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REVIEW

A Review on Processing Opportunities for the Development of Camel Dairy Products

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Abstract Camel milk has a significant and pivotal role in the diet of people residing in semi-arid and arid regions. Ever since ancient times, marketing of camel milk has remained insignificant due to nonexistence of processing amenities in the camel nurturing areas, hence the utilization of unprocessed camel milk has continuously remained limited at family level by the nomads. Due to the superior medicinal values and health promoting effects, incredible growth in the demand of camel milk and dairy products have been noticed all over the world during last two decades. Such emergence has led dairy industry to provide diversified camel dairy products to the consumers with superior nutritional and functional qualities. In contrast to bovine, very few food products derived from camel milk are available in the present market. With the advancements in food processing interventions, a wide range of dairy and non-dairy products could be obtained from camel milk, including milk powder, cheese, yogurt, ice cream, and even chocolate. In some regions, camel milk is used for traditional dishes such as fermented milk, camel milk tea, or as a base for soups and stews. Current review highlights the processing opportunities regarding the transformation of camel milk into various dairy products via decreasing the inherent functionality that could be achieved by optimization of processing conditions and alteration of chemical composition by using fortification method. Additionally, future research directions could be devised to improve the product quality.

Keywords camel milk, cheese, yogurt, dairy products, processing opportunities

Introduction

Since prehistoric time milk has played an important role in the diet of human to fulfill the nutritional requirement and maintain the health of consumer. Milk and milk- derived products are the excellent source of high-quality protein, carbohydrate, fat, minerals and vitamins and also serve as an important source of essential micronutrient, bioactive compounds, lactic acid bacteria (LAB) and immune-boosting substances (Arain et al., 2022). Camel milk (CM) serve as an important source of nutrition and contributes to the food security for the survival of human population belongs to the arid and semi-arid areas of Africa, Asia and Arabian deserts. CM naturally occupies unique chemical features and inherent functionality which is quite different from the milk of other mammals (Muthukumaran, 2022). The gross chemical composition of major nutrients (water, lactose, fat and protein) found in CM is more or less similar to the cow milk, while significant variation has been observed in the micronutrient including immunoglobulin G and A, vitamins specially A, B_2 and C and minerals salts (Hammam, 2019; Mullaicharam, 2014). On the other hand, molecular structure of major ingredients of CM is also dissimilar to the bovine milk which is the major obstacle for dairy industry to transform CM into valuable dairy products (Baig et al., 2022; Ho et al., 2022). CM contains lower concentration of short chain fatty acids and carotene while, it contains higher quantity of long chain fatty acids (Al-Nasseri et al., 2019). Since last decades the growing interest and remarkable increase in the demand of CM and dairy products were noticed all over the world due to the superior medicinal value and health-promoting effects. Such emergence has led to the dairy industry to provide diversified camel dairy products to the consumers with superior nutritional and functional quality. The worldwide CM production is growing at the rate of 2.45% per year due to multiple reseasons: (1) contributed to food security under harsh environmental conditions, (2) increasing market demand owing to the exceptional functional properties, and (3) development of camel dairy industry which could be beneficial for camel owners (Konuspayeva and Faye, 2021).

In general, the majority of milk obtained all around the world exposed to various processing treatments by using modern technological procedures to increase the shelf life and developed the functional dairy products with superior nutritional value and health-promoting potential. The transformation of milk into fermented and non-fermented dairy products is commonly practiced for preservation and improve the value of rising yield. The techno-functional properties of milk including solubility, water holding capacity, physical behavior, chemical structure, foaming capability, gelling formation and emulsifying properties are known to play a vital role in milk processing techniques and could be considered substantial contributors in transformation of new food products from animal origin (Shokri et al., 2022). The possible use of CM for the development of dairy products is dependent on physicochemical and techno-functional properties (Konuspayeva and Faye, 2021). The functional properties of food can be affected by application of processing technologies, quality of food, utilization of food, formulation and finally their acceptability (Mahajan and Dua, 2002). The transformation of CM into processed dairy products is a challenging task and requires suitable technologies due to multiple factors such as unique chemical composition, inherent functionality, presence of multicomponent colloidal system, size of protein micelles, size of fat globules and presence of antibacterial compounds (Arain et al., 2022; Bornaz et al., 2009). Recently, the techno-functional properties of CM are of greatest interest for scientific community due to same technologies used for cow milk are not suitable for transformation of CM into dairy products. However, it could be possible through the application of new technologies, optimization of processing condition and adjustment of inherent functionality through the application of synthetic compounds or fortification of camel to overcome the associated challenges regarding the transformation of CM into dairy products. The aim of this review is to highlight the recent development regarding the processing and transformation of CM in to functional dairy products. Additionally, based on published literature it is also envisaged to identify the suitable processing conditions for the development of innovative dairy products at industrial level.

Fermentation as a Processing Technology

The process of converting natural carbohydrates such as starch and sugar into acids or alcohol by addition of nonpathogenic bacteria or yeast (starter culture) called as fermentation. The acid and alcohol production during the fermentation process act as a natural preservative and provides new food product with exceptional nutritional and functional properties. The fermentation of food is one of the oldest methods of food preservation, processing and product development that was practiced by nomads and these techniques were transferred and/or transformed from generation to generation from prehistoric times to the modern era of science and technology (Nduko et al., 2016). Fermentation of milk could be accomplished by enhancing the growth and activities of non-pathogenic bacteria, which can alter the composition and consistency of final product (MacDonald and Reitmeier, 2017). In prehistoric times, the main purpose of fermentation was to enhance the shelf life of perishable food commodities along with improving the nutritional and sensory quality of dairy products (Hui et al., 2004; Terefe, 2016). Since the prehistoric time the fermentation method has been continuously used all around the world mainly for food preservation and transformation milk into other dairy products including cheese, butter and yogurt.

Yogurt as a Fermented Dairy Product

Yogurt is one of the oldest and most important fermented dairy product, it remains very popular in modern world due to its image as a functional food with superior nutritional value and its growing diversification associated to the manufacturing at industrial scale. Yogurt are the fermented dairy product obtained from lactic acid fermentation of milk by two species of LAB. Yogurt is also known as a healthy food and people like to consume all around the world due to its superior digestibility than milk, provide health-promoting nutrients and restore the pathophysiological disorders associated to the gastrointestinal tract (GIT; Temerbayeva et al., 2018). Yogurt can be obtained by fermentation of milk from various species of dairy animals like sheep, goat, cow buffalo, mare and camel however, the last two is not considered for the production of fermented dairy product on commercial level (Akanova et al., 2017). The nutritional quality of yogurt can be influenced by numerous factors including; (1) the amount of lactic acid (LA) production, which is crucial for the lactose intolerant consumers owing to safe the peoples by minimizing the production of methane, hydrogen, organic acid and carbon dioxide in GIT; (2) bioavailability of macro-minerals including potassium, calcium and phosphorus, which was improved in yogurt than non-fermented milk due to non-fat solid adjustment (Corrieu and Béal, 2016); (3) quantity of folic acid content which was higher in yogurt in compression to the milk (Corrieu and Béal, 2016).

Yogurt Manufacturing Methods and Classification

In this modern era of food processing and preservation, the yogurt manufacturing required three main steps: (1) preparation of the mix for transformation of milk into yogurt by applying several processing treatments/condition like pasteurization (63 for 30 minutes or 72℃ for 15–20 seconds), homogenization, cooling and deaeration; (2) addition of starter culture microorganisms and incubation (43℃–45℃) to initiate the fermentation process, this step considered the cornerstone to produce the fermented dairy product; (3) the harvesting of yogurt, post-treatment and packaging (Corrieu and Béal, 2016; Weerathilake et al., 2014). In commercial dairy the fermentation process of milk could be achieved by using the mixture of starter culture bacteria such as *Lactobacillus bulgaricus* and *Streptococcus thermophilus.* These are the most important starter culture found in yogurt and play a vital role in fermentation process to convert the lactose (milk sugar) into lactic acid and drop the pH required for the development of texture and flavor of the end product/yogurt (Ifeanyi et al., 2013). The yogurt can be classified into four types depending on the processing steps, source of milk used for yogurt preparation, total solid content, flavor, texture and storage temperature. Commonly milk used for yogurt manufacturing obtain from cow, buffalo sheep and goat. Additionally, yogurt can also be classified on the basis of physical appearance and flavor (sweet, flavored and plain) or on the basis of texture (concentrated, stirred, frim, drinking, frozen and powder; Corrieu and Béal, 2016). The comprehensive details regarding the classification and manufacturing of yogurt was mentioned in the study of Corrieu and Béal (2016).

Opportunities for Yogurt Making from Camel Milk (CM)

Several attempts have been reported in literature to improve the organoleptic and rheological characteristics of CM yogurt however, there is no clear technological solution is available to meet the commercial production of camel yogurt (Ibrahim and Khalifa, 2015; Mohsin et al., 2019; Mudgil et al., 2018). Normally, the coagulation process of CM required long time than other bovine milk due to exceptionally larger size of casein micelles and presence of antibacterial compounds leading to decrease the functionality of starter culture bacteria (Ibrahem and El Zubeir, 2016). The fortification of CM with other milk significantly decrease the inherent functional properties, and subsequently addition of hydrocolloid and single stabilizer or their combination has been studied to enhance the consistency and physicochemical properties of CM yogurt as indicated in Table 1. The method of CM yogurt preparation and way to overcome processing challenges are presented in Fig. 1. The addition of 0.08% Na_2EDTA or 2.5% bovine no-fat milk powder had no positive effect on the quality parameters of CM yogurt. The unacceptable organoleptic quality (taste and flavor) of yogurt has been observed in response to the application of either carboxymethyl cellulose or pectin 0.6%, as a stabilizing agent (Al-Zoreky and Al-Otaibi, 2015). Furthermore, Hashim et al. (2009), suggested that carboxymethyl cellulose (0.5%–1.0%) fortified CM had no significant impact on the texture of CM yogurt. It has also reported that the transformation of CM into yogurt did not achieved by supplementation of milk with samphire molasses (3%), bovine whey protein isolate (3%) and k-carrageenan (0.1%; Kavas and Kavas, 2016). Results also showed that the manufactured yogurt had inferior quality of yogurt (sensory, rheological, physicochemical and microbiological). Moreover, these parameter was improved significantly and increase consumer acceptability by replacing the k-carrageenan with xanthan gum at the concentration of (0.5%) by using same methodology. Another study, demonstrated that adding 0.75% biosynthesized xanthan to CM yogurt significantly improved the firmness, texture and organoleptic attributes of manufactured product (Mohsin et al., 2019). Additionally, the added biosynthesized xanthan build the compact and uniform microstructure along with dense network of casein micelles. Likewise, Mudgil et al. (2018) suggested that the appearance, rheological properties and texture of CM yogurt could be improved and comparable characteristics to those of cow milk by adding the gelatin as a stabilizing agent at the level of 0.75%–0.1%. Conversely the sensory attributes of CM yogurt (flavour and taste) was insignificantly influenced when compare with cow milk yogurt. The study of Jasim et al. (2018) demonstrated that adding arabic gum (1%–2%) significantly enhance the texture, appearance and viscosity while decline the syneresis however, the higher concentration of arabic gum led to the off-taste in CM yogurt.

Another approach has been applied to address the processing challenges associated to the production of CM yogurt by mixing the CM with other mammalian milk such as sheep, goat, cow and buffalo milk (Ibrahem and El Zubeir, 2016). The author reported that the CM fortified with sheep milk (40%–60%), showed higher nutritional value with better quality attributes and consumer acceptability than yogurt produced from CM alone. Similarly, another study reported that the mixing of CM with sheep, goat and cow milk produce better quality yogurt owing to enhance the total solid contens and neutralize or reduce the inharent funtionality of CM (Park et al., 2007). This approach not only improve the weak texture and thin consistanct of CM yougurt but also increases the nutritional properties of end product by replacing the deficient

Table 1. A summary of studies to overcome the yogurt processing from camel milk (CM) by altering the milk composition and optimize the processing conditions

No.	Objective of study	CM fortification	Optimization of processing conditions	Key findings/results	References
1	To assess the impact of added casein, whey protein, $CaCl_2$, hydrocolloid gum, gelatin, sodium alginate and pectin on the quality characteristics of CM yogurt.	CM supplemented with various additives CN (1%–3%) WP (1%–3%) $CaCl_2$ (0.1%–0.3%) GA (0.05%–0.15%) GL (0.2%–0.4%) ALG (0.1%–0.3%) PC (0.1%–0.3%).	Pasteurization at 85°C for 30 min. Add (0.05%) starter culture and incubate at 43°C for 12 h.	CM yogurt obtained with the addition of whey protein and casein alone or in combination with pectin alginate showed better quality and consumer acceptability.	(Sobti et al., 2020)
2	To evaluate the gelation and sensory attributes of CM yogurt by using food grade additive formulations.	CM fortified by addition of sugar (5 g), gelatin (4 g), SMP (50 or 70 g) and starch (12 g) in 1 liter of milk.	Pasteurization of mix at 85°C for 30 min and cooled at 45°C. Addition of chymosin (20 and 40 IMCU L^{-1}) Addition of starter culture (3%) and incubate for fermentation.	The sensory attributes of CM yogurt were improved by addition 7% SMP. The gelation properties of CM was improved with the addition of chymosin enzyme.	(Benkerroum et al., 2022)
3	To analyze the impact of graded level of bovine milk supplementation on quality characteristics of CM yogurt.	Fortification of CM with bovine milk at the level of (0%, 10%, 20%, 30%, 40%, 50% and 60%, v/v).	Both milks were subjected to pasteurization at 85°C for 5 min, then cooled at 42°C. Adding (0.2%) commercial starter culture and incubate for fermentation up to 24 h.	Results indicated that the addition of CM with BM (10%–60%, v/v) was negatively affect the coagulation behavior leading to weak gel formation.	(Kamal-Eldin et al., 2020)
4	To examine the influence of graded level of monk fruit sweetener on the physicochemical properties and microbiological counts of drinking yogurt made from CM.	CM fortified by 0, 0.42, 1.27, and 2.54 g/L of monk fruit sweetener.	CM was reconstituted from powder. Pasteurization of yogurt mix at 82.2°C for 30 min and cooled at 40°C. Add 2.4 mL of fresh thawed starter culture and allowed for fermentation at 40°C.	Results showed that the addition of monk fruit with CM effectively reduce the pH and enhance the viscosity of yogurt. The color and sensory quality were also improved.	(Buchilina and Aryana, 2021)
5	To investigate the partial replacement of CM with oat milk on physicochemical, antioxidant, sensory and microbiological properties of CM yogurt.	Milk used in this study was fortified with 2% dried whey protein concentrate (DWPC). Addition of CM with various level of oat milk (10%, 20%, 30%, and 40%).	Yogurt mix was homogenized at 55°C–60°C for 2 min. Pasteurization of mix at 85°C for 30 min and cooled at 42°C. Add starter culture (5%) and allowed for fermentation at 42°C for 6–8 h.	CM yogurt produce with the replacement of oat milk have superior rheological, sensory and antioxidant properties.	(Atwaa et al., 2020)
6	To investigate the synergistic effect of trisodium citrate and microbial transglutaminase (mTGase) on the textural properties of CM gels.	CM supplemented with various concentration of trisodium citrate and microbial transglutaminase.	Prepared reconstituted CM and fat was removed by centrifugation. Add trisodium citrate (0, 10, 20, 30, and 40 mmol/L). Add mTGase (0, 10, 20, 30, and 40) to the yogurt mix. Incubate the samples at 43°C for 4 h.	Adding trisodium citrate (30 mmol/L) to CM significantly improved the textural properties of the gel. Moreover, trisodium citrate induce chelating effect and dissociated the casein micelles leading to produce stable gel.	(Chen et al., 2019)

Table 1. A summary of studies to overcome the yogurt processing from camel milk (CM) by altering the milk composition and optimize the processing conditions (continued)

No.	Objective of study	CM fortification	Optimization of processing conditions	Key findings/results	References
7	To evaluate the effect of various level of passion fruit juice on fermentation, physicochemical and functional properties of CM set type yogurt.	Reconstituted CM fortified by supplementing various levels of passion fruit juice (0%–10%) along with table sugar.	Reconstituted CM were mixed with 6 g of sugar and subsequently subjected to homogenization. Pasteurization of yogurt mix at 90°C for 10 min and cooled at 42°C. Add starter culture (0.1%) followed by incubation to complete the fermentation process.	Results indicated that passion fruit juice improves the gel strength and enhance fermentation process at early stage. The sensory quality of yogurt (aroma and flavor) were also improved. Moreover, the antioxidant capacity of yogurt was improved owing to the production phenolic compounds.	(Ning et al., 2021)
8	To study the impact of mixed starter culture with supplementation of pectin (0.1%–0.3%) or sodium alginate (0.1%–0.5%) on sensory, structural and rheological properties of CM yogurt.	CM supplemented by two hydrocolloids including pectin (0.1%–0.3%) and sodium alginate (0.1%–0.5%).	Pasteurization of yogurt mix at 85°C for 30 min. Add (0.05%) mix starter culture and incubate at 43°C for 12 h.	Yogurt supplemented with intermediate level of pectin or sodium alginate have better consistency and palatability.	(Sobti et al., 2021)
9	To evaluate the impact of different level of plant seed gum (0%, 0.1%, and 0.2%) as the stabilizer on flow behavior, textural and sensory quality of CM frozen yoghurt.	Standardization of camel and cow milks using skim milk powder and addition of different levels of plant seed gums.	Milk was heated at 85°C for 30 min and cooled to 42°C, then inoculated the commercial yoghurt culture and allowed for fermentation up to 4 h, than store at refrigerated temperature.	Supplementing plant seed gum significantly influenced the viscosity, melting rate textural and sensory quality of frozen yoghurt obtained from camel and cow milk.	(Azari-Anpar et al., 2021)
10	To study the impact of xanthan gum supplementation on quality attributes of CM yoghurt.	CM supplemented with biosynthesize xanthan (0.25%, 0.50%, and 0.75%) as the stabilizing agent.	Yoghurt mix was subject to pasteurization at 60°C for 30 min, then cooled at 40°C. Addition of 10% pasteurized date past in all treatment and mix the blend. Add 0.002% freeze dried culture and allowed for incubation at 43°C for 6–8 h.	Results indicated that yogurt supplemented with biosynthesized xanthan at the level of 0.75% produce stronger gel. Additionally, 0.75% xanthan supplementation along with 10% date past improved the sensory quality of yogurt.	(Mohsin et al., 2019)

components of CM such as k-CN and β-LG along with balancing the casein to whey protein ratio (Shamsia, 2009). Another study demonstrated that the mixing of CM with bovine milk powder at the concentration of 5% along with addition of stabilizer (gelatin 1.2% and $CaCl_2$ 1.5 mL/L) and strawberry flavor led to improve the quality characteristics of yougurt (Galeboe et al., 2018). Interestingly, another study using the combined approach to mix the bovine milk and gelatine as a stabilizer into CM and investigated the sensory characteristics, rheological attributes and micro-structure of CM yogurt (Mudgil et al., 2018). The results indicated that the higher concentration of gelatin significantly improved the appearance and texture of CM yougurt, but negatively influenced on the organoleptic attributes of end product. Altogather, it has been concluded that studies found in litrature used numerous opproaches and method to produce CM yugurt with minor

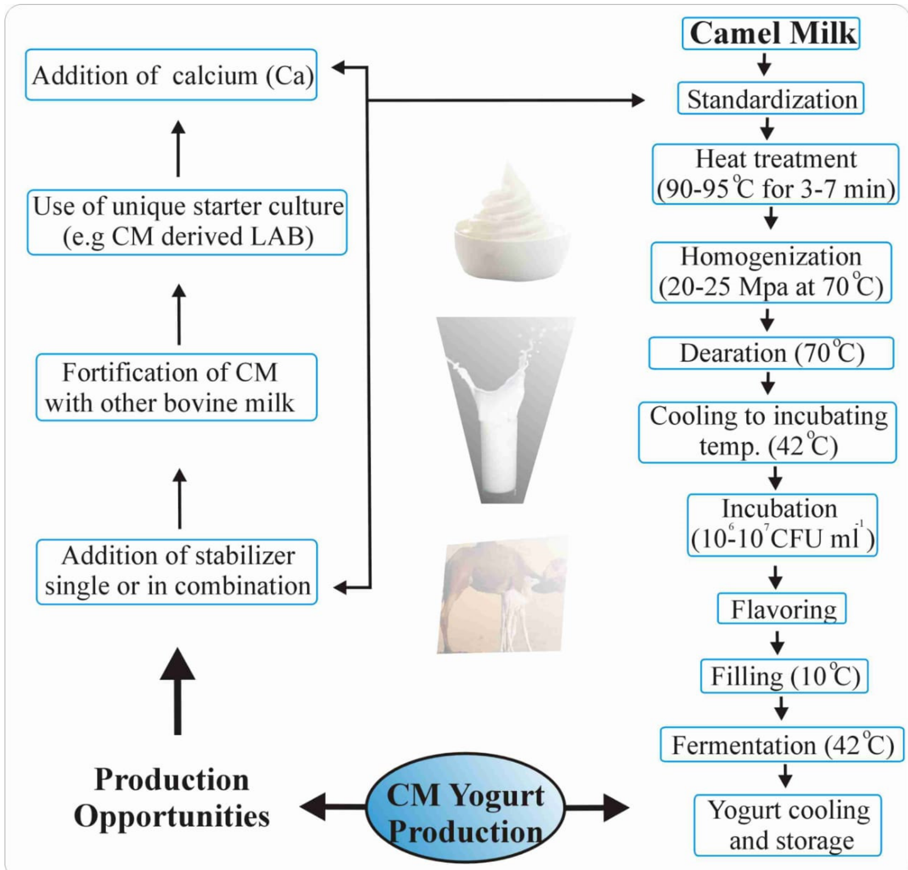

Fig. 1. Schematic overview of CM yogurt processing opportunities by optimization of processing conditions. CM, camel milk.

modification either by mixing bovine milk into CM or adding stabilizers leading to improve the quality atrubutes of CM yogurt.

Camel Milk (CM) Kefir Processing

Kefir is a fermented dairy product that is similar to yogurt but has a thinner consistency and a tangy taste. It is made by fermenting milk with kefir grains, which are a combination of bacteria and yeast. Kefir is a popular drink in many parts of the world and is known for its probiotic properties, which can benefit the digestive system. CM kefir is similar to traditional kefir made from cow's milk, but it has some distinct differences in terms of taste, texture, and nutritional content. CM kefir is said to have a slightly tangy flavor with a creamy texture, and it may also be slightly less tart than cow's milk kefir. In terms of nutrition, CM kefir is high in protein, vitamins, and minerals, and it may be easier to digest than cow's milk kefir due to its lower lactose content. CM kefir is famous dairy product commonly produced in the camel nurturing areas of Central Asia (Rao et al., 1970). CM kefir can be produced using the same basic process as regular milk kefir. The process involves combining CM and kefir grains, then allowing the mixture to ferment at room temperature for a period of time. It is produced by pasteurizing the CM at 85°C then add kefir culture at the level 3.6% after cooling the milk at 26°C and allowed for fermentation at room temperature for 10–12 h (El-Agamy, 2017). The product can further be ripened for 24–48 h (El-Agamy, 2017; Kamal-Eldin et al., 2022). The commercial production and marketing of kefir is limited, however further in depth research are needed to promote the neutraceutical potential of camel kefir.

Camel Milk (CM) Cheese and Its Production Opportunities

Fig. 2 summarizes the important processing, coagulation and compositional factors and how to address these hurdles during cheese manufacturing from CM. The most important processing constraints associated with the utilization of CM for cheese-making is the lower cheese yield with inferior product quality. Despite these limitation of CM, several attempts have been made to obtain various types of CM cheeses, and the findings are summarized in Table 2. Many attempts have been made to address these aforementioned challenges, for example, using camel gastric enzyme as an alternative to chymosin for camel cheese processing (Haroun et al., 2012). Camel-derived chymosin exhibited excellent clotting activity (approximately 70% higher) and κ-casein cleavage potential than the chymosin from other sources (Langholm Jensen et al., 2013). Similarly, many other different additives have been supplemented in CM to improve the quantity and quality of CM cheese. For example, addition of calcium chloride to the CM during cheese manufacturing significantly decrease the coagulation time and improve the cheese yield along with acceptable organoleptic quality (El Zubeir and Jabreel, 2008). Siboukeur et al. (2005) indicated that the utilization of camel gastric enzyme (camel rennet) rather than bovine rennet showed strong coagulation effect and significantly reduced the coagulation time. The improved clotting efficiency might be attributed to the use of pepsin enzyme during rennet preparation. Addition of yoghurt culture or other LAB along with rennet to the CM effectively accelerated the coagulation process by increasing the lactic acid content and ultimately improve the texture and firmness of curd (Gassem and Abu-Tarboush, 2000; Mehaia, 2006). On the other hand, addition of LAB or yoghurt culture without rennet could not improve coagulation efficiency.

Another approach to increase the casein content in CM by mixing the milk of other bovines such as cow, buffalo, sheep and goat milk led to resolve the challenges associated to the camel cheese production. The study of Inayat et al. (2007)

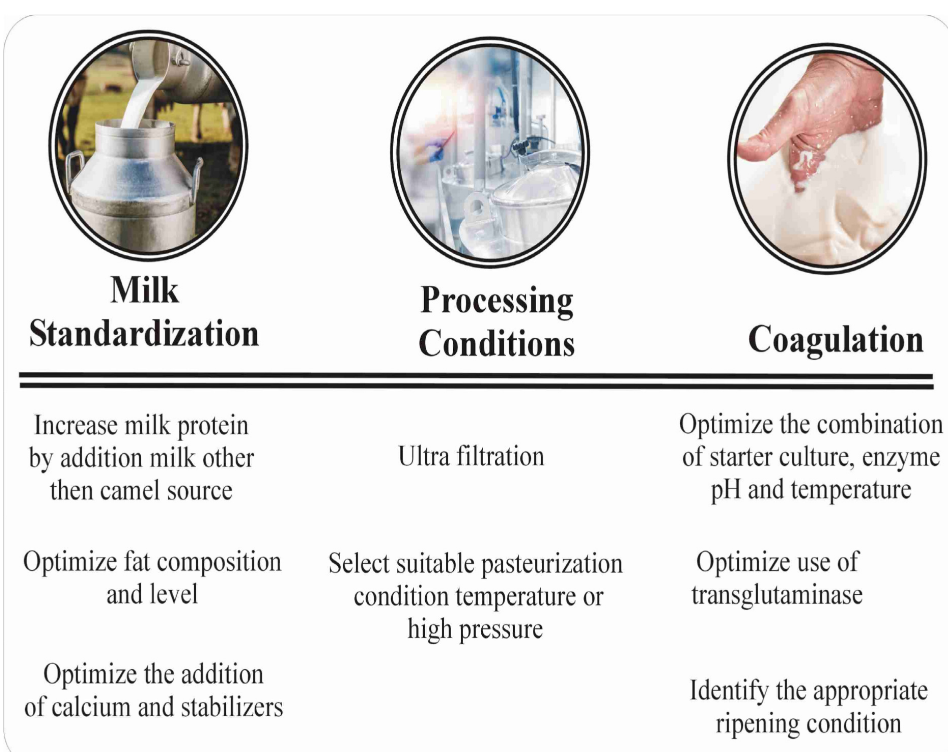

Fig. 2. Schematic overview of CM cheese processing opportunities by optimization of processing conditions. CM, camel milk.

Table 2. A summary of studies to overcome the cheese processing from camel milk (CM) by altering the milk composition and optimize the processing conditions

No.	Type of cheese produced	Objective of study	Fortification of CM with other milks or non-milk ingredients	Processing condition	Results/findings	References
Comparing the effect of milk composition (CM vs other milks) on cheese production and quality attributes.						
1	Soft cheese	To study the chemical properties of cheese made from CM or a mixture of CM and sheep milk.	T1: 100% CM. T2: 75% CM and 25% sheep milk. T3: 75% sheep milk and 25% CM. T4: 50% CM and 50% sheep milk. T5: 100% sheep milk.	Pasteurization at 71℃, for 30 s. Trypsin enzyme (0.5 g), in 5 kg milk. $CaCl_2$ (0.5 g), in 5 kg milk.	Total solid, protein and fat percentage was improved by increasing the amount of sheep milk. Quality attributes of cheese were also improved by mixing the sheep milk into CM.	(Saadi et al., 2019)
2	Low fat Akawi cheese	To assess the *in vitro* biological activities and protein degradation of low fat Akawi cheese produced from camel and bovine milk.	Bovine milk 100%. CM 15% and bovine milk 85%. CM 30% and bovine milk 70%.	Pasteurized CM and BM obtained from market. Use camel derived chymosin. Add starter culture 0.5 g/vat. Incubation at 42℃ for 60 min.	Cheese produced from camel and bovine milk blends have superior functional properties in comparison to the bovine milk cheese.	(Ayyash et al., 2021)
3	White brined cheese	To determine the clotting behavior of CM with that of cow milk.	Natural composition after skimming.	Addition of sodium azide (0.02%), starter culture (3%). Chymosin (55 IMCU/L) and allowed for coagulation up to 2 h.	The sensory attributes (color and texture) was higher in cow cheese, however, panelist preferred CM cheese.	(Bouazizi et al., 2021)
4	Cheddar cheese sauce	Evaluate the effect of CM powder supplementation (5%–15%) on the quality of bovine milk cheddar cheese sauce.	Adding CM power (5%–15%) to the bovine milk.	Cheddar cheese sauce was prepared by mixing hot water with disodium phosphate, sodium citrate, chopped cheese with or without CM powder replacement (5%, 10%, and 15%).	The textural properties of final product were improved by increasing the ratio of CM powder in the blend used for cheese preparation.	(Desouky et al., 2019)
5	Soft cheese	To assess the impact of adding milky component (BMR) and sweet potato powder (SPP) on quality characteristics of cheese.	Mixing BMR (20% or 30%). Mixing SPP (1%, 2%, or 3%).	CM supplementation with BMR (20% or 30%) and SPP (1%, 2%, or 3%). Heating (65℃, 30 min) and cooling to (42℃). Addition of calcium chloride (0.04%) and sodium chloride (3%). Add yogurt culture (1%) and incubated at (42℃ for 30 min). Addition of bovine pepsin (4 mg/100 g). Packing in brine solution and stored at 5℃.	Clotting time was reduced in response to BMR and SPP addition. Improved physicochemical properties of final product. pH and syneresis were decrease significantly.	(Elnemr et al., 2020)

Table 2. A summary of studies to overcome the cheese processing from camel milk (CM) by altering the milk composition and optimize the processing conditions (continued)

No.	Type of cheese produced	Objective of study	Fortification of CM with other milks or non-milk ingredients	Processing condition	Results/findings	References
Optimization of processing conditions						
6	Soft cheese	To examined the effect of ultrafiltration and supplementation of allium roseum on CM cheese.	CM fortified with allium roseum powder and using two fat combination (full fat and skim milk) along with ultrafiltration processing.	Ultrafiltration and pasteurization at (90℃ for 10 min) than cooling at (45℃). Adding $CaCl_2$ (0.2 g/L), starter culture (1%) and camel derived chymosin. Allowed for coagulation and addition of allium. Roseum.	Ultrafiltration improved the texture attributes, enhanced fat and protein availability in cheese. The cheese obtained from allium roseum blend have higher antioxidant activities.	(El Hatmi et al., 2020)
7	Soft un-ripened cheese	To analyze the clotting behavior of CM and BM in response to acetic acid, citric acid and chymosin enzyme.	CM was supplemented with organic acid (citric acid or acetic acid). Also add $CaCl_2$ (3%) for curd production.	Pasteurization at (63℃, 30 min), cooling (40℃). Mixing $CaCl_2$ (3%), starter culture (3%). Addition of chymosin (50 IU/L), coagulation time (8 h).	The camel chymosin and acid coagulation induce positive impact on quality attributes of CM cheese in comparison to the cheese obtained from BM.	(Mbye et al., 2020)
8	Soft-brined cheese	To assess the impact of storage temperature on physicochemical, structural and sensory characteristics of camel and bovine cheese.	The natural composition of cow and CM.	Pasteurization (63℃ for 30 min) and cooling at (35℃). Addition of $CaCl_2$ (0.02%), starter culture (75 U/L) and camel chymosin (55 IMCU/L). Allowed for coagulation up to (2 h). Addition of NaCl (2%) and store at 10℃–15℃.	The hardness value of camel and cow cheeses were improved at 15℃ ripening condition. The panelist suggested that the appropriate ripening condition for camel cheese is 10℃.	(Felfoul et al., 2021)
9	Not specified	To determine the impact of pre-heating conditions and salt addition on rheological properties of camel and bovine milk cheeses.	The natural composition of cow and CM.	Pre-heating at (50℃ or 70℃ for 10 min), cooling at (36℃ for 5 min). Adding 10 or 20 mM $CaCl_2$ or $Na_2HPO_4 \cdot 2H_2O$ (hydrogen phosphate dehydrate). Addition of rennet (6.25 μL) in 25 mL of milk.	Pre-heating of CM at 50℃ or 70℃ negatively affect the gel formation, in comparison to the BM. However, addition of $CaCl_2$ enhance gel firmness and reduce gelation time. Addition of $Na_2HPO_4 \cdot 2H_2O$ produced week gel or even no gel formation.	(Kamal et al., 2017)

Table 2. A summary of studies to overcome the cheese processing from camel milk (CM) by altering the milk composition and optimize the processing conditions (continued)

No.	Type of cheese produced	Objective of study	Fortification of CM with other milks or non-milk ingredients	Processing condition	Results/findings	References
10	Not specified	To identify the optimum processing conditions for clotting of CM with the addition of *Moringa oleifera* enzyme extract.	The natural composition of cow and CM.	Pasteurization at (55°C, 60°C, and 65°C). pH ranges (4.5, 5, and 5.5). Addition of $CaCl_2$ (0.15 g/L), and various volume of partially purified. *Moringa oleifera* (0%, 10%, 20%, 30%, and 40%) in 10 mL of milk.	The clotting activity was improved at pH 5 alongside pasteurization at 65°C and 10% purified extract of *Moringa oleifera.*	(Terefe et al., 2017)
Effect of coagulating ingredients (enzymes, acid and starter culture)						
11	Fresh CM cheese	To determine the clotting behavior of CM in response to the Withania coagulant, camel chymosin or mixture of both enzymes.	Natural composition without any alteration.	Pasteurization (65°C, 30 min), cooling (40°C). Addition of 270 mmol $CaCl_2$/L. addition of starter culture 3%. Add chymosin (50 IMCU/L) and allow for coagulation up to (8 h).	The quality attributes of cheese was improved by using mixture of withania coagulant and enzyme.	(Mbye et al., 2021)
12	White soft cheese	To evaluate the clotting behavior of CM in response to recombinant camel chymosin with or without starter culture.	Natural composition without any alteration.	Pasteurization (63°C, 30 min), cooling (35°C), Addition of $CaCl_2$ (0.02%) and starter culture (0% or 0.5%. Addition of chymosin (CHY-Max M 2,500, 50 IMCU/L) and allow for coagulation at 37°C for 110 min. Addition of salt (1%) and stored at refrigeration temperature.	Application of recombinant camel chymosin and thermophilic starter culture significantly enhance the yield and quality characteristics of CM cheese.	(Al-Zoreky and Almathen, 2021)
13	Not mentioned	To assess the CM clotting efficiency by using chymosin, kiwi, ginger and pineapple extract during cheese making.	Natural composition without any alteration.	Pasteurization (65°C, 30 min), cooling (40°C). Addition of starter culture and enzyme (10%), and allow for coagulation.	Kiwi enzyme extract showed the highest clotting efficiency in comparison to other extract used for cheese preparation.	(Fguiri et al., 2021)
14	Soft cheese	To evaluate the coagulating effects of various level of lemon juice on CM cheese.	Natural composition without any alteration.	Tests were performed with different volumes of lemon juice (150, 200, 250, 300, 350, 400, 450, and 500 mL) and allow for coagulation at ambient temperature for 34 h.	The optimum cheese yield was obtained by using lemon juice 500 mL/2L of CM. However, the cheese has higher moisture content and soft texture with fatty appearance. Overall the acceptability were improved with the addition of lemon juice.	(Mihretie et al., 2018)

reported that the yield, sensory attributes and physical characteristics of soft un-ripened buffalo cheese was higher than the CM cheese. However, the addition of buffalo milk 30% (w/w) into CM leading to enhance the clotting efficiency of rennet, improve firmness of curd, increase curd yield, minimize weight loss and superior sensorial and microbiological quality of final product (Shahein et al., 2014). In recent study, Saadi et al. (2019) used same approach of adding sheep milk into CM for the production of soft cheese and found the significant improvement in terms of yield and quality characteristics of end product. Moreover, ultrafiltration of CM before cheese making significantly improved the yield and sensory quality of soft white cheese (Mehaia, 2006). Cheese manufacturing from CM at industrial scale is still limited due to several reasons such as technological issues, hygienic quality of raw CM, methodological constraints and cost of camel cheese (Gioacchini et al., 2010; Konuspayeva et al., 2017).

Several study attempted have been made to produce soft cheese from CM by using various methodological interventions to improve the coagulation time and quality characteristics of CM cheese. It has been reported that soft cheese with superior quality attributes can be obtained by using 60% acetic acid for coagulation of CM (Mohamed et al., 2013). Recently, another study adopted the same approach and used 30% acetic acid as a coagulant to produce soft cheese from CM (Mbye et al., 2020). Results revealed that acetic acid coagulation induces the unpleasant odor and sour taste of final product. The study of Mehaia (1993) suggested that CM cheese produced without adding starter culture bacteria, resulted the poor sensory properties, higher pH and low yield with poor water holding capacity of final product. Conversely, it has been documented that using CM derived LAB (*Lactococcus lactis* and *Leuconostoc mesenteroides* ssp. *cremoris*) significantly improved the yield and quality attributes of CM soft cheese (Ahmed and Kanwal, 2004). On the other hand, the application of mixed type starter culture containing various strains of LAB showed the positive impact on physicochemical and organoleptic properties of CM cheese and yogurt (Abu-Tarboush, 1996). Based on published literature review, it has been concluded that use of various strategies including addition of milk other than camel source, using various types of stabilizers and organic acids, adding appropriate starter culture and optimization of processing condition are the most important scientific approaches to resolve the technological constraint regarding cheese manufacturing from CM.

Camel Milk (CM) Butter and Its Production Opportunities

Fig. 3 illustrates the butter production opportunities from CM however, the method of butter preparation from CM through the optimization of processing conditions are shown in Fig. 4. The butter preparation from CM can be achieved by vigorous shaking of soured or fresh CM at higher temperature (24℃–25℃), and can recovered approximately 80% of the milk-fat (Brezovečki et al., 2015). Furthermore, preparation of clarified butter (Ghee) from CM revealed the lower yield and shelf life. The physical parameters indicated that CM butter are prominantly whiter in color and more viscous and soft or spreadable consistancy than butter obtain from other animal species (Berhe et al., 2017; Brezovečki et al., 2015). Additionally, camel rearing communities produce small amount of butter by using traditional methods and they usually utilized it for therpeutic and cooking purpose (Asresie et al., 2013). Another approach to increase the fat content and neutalize the inharent functionality of CM through the mixing of milk other than camel such as cow, buffalo, sheep and goat, led to increase the fat recovery during butter production (Asresie et al., 2013; Berhe et al., 2017). Recently, it has been evaluated that the churning temperature, agitation force and ripening conditions have effects on the physical characteristics and fat recovery from CM. The result revealed that the optimum temperature required for CM butter production is 21℃ (Mtibaa et al., 2021). Based on the above evidences the processing of CM butter have little industrial future unless the discovery of new technologies, which are efficient and easy to use.

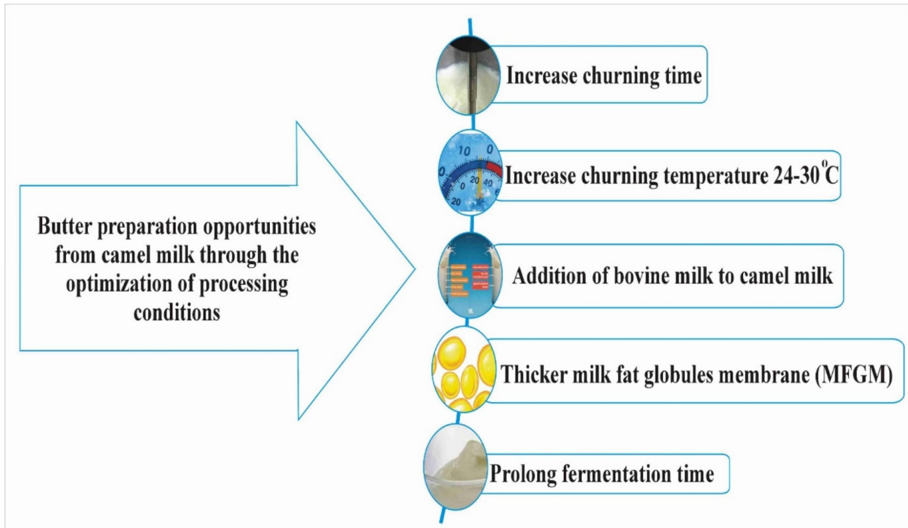

Fig. 3. Butter production opportunities from camel milk through the optimization of processing conditions.

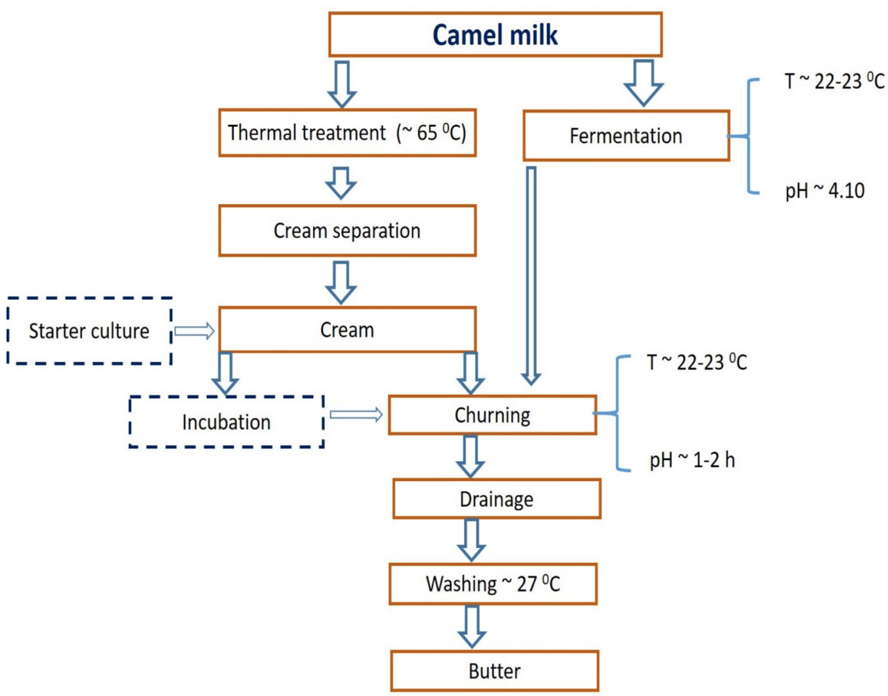

Fig. 4. Technological chain for butter preparation from camel milk.

Opportunities for the Preparation of Camel Milk (CM) Powder

The transformation of liquid milk into powder is the best way to preserve the CM, which was produced in remote areas far away from the consumption basin, where the transportation and preservation facilities are rare. Usually two modern processing technologies have been used for transformation of CM powder, for example freeze-drying (lyophilization) and hot-drying (spray-drying; Konuspayeva and Faye, 2021).

Currently, the study was conducted at laboratory scale to evaluate the thermal stability of CM powder and its constituents by using freeze-drying technology (Zhang et al., 2020). Results indicated that the obtained CM powder showed higher stability at 11.3% humidity. Similarly, another study was conducted to assess the effect of drying techniques (freeze-drying) on the nutritional quality of CM in comparison to the fresh milk. It was concluded that the drying technology positively maintained the relative nutritional quality and improved the stability of most milk constituents (such as vitamins and minerals; Ibrahim and Khalifa, 2015). Regarding the spray-drying technology few studies have been reported in literature. Interestingly, Sulieman et al. (2014) explored the comparative physical properties of camel and cow milk powder by using spay-drying technology. Results suggested that this method significantly improve the shelf life of CM powder by efficiently removing the water content from milk (approximately 98.2%). Recently, another study also demonstrated the effect of spray-drying technology on nutritional constituents of CM (including fatty acid profile and vitamin C) Habtegebriel et al. (2018). Results showed that the yield of milk powder are influenced by temperature, highest air intake, and lowest feed flows of the equipment, while high temperature and air intake significantly decrease the concentration of vitamin C in final product (Habtegebriel et al., 2018). Based on the above literature the spray-drying technology seems to be more suitable for production of CM powder, but the investment for the dairy industry is required to instal the costly milk roller drier and spray drier. Additionally, the spray-drying technology demands more energy for the production of milk powder. Therefore, for the establishment of camel dairy industry, it is the urgent need to improve the productive performance of camel and establish the large scale camel farms along with collection network between the farms.

Conclusion and Future Direction

CM and its dairy products are the prime source of food and income for the peoples living in extremely harsh environmental condition where the survival of cattle and other milk-producing species is rather difficult. In fact processing of camel dairy products is not possible through conventional methods traditionally used for other livestock species. However, processing of camel dairy products such as yogurt, cheese, butter, milk powder and pasteurized milk, is possible through the modification of conventional/traditional methods and also making some alteration in chemical composition of CM to reduce the inherent functionality and improve the organoleptic characteristics of final product. Even then the processing constraints for CM, studying and developing dairy products from CM has remained an interesting topic which has opened new research avenues for research consequently several dairy products have been investigated successfully. Further in-depth research is required to improve the nutritional and organoleptic quality of camel dairy products to compete their counterpart (other livestock species). Additionally, the development of new technologies and improvement of processing methods are required suitable for transformation of CM into different varities of dairy products such as low fat milk, skim milk and those with different flavors and products for special dietary or medical uses.

Conflicts of Interest

The authors declare no potential conflicts of interest.

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Ethics Approval

This article does not require IRB/IACUC approval because there are no human and animal participants.

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