J Food Sci Technol (February 2024) 61(2):220–229
https://doi.org/10.1007/s13197-022-05664-1

REVIEW ARTICLE

Camel milk products beyond yoghurt and fresh milk: challenges, processing and applications

Philip K. Marete[1] · Alfred M. Mariga[1] · Guyo Huka[2] · Levi Musalia[3] · Eunice Marete[4] · Julius M. Mathara[5] · Joshua M. Arimi[1]

Revised: 8 November 2022 / Accepted: 29 December 2022 / Published online: 9 January 2023

Abstract Camel (*Camelus dromedarius* and (*Camelus bactrianus*) are commonly domesticated in the arid and semi-arid regions because they are well adapted to live in harsh climatic conditions. Camel milk is widely consumed in these regions due to its high nutritional value and medicinal properties. It is rich in protein, minerals and vitamins. Moreover, it possesses therapeutic properties such as antimicrobial, anti-oxidants, anti-viral and anti-cancer. Camel milk can be processed into value added products with the aim of extending shelf life and diversifying its usage. However, there are various challenges experienced in processing of camel milk products. This study aims at reviewing published literature on camel milk products processing, processing challenges, the available solutions and applications. To achieve these aims, literature search was carried out using narrative methodology. Literature review provided information concerning processing of camel milk products, the challenges, how to overcome these processing challenges and applications. From this review of literature on camel milk products it can be concluded that it's possible to process these products with some challenges but scientific and technological solutions are available that are improving over time.

Keywords Camel milk · Challenges · Processing · Applications

Abbreviations

FAOSTAT	Food and Agriculture Organization Statistics
β-LG	β-Lactoglobulin
κ-CN	κ-Casein
MFGM	Milk fat globules membrane
αs1-CN	Alpha S1-casein

Introduction

Camel (C. *dromedarius* and *C. bactrianus*) is an artiodactyl mammal within the genus *Camelus* that bears a particular fatty deposits called humps on its back. Camels are well *accustomed* to live in harsh atmospheric conditions and may survive up to fourteen days without water (Elkhawad 1992). This makes them the ideal animals to domesticate in areas that experience water scarcity.

Milk is widely regarded as nature's most ideal food. It gives nutrition to people of all ages. According to FAOSTAT (2020), the total camel milk production worldwide was 3,149,997 tonnes. Kenya was the leading producer in the world with 1.125 million tonnes. Camel milk possess therapeutic properties and is especially active against diabetes resulting from the activity of the various bioactive compounds in the milk (Malik et al. 2012; Faris et al. 2020). Allergic reactions are not experienced following consumption of camel milk due to the absence of a major protein called β-lactoglobulin (β-LG) (Merin et al. 2001). Bioactive agents including lactoferrin, lysozyme, immunoglobulin and

✉ Joshua M. Arimi
jarimi@must.ac.ke

1 Department of Food Science, Meru University of Science and Technology, Meru, Kenya

2 Department of Business Management, Meru University of Science and Technology, Meru, Kenya

3 Department of Dry Land Agriculture and Natural Resources, Tharaka University, Tharaka-Nithi, Kenya

4 Department of Physical Sciences, Meru University of Science and Technology, Meru, Kenya

5 Department of Food Science and Technology, Jomo Kenyatta University of Agriculture and Technology, Juja, Kenya

lactoperoxidase confer camel milk with antimicrobial properties (Agamy et al. 1992). In terms of its precise protein composition and colloidal structure, camel milk is known to differ significantly from bovine milk. The absence of *β*-lactoglobulin (*β*-LG), low amount of κ-casein (κ-CN), and high proportion of β-casein in the milk's casein micelles are noteworthy differences (Richard 2017). Several studies have been conducted to address the challenges associated with the processing of camel milk. As a result, there are claims that camel milk cannot be processed into value-added products but can only be utilized for drinking as fresh or sour milk. However, processed camel milk products including butter, cheese, milk powder, yoghurt, ghee, and whey proteins have been documented (Berhe et al. 2017). It is important to note that, however, using the same technology as used to produce bovine milk products, somewhat, products with inferior quality, including butter, yoghurt and cheese are obtained from camel milk (Berhe et al. 2017). This is owing to the fact that camel milk has a different relative distribution and molecular structure compared to bovine milk. Notwithstanding, scientific studies through optimization of the technological processing procedures have shown evidence of achieving excellent camel milk products (Berhe et al. 2017).

Different products have been processed with sensory qualities and consumer acceptability evaluated since camel milk is well known to have a salty taste. In evaluating the consumer acceptability of camel milk products in North Eastern parts and urban section in Kenya's capital, Nairobi, Okoth and Gitao (2012) reported that in Garissa town, out of a total of 50 respondents, 72% of respondents indicated that all family members consume camel milk products. Out of a total of 50 subjects studied in Wajir town, all family members, including adults, consumed camel milk products. Studying a total of 38 respondents from Nairobi, 73% of the families consumed camel milk and camel milk products. The taste of natural fermented camel milk was the most important attribute both in Garisa (30%) and Eastleigh (24%).

In a study to compare the physical appearance, body and texture and taste/ flavor of camel and Buffalo milk cheese Inayat et al (2007) reported that buffalo milk cheese significantly showed the highest score in all aspects. Evaluation of camel milk cheese processed using Camifloc (a portable cheese making kit manufactured by French biotechnology company Bio Serae Laboratoires) in addition to $CaCl_2$, El zubeir and Jabreel (2008) reported that higher mean scores were observed for the Camifloc cheese than the Camifloc and $CaCl_2$ cheese. The Camifloc cheese and the Camifloc and $CaCl_2$ cheese differed in terms of saltiness and overall acceptability.

In a study to compare sensory characteristics of fermented camel milk using different starter cultures using a 9-point hedonic rating scale (9 = excellent; 1 = extremely poor), Ibrahim et al. (2009) reported that using *Lactococcus lactis* and *Streptococcus thermophiles* showed the best color results. The highest score for aroma, consistency, taste and overall acceptability was exhibited by using yoghurt culture as the starter culture. An observation made by Berhe et al. (2013) in an experiment to process camel milk butter revealed that camel milk butter had a milder flavor than cow milk butter, which the low butyric acid concentration in camel milk butter samples may have contributed to.

The aim of this review is to identify challenges in processing camel milk products including camel milk butter, ghee, cream, naturally fermented products, cheese, ice cream, confectionaries and cosmetics, solutions documented and the various applications of these camel milk products.

Camel milk processed fat products

Butter

Butter is made from fat and protein components of milk. It is composed of 80% butter fat, 16% water and 2% non-fat solids (Farah et al. 1989). Camel milk butter has neutral taste aroma and is white in color with a viscous consistency (Farah et al. 1989).

Challenges

Camel milk has unique fat qualities, such as fat distribution as minute globules securely attached to the protein and the presence of long chain fatty acids, making it difficult to produce butter using the same technology as bovine milk (Farah 1996).

Processing

By using optimum conditions during processing, camel milk butter can be processed. The optimum conditions are applied during churning and agitation by optimizing temperature and shaking method respectively (Berhe et al. 2013). When buttermilk has a milk fat percentage of less than 0.5%, churning is considered optimal (Ganesan et al. 2013). The optimum churning temperature of bovine milk cream is 10–14 °C. Churning of camel milk has been done at 24–25 °C to process butter from fresh or soured milk, a temperature much higher than that used for bovine milk (Farah et al. 1989). By optimizing agitation conditions and temperature during churning, 80% fat recovery efficiency was achieved in extracting butter from camel milk. This was carried out using a relatively higher temperature for churning (22–23 °C) and by changing the shaking method from traditional back- and forth-agitation to vertical motion using fermented camel milk (Berhe et al 2013). In this method fat globules membranes are raptured as a result of more force allowing globules to adhere to one another (Berhe et al. 2013). Mixing camel milk with milk from other animals is another efficient method of processing butter. In a study by Asresie et al. (2013) it was reported that mixing camel milk with goat milk improved churning efficiency and microbial quality of butter at different blending levels. Different methods are used to traditionally produce small amounts of butter by Africa pastoralists who domesticate camels, which has been reported to be used for cooking and medicinal purposes (Bereda et al. 2014). Cream was standardized to 20–30% fat in order to process camel butter in an industrial production venture in pastoralist communities in Northern Kenya. The butter was then flushed with water at 27 °C after further churning between 15 and 36 °C. From the experiment the best results were achieved by churning cream with 22.5% fat at 25 °C for 11 min (Farah et al. 1989).

Comparison of camel milk butter to other processed milk butters

The Refractive index (RI) of processed camel milk butter was found to have an average value of 1.4530 ± 0.0002 (Berhe et al. 2013) while Akgül et al. (2021) found that the mean RI values of cow's milk butter samples in Trabzon, Turkey region was 1.4611. According to Idoui et al. (2010) the values for pH of cow milk butter ranged between 4.64 and 5.53 compared to 4.90 ± 0.15 for camel milk reported by Berhe et al. (2013). The average values of fat content in camel milk butter and the melting point were 55.8 ± 1.6% and 43.2 ± 0.8 °C (Berhe et al. 2013) compared to 82.50% and 28.32 °C for cow milk butter (Mohamed et al. 2020). The values for caproic (C6:0), caprylic (C8:0), capric (C10:0), lauric (C12:0), myristic (C14:0), palmitic (C16:0), palmitoleic (C16:1), stearic (C18:0) and oleic (C18:1) fatty acids in camel milk butter were reported to be 0.39, 0.24, 0.34, 0.87, 12.14, 32.04, 7.73, 11.85 and 20.10% respectively (Berhe et al. 2013). Compared to cow milk butter caproic (C6:0), caprylic (C8:0) capric (C10:0), lauric (C12:0), myristic (C14:0), palmitic (C16:0), palmitoleic (C16:1), stearic (C18:0) and oleic (C18:1) fatty acids were reported to be 1.62, 2.25, 4.37, 3.11, 10.06, 24.23, 3.79, 14.66 and 35.41% respectively (Mohamed et al. 2020).

Applications

Sweet cream unsalted, sweet cream salted, cultured unsalted, cultured salted butter, and conventional sour cream butter are the different types of butter. As an ingredient, butter is used in several cooking procedures such as pan frying, sauce making, baking, also melted as condiment and used as spread at room temperature.

Ghee

Ghee is a clarified butter fat that is manufactured and used all over the world. It is processed using milk, cream, or butter from a variety of animals, including camels. Ghee can be made by extracting water from milk, cream, or butter by heating it directly, with or without fermentation (Kumar and Naik 2018). Ghee is a unique sort of fat with a distinct flavor that is the primary criterion for its acceptance. The flavor is highly impacted by the processing procedures, which include cream, butter, or milk fermentation, as well as heating processes. Because of the low moisture content and the presence of natural antioxidants, it has a long shelf life. Ghee has a significant proportion of short chain fatty acids, which contribute to its higher digestion as a human diet. In addition to possessing rich and pleasant sensory characteristics, ghee is a major carrier of fat-soluble vitamins (A, D, E, and K) and vital fatty acids (linolenic acid and arachidonic acid) (Kumar and Naik 2018).

Challenges

Fat losses are encountered during the manufacturing of ghee which reduces the yield. These losses have a direct impact on the productivity of the operation and serious economic concern (Kumar et al. 2017).

Processing

Camel milk ghee can be processed by direct creamery method as reported by De Sukumar, (2001). A cream separator was used to separate the cream from the milk. The cream obtained was heated in a stainless steel vessel (pan) with continuous stirring to a final temperature of 115 °C. The ghee residues were allowed to settle and supernatant was filtered at 105 °C through a muslin cloth. The samples were weighed and filled in a clean dry glass bottles, cooled and stored at room temperature. A study by Parmar et al. (2018) compared the yields of camel, cow, and buffalo milk ghee and found significant differences. The yield of ghee obtained from milk basically depends on fat content of the milk used in its production. Camel milk had a fat level ranging from 3.8 to 5.81%, with an average of 5.07%, which was significantly higher than cow milk but lower than buffalo milk. Nevertheless, the lowest yield of ghee was obtained from camel milk, in spite of having a higher fat content than the cow milk. In making camel ghee an average yield of 3.52 g/100 g of milk was obtained, giving a corresponding recovery of 69.43% fat content compared to 88.84 and 88.46% for cow and buffalo milk respectively (Parmar et al. 2018).

Comparison of camel milk ghee to other processed milk ghees

According to Parmar et al (2018) the levels of unsaponifiable matter in camel, cow and buffalo were found to be 0.375, 0.168 and 0.125% respectively, while the camel ghee had a higher cholesterol that cow and buffalo ghee at 0.528, 0.286 and 0.136% respectively. The oleic acid levels were reported to be 0.450%, 0.245% and 0.153% in ghee made using camel, cow and buffalo milk respectively.

Applications

Ghee utilization vary and its use is influenced by many factors including local food habits (Rajorhia 2003). Generally, ghee is mainly utilized for culinary purposes. This encompasses a wide range of applications, including unleavened breads, cooked rice, and lentils (dhal), as well as seasoning, cooking and frying medium. Minor utilization of ghee includes hair dressing, body massage and indigenous pharmaceutical drugs formulation. In addition ghee is used as a flavoring agent following its conversion to powder (Rajorhia 2003).

Cream

One of the most significant dairy products is cream. It was once considered a luxury item, but it is now widely available in a number of forms and for a variety of applications. Classification of cream is primarily based on the fat content and according to United Nations Food and Agriculture Organization standards, cream is grouped into the following classes: Cream: 18–26%, light cream (or coffee cream): > 10%, whipping cream: > 28%, heavy cream: > 35% and double cream: > 45% (Ellen Muehlhoff et al. 2013).

The processing method of cream products can also be used in its classification. Pasteurized cream, ultra-high-temperature treated cream, cultured or sour cream, frozen and dried cream are only a few examples. The state of the lipid globule membrane and lipid globules, as well as the concentration and type of nonfat milk solids (proteins, salts and added emulsifiers and stabilizers) in the cream, all affect the physicochemical qualities of cream. The disruption or agglomeration of the globules resulting from the physical handling of the cream (e.g., agitation, aeration and pumping) can also affect the properties of the cream, as well as the temperature of the cream (Deosarkar et al. 2016).

Challenges

Camel milk fat is dispersed in milk in the form of small droplets called fat globules (Islem Mtibaa et al. 2020). When compared to cow milk, these camel milk fat globules have two distinct characteristics. The first, camel milk has a lower mean fat globule diameter. The mean fat globule diameter for camel milk is 2.99 µm while for cow milk is 3.95 µm (El-Zeini 2006). The milk fat globules membrane (MFGM), which is thicker than that of cow milk fat globules, is the second distinguishing feature (Islem Mtibaa et al. 2020). The MFGMs of camel milk fat globules in addition, is rich in phospholipids, neutral lipids but poor in proteins (Laadhar Karray et al. 2006). These properties lead to challenges during cream processing in milk skimming by centrifugation and a slow rate of spontaneous creaming during storage (Islem Mtibaa et al. 2020). The absence of agglutinin is another factor that contributes to low spontaneous creaming of camel milk cream (Farah 1993). Agglutinin is present in cow milk and facilitates clustering of cold fat globules by attaching to the surface by adsorption (Islem Mtibaa et al. 2020).

Processing

Gravity or centrifugal force are both employed to separate cream from milk. In a study to process camel milk cream by centrifugation, fat was separated by a pilot separator after preheating to 37 °C (skimmed milk 1.6 g/100 mL fat). Camel creams with 18 g/100 ml fat were then prepared by mixing separated fat with camel milk. Pasteurization was then carried out for 1 min at 80 °C. The cream was then cooled down (Kashaninejad and Razavi 2020). Camel milk crema properties can be improved by additional methods. Ultrasonication, for example, has been used to improve the emulsion stability of camel milk cream and reduce the size of fat particles. In a study by Kashaninejad and Razavi, (2020) investigating how the emulsion stability, texture, color, average size of fat globule and rheological properties of camel milk cream were affected by different ultrasonic conditions including power, time and temperature, concluded that the optimal conditions in processing camel milk cream with high emulsion and adhesiveness, stability, consistency, dynamic viscosity and low average size of fat globules were 81 W, 5.9 min and 41 °C.

Comparison of camel milk cream to other processed milk creams

To compare the properties of creams processed using camel and cow milk, Farah and Rüegg (1991) showed that at all temperatures, camel milk exhibited a very slow rate of creaming compared to cow milk at 4 °C. Camel milk samples creamed at room temperature did not differ significantly from samples creamed at 4 °C. They concluded that this might be an indication that camel milk lacks the agglutinative component necessary to cluster fat globules.

Applications

Cream is used for a variety of purposes and readily used in many forms. For example, in the manufacture of table butter, cream is the main raw material, also in preparation of ghee. Cream is used in both sweet and savory dishes like ice cream, cakes, soups, and custard bases (Varnam and Sutherland 1994).

Camel milk fermented products

Natural fermented products

Natural fermented products are processed by spontaneous fermentation of milk into products with superior nutritive qualities. Natural Fermented dairy foods offer exceptional nutritional and healthful attributes to society.

Challenges

The problem experienced in processing natural fermented camel milk products is non-usage of specific microorganisms to ferment the milk. This may result in non-uniform products.

Processing

Fermentation is an ancient method of food processing carried out to improve food quality and prolong shelf life. Camel milk products that have naturally fermented have been given various names all across the world. The following are some of the naturally fermented camel milk products: *Suusa* is a naturally fermented raw camel milk product popular among Kenya's pastoralists in the North Eastern region. It has a whitish color, low viscosity, a smoky and astringent flavor (Lore et al. 2005*)*. In North and Eastern Kenya, Borana and Somali communities produce *suusa* by allowing camel milk to be coagulated slowly by inherent microorganisms in plastic containers for 1 to 3 days (Mwangi et al. 2016). The inherent microorganisms isolated from *suusa* include gram positive rods (*Lactobacillus* and *Bacillus*) and gram positive cocci including *Streptococcus*, *Sicrococcus* and *Staphylococcus*. Moreover, *Enterobacter*, *Estcherichia. coli* and *Pseudonomas,* gram negative rods were isolated (Mwangi et al. 2016).

Another traditional popular Middle Eastern fermented camel milk product is *Kefir.* It gets its name from the Turkish term Keyif, which means "good feeling," because it gives one a sense of overall well-being and health after drinking it (Otles and Çağındı, 2003). Non-pathogenic bacteria especially *Lactobacillus sp.* and yeasts are the most common microorganisms present in *kefir.* The reported therapeutic properties of *Kefir* include anticancer (Fatahi et al. 2021), cholesterol lowering effect (Liu et al. 2006) and antimicrobial (Kim et al. 2016). *Kefir* is prepared by inoculating milk with kefir grains resulting in a symbiotic matrix of bacteria and yeast and can be produced using any type of milk (John and Deeseenthum 2015).

Shubat is another homemade camel milk product among Turkmenistan, Uzbekistan and Kazakhstan, produced through fed-batch or semi-continuous methods. After inoculating fresh or diluted camel milk with warm water (1:1) and one-third to one-fifth of previously soured milk, incubation is then done at 23–30 °C. To obtain the typical taste, the milk is left to coagulate for 8 h at the same temperature, although the initial coagulations starts from 3–4 h. To improve *shubat*, starter cultures such as *Lactobacillus casei* and lactose-fermenting yeasts can be introduced (Marynenko et al. 1997). Studies on the micro flora in *shubat* using biochemical tests by Rahman et al. (2009) from seven Bactrian samples in china showed the predominant microorganisms to be *Enterococcus* and *Lactobacillus*. Camel milk has been found to have a variety of natural biofunctional components with therapeutic effects. These health benefits include hypocholesterolaemic effect (Elayan et al. 2008), antioxidant activity (Shori and Baba 2014), activity against diarrhea (Mona et al. 2010) and antimicrobial activity (Yateem et al. 2008). Through in vivo experiments with rats, fermented camel milk has been shown to have hypocholesterolaemic effect (Elayan et al. 2008; Ali, 2013). Jarallah et al. (2014) discovered that fermented camel milk had antimicrobial properties against a variety of infections. Mahmoudi et al. (2016) isolated lactic acid bacteria and showed their ability in inhibiting the growth of *Staphylococcus aureus, Listeria monocytogenes, Escherichia coli* and *Salmonella typhimurium.* Mona et al., (2010) used rat models to conduct experiments on diarrhea and concluded that fermented camel milk was effective in reducing diarrhea due to high amount of sodium and potassium. Anti-viral or virucidal properties against viruses such as ortho- and paramyxovirus was observed by Chuvakova, et al. (2000) in '*shubat'*, a national drink in Kazakhstan. *Shubat* also reduced lead availability, therefore fermented camel milk protects against lead intoxication, which can cause cancer, anemia, and saturnism. (Chuvakova et al. 2000).

Comparison of camel milk fermented milk to other fermented milk products

A study on naturally fermented camel milk called Chal produced in Iran revealed that the values of fat, protein and total solids were 5.82 ± 0.27%, 3.07 ± 0.073%, and 12.24 ± 0.16% respectively (Salami et al. 2016) while the levels of fat, protein and carbohydrates in naturally fermented buffalo milk from different regions in Indonesia were reported to be 5.70–18%, 5.01–12.41% and 8.03–14.92% respectively (Usmiati and Risfaheri 2013; Helmizar et al. 2018). |According to Hassan and EL- Zubeir, (2008) the levels of fat, protein, total solids and carbohydrates in naturally fermented camel milk beverage (Gariss) were 5%, 3.4%, 11% and 5% compared to another fermented camel milk beverage (Suusac) that was reported to contain 4%, 3%, 12.5% and 5% respectively (Farah et al. 1990). The acidity of gariss and suusac was shown to be 2.3% (Farah et al. 1990) and 0.17% (Hassan and EL- Zubeir 2008) while naturally fermented buffalo milk had an acidity level of between 0.51 and 1.70% (Usmiati and Risfaheri 2013; Helmizar et al 2018). The pH of Suusac was reported as 3.6 while Gariss pH was 4.35 compared to 4.80 in naturally fermented buffalo milk.

Cheese

Cheese is described as a fresh or ripened solid or semi-solid product in which the whey protein/casein ratio does not surpass that of milk (Bylund 1995). The type of fermentation (butyric acid, lactic acid, and propionic acid), the milk used (cow, sheep, camel, goat, and buffalo), the consistency (extra-hard, hard, semi-hard, soft, and semi-soft), the method of manufacture (rennet, sour milk cheese, ultrafiltration), the fat content (double cream, cream, full fat, three quarters fat, half fat, quarter fat cheese), and the surface of the cheese (hard, soft, with smear, moulds) can all be used to classify cheese.

Challenges

Low yield in the end product, long coagulation time, and failure to create a genuine curd structure but only produces flakes that lack firmness are all reported challenges related with the manufacturing of camel milk cheese (Bornaz et al. 2009). This is mostly owing to the milk's unique composition, which includes low total solids concentration and casein characteristics (Khan et al. 2004). Compared with bovine milk, camel milk caseins composition includes low kappa casein (κ-CN) (3.5% versus 13%), high beta casein (β-CN) (65% versus 39%) and low alpha S1-casein (αs1-CN) (22% versus 38%) (Kappeler et al. 1998). Gelation properties of bovine milk is better, compared with the camel milk because bovine milk has smaller casein micelles (Glantz et al. 2010). Camel milk casein has a diameter of 380 nm, compared to 150, 260, and 180 nm for bovine, caprine, and ovine milk respectively according to Bornaz et al. (2009). Hence, the low casein to whey ratio and larger micelles in camel milk results in difficulties during cheese processing. These properties lead to a decrease in yield and a less firm coagulum during cheese making. Micelle size also affects the rennet clotting time of milk, which reaches an optimum in the medium and small size micelles (Bornaz et al. 2009). In a study by Konuspayeva et al. (2013) lactation period was shown to have an impact on cheese processing using camel milk. In addition, the study indicated that the suitable time for processing was 20 days after post-partum.

Processing

Efforts have been made to overcome the difficulties experienced in processing of camel milk cheese with the aim of improving the final product quality. Firstly, by substituting the commercial chymosin for cheese making with dromedary camel gastric enzyme extracts, the coagulation of camel milk has been improved (Haroun et al. 2012). Secondly, compared to bovine chymosin, camel chymosin has a 70% higher clotting activity towards milk and more selectively to cleave (κ-CN)(Langholm Jensen et al. 2013). Furthermore, blending camel milk with bovine milk (1:1) resulted in a larger output of cheese from camel milk with improved microbiological quality and organoleptic qualities (Siddig et al. 2016). Lastly, yield has been shown to increase by the addition of calcium chloride and lactic acid bacteria as the starter culture and this also reduced coagulation time (Khan et al. 2004).

Comparison of camel milk cheese to other processed milk cheeses

Studies on soft cheese processed using camel milk revealed the levels of pH, yield, total solids, protein, fat and ash were 5.80, 11.70, 41.16, 17.67, 16.50 and 2.99% (Khan et al. 2004) compared to 5.85, 7.21, 34.19, 25.87, 2.90 and 3.31% reported in donkey milk soft cheese and 5.61, 23.52, 49.88, 17.29, 23.76 and 4.83% in cow milk soft cheese (Faccia et al. 2019). The values for total solids, fat, ash, protein and lactose in camel milk cheese were shown to be 11.89, 4.39, 0.72, 2.9 and 4.15% compared 13.12, 4.62, 0.69, 3.28 and 4.37% in cow milk cheese and 15.56, 6.41, 0.7, 3.82 and 4.63% in buffalo milk cheese respectively (Sagar et al. 2016).

Applications

Cheese is used as table cheese or as an ingredient in cheese dishes, shredding, processed products, cheese powder and enzyme modified cheese.

Camel milk ice cream

Ice cream is a high calorie dairy dessert that's frozen and consumed by all age groups (Rajarajan 2010). In order to enhance the nutritive value and organoleptic characteristics, other food products such as fruits may be incorporated into ice cream. Ice cream should not contain less than 3.5% protein, 36% solids and 10% fat (Rajarajan 2010). The type of milk used in the preparation is one of the aspects that affect the quality of ice cream.

Processing

Production of ice cream with acceptable qualities has been done using camel milk. In a study by Salem and El-Rashody (2017) camel milk and various dates ratios were used to make ice cream. In another study camel milk ice cream was produced by pasteurizing camel milk at 72 °C for 15 s and to this skim milk powder, sugar, honey and gum Arabic were added and homogenized. The mix was then cooled in a refrigerator at 5 °C and flavor added. Ice cream was then processed using ice cream machine, packaged and stored at – 18 °C (Ahmed and El-Zubeir 2015). From their study Ahmed and El-Zubeir, (2015) showed that camel milk can be utilized in making ice cream. They recommended that to improve the nutritional value of camel milk ice cream, honey can be incorporated.

Ice cream with varied flavor has been made using pure camel milk as well as combinations of camel and bovine milk. From their study Soni and Goyal, (2013) concluded pure camel milk can be applied to produce ice cream with good sensory acceptability as a way of value addition of camel milk. This was done with no changes in processing parameters, however it was noted that quality and storage stability might be affected by differences in composition and colloidal structure. Using the same technology as for other milk ice creams, camel milk ice cream with various flavors is commercialized in the United Arab Emirates, Morocco, and Kazakhstan. Camel milk ice cream provokes less reluctance among consumers than other camel milk based products (Ahmed and Zubeir 2015).

Comparison of camel milk ice-cream to other processed milk ice-creams

In their study on camel milk ice cream, Ahmed and El-Zubeir (2015), reported the values of total solids, protein, fat and ash were 21.79, 2.19, 3.09 and 3.72% respectively. In another study, the the levels of total solids, fat, acidity and pH of ice-cream from Lassi camel milk were 31.85, 9.91, 0.16% and 6.47 respectively (Illahi and Zohaib 2021). Whereas in cow's milk ice cream the total solids, protein, fat and ash were reported to be 28.98, 7.38, 10.33 and 1.71% respectively by Umelo et al. (2014).

Other products: Confectionery and cosmetics

Confectionery products represent a large group foods with high sugars and carbohydrate. Traditional camel sweets are available, as well as a caramel from Kazakhstan known as Balkailmak, which is made following a lengthy thermal processing of roughly 10 h at boiling temperature (Konuspayeva and Faye 2021).

Cosmetic comes from the Greek word cosmeticos, which meaning 'to decorate' (addition of something decorative to a person or a thing). The functions of cosmetics are to improve or change the outward show of the body and mask body odor. They keep the skin in good condition and also offer protection. They are substances that comes in contact with body parts including hair, skin, nail, lips and teeth. They are in general external preparations applied on external parts of the body (Sharma et al. 2018). Manufacturing soaps and other cosmetic creams with camel milk is now a popular practice in many countries; however, these industries are generally on a semi-industrial or artisanal scale. Cosmetic products including lipsticks, shampoos, lotions and moisturizers are available in china. Moreover, anti-aging effect can be enhanced by including liposome that exist in camel milk as ingredient in cosmetic products (Choi et al. 2014). Camel milk is also used in cosmetics due to the presence of α-Hydroxyl acids that smoothens the skin. They act by helping to shed the epidermis (outer layer of skin) by breaking down sugars holding the skin cells together and reveal new skin cells. Hydroxyl acids thin the upper layer of the skin and thicken the lower layer of the dermis, which helps to remove wrinkles and age spots and relieve dryness (Choi et al. 2014).

Conclusion

Processing camel milk with the same technology as bovine milk is difficult due to the unique structural and functional features of the milk components. From this review, however, it has been shown that to overcome these constraints and challenges, optimization and adjustments in processing steps have been done and various camel milk products with acceptable qualities have been successfully processed. Therefore, by modification of processing conditions, various camel milk products can be processed. During these processes, it is however important to ensure that the nutritional and medicinal benefits of the camel milk are not lost. This will enable increased derivation of the nutritional and medicinal benefits of camel milk by consumers of these products. This will also have a positive impact on the camel milk value chain which will be developed as an enterprise to generate income to Arid and semi-arid inhabitants.

Acknowledgements We acknowledge funding from Kenya's National Research Fund (NRF) as part of the 2nd multi-institutional, multidisciplinary research grant round. We also appreciate the camel milk provided by the Anolei Women Group Isiolo.

Author contribution PKM—preparing original manuscript and corrections. Dr. AMM—preparing original manuscript, supervision and corrections. Dr. GH—Reading and corrections. Prof. LM—Reading and corrections. Dr. EM—Reading and corrections. Prof. JMM—Reading and corrections. Prof. JMA—Funding, preparing original manuscript, supervision and corrections.

Funding This research is funded by National Research Fund, Kenya. The funding was awarded to Meru university of Science and Technology as the lead institution with Jomo Kenyatta University of Agriculture and Technology, Tharaka Nithi University and Chuka University as collaborating institutions. The grant was awarded to Prof. Joshua Arimi as the principle investigator.

Availability of data and material All the data used in preparing the manuscript is available upon request.

Code availability Not applicable.

Declarations

Conflict of interest We declare no conflict of interest.

Consent for publication All authors have consented to the publication of this manuscript in Journal of Food Science and Technology.

Ethical approval The preparation of this manuscript didn't involve any study that required ethics approval.

Consent to participate Not applicable.

References

Agamy EI, Ruppanner R, Ismail A, Champagne CP, Assaf R (1992) Antibacterial and antiviral activity of camel milk protective proteins. J Dairy Res 59:169–175

Ahmed ASM, El-Zubeir I (2015) processing properties and chemical composition of low fat ice cream made from camel milk using natural additives. Int J Dairy Sci 10:297–305. https://doi.org/10.3923/ijds.2015.297.305

Ahmed ASM, Zubeir E (2015) Microbiological and sensory properties of low fat ice cream from camel milk using natural additives, In Camel milk products conference

Akgül Hİ, Şengül M, Ürkek B, Kotan TE (2021) 'Determination of physicochemical and microbiological properties and fatty acid composition of butter produced in Trabzon, Turkey. Acta Sci Technol 43:e48905. https://doi.org/10.4025/actascitechnol.v43i1.48905

Asresie A, Seifu E, Kurtu F (2013) Churning efficiency and microbial quality of butter made from camel milk alone and blending it with goat milk. Net J Agric Sci 1:75–80

Bereda A, Guya M, Yilma Z (2014) Microbial properties of Ethiopian dairy products: a review. Afr J Microbiol Res 8:2264–2271. https://doi.org/10.5897/AJMR2014.6733

Berhe T, Seifu E, Ipsen R, Kurtu MY, Hansen EB (2017) Processing challenges and opportunities of camel dairy products. Int J Food Sci. https://doi.org/10.1155/2017/9061757

Berhe T, Seifu E, Kurtu MY (2013) Physicochemical properties of butter made from camel milk. Int Dairy J 31(2):51–54. https://doi.org/10.1016/j.idairyj.2013.02.008

Bornaz S, Sahli A, Attalah A, Attia H (2009) Physicochemical characteristics and renneting properties of camels' milk: a comparison with goats', ewes' and cows' milks. Int J Dairy Technol 62:505–513. https://doi.org/10.1111/j.1471-0307.2009.00535.x

Bylund G (1995) Dairy Processing Handbook. Sweden: Tetra pak. https://dairyprocessinghandbook.tetrapak.com/chapter/cheese.

Choi SK, Park KD, Kim DA, Lee DW, Kim YJ (2014) Preparation of camel milk liposome and its anti-aging effects. J Soc Cosmet Sci Korea 40(2):155–162

Chuvakova ZK, Mal G, Kumar D, Patil NV, Pathak KML (2000) Chemical composition, microbial control and antiviral properties of freshly made and conserved shubat "Bota", In: Agroeconomics of camelid farming. Int Camelid Conf Almaty, Kazakhstan, p 97

Deosarkar SS, Khedkar CD, Kalyankar SD, Sarode AR (2016) 'Cream: Types of cream'. In: Food & Health (Encyclopedia of Food & Health) Edition: Elsevier, London, pp 331–337

El-Zeini HM (2006) Microstructure, rheological and geometrical properties of fat globules of milk from different animal species. Pol J Food Nutr Sci 56(2):147–154

Elayan A, Sulieman AM, Saleh F (2008) The hypocholesterolemic effect of gariss and gariss containing bifidobacteria in rats fed on a cholesterol-enriched diet. Asian J Biochem 3:43–47. https://doi.org/10.3923/ajb.2008.43.47

Elkhawad AO (1992) Selective brain cooling in desert animals: the camel (*Camelus dromedarius*). Comp Biochem Physiol Part A Physiol 101(2):195–201. https://doi.org/10.1016/0300-9629(92)90522-R

FAOSTAT Statistical database (2020) Rome: Food and Agriculture organization of the United Nations

Faccia M, Gambacorta G, Martemucci G, Difonzo G, D'Alessandro AG (2019) Chemical-sensory traits of fresh cheese made by enzymatic coagulation of donkey milk. Foods. https://doi.org/10.3390/foods9010016

Farah Z (1993) Composition and characteristics of camel milk. J Dairy Res 60:603–626

Farah Z (1996) Camel milk properties and products, 1st edn. Swiss Centre for Development Cooperation in Technology and Management, Sweden

Farah Z, Rüegg M (1991) The creaming properties and size distribution of fat globules in camel milk. J Dairy Sci 74(9):2901–2904. https://doi.org/10.3168/jds.S0022-0302(91)78472-5

Farah Z, Streiff T, Bachmann MR (1989) Manufacture and characterization of camel milk butter. Milchwissenschaft-Milk Sci Int 44:412–414

Farah Z, Streiff T, Bachmann MR (1990) Preparation and consumer acceptability tests of fermented camel milk in Kenya. J Dairy Res 57:281–283

Faris M, Ghazzawi H (2020) Potential anti-diabetic effect of camel milk, In: Research on health and environmental benefits of camel products. IGI Global, pp 185–196

Fatahi A, Soleimani N, Afrough P (2021) Anticancer activity of kefir on glioblastoma cancer cell as a new treatment. Int J Food Sci 2021:1–5. https://doi.org/10.1155/2021/8180742

Ganesan P, Hae-Soo K, Al G (2013) Butter, ghee, and cream products. In: Park YW, Haenlein GFW (eds) Milk and dairy products in human nutrition: production, Composition and Health. Wiley, pp 412–434. https://doi.org/10.1002/9781118534168.ch18

Glantz M, Devold TG, Vegarud GE, Lindmark Mansson H, Stalhammar H, Paulsson M (2010) Importance of casein micelle size and

milk composition for milk gelation. J Dairy Sci 93(4):1444–1451. https://doi.org/10.3168/jds.2009-2856
Haroun B, Laleye S, Chahra LCS, Mati A (2012) Coagulation of camel milk using dromedary gastric enzymes as a substitute of the commercial rennet. Am J Food Technol 7:409–419. https://doi.org/10.3923/ajft.2012.409.419
Hassan RA, Zubeir EL (2008) Chemical and microbial measurements of fermented camel milk "'Garris'" from transhumance and nomadic herds in Sudan. Aust J Basic Appl Sci 2(4):800–804
Helmizar H, Yuswita E, Putra A (2018) Analysis of the nutrients and microbiological characteristics of the Indonesian Dadih as a food supplementation. Global J Health Sci 11:155. https://doi.org/10.5539/gjhs.v11n1p155
Ibrahim EAR, Hamid AD, Magdi AO (2009) Microbiological and biochemical changes and sensory evaluation of camel milk fermented by selected bacterial starter cultures. Afr J Food Sci 3
Idoui T, Benhamada N, Leghouchi E (2010) Microbial quality, physicochemical characteristics and fatty acid composition of a traditional butter produced from cows milk in East Algeria. Grasas Aceites. https://doi.org/10.3989/gya.110209
Illahi BM, Zohaib AB (2021) Physiochemical and sensory characteristics of ice cream from lassi camel milk. Pak Euro J Med Life Sci. 4(4):191–194. https://doi.org/10.31580/pjmls.v4i3.2413
Inayat S, Arain MA, Khaskheli M, Farooq AA (2007) Study on the production and quality improvement of soft unripened cheese made from buffalo milk as compared with camel milk. Italian J Anim Sci 6(2):1115–1119. https://doi.org/10.4081/ijas.2007.s2.1115
Ipsen R (2017) Opportunities for producing dairy products from camel milk: a comparison with bovine milk. East Afr J Sci 11(2):93–98
Jarallah E, Lafta H, Darwash A (2014) Antibacterial activity of fermented camel milk using two lactic acid bacteria. J Babylon Univ Pure Appl Sci 22:2377–2382
John S, Deeseenthum S (2015) Properties and benefits of kefir—a review. Songklanakarin J Sci Technol 37:275–282
Kappeler S, Zakaria F, Puhan Z (1998) Sequence analysis of *Camelus dromedarius* milk caseins. J Dairy Res 65:209–222. https://doi.org/10.1017/S0022029997002847
Kashaninejad M, Razavi SMA (2020) Influence of thermosonication treatment on the average size of fat globules, emulsion stability, rheological properties and color of camel milk cream. LWT 132:109852. https://doi.org/10.1016/j.lwt.2020.109852
Khan HA, Athar IH, Aslam MU (2004) Evaluation of cheese prepared by processing camel milk. Pak J Zool 36:323–326
Kim DH, Jeong D, Kim H, Kang IB, Chon JW, Song KY, Seo KH (2016) Antimicrobial activity of kefir against various food pathogens and spoilage bacteria. Korean J Food Sci Anim Resour 36:787–790
Konuspayeva G, Camier B, Gaucheron F, Faye B (2013) Some parameters to process camel milk into cheese. Emir J Food Agric. https://doi.org/10.9755/ejfa.v26i4.17277
Konuspayeva G, Faye B (2021) Recent advances in camel milk processing. Animals 11(4):1045
Kumar M, Pandya HB, Dodiya KK, Bhatt R, Mangukiya M (2017) Advancement in industrial method of ghee making process at Sarvottam dairy, Bhavnagar, Gujarat (India). Int J Sci Environ Technol 6(3):1727–1736
Kumar, A. and Naik, S. (2018) 'Ghee : Its Properties, Importance and Health Benefits'. Centre for Rural Development & Technology, Indian Institute of Technology. Delhi
Laadhar Karray N, Danthine S, Blecker C, Attia H (2006) Contribution to the study of camel milk fat globule membrane. Int J Food Sci Nutr 57(5–6):382–390. https://doi.org/10.1080/09637480600858233
Langholm Jensen J, Mølgaard A, Navarro Poulsen JC, Harboe MK, Simonsen JB, Lorentzen AM, Hjernø K, van den Brink JM, Qvist KB, Larsen S (2013) Camel and bovine chymosin: the relationship between their structures and cheese-making properties. Acta Crystallogr Sect D 69(5):901–913. https://doi.org/10.1107/S0907444913003260
Liu JR, Wang SY, Chen MJ, Chen HL, Yueh PY, Lin CW (2006) Hypocholesterolaemic effects of milk-kefir and soyamilk-kefir in cholesterol-fed hamsters. Br J Nutr 95:939–946. https://doi.org/10.1079/BJN20061752
Lore TA, Mbugua SK, Wangoh J (2005) Enumeration and identification of microflora in suusac, a Kenyan traditional fermented camel milk product. LWT Food Sci Technol 38(2):125–130. https://doi.org/10.1016/j.lwt.2004.05.008
Mahmoudi I, Ben Moussa O, El Moulouk Khaldi T, Mounira K, Claire SS, Yves L, Mnasser H (2016) Functional in vitro screening of Lactobacillus strains isolated from Tunisian camel raw milk toward their selection as probiotic. Small Rumin Res. https://doi.org/10.1016/j.smallrumres.2016.03.016
Malik A, Al-Senaidy A, Skrzypczak-Jankun E, Janku J (2012) A study of the anti-diabetic agents of camel milk. Int J Mol Med 30:585–592. https://doi.org/10.3892/ijmm.2012.1051
Marynenko NI, Yagodinswkaya SG, Akhundov AA, Charyev KC, Khummenov O (1997) Contents of trace elements (cooper, manganese, selenium) in cultures chal and camels milk and their clinical significance. Zdravookhr Turkm 3:20–22
Merin U, Bernstein S, Bloch-Damti A, Yagil R, van Creveld C, Lindner P, Gollop N (2001) A comparative study of milk serum proteins in camel (*Camelus dromedarius*) and bovine colostrum. Livest Prod Sci 67:297–301. https://doi.org/10.1016/S0301-6226(00)00198-6
Mohamed OMA, Ahmed SSJ, Rahamtalla SA (2020) Physicochemical and sensory characteristics of cows' milk butter processed in Khartoum State, Sudan. Adv Food Res 9:1–8
Mona E, Ragia OM, Abeer AKH, Mosa TE (2010) Biochemical effects of fermented camel milk on diarrhea in rats. N Y Sci J 3(5):106–111
Mtibaa I, Purcaro G, Attia H, Ayadi MA (2020) 'Characteristics and processing challenges of camel milk cream', June. https://www.informmagazinedigital.org/informmagazine/june_2020/MobilePagedArticle.action?articleId=1588615#articleId1588615.
Muehlhoff E, Bennett A, McMahon D (2013) Milk and dairy products in human nutrition. Food and Agriculture organization of the United nations, Rome
Mwangi LW, Matofari JW, Muliro PS, Bebe BO (2016) Hygienic assessment of spontaneously fermented raw camel milk (Suusa) along the informal value chain in Kenya. Int J Food Contam. https://doi.org/10.1186/s40550-016-0040-8
Okoth MW, Akweya BA, Gitao CG (2012) The acceptability of camel milk and milk products from north eastern province in some urban areas of Kenya. Afr J Food Sci 6(19):465–473
Otles S, Çağındı Ö (2003) Kefir: a probiotic dairy-composition, nutritional and therapeutic aspects. Pak J Nutr. https://doi.org/10.3923/pjn.2003.54.59
Parmar N, Mehta B, Aparnathi K (2018) Composition of ghee prepared from camel, cow and buffalo milk. J Camel Pract Res 25:321. https://doi.org/10.5958/2277-8934.2018.00046.2
Rahman N, Xiaohong C, Meiqin F, Dong M (2009) Characterization of the dominant microflora in naturally fermented camel milk shubat. World J Microbiol Biotechnol 25:1941–1946
Rajarajan (2010) Incorporation of whey protein concentrate in ice cream C. Pandiyan*, G. Kumaresan, R. Annal Villi and G. Rajarajan, Int J Chem Sci, 8(5), S563–S567
Rajorhia GS (2003) GHEE. In: Caballero B (ed) Encyclopedia of Food sciences and nutrition, 2nd edn. Academic Press, Oxford, pp 2883–2889
Sagar SP, Mehta BM, Wadhwani KN, Darji VB, Aparnathi KD (2016) Evaluation of camel milk for selected processing related

parameters and comparisons with cow and buffalo milk. Int J Health Anim Sci Food Saf. https://doi.org/10.13130/2283-3927/7446

Salami M, Zahedi M, Moslehishad M (2016) Fermented camel milk (Chal): chemical, microbial and functional properties. J Pharm Health Sci. 4:193–204

Salem SA, Fardous M, El-Rashody MG (2017) Effect of camel milk fortified with dates in ice cream manufacture on viscosity, overrun, and rheological properties during storage period. Food Nutr Sci 08:551–564

Sharma, G., Gadhiya, J. and Dhanawat, M. (2018) *Textbook of Cosmetic Formulations*. pothi.com, India

Shori AB, Baba AS (2014) Comparative antioxidant activity, proteolysis and in vitro α-amylase and α-glucosidase inhibition of *Allium sativum*-yogurts made from cow and camel milk. J Saudi Chem Soc 18(5):456–463. https://doi.org/10.1016/j.jscs.2011.09.014

Siddig SM, Abdel ME, Sulieman ZA, Salih A, Abdelmuhsin A (2016) Quality characteristics of white cheese (Jibna-beida) produced using camel milk and mixture of camel milk and cow milk. Int J Food Sci Nutr Eng 6:49–54

Soni V, Goyal M (2013) Potential of using camel milk for ice cream making. J Camel Pract Res 20:271–275

Sukumar De (2001) Outlines of dairy technology. Oxford University Press, New Delhi

Umelo C, Uzoukwu AE, Odimegwu EN, Agunwah IM, Njoku NE, Alagbaoso SO (2014) Proximate, physicochemical and sensory evaluation of ice cream from blends of cow milk and tigernut (*Cyperus esculentus*) milk. Int J Sci Res Innov Technol 1:63–76

Usmiati S, Risfaherim (2013) Improvement of Dadih as an indigenous probiotic functional food of West Sumatra. J Litbang Pertan 32:20–29

Varnam AH, Sutherland JP (1994) Cream and cream-based products. In: Varnam AH, Sutherland JP (eds) Milk and milk products: technology, chemistry and microbiology. Springer, US, Boston, MA, pp 183–223. https://doi.org/10.1007/978-1-4615-1813-6_5

Yateem A, Balba MT, Al-Surruyai T, Al-Mutairi B, Al-Daher R (2008) Isolation of lactic acid bacteria with probiotic potential from camel milk. Int J Dairy Sci 3:194–199. https://doi.org/10.3923/ijds.2008.194.199

El Zubeir IEM, Jabreel SO (2008) Fresh cheese from camel milk coagulated with Camifloc. Int J Dairy Technol 61(1):90–95. https://doi.org/10.1111/j.1471-0307.2008.00360.x