberculosis, asthma, and leishmaniasis or kala-azar (Abdelgadir *et al.*, 1998; Shalash, 1984). These potential health benefits are obtained through a number of bioactive components in camel milk. These components were reported to exist naturally in camel milk (Agrawal *et al.*, 2007a; El-Agamy, Ruppner, Ismail, Champagne, & Assaf, 1992); or derived from camel milk proteins using probiotic strains (Elayan *et al.*, 2008; Quan *et al.*, 2008). These bioactive components and activities will be discussed individually in the following sections.

Angiotension I-converting enzyme (ACE) inhibitor activity

ACE is one of the major regulators of blood pressure (Smith & Vane, 2003). ACE (peptidyl dipeptide hydrolase, EC 3.4.15.1) was defined by (Pan, Luo, and Tanokura 2005) as "an exopeptidase that cleaves dipeptides from the C-terminal ends of various peptide substrates and regulates the activity of several endogenous bioactive peptides". ACE-inhibitory peptides are present in the primary structure of various food protein sources including milk proteins (Jang & Lee, 2005; Li, Le, Shi, & Shrestha,

2004; Minervini *et al.*, 2003). These peptides are also found in fermented Dromedary camel milk (Quan *et al.*, 2008). To produce these bioactive peptides, which have been reported to have health benefits, milk proteins (casein and whey) were hydrolyzed by proteolytic digestion, such as by lactic acid bacteria (probiotic) or proteolytic enzymes (Alhaj, Kanekanian, & Peters, 2006). Probiotic bacteria have been shown to hydrolyze the major components of milk proteins to increase the number of peptides and amino acids to enable their growth (Alhaj, Kanekanian, & Peters, 2007). *Lactobacillus helveticus* 130B₄ was used to release the ACE-inhibitory peptides from camel milk proteins; the amino acid sequence was identified as Ala-Ile-Pro-Pro-Lys-Lys-Asn-Gln-Asp (Quan *et al.*, 2008). This strain (*Lb. helveticus*) has been extensively used to produce ACE-inhibitory peptides from bovine milk proteins (Minervini *et al.*, 2003; Pan *et al.*, 2005; Yamamoto, Akino, & Takano, 1994). The mechanism of ACE-inhibitory activity was reported to depend on the structure-activity of the ACE-inhibitory peptide (Li *et al.*, 2004). Such an ACE-inhibitory peptide should have the ability to bind to the active site of the ACE to inhibit ACE activity. The C-terminal sequence of these ACE-inhibitory peptides was found to play a predominant role in the binding to the ACE (López-Fandiño, Otte, & Van Camp, 2006).

Hypocholesterolaemic effect

Coronary heart disease is one of the major causes of death in the industrialized countries (Pereira & Gibson, 2002). Elevated levels of blood and dietary cholesterol are considered to be a major risk factor for coronary heart diseases (Reddy, Mastromarini, & Wynder, 1977). Fermented camel milk (Gariss) and Gariss

containing *Bifidobacterium lactis* (BB-12) administration have been reported to possess a hypocholesterolaemic effect in vivo in rats (Elayan *et al.*, 2008). This strain was previously shown to reduce cholesterol in bovine milk and MRS broth (Alhaj *et al.*, 2006) as well as in trypticase-peptone yeast extract medium (Tahri, Crociani, Ballongue, & Schneider, 1995). The hypocholesterolaemic mechanism of camel milk is still unclear, but different hypotheses have been proposed, including: interaction between bioactive peptides derived from camel milk proteins and cholesterol which result in cholesterol reduction (Li & Papadopoulos, 1998; Seelig & Seelig, 1996), and the presence of orotic acid in camel milk which is thought to be responsible for lowering cholesterol level in human subjects (Buonopane, Kilara, Smith, & McCarthy, 1992) and in rats (Rao, Chawan, & Pulusani, 1981).

Hypoglycaemic effect

Dromedary camel milk consumption has been reported to be responsible for the low prevalence of diabetes in the Raica community in India (Agrawal *et al.*, 2007a; Singh, Fotedar, & Lakshminarayana, 2008). Camel milk consumption also provides effective management for patients with type 1 diabetes (Agrawal *et al.*, 2003). These were related to various factors, including the presence of high concentration of insulin/insulin like substances in camel milk, such as half cystine (Agrawal *et al.*, 2003; Beg, Bahr-Lindström, Zaidi, & Jörnvall, 1986). The effect of small size immunoglobulins of camel milk on cell (Agrawal *et al.*, 2007a, 2007b) and the lack of coagulation of camel milk in the human stomach (Agrawal *et al.*, 2003) have also contributed to the hypoglycemic effect.

Antimicrobial effect

Camel milk was reported to have an antimicrobial effect against Gram positive and Gram negative bacteria, including *Escherichia coli*, *Listeria monocytogenes*, *Staphylococcus aureus* and *Salmonella typhimurium* (Benkerroum, Mekkaoui, Bennani, & Kamal, 2004; El-Agamy *et al.*, 1992). This inhibitory activity was attributed to the presence of antimicrobial substances in camel milk, including lysozyme, hydrogen peroxide, lactoferrin, lactoperoxidase and immunoglobulins (El-Agamy *et al.*, 1992). The inhibitory action of camel milk against *L. monocytogenes*, *S. aureus* and *E. coli* might be attributed to the presence of lactoperoxidase, hydrogen peroxide and lysozyme respectively (Benkerroum *et al.*, 2004). The growth of *Sal. Typhimurium* was inhibited by lactoferrin in camel milk through binding iron and making it unavailable for its growth (El-Agamy *et al.*, 1992; Ochoa & Cleary, 2009).

The amounts of lysozyme, lactoferrin and immunoglobulins were found to be greater in Dromedary camel milk than bovine or buffalo milk (Benkerroum, 2008; El-Agamy, 2000; Kappeler *et al.*, 1999; Konuspayeva *et al.*, 2007). This property has been shown to be a disadvantage in yoghurt production. The growth of yoghurt culture in camel milk is delayed due to the presence of lysozyme (Abu-Taraboush, 1996; Jumah, Shaker, & Abu-Jadayil, 2001) which prolongs the gelation process (Jumah *et al.*, 2001). These antimicrobial agents were reported to completely lose their activity in camel milk if heat-treated at 100°C for 30 min (El-Agamy, 2000). However, compared with bovine milk, the molecular masses of lactoferrin (79.5 kDa) and lactoperoxidase (78kDa) were found to be higher in Dromedary camel milk, whereas lysozyme (14.4 kDa) was found to be similar (El-

Agamy, Ruppner, Ismail, Champagne, & Assaf, 1996). The differences in composition and structure of these antimicrobial substances between both animals' milk might partially explain the differences in their inhibitory activity against various Gram positive and Gram negative bacteria (El-Agamy *et al.*, 1996).

Hypoallergenicity effect

Mothers' milk provides the ideal nutrition for newborn infants during the early stage of life, however, some infants are only partly breast-fed, or not at all. Hence, different alternatives to human milk can be employed, such as soy milk and extensively hydrolyzed milk protein formulae (El-Agamy, 2007). Researchers report that children (10-20%) possessing allergenicity to bovine milk are also not tolerant to soy derivatives (Businco, Bruno, Giampietro, & Cantoni, 1992; El-Agamy *et al.*, 2009; Maldonado, Gil, Narbona, & Molina, 1998; Zeiger, Sampson, & Bock, 1999). Dromedary camel milk was recently suggested as a food alternative to children with allergenicity to bovine milk. Hypoallergenicity of mothers' milk was reported to be due to the high percentage of beta-CN, low percentage of alfa s-CN (El-Agamy *et al.*, 2009), deficiency of beta-lactoglobulin (Kappeler, 1998) and similarity of the immunoglobulins (Shabo, Barzel, Margoulis, & Yagil, 2005). Bovine milk shows a high incidence of allergenicity in infants because of the high percentage of alfa s-CN (Taylor, 1986) and beta-lactoglobulin (El-Agamy, 2007) in milk proteins. (El-Agamy *et al.*, 2009) undertook an *in vitro* study based on human sera prepared from 40 blood samples of children allergic to bovine milk or its products. The authors reported that camel milk could be a new protein source for children allergic to bovine milk. It is expected to cause little

hypersensitivity reactions because camel milk protein percentages are similar to that found in human milk (El-Agamy *et al.*, 2009).

CONCLUSIONS

Fresh dromedary camel milk and their products are a good nutritional source for the people living in the arid and urban areas. The production of camel milk is gradually increasing due to an increased interest by consumers in recent years. Camel milk was found to be different in some aspects from milk of other animal species, such as bovine milk. Variations observed in camel milk composition were attributed to several factors, such as different analytical procedures, geographical locations, seasonal variations, feeding conditions and breed of camel. Various dairy products were reported to be produced successfully from camel milk with some modifications to their production procedure. Some difficulties were reported in producing cheese. Fresh and fermented camel milk were reported to provide particular health benefits to the consumer depending on the bioactive substances in milk. More extensive research is needed to confirm these proposed health benefits. Studies need to be carried out to investigate the fat globule membrane, and protein composition and structure. Further work is also needed on camel milk protein coagulation by acid and chymosin enzyme to solve problems associated with cheesemaking.

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Corresponding author: Mr. Aleme Asresie, College of Agriculture and Environmental Sciences, Department of Animal Science, Adigrat University, Adigrat, Ethiopia
Email: almasres06@gmail.com, Phone cell: +251-932163053