

## Opportunities for producing dairy products from camel milk: A comparison with bovine milk

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**Abstract:** Camel milk is known to differ markedly from bovine milk in terms of its detailed protein composition and colloidal structure. Noteworthy is the lack of  $\beta$ -lactoglobulin, the small content of  $\kappa$ -casein and high proportion of  $\beta$ -casein in the casein micelles of the milk. The colloidal structure is also different with larger casein micelles and smaller fat globules. The present review presents and discusses current knowledge on the composition and colloidal structure of camel milk, relates this to bovine milk, and points out where research is lacking and what opportunities for processing of camel milk appears to be most promising. Pasteurized camel milk appears straightforward and is used industrially, but UHT and sterilization treatment of camel milk cause protein instability. Hence, research is needed to solve this problem. Acidified milk drinks appear promising as do production of camel milk cheese. Butter and ghee production is possible and camel milk can be made into palatable ice cream. The different colloidal structure of camel milk, compared to bovine milk, means that most processing technology cannot be directly transferred and there is hence a need for suitable research-based adaptations.

**Keywords:** heat treatment; casein micelle; protein composition; fermented milk products; butter

### 1. Introduction

Camel milk is underutilized in terms of being processed into dairy products. The milk is mainly self-consumed or spontaneously fermented (Faye and Konuspayeva, 2012) and thus never reaches the market. 60% of the world camels live in the region of the Horn of Africa (Somalia, Sudan, Ethiopia, Kenya) and 10% of milk produced in the region is camel milk (Faye and Konuspayeva, 2012). The interest in utilizing camel milk for products with increased shelf-life is increasing in the region. It is, however, not straightforward to transfer existing knowledge on dairy processing and technology from other species (i.e. primarily cows, buffaloes, goats and sheep) to camel milk. Even though the gross composition might at first glance appear similar, there are subtle, but important, differences in the protein and fat composition as well as major differences in the colloidal structure (i.e. the casein micelle and the milk fat globule).

These differences are known to e.g. cause thin consistency in fermented camel milk products (Abdel Rahman *et al.*, 2009), impair rennetability (Farah and Bachmann, 1987; Bornaz *et al.*, 2009) especially when using bovine rennet (Ramet, 2001; Hailu *et al.*, 2016), decreased heat stability (Farah and Atkins, 1992; Kouniba *et al.*, 2005) and render butter making difficult (Berhe *et al.*, 2013). However, pastoralists in various parts of the world have traditionally processed camel milk into products for household use and a number of recipes have been successfully developed based on such knowledge (Bruntse, 2016). Solutions have also been found for larger scale production and camel milk processing plants have been established in a number of countries. Examples are Tiviski in Mauritania (Gaye, 2007), Camelicious in Dubai, Berwako and Addis Kidan Milk processing enterprises in Ethiopia and Vital Camel Milk Ltd in Kenya. However, though products development has ensured e.g. production of camel cheese, most camel milk is simply pasteurized and appropriately packaged and does not undergo further

processing. It is also evident that if export is to be expanded and encouraged, solutions for producing camel milk products with extended shelf life must be found.

In addition, there is no doubt that the unique properties of camel milk offer novel opportunities for product development and can be exploited to make products adapted to small as well as larger scale production. Therefore, the present review will present and discuss current knowledge on the composition and colloidal structure of camel milk, relate this to bovine milk, and point out where research is lacking and what strategies for processing of camel milk appears to be most promising.

### 2. Camel Milk Compared to Bovine Milk

#### 2.1. Protein Composition in Camel Milk

The protein composition in camel milk compared to cow milk is shown in Table 1, which has been compiled from existing literature. Discrepancies are evident for the protein composition in camel milk, possibly due to variation in samples (breed, lactation stage, feeding etc.) and experimental procedures as well as sample treatment after milking

Even though there appears to be some lack of agreement concerning the composition of the whey protein fraction of camel milk, there is one striking difference all literature points to: The lack of  $\beta$ -lactoglobulin (BLG) in camel milk. This protein is the major whey protein of bovine milk (approximately 50% of the total whey protein amount in bovine milk, Table 1) and occurs in milk from many mammals, including buffalo, yak and donkey (Medhammar *et al.*, 2012). It is also absent from human milk, which has been put forward as an argument for camel milk being used in production of infant nutrition products (Hinz *et al.*, 2012) and/or children allergic to cow's milk (Al Haj and Al Kanhal, 2010). In terms of processing, BLG plays a major role in many aspects of processing of bovine milk. It provides increased texture in fermented milk made

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from extensively heat treated bovine milk (i.e. equivalent to 90°C and above for several minutes) due to disulphide bonding of BLG to  $\kappa$ -casein ( $\kappa$ -CN) on the surface of the casein micelle as well as formation of soluble aggregates with other whey proteins and  $\kappa$ -casein (Donato and Guyomarc'H, 2009). This effect is known to provide an increase in texture (as indicated by the storage modulus) of 10 times or more (Lukey *et al.*, 1998). There is little doubt that the absence of BLG in camel milk is responsible for the resultant lack of texture in fermented camel milk products, even if high heat processing has been applied prior to fermentation (Abdel Rahman *et al.*, 2009).

Table 1: Major caseins and whey proteins from camel and bovine milk and their approximate amount.

Protein	Camel Milk	Bovine Milk
<i>Caseins (g/L)</i>	24.7-30.9	25
<i>Approximate % of total casein:</i>		
$\alpha_{s1}$	22	38
$\alpha_{s2}$	9.5	10
$\beta$	65	39
$\kappa$	3.5	13
<i>Whey proteins (g/L)</i>	9-9.9	6.5
<i>Approximate % of total whey protein:</i>		
$\beta$ -lactoglobulin	None	51
$\alpha$ -lactalbumin	21-50	19
<i>Glycosylation-dependent cell adhesion molecule (GlyCam-1)</i>		
Lactophorin	10	9
Serum Albumin	4-10	6
Immunoglobulins	16	13
Lactoferrin	2-18	2
Whey Acidic Protein	2	None

Note: Data compiled from a number of sources (El Agamy *et al.*, 1996; Kappeler, 1998; Kappeler *et al.*, 1998; Kappeler *et al.*, 1999; El-Agamy, 2006; Walstra *et al.*, 2006; El-Hatmi *et al.*, 2007; Omar *et al.*, 2016).

In cheese making from bovine milk, heating above 72°C/15 s is generally avoided since this causes denaturation of BLG and consequently impairs rennet induced coagulation (Waungana *et al.*, 1996). Heat treatments more severe than standard low pasteurization will cause BLG to covalently link to casein through disulphide bridges and it is not broken down during maturation of e.g. Cheddar cheese (Calvo *et al.*, 1992). The absence of BLG in camel's milk could thus possibly provide possibilities of more severe heat treatment of camel milk for cheese making. However, the yield of camel milk cheese has been found to decrease at temperature treatments exceeding 65°C/30 min (Qadeer *et al.*, 2015).

The presence of BLG in bovine whey ensures good functionality (e.g. foaming, emulsification) of bovine whey proteins and the lack of BLG in camel milk consequently decreases functionality (Laleye *et al.*, 2008), though it is still possible to produce stable foam and emulsions at pH 7 from camel milk whey. Laleye *et*

*al.* (2008) also note that camel milk whey proteins are slightly more susceptible to heat denaturation than bovine whey proteins, but recent work (Felfoul *et al.*, 2015) have indicated that the denaturation temperatures for camel rennet whey was 73.8°C compared to 70.5 °C for bovine milk. The opposite trend, however, was observed for acid whey, where camel milk exhibited a lower denaturation temperature (60.5 °C compared to 63.9 °C in bovine acid whey). This could be due to the relative higher amount of  $\alpha$ -lactalbumin (ALA) found in camel milk, since this protein loses its calcium and consequently structure at low pH (Permyakov and Berliner, 2000).

In bovine milk, disulphide induced complexes formed between BLG and  $\kappa$ -CN is assumed to influence the pH dependence of heat stability, i.e. the increasing heat coagulation time observed with increasing pH with an initial maximum around pH 6.7 followed by a decrease and subsequent increase (Gallagher and Mulvihill, 1997). When the disulphide interchange does not occur (as is the case when using porcine BLG) the maximum does not occur and the heat stability increases more or less linearly with pH (Gallagher and Mulvihill, 1997). The heat stability of camel milk, i.e. stability to coagulate between temperature from 100-130°C was initially investigated by Farah and Atkins (1992) at a range of pH values (6.3-7.1). They found decreased heat stability compared with bovine milk with increased heat stability at higher pH, and attributed this to the absence of BLG and the low amount of  $\kappa$ -CN in camel milk. The decreased heat stability was corroborated by Kouniba *et al.* (2005) and it has been shown that addition of  $\kappa$ -CN (of bovine origin) of EDTA in combination with a pH of 7.0-7.2 optimizes heat stability as indicated by visual protein precipitation (Al Haj *et al.*, 2011). Thus, it would appear that the issues with low heat stability in camel milk in fact does have its root in the lack of BLG and the low amounts of  $\kappa$ -CN since disulphide linked complexes between the two appear to be the cause of the better heat stability in bovine milk. In addition, for bovine milk it has been shown that addition of soluble calcium salts negatively affect the heat stability in UHT milk (Omoarukhe *et al.*, 2010). Changing the salt content (i.e. removing ionic calcium from the milk) might thus be a potential viable strategy for improving heat stability in camel milk.

## 2.2 The Camel Casein Micelle

As stated above, there are major differences between the proportion of the various casein species in camel milk compared to bovine milk, most strikingly the lower ratio of  $\kappa$ -CN to  $\beta$ -casein ( $\beta$ -CN) in camel milk (Kappeler *et al.*, 1998). Camel casein micelles also have a larger average diameter than those found in milk from other dairy animals and exhibit a maximum between 260 and 300 nm compared to 100-140 nm for bovine milk (El-Agamy, 2006). There is thus a sparse coverage of  $\kappa$ -CN on the surface of casein micelles in camel milk, and it also seems that non-glycosylated  $\kappa$ -CN is predominant in camel milk (Kappeler, 1998) and glycosylated forms (more prevalent in bovine milk) have increased

stabilizing ability due to steric repulsion caused by charged sialic acid groups and increased hydrophilicity (Kappeler, 1998). Hydrophobic interactions could hence be the major driving force in camel milk coagulation as also indicated by the high amount of  $\beta$ -CN in the micelles, and this could possibly also account for the observed decreased heat stability (Kappeler, 1998).

Attia *et al.* (2000) investigated how chemical acidification (using glucono-delta-lactone) affected the properties of the casein micelle in camel milk. They found higher amounts of soluble calcium at neutral pH (~15%) compared to bovine (~7%) and demineralization of micelles started at around pH 5.8 whereas in bovine milk demineralization is initiated at the onset of acidification. A sharper drop was also observed in camel milk, and the authors speculate whether this might be partly the reason for the weaker curd found in fermented products from camel milk (Attia *et al.*, 2000). Results also indicated an initial marked drop in hydration of micelles (~50% between pH 6.6 and 5.5), whereas this was only 10-20% for bovine milk, which could indicate that water is more directly associated to the caseins in camel milk.

### 2.3 Milk Fat Composition and the Milk Fat Globule Membrane in Camel Milk

The size of the fat globules in camel milk is reported to be on average 4.40  $\mu\text{m}$  compared to 5.32  $\mu\text{m}$  for bovine milk (Farah and Ruegg, 1991). In a review comparing milk from a number of minor dairy species with bovine milk, Medhammar *et al.* (2012) note that the content of monounsaturated fatty acids content is reported as high (73 g 100 g<sup>-1</sup> of total fatty acids) in camel milk compared with other dairy species, and has a low content of  $\alpha$ -linoleic acid (2 g 100 g<sup>-1</sup> of total fatty acids). It is also noteworthy that the content of very short-chain fatty acids (i.e. C4-C8) is reported as lowest in dromedary milk among all the investigated dairy species (Medhammar *et al.*, 2012) and these fatty acids, produced through cellulose fermentation in the rumen, have been suggested to be rapidly metabolized by camel tissue and hence not be excreted into the milk (Gorban and Izzeldin, 2001).

Compared to bovine milk fat, the fat in camel milk melts at a higher temperature. The melting of camel milk was complete just below 43°C and camel milk fat contains a higher amount of high melting triglycerides and a lower percentage of triglycerides than bovine milk fat (Ruegg and Farah, 1991). This could be part of the reason for the impaired butter making ability of camel milk, but also has consequences for the sensory properties, since this means that camel milk fat does not totally melt in the mouth, leaving a somewhat gummy residue.

In bovine milk, creaming of raw whole milk in the cold proceeds faster than what can be predicted from Stokes' law due flocculation of milk fat globules which is promoted by certain proteins known as agglutinins. In bovine milk the main agglutinin is immunoglobulin M (IgM), although several others have been identified (Huppertz *et al.*, 2003). This enhanced creaming rate is

not observed in camel milk, where agglutinins are assumed not to be present (Farah and Ruegg, 1991).

## 3. Possible Strategies for Processing of Camel Milk into Dairy Products

### 3.1 Heat Treatment and Fluid Milk Products from Camel Milk

Presently, most camel milk being processed undergoes some sort of low heat pasteurization, i.e. temperature treatments comparable to 72°C/15sec. Small scale operators usually pasteurize the milk directly in the package. Ultra-high temperature processing (UHT) treatment has been tried both direct (150°C/2 sec) and indirect (138°C/4 sec) at pilot scale (Farah *et al.*, 2004), but was not found to be suitable due to sedimentation of protein and mild UHT treatment in combination with refrigeration was required to achieve only 5 weeks of shelf life.

Plasmin is the major indigenous protease in bovine milk and is not inactivated by UHT treatment nor by pasteurization to 72°C, hence a more severe pre-heat treatment (e.g. 95°C for several minutes) is required to inactivate the enzyme (Rauh *et al.*, 2014). If not inactivated, plasmin causes degradation of casein with age gelation and sensory bitterness as a result. Baer *et al.* (1994) investigated plasmin in camel milk from a number of individual camels from various breeds and found that the proteolytic activity, as well as the activation of plasmin from its zymogen, plasminogen, was similar to what has been reported from bovine milk. They note, however, that the plasminogen found in camel milk might be structurally different from the bovine. The presence of plasmin in camel milk and its similarity to bovine plasmin thus poses an additional challenge for production of UHT treated camel milk with a long shelf life, but more research should be conducted to explore the possibilities of various additives such as phosphates (to reduce ionic calcium and hence improve heat stability) and hydrocolloid stabilizers such as carrageenan (to increase viscosity and reduce sedimentation).

### 3.2 Fermented Camel Milk Products

Since the absence of BLG in camel milk causes fermented products to remain thin and drinkable, even after severe heat treatment, an obvious opportunity is to exploit this property and make drinkable fermented camel milk product in various forms. Numerous traditional fermented camel milk products exist around the world (Konuspayeva *et al.*, 2014), for example *shubat* (Kazakhstan), *chal* (Turkmenistan), *keboormog* (Mongolia), *garis* (Sudan), *sunsac* (Kenya), *zrig* (Mauritania) and *dhanaan* (Ethiopia). The company Camelicious in Dubai also markets fresh laban from camel milk. Flavours and appropriate stabilizers (often high methoxylated pectin is used) could be added and it is possible to pasteurize such products to prolong shelf life, though this of course will kill the lactic acid bacteria present in the product. Direct acidification using e.g. lactic or citric acid or fruit juices is also a possibility.

In order to create a thicker consistency in fermented camel milk products it is possible to use exopolysaccharide producing starter cultures to enhance viscosity, texture and mouthfeel and to avoid syneresis (Ibrahim, 2015). Additives such as starches and hydrocolloids could also be used and in a pastoralist setting addition of maize starch or similar can be appropriate. Concentration of the milk, either by boiling, evaporation or ultrafiltration is commonly used for fermented products from bovine milk, and could also be applied in the production of fermented camel milk.

### 3.3 Camel Milk Cheese and Cheese-like Products

Cheese from camel milk has never been produced traditionally (Konuspayeva, *et al.*, 2014), possibly due to the poor rennetability of camel milk. However, recently transgenic camel chymosin (Chy-Max M, from Chr. Hansen A/S, Hørsholm, Denmark) has become available and this markedly improves the curd formation in camel milk (Hailu *et al.*, 2016). Concentration of the milk (2- or 4-fold using ultrafiltration) further improves rennet induced gelation (Hassl *et al.*, 2011). It should be noted, however, that the lactation stage is important at that a good curd has been shown only to form from the 20<sup>th</sup> day post-partum (Konuspayeva *et al.*, 2014) even when using camel chymosin.

Thus, a number of camel cheese products, mainly of the soft white cheese variety, have been developed (Ahmed and El Zubeir, 2011; Konuspayeva *et al.*, 2014; Qadeer *et al.*, 2015). Small scale recipes based on use of camel chymosin powder and intended for use by pastoralist are also available (Bruntse, 2016) and include suggestions for further processing of camel cheese, e.g. cream cheese, dried cheese, spiced cheeses and cheese sweets. A viable possibility also seems to be making cheese from raw milk, followed by heating of the drained cheese curd to pasteurization temperature (63°C or above).

With the availability of camel chymosin numerous opportunities for processing of camel milk into products with extended shelf life have appeared and could provide the basis for a future camel milk processing industry, small as well as large scale.

### 3.4 Ice Cream from Camel Milk

Soni and Goyal (2013) explored the use of pure camel milk as well as mixtures of camel and bovine milk in manufacturing of ice cream with various flavour additions. They found that even pure camel milk was applicable for production of ice cream with high sensory acceptability and note that ice cream manufacture could be a way of adding value to camel milk. Use of camel milk in ice cream apparently does not require any changes in processing parameters, though the differences in composition and colloidal structure might affect quality and storage stability. It should also be noted that ice cream manufacture requires advanced processing equipment and a developed distribution chain able to keep the product at below -18°C.

### 3.5 Butter and Other Milk Fat Products

Despite the reported difficulties in making butter from camel milk, pastoralist do make butter as well as ghee type products (Berhe *et al.*, 2013) and commercial products are also available (e.g. from Camelicious in Dubai). The advantage of decreasing the moisture content by evaporation and make ghee is the increased storage stability.

Camel milk butter is not only used for cooking but is also reported to be used for medicinal purposes or as hair pomade, and butter (or ghee) made from camel milk could constitute a product with high consumer demand (Berhe *et al.*, 2013).

### 3.5 Other Camel Milk Products

Bruntse (2016) tried with success to make savoury Indian snacks (pakora/bhajia) by deep frying batter covered camel cheese pieces and in general much inspiration of camel milk processing can be had from the Indian dairy tradition. Especially the milk-cereal mixed type products (kheer) widely liked and consumed in India offers opportunities for camel milk based products, as does the great variety of milk based sweets or deserts such as gulab jamun and dalia (Chetana *et al.*, 2004; Jha *et al.*, 2012). The high sugar content of such will also aid in prolonging shelf life.

## 4. Conclusion

Camel milk differs markedly from bovine milk in terms of composition of individual proteins, most notably in lack of  $\beta$ -lactoglobulin, a small content of  $\kappa$ -casein and a high proportion of  $\beta$ -casein. The colloidal structure is also different with larger casein micelles and smaller fat globules. These differences necessitate careful choices of what camel milk products to produce, both at small- and large scale, but also offers opportunities for creating novel and unique products with high consumer value and increased shelf life. Pasteurized camel milk can be produced without any adaptation but UHT and sterilization treatments will require considerably more research before the inherent instability problems can be solved. When it comes to fermented products, acidified milk drinks appear promising and can be explored further. Camel milk cheese can be produced with the aid of camel chymosin and offers numerous possibilities for making value added products. Camel milk cheese can also be further processed into more shelf stable products. Butter and ghee as well as ice cream can also be produced from camel milk. Finally, building on the existing Indian tradition for making products from cow and buffalo milk, making products with cereal addition as well as milk-based sweets from camel milk would be worth considering.

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