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Review Article

Camel Milk Products: A Promising Sustainable Food Confronts Technological Challenges

^{1,2}Sally S. Sakr, ¹Reham M. Algheshairy, ¹Hend F. Alharbi, ¹Asmahan A. Ali, ³Woroud A. Alsanei, ¹Tahani A.O. Alharbi, ¹Safyah A. Aladel, ¹Faez A. Albaqami, ¹Raghad M. Alhomaid, ¹Essam M. Hamad and ²Hany Elkashef

¹Department of Food Science and Human Nutrition, College of Agriculture and Food, Qassim University, Buraydah 51452, Saudi Arabia

²Dairy Foods Department, Faculty of Agriculture, Cairo University, Giza 12613, Egypt

³Department of Food and Nutrition, Faculty of Human Sciences and Design, King Abdulaziz University, Jeddah 21589, Saudi Arabia

Abstract

Climate change challenges sustainable development, as it affects the availability of cattle feed, water and thermal comfort in the drylands, impacting food security. Thus, transitioning to livestock species other than bovine can enhance food security and help reduce emissions. In this regard, camels are considered one of the promising species that perform better under harsh climatic conditions. Dromedary camels (*Camelus dromedarius*) are considered one of the most important animals in rural economy in arid zones across the Middle East, East and North Africa, Central Asia and India because they are the main source of milk and meat products. In recent years, various dairy products derived from camel milk have gained popularity in the Gulf and European countries. Moreover, camel milk and its products have been recognized for their beneficial characteristics. They are considered a healthier alternative to bovine milk, especially for diabetics, digestion and gastrointestinal problems and bovine milk protein allergenicity. Consequently, the potential market for camel milk and its products could experience dramatic growth. The importance of camels and their products was reflected by the United Nations' Declaration of 2024 as the International Year of Camelids (IYC 2024). In the Kingdom of Saudi Arabia, camel milk products are gaining great attention and this was reflected by the Ministry of Culture's designation of 2024 as the year of camel. Unfortunately, dairy products made from camel milk still encounter significant technological challenges. The coagulation process of camel milk complicates the production of fermented milk products such as yogurt and cheese with the desired texture and structure. Current technological processes that apply to bovine milk may not yield satisfactory results when applied to camel milk. Based on the above, this review addresses the challenges of processing camel milk for various dairy products and recent endeavors to develop camel milk-based dairy products.

Key words: Sustainability, food security, agriculture climate change, camel milk, dairy products, cheese, yogurt

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Corresponding Author: Sally S. Sakr, Department of Food Science and Human Nutrition, College of Agriculture and Food, Qassim University, Buraydah 51452, Saudi Arabia Tel: +966 545727011

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INTRODUCTION

Camel milk has emerged as a promising protein source, offering a sustainable solution to the growing demand for high-nutritional dairy products. In 2020, the Food and Agriculture Organization (FAO) reported that the total numbers of camels were counted to be around 35 million and 492,853 heads in the world and in Saudi Arabia, respectively¹. In Saudi Arabia, the dromedary camel (*Camelus dromedarius*) is considered the most important source of meat and milk². Nowadays, dairy products from camel milk attract consumers not only in the Gulf but in European markets as well³. Camel milk has been acknowledged for its potential therapeutic properties, including anti-diabetic, antiallergic and more. The therapeutic effects of camel milk were well explained, especially for cow milk-allergic people and those who have problems with the gastrointestinal system⁴⁻⁶. Therefore, camel milk and its products may possess the potential for advancement in the dairy industry⁷. Thus, in 2024, the United Nations officially designated the International Year of Camelids⁸. In the same year, the Kingdom of Saudi Arabia declared it the Year of the Camel, focusing on investments in camel milk. This initiative presents opportunities to enhance production and transform traditional husbandry into profitable farming systems⁹. This dual recognition underscores the significance of camels in cultural, ecological and economic contexts.

Camels emerge as highly dependable milk producers, particularly during the seasonality of dry spells and droughts when milk sources from cattle, sheep and goats become scarce. In regions affected by prolonged drought, where cattle, sheep and goat populations are severely diminished, camels stand resilient, consistently providing milk. Thus, camels possess substantial socio-economic significance in global arid and semi-arid areas and their milk is an essential component of human dietary habits in these areas. The significance of camel milk extends beyond sustenance, playing a crucial role in ensuring food security and supporting the rural economy in arid zones across North and East Africa, the Middle East, Central Asia and the Indian subcontinent¹⁰. Both fresh and fermented camel milk have been employed in various regions worldwide, notably in Africa and the Middle East, for the treatment of food-related diseases¹¹.

Camel milk, both fresh and fermented, is an essential diet element in drylands around the world where camels are raised for many uses including food¹². Therefore, it is not only consumed as food but also as a remedy to reduce the increasing risk of chronic food-related diseases such as diabetes^{13,14}, cholesterol and heart diseases⁴. The composition

of camel milk is closer to human milk but differs from other animal milk because it contains a small amount of sugar and cholesterol while it consists of minerals in larger quantities, especially for magnesium, sodium, iron, potassium, zinc and copper^{15,16}. As a result, it has been regarded for centuries as the main source of nutrition in arid regions for nomadic and pastoral cultures. Recently, there has been increasing attention to camel milk as a food product and an alternative to cow's milk due to its highly nutritional and beneficial properties¹⁷. Moreover, camel milk contains reactive proteins that may potentially improve the immune defense mechanism. Additionally, the proteins in camel milk have antiviral and antibacterial properties.

Camel milk presents a promising alternative for individuals with milk protein allergies as it is less likely to trigger adverse reactions, is more easily digestible and has a higher nutritional value than conventional bovine milk^{12,18}. According to Khatoon and Najam¹⁹, the medicinal efficacy of camel milk is due to the presence of certain bioactive components that may be used to cure and prevent diseases. Some of the purported medical benefits of camel milk include its antihypertensive, anti-diabetic, anti-microbial, anti-carcinogenic, anticholesterolemic, anti-inflammatory, immunomodulatory, antioxidant, insulin-like and anti-apoptotic properties²⁰⁻²², as well as immune system booster properties²³. Moreover, bioactive peptides derived from camel milk either by enzymatic hydrolysis or fermentation have gained increasing interest in recent years, particularly for their potential anti-hypertensive and anti-diabetic properties. Research into the health-enhancing properties of these peptides, either directly from whole milk or different proteins such as whey or casein, has become an area of interest, as shown by many studies^{12,24,25}.

Despite its potential benefits, the commercial application of camel milk in dairy products faces significant challenges related to consumer acceptability and manufacturing processes¹¹. Camel milk takes a longer time to coagulate and its fermented products have weak and poor structure. The loss of β -lactoglobulin (β -lg), great size of casein micelles and the proportional distribution of casein fragments in camel milk are considered the main causes for this characteristic. In addition, camel milk has fat globules with small size and this property might be another cause for the weak texture of the fermented camel milk products.

To ensure the efficacy and consistency of the production of camel milk products, it is incumbent upon us to undertake further research and establish a standardized manufacturing protocol. Therefore, the main objective of the current review is to present the most suitable manufacturing trials applied to

improve the quality of dairy camel milk products. Modifying camel milk protein either by fortifying with dairy or non-dairy materials and adding trisodium citrate can be a good approach. Thus, those products can be a sustainable solution to poverty and hunger and beneficial for people with malnutrition, cow milk protein allergy and digestibility issues.

BACKGROUND AND MOTIVATION

There are about 10 species among the 2000 species of mammals that are used regularly for providing milk to humans and 7 of them are presented in Fig. 1. As shown in Fig. 2, 85% of the produced milk in the world is provided by cows^{2,26}. After that, the most important dairy animals are buffalo, goat, sheep and camel which produced 10.7, 2.4, 1.4 and 0.4%, respectively, of the global milk production. Although yak, horse, donkey, reindeer and lama are used for milk production, little research has been conducted on their potential for global production, as they are not widely utilized and, therefore, do not significantly contribute to global milk production figures^{10,27}. While cattle are kept in a broad range of environments, other dairy-producing species facilitate dairy farming in difficult environments that often cannot support any other type of agricultural activities. Buffaloes contribute to milk production in wet tropical regions, sheep in semi-arid areas adjacent to the Mediterranean, goats in African regions with poor soils, horses in Central Asia, yaks in the Tibetan Plateau and similar high mountainous regions and camels in arid lands.

Although the overall consumption of non-bovine milk represents a small fraction of the total milk consumption globally, non-bovine dairy species collectively contributed a significant amount of 110 million tons of milk in 2013¹, particularly in remote regions. The convention of having non-bovine milk dates Thousands of years ago where Arabian Peninsula, the Mediterranean District, several European and Asian countries, Mongolia, Northern China, Kazakhstan and the North of Russia and Europe Districts live on the consumption of sheep and goat milk, camel milk, mare milk and deer milk, respectively. Using non-bovine milk has become reserved for definite conventional milk products because of the prevalence of bovine farming and cows have become the main source of milk globally.

However, the growing awareness of the potential health benefits and superior quality of non-bovine milk sources has sparked interest in these alternatives. The traditional knowledge, combined with the rapid dissemination of information, highlights the critical role of non-bovine milk in enhancing food security²⁸. Hence, it is essential to emphasize the need to acknowledge and sustain the utilization of these valuable resources.

Camel milk: Camelinae (Old World Camelids) and Laminae (New World Camelids) are two primary subfamilies of the Camelidae family. Old world Camelids are composed of two domesticated types or species including the Dromedary or single-humped camel (*C. dromedarius*) and the Bactrian camel (*C. bacterianus*). Globally, these major Camelids are predominantly in different districts. The

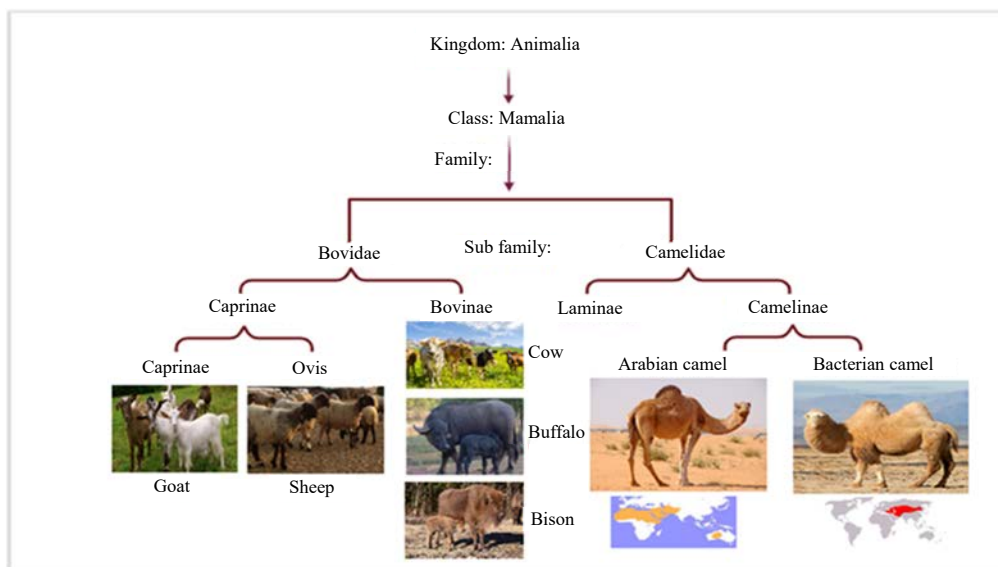


Fig. 1: Most species of mammals producing milk for human consumption



Fig. 2: Most Milk producers' species and global milk production between 1961 and 2022

Arabian camel (*C. dromedarius*) inhabits essentially warm regions of the Middle East and Africa, while *C. bactrianus* species are spreading in cold regions of Central China and Asia. Otherwise, new world Camelids compose four paramount species particularly located in South America and are commonly recognized as little or small Camelids. The vicuna (*V. vicugna*) and guanaco (*L. guanicoe*) are wild species, whilst the llama (*L. glama*) and alpaca (*V. pacos*) represent domestic species. Figure 3 shows the geographical distribution and the categorization of species of the Camelidae family²⁹.

Camel milk health benefits: Camel milk, latterly called “desert white gold”, is a key part of diets in arid regions where camels are raised. It has been recognized for its health benefits in Africa and Asia for over 5000 years. Recently, bioactive peptides from camel milk have attracted interest, particularly for their anti-hypertensive and anti-diabetic properties¹². Earlier, Al-Shamsi *et al.*²⁴ reported that the suitability of milk-derived peptides for technological and functional applications in food has been investigated. According to the studies of Redha *et al.*¹² on the health-promoting characteristics of bioactive peptides derived from whole camel's milk proteins, or specific proteins (such as whey or casein) became one of the research fields of interest.

Over the past decade, according to Al-Shamsi *et al.*²⁴ and Redha *et al.*¹², the production of bioactive peptides from camel milk (CM-BAPs) has begun to attract considerable interest from many researchers. The CM-BAP exhibits more pronounced bioactive properties compared to intact camel

milk protein. The CM-BAP can be produced by enzymatic hydrolysis or fermentation processes that form hydrolysates.

SUSTAINABILITY ASPECTS RELATED TO CAMEL MILK PRODUCTION

Climate change and food security: In recent decades, global climate patterns have undergone alterations and are projected to continue shifting, leading to phenomena such as global warming, intense precipitation and droughts in various regions worldwide. These transformations have notably affected the accessibility of livestock feed, water supplies and thermal comfort, particularly in numerous arid regions. Examination of historical climate data (1981-2010) and future forecasts (2021-2050 and 2071-2100) suggests that approximately 11-15% of current milk output in East Africa originates from areas where the likelihood of detrimental heat stress incidents is anticipated to escalate by 2071-2100. Consequently, environmental changes in cattle-dominated systems have impacted food security in drylands, undermining food production and accessibility and contributing to global food insecurity³⁰. Recently, the number of people who are suffering from food insecurity was estimated at about 380 million worldwide³¹.

Sustainable food systems: It was evidenced that changes in the food system and nutrition practices are needed to improve human health and contribute to the achievement of the Sustainable Development Goals (SDG)³². Nevertheless, dietary changes are considered a crucial factor that can help in the

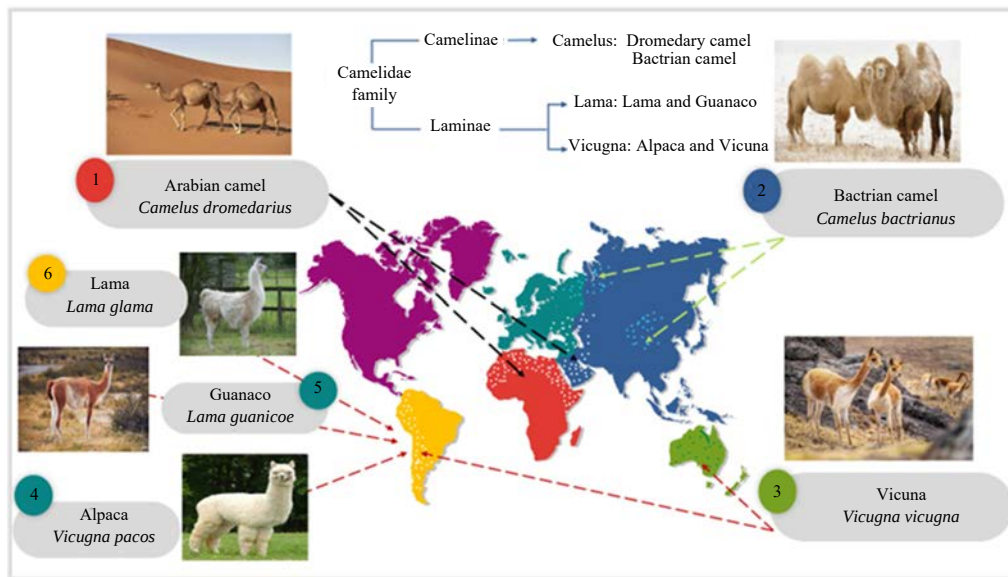


Fig. 3: Schematic classification and geographic distribution of members of the Camelidae family²⁹

implementation of sustainability in the food system³³. Taking into account all of the environmental assessments of food production, the food system is producing more than 30% of Greenhouse gas emissions (GHGE) globally³⁴. Therefore, there are calls for an urgent transformation to sustainability-related practices in food production and consumption. On the other hand, about 50% of GHGE from the production of food is due to livestock production³⁵. This is due to the huge amount of water and foods that are consumed by animals as well as its GHGE production. Furthermore, the term or notion of sustainable food products has grown and is known as “those food products that has low negative effects on the environment and participate in promoting food security, nutrition and enhance the healthy life for the current and future generations”. Sustainable food products are characterized by respecting and protecting the ecosystems and biodiversity, conventionally acceptable, attainable, rationally priced, safe, nutritionally adequate and valuable while promoting human and natural resources³⁶.

CAMEL MILK PRODUCTION AND ACHIEVEMENT OF SUSTAINABLE DEVELOPMENT GOALS

According to the report of Rahimi *et al.*³⁰, the demand for milk is increasing each year due to the growth of the human population and rising per capita consumption. As a result, it is anticipated that milk production will also increase, primarily from cattle. From an environmental point of view, this increased demand for milk will result in more wasting of water and land and more GHGE production.

Moreover, climate changes put more stress on cattle which will affect its milk production. They suggested that shifting milk production from cattle to goats and camels can reduce environmental impacts and ensure a stable supply. A model was used to examine the effects of transitioning from cattle to 100% camel milk production. Also, they noted a reduction in feed consumption, water consumption and GHGE by 40, 38 and 39%, respectively. This supports the shifting in milk production from cattle to camels as a way to lower the environmental impacts of milk production. Therefore, it is essential to promote scientific research on the benefits of camel milk in producing healthy milk products that can enhance human health. (Achieving the SDG 2: “Zero Hunger” and SDG 3: “Good Health and Well-Being”) and lowering the environmental impacts of milk production (achieving SDG 13: “Climate Action”).

TECHNOLOGICAL CHALLENGES CONFRONT CAMEL MILK PROCESSING

Camel milk is underutilized due to a lack of awareness and reluctance to convert it into dairy products. Although technical interventions have enabled the production of various camel milk products, no commercial camel milk cheese or yogurt is available. Poor heat stability, weak acid fermentation and the unsuitable traditional rennet coagulation methods used for bovine milk coagulation are the three main technological challenges that hinder the processing of camel milk into commercially acceptable dairy product forms³⁷.

	Goat	Sheep	Cow	Camel
Protein (%)				
Casein (%)	3.70	5.50	3.42	1.56
WP (%)	0.6	0.8	0.45	0.67
β -Ig	0.21 	0.59	0.41	-
Fat (%)	3.8	5.9	3.3	4.1
Fat particle size	  2.2-2.8 μ m	 2.8-4.9 μ m	 3.5-5.5 μ m	  2.3-2.9 μ m

Fig. 4: Differences in the main components of camel milk in comparison with milk from other species

POOR HEAT STABILITY OF CAMEL MILK

Research has demonstrated that camel milk exhibits lower heat stability compared to bovine milk when subjected to thermal treatment. This is largely attributed to the larger size of its casein micelles, a reduced concentration of κ -casein (5% in camel milk as opposed to 13.6% in bovine milk) and the absence of β -lactoglobulin (Fig. 4). Furthermore, the concentration of whey proteins in camel milk are higher than that in cow milk and these proteins display greater sensitivity to heat compared to casein. Collectively, these factors render camel milk more sensitive to heat treatment, resulting in processes such as denaturation, aggregation and precipitation. Such changes may negatively influence the organoleptic, nutritional and functional characteristics of the milk and its derivatives^{38,39}.

Moreover, the evidence shows that the pasteurization indicators for camel milk are significantly different from those for bovine milk. In bovine milk, the deactivation of Alkaline Phosphatase (ALP) serves as a key indicator; however, ALP is heat-resistant in camel milk and remains active at 90°C^{40,41}. Lorenzen *et al.*⁴² reported that glutamyl transpeptidase and leucine arylamides are considered efficacious indicators for camel milk pasteurization where they are heat sensitive to 75°C for 30 and 28 sec, respectively. Moreover, Konuspayeva and Faye⁴³ proposed utilizing γ -Glutamyl Transferase (GGT) as an indicator for heating of camel milk at 72°C for 20 min, while Tayefi-Nasrabadi *et al.*⁴⁴ stated that GGT stays active in pasteurized camel milk. In another study, lactoperoxidase (LPO) is considered a more appropriate indicator since it is more heat-sensitive in camel milk as compared to cow or buffalo milk.

PROBLEMS RELATED TO CAMEL MILK FERMENTATION

Fermentation of camel milk is a technique used for preservation and prolongation⁴⁵. Unfortunately, it is hard to make fermented milk products such as cheese and yogurt from camel milk because it does not curdle easily⁴⁶. Moreover, the decrease of pH in camel milk is slower than that of the other species, which is mostly due to the presence of higher levels of natural antimicrobials (such as lactoferrin and lysozyme) in camel milk during fermentation⁴⁷. Camel milk does not form an acceptable curd during the lactic acid fermentation process. The fermented camel milk showed a watery-like consistency with a fragile and poor structure. This behavior is probably more due to the bigger size of casein micelles, the casein fractions' relative distribution, the absence of β -Ig in camel milk, the small size of camel fat globules and the higher whey protein to casein ratio in camel milk than cow milk³. Therefore, it was not easy to ferment camel milk and the acidification rate of camel milk was lower than that of cow's milk⁴⁶. Since camel milk does not coagulate easily and its fermented products have a watery texture and a weak and brittle structure, it is hard to prepare fermented milk products such as yogurt and cheese from camel milk with an acceptable structure⁴⁸.

ATTEMPTS MADE TO PRODUCE FERMENTED CAMEL MILK PRODUCTS

The challenge in producing products from camel milk primarily stems from the distinctive structural and functional properties of its components. As a result, utilizing the same manufacturing processes as those used for dairy products

Table 1: Collection of the known traditional fermented camel milk products in different areas around the world¹⁸

Product name	Origin	Product characterization
In Asia continent		
Laban	Gulf countries	Laban, the fermented product is commercially produced from camel milk
Shubat	Kazakhstan	Fermented product made from raw camel milk and includes mixed lactic acid bacteria (LAB) and yeast fermentation
Chal	Turkmenistan	Made by inoculating raw camel milk with previously fermented milk through a back-slopping technique and incubating it at room temperature
Khormog	Mongolia	A traditional fermented mild alcoholic beverage made from raw camel milk
In Africa continent		
Gariss	Sudan	A traditional sour milk made through spontaneous fermentation of raw camel milk by placing it in a skin bag
Shubat	Kenya and Somalia	Made by spontaneous fermentation of camel milk by placing it in smoked wooden buckets for 1-3 days
Dhanaan	Ethiopia	A spontaneously fermented sour milk made by placing fresh camel milk in a clean/smoked container and keeping it in a warm place for about 1 day
Zrig	Mauritania	A well-known drink in the Saharan Region made from a mixture of milk, water and sugar

from bovine milk often leads to processing complications. Analysis of the composition has revealed that camel milk bears similarities to human milk, suggesting its potential in infant formulations as a substitute for relieving bovine milk allergy in children. Beside to nutritional value, camel milk is known as a worthy source of bioactive molecules that contribute to the therapeutic prospectives of this milk. On the other hand, information concerning the manufacturing technology and functional attributes of camel milk stays confined. Hence, a more holistic and comprehensive strategy is substantial to completely exploit its functional and technological possibilities. Further in-depth research is required to better understand the intricacies of camel milk and to unlock its complete utilization in various products⁴⁹.

A comprehensive analysis of the camel milk literature, presenting a synthesis of recent developments, processing limitations and opportunities for the development of new and improved camel milk products has been recently reported¹⁸. Regarding the traditional fermented camel milk products, they tabulated the known traditional fermented camel milk products in different areas around the world and an overview of this table (Table 1).

Hashim *et al.*⁵⁰ tried to produce camel milk-set yogurt using camel milk, cow milk, stabilizers of gelatin and Arabic gum utilizing a D-optimal design. The results showed that using camel milk at a ratio of 56%, cow milk at a ratio of 42 and 2% stabilizers led to producing a favorable hardness of set yogurt. The increase in the gelatin concentration led to a considerable increase in the consistency index, hardness, viscosity and a decrease in the syneresis of camel milk-set yogurt. They concluded that it could be possible to manufacture set yogurt from camel milk using a combination of camel milk and cow milk at a ratio of 1.3:1 and a mixture of stabilizers (1 or 1.5% gelatin: 1% Arabic gum).

Abou-Soliman *et al.*³ investigated the effect of microbial transglutaminase (MTGase) with or without the supplementation of skim milk powder (SMP), whey protein concentrate (WPC) or β -lactoglobulin (β -lg) on the different properties of camel milk-yogurt during storage at 5°C for 15 days. They found that the treatment with MTGase decreased significantly the fermentation time of camel milk supplemented with or without SMP. In addition, camel milk without MTGase flopped to convert into a set type of yogurt. Moreover, the treatment of un-supplemented camel milk with MTGase resulted in essential betterments in the viscosity and body of yogurt treatments. Regarding the gel microstructure, the supplementation of MTGase-treated camel milk exhibited positive effects on the protein matrix coherence, water-holding capacity and viscosity. The researcher concluded that the supplementation of camel milk with 0.4% MTGase along with the starter culture was as efficient approach to overcome the difficulties related to manufacturing set yogurt from camel milk.

In another study, Chen *et al.*⁷ reported that the fortification of camel milk with 0-30 mmol/L of trisodium citrate led to an increase in the water-holding capacity of MTGase-treated camel milk acid gels from 41.0 to 99.6%, firmness from 0.7 to 1.8 N and the final storage modulus from 11.9 to 72.5 Pa. At a level of 30 mmol/L of trisodium citrate, they observed a denser gel network matrix where this level was recognized as the optimal concentration. Also, the authors reported that the presence of trisodium citrate resulted in a significant reduction in the average diameter of casein particles from 183.5 to 37.4 nm and a significant increase in the degree of crosslinking of the acid gel from 19.3 to 38.9%. These changes facilitated the creation of camel milk gel with enhanced textural attributes. These results highlight the considerable potential for the production of acid-induced camel milk gel products.

Desouky⁵¹ examined the possibility improvement of the precise texture of camel milk-Rayeb via the incorporation of camel sweet curd. Camel sweet curd was conventionally prepared and mixed thoroughly at different levels of 0, 5, 10, 15, 50 or 25% with camel milk before manufacturing Rayeb milk. The results revealed that the addition of camel sweet curd led to decrease a in fermentation time, essentially at a high level ($\geq 15\%$). During the storage period, whey syneresis and pH values reduced significantly, while dynamic viscosity increased in all treatments. Microstructure assessment demonstrated the presence of coveted and regular protein matrix aggregates among different treatments. The researcher concluded that Rayeb camel milk might be manufactured successfully utilizing camel sweet curd achieving desirable quality characteristics and high sensory scores.

Jrad *et al.*⁵² compared the characteristics of camel milk yogurt achieved through a co-fermentation process involving either plant-based ingredients (carob powder) or autochthonous bacteria (*Enterococcus faecium* and *Streptococcus macedonicus*). They utilized an ultrafiltration process to concentrate the total solids in dromedary milk within the necessary range for yogurt preparation. They introduced carob powder or autochthonous bacteria at a 2% level into the ultrafiltered milk, followed by fermentation with *Lactobacillus bulgaricus* and *Streptococcus thermophilus*. The findings concluded that the ultrafiltration process effectively concentrated dromedary milk, rendering it suitable for yogurt production. The co-fermentation technique significantly enhanced the quality of dromedary yogurts. Specifically, co-fermentation with plant material (carob powder) exhibited a notable radical scavenging potential and improved texture characteristics. Meanwhile, camel milk yogurt co-fermented with autochthonous strains improved notably the lipid profile and aroma compounds. Furthermore, both yogurts, co-fermented with either plant or autochthonous strains, maintained high counts of lactic acid bacteria during cold storage, thereby meeting the criteria for a potent probiotic product. Bulca *et al.*⁵³ manufactured yogurt from camel milk utilizing microbial MTGase at levels of 3 and 6 U/g protein and with the addition of micellar casein, WPC, or sodium caseinate. The findings revealed that the most desirable microstructure was noted in the yogurt made with 6 U/g MTGase and 6.2% WPC. Also, using 6 U/g MTGase and micellar casein led to the manufacture yogurt with highly favorable sensory attributes. They concluded that the addition of MTGase mainly participated in the improvement of the sensory characteristics and gel structure of the camel milk yogurt. Earlier, the impact

of adding 25% oat beverage and date palm fruit to fermented camel milk on its nutritional characteristics was investigated by Algonaiman and Alharbi⁵⁴. The key findings from the study reveal a 2-7% increase in microbial activity when storing 100% camel milk at 4°C. Additionally, there was a noteworthy enhancement in total phenolic content and antioxidant activity, along with a slight rise in β -glucan levels. The increase in iron content can be attributed to this microbial activity. Notably, the oat beverage provides adequate protein while remaining low in fat, making it an excellent choice for individuals with high cholesterol. Sensory evaluations indicated that the mixture received higher ratings, while concentrations of the oat beverage above 50% tended to score lower. The researchers suggested that future studies should explore oat supplementation at levels of 25-50% and also consider experimenting with various date varieties or natural sweeteners.

CAMEL MILK CHEESE

Although camel milk can be processed into the cheese using camel chymosin and the addition of starter cultures for acidification, it is known for its poor coagulation properties and fragile and heterogeneous structure. Camel milk is still facing a challenge to convert into a cheese matrix with acceptable properties to consumers. This challenge is seriously attributed to the chymosin breakdown site of κ -casein of camel milk, which exist on the Phe97-Ile98 amino acids sequence site, whilst the cleavage site in bovine κ -casein is Phe105-Met106. In addition, the quantity of κ -CN in camel milk is proportionally small compared to bovine milk. Furthermore, camel milk is reported to be difficult to make cheese in part due to its low amount of κ -CN, low casein-to-whey protein ratio and larger casein micelles^{7,55}. Thus, making cheese from camel milk is possible but more difficult than making cheese from other dairy animals and there are a few producers who have successfully created pure cheese from camel milk⁵⁶.

Previous studies have been focused on using mesophilic cultures, cooking temperatures or bovine chymosin to manufacture soft unmaturing cheese. Production of cheese from camel milk will preserve its nutritional and bioactive components during maturation⁵⁷. Consequently, the main challenge for the dairy industry is producing cheese from camel milk with a suitable rigid coagulum⁵⁸. Various studies conducted on cheese production from camel milk are displayed in Table 2.

Table 2: Studies on cheese production from camel milk

Main findings	References
Camel milk cheese can be successfully made using chicken gizzard layer extract as a substitute for rennet	Sboui <i>et al.</i> ⁶⁵
The best coagulation happens at a temperature of 45 °C and an acidic pH, leading to a significant increase in cheese yield, rising from 18.12 to 26.38%	
The optimal chymosin concentration for camel cheese making is 1.7 mL/L of milk with a yield of 16.74 g/100 mL high sensory properties and acceptable microbiological quality	Benkerroum <i>et al.</i> ⁶⁶
Fortifying camel's milk with sheep's milk improves cheese processing properties, yield and acceptability, with 75 and 50% sheep's milk additions yielding the most acceptable cheeses	Derar and El Zubeir ⁶⁷
Optimizing the production process of soft cheese from camel milk using a linear programming technique that can produce acceptable quality and a yield of 14.57%	Habtegebriel and Admassu ⁶⁸
Mixing raw camel and cow milk improves the microbiological and sensory quality of white cheese with preference for those prepared with lactic acid bacteria	Suliman <i>et al.</i> ⁶⁹
A mixture of camel milk and cow milk (1:1) can produce acceptable quality white cheese (Jibna-Beida) with higher protein, fat and mineral contents	Siddig <i>et al.</i> ⁷⁰
Increasing levels of camel chymosin in coagulant blends resulted in less protein breakdown and a more solid-like viscoelastic structure in Iranian ultrafiltered white cheese	Soltani <i>et al.</i> ⁷¹
Dry-salted soft camel cheese (SCC-D) and brine-salted soft camel cheese (SCC-B) have a comparable cheese yield and whey dry matter loss compared to bovine cheese made from bovine milk standardized to simulate camel milk	Konuspayeva <i>et al.</i> ⁷²
Using medium-level chymosin concentration (70 IMCU/L) and cooking camel milk curd at 55 °C are suitable approaches for making soft unripened cheese from camel milk	Walle <i>et al.</i> ⁷³
Blending bovine and camel milk improves the rheological properties and microstructure of low-fat Akawi cheese, resulting in higher moisture, calcium and soluble calcium contents and higher pH compared to those made from bovine milk alone	Abdalla <i>et al.</i> ⁷⁴
Standardizing camel milk to 0.90 casein/fat ratio leads to high cheese yield and low mineral and solids losses in whey, improving cheese quality	Baig <i>et al.</i> ⁷⁵
Camel milk cheese has lower hardness and rheological properties than bovine milk cheeses with a higher coagulation rate and better sensory quality	Mbye <i>et al.</i> ⁷⁶

Table 3: Plant coagulants for camel milk cheese processing

Plant source	Main findings	References
Ginger	Ginger crude extract (GCE) can coagulate camel milk, resulting in a soft unripened cheese with high acidity and ash but low fat, total solids and protein compared to cheese made using camel chymosin	Fguiri <i>et al.</i> ⁶²
Withania	Pure Withania extract has a low coagulating effect, leading to low yield, hardness, fat, protein and total solids in camel and bovine milk cheeses, while a mixture of both extracts and chymosin provides optimal cheese quality	Mbye <i>et al.</i> ⁶⁴
<i>Capparis decidua</i>	<i>Capparis decidua</i> fruit extract at 5% can be used as a coagulant for camel milk with good yield and acceptable shelf life (5 weeks)	Ishag and El Zubeir ⁷⁷
Kiwi	Kiwi proteases show the best potential for use as a milk coagulant in cheese production, with pineapple, kiwi and ginger extracts also showing promising results	Fguiri <i>et al.</i> ⁷⁸
Moringa leaves	Low-fat herbal cheeses with 20% moringa leaves extract showed the highest yellowness, while full cream milk produces fresh cheeses with high total solid and brightness	Setyawardani <i>et al.</i> ⁷⁹

PLANT COAGULANTS FOR CAMEL CHEESE PRODUCTION

The utilization of recombinant enzymes are faced with restricted approval in different countries because of religious persuasions and diet limitations. The increasing request for cheese consumption globally, high costs and reduced supply of calf rennet production have stimulated a developing interest in using of plant-based curdling enzymes as replacers for conventional rennet in cheese manufacturing. Moreover, various rennet replacers have appeared because of religious concerns and those related to some vegan consumers^{59,60}. Recently, various milk-coagulum enzymes extracted from different plants are utilized in cheese manufacturing. Several trials have been conducted to compare the effects of plant enzymes with those obtained by calf rennet on the textural, microstructural and sensory properties of cheese. However, plant-coagulum enzymes are still used partially for cheese

manufacturing because of their strong proteolytic ability that leads to form a bitter flavor⁵⁸. Plant proteolytic enzymes have been classified into groups depending on the hydrolysis action or mechanism, serine, cysteine and aspartate proteases⁶¹. Various studies carried out on plant-coagulum enzymes such as *Zingiber officinale* enzyme extracts⁶², cysteine enzymes isolated from *Ficus carica*⁶³ and aspartic enzymes isolated from *Withania coagulans*⁶⁴ and they have utilized these enzymes to produce cheese from camel milk and the obtained cheese was acceptable. Also, an experiment was carried out to assess the coagulum ability of partially purified *Moringa oleifera* extract on camel milk and determine the optimum temperature, pH and level of partially purified extract that could lead to a firm curd of camel milk. In this respect, various plant-coagulants were investigated for their capacity to precipitate camel milk proteins and these coagulants are presented in Table 3.

CONCLUSION

Climate change poses considerable challenges to sustainable development, affecting the availability of cattle feed, water and thermal comfort in arid regions, which in turn impacts food security. Conversion to livestock species other than cattle can enhance food security and help reduce emissions. Camel milk is particularly promising, as it performs well under harsh climatic conditions. However, there are technological challenges associated with processing camel milk into various dairy products. Therefore, future research should focus on optimizing and standardizing the manufacturing processes for camel milk products in acceptable and commercially viable forms. This could contribute to food security as a sustainable food source in the future.

SIGNIFICANCE STATEMENT

This review article was planned to cover the challenges of camel milk manufacturing and its convert to different dairy products and outline various novel attempts to develop camel milk-based dairy products. Camel milk is considered one of the promising milk types that perform nutritional and bioactive components under tough climate conditions. Compared to bovine milk, camel milk processing possessed some technological obstacles and there are several studies explored the approaches that affect and enhance the properties of camel milk, developing some dairy products. However, future scientific works should be carried out to optimize and standardize the manufacturing processes and find novel strategies to easy making camel milk products with acceptable and marketing available types. Thus, this might participate in achieving food sustainability goals.

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REFERENCES

1. Faye, B., 2020. How many large camelids in the world? A synthetic analysis of the world camel demographic changes. *Pastoralism: Res, Policy. Pract*, Vol. 10. 10.1186/s13570-020-00176-z.
2. El-Hanafy, A.A., Y.M. Saad, S.A. Alkarim, H.A. Almehdar and F.M. Alzahrani *et al*, 2023. Yield and composition variations of the milk from different camel breeds in Saudi Arabia. *Sci*, Vol. 5. 10.3390/sci5010002.
3. Abou-Soliman, N.H., S.S. Sakr and S. Awad, 2017. Physico-chemical, microstructural and rheological properties of camel-milk yogurt as enhanced by microbial transglutaminase. *J. Food Sci. Technol.*, 54: 1616-1627.
4. Kaskous, S., 2016. Importance of camel milk for human health. *Emir. J. Food Agric.*, 28: 158-163.
5. Mudgil, P., H. Kamal, G.C. Yuen and S. Maqsood, 2018. Characterization and identification of novel antidiabetic and anti-obesity peptides from camel milk protein hydrolysates. *Food Chem.*, 259: 46-54.
6. Mbye, M., B. Sobti, M.K. Al Nuami, Y. Al Shamsi and L. Al Khateri *et al*, 2020. Physicochemical properties, sensory quality, and coagulation behavior of camel *versus* bovine milk soft unripened cheeses. *NFS J.*, 20: 28-36.
7. Chen, C., P. Wang, N. Zhang, W. Zhang and F. Ren, 2019. Improving the textural properties of camel milk acid gel by treatment with trisodium citrate and transglutaminase. *LWT*, 103: 53-59.
8. Abu-Seida, A.M., M.H. Hassan, A. Abdulkarim and E.A. Hassan, 2024. Recent progress in camel research. *Open Vet. J.*, 14: 2877-2882.
9. Abdullah, H.M. and A. Sheikh, 2024. History of a dairy camel (NAQA) and machine milking in Saudi Arabia; challenges and prospective. *Trop. Anim. Health Prod.*, Vol. 56. 10.1007/s11250-024-04211-8.
10. Faye, B. and G. Konuspayeva, 2012. The sustainability challenge to the dairy sector-The growing importance of non-cattle milk production worldwide. *Int. Dairy J.*, 24: 50-56.
11. Abou-Soliman, N.H.I., S. Awad and M.I. El-Sayed, 2020. The impact of microbial transglutaminase on the quality and antioxidant activity of camel-milk soft cheese. *Food Nutr. Sci.*, 11: 153-171.
12. Redha, A.A., H. Valizadenia, S.A. Siddiqui and S. Maqsood, 2022. A state-of-art review on camel milk proteins as an emerging source of bioactive peptides with diverse nutraceutical properties. *Food Chem.*, Vol. 373. 10.1016/j.foodchem.2021.131444.
13. Khalid, N., D.N. Abdelrahim, N. Hanach, R. AlKurd and M. Khan *et al*, 2023. Effect of camel milk on lipid profile among patients with diabetes: A systematic review, meta-analysis, and meta-regression of randomized controlled trials. *BMC Complementary Med. Ther.*, Vol. 23. 10.1186/s12906-023-04257-5.
14. Sboui, A., C. Atig, A. Khabir, M. Hammadi and T. Khorchani, 2022. Camel milk used as an adjuvant therapy to treat type 2 diabetic patients: Effects on blood glucose, HbA1c, cholesterol, and TG levels. *J. Chem.*, Vol. 2022. 10.1155/2022/5860162.
15. Yadav, A.K., R. Kumar, L. Priyadarshini and J. Singh, 2015. Composition and medicinal properties of camel milk: A review. *Asian J. Dairy Food Res.*, 34: 83-91.
16. Abdel Gader, A.G.M. and A.A. Alhaider, 2016. The unique medicinal properties of camel products: A review of the scientific evidence. *J. Taibah Univ. Med. Sci.*, 11: 98-103.

17. Zhang, B.Y., S. Xu, J.A. Villalobos-Santeli and J.Y. Huang, 2020. Fouling characterization of camel milk with comparison to bovine milk. *J. Food Eng.*, Vol. 285. 10.1016/j.jfoodeng.2020.110085.
18. Seifu, E., 2023. Camel milk products: Innovations, limitations and opportunities. *Food Prod. Process Nutr.*, Vol. 5. 10.1186/s43014-023-00130-7.
19. Khatoon, H. and R. Najam, 2017. Bioactive Components in Camel Milk: Their Nutritive Value and Therapeutic Application. In: *Nutrients in Dairy and Their Implications for Health and Disease*, Watson, R.R., R.J. Collier and V.R. Preedy (Eds.), Academic Press, Cambridge, Massachusetts, ISBN: 9780128097625, pp: 377-387.
20. Mihic, T., D. Rainkie, K.J. Wilby and S.A. Pawluk, 2016. The therapeutic effects of camel milk: A systematic review of animal and human trials. *J. Evidence-Based Complementary Altern. Med.*, 21: NP110-NP126.
21. Swelum, A.A., M.T. El-Saadony, M. Abdo, R.A. Ombarak and E.O.S. Hussein *et al.*, 2021. Nutritional, antimicrobial and medicinal properties of camel's milk: A review. *Saudi J. Biol. Sci.*, 28: 3126-3136.
22. Muthukumaran, M.S., P. Mudgil, W.N. Baba, M.A. Ayoub and S. Maqsood, 2023. A comprehensive review on health benefits, nutritional composition and processed products of camel milk. *Food Rev. Int.*, 39: 3080-3116.
23. Kumar, A., A. Kaur and V. Tomer, 2020. Process optimization for the development of a synbiotic beverage based on lactic acid fermentation of nutriceals and milk-based beverage. *LWT*, Vol. 131. 10.1016/j.lwt.2020.109774.
24. Al-Shamsi, K.A., P. Mudgil, H.M. Hassan and S. Maqsood, 2018. Camel milk protein hydrolysates with improved technofunctional properties and enhanced antioxidant potential in *in vitro* and in food model systems. *J. Dairy Sci.*, 101: 47-60.
25. Al-Nassir, N.S.M. and S.S. Sakr, 2024. *In vitro* digestibility assessment of whey from goat and camel milk fermented with *Lactobacillus helveticus* for use as a base in formulating follow-on formula. *Foods*, Vol. 13. 10.3390/foods13040570.
26. Numpaque, M., T. Şanlı and E.A. Anli, 2019. Diversity of milks other than cow, sheep, goat and buffalo: In terms of nutrition and technological use. *Turk. J. Agric. Food Sci. Technol.*, 7: 2047-2053.
27. Morin, D.E., L.L. Rowan and W.L. Hurley, 1995. Comparative study of proteins, peroxidase activity and *N*-acetyl- β -D-glucosaminidase activity in llama milk. *Small Ruminant Res.*, 17: 255-261.
28. Bekhit, A.E.D.A., I.A.M. Ahmed and F.Y. Al-Juhaimi, 2022. Non-bovine milk: Sources and future prospects. *Foods*, Vol. 11. 10.3390/foods11131967.
29. Hoter, A., S. Rizk and H.Y. Naim, 2019. Cellular and molecular adaptation of Arabian camel to heat stress. *Front. Genet.*, Vol. 10. 10.3389/fgene.2019.00588.
30. Rahimi, J., E. Fillol, J.Y. Mutua, G. Cinardi and T.P. Robinson *et al.*, 2022. A shift from cattle to camel and goat farming can sustain milk production with lower inputs and emissions in North Sub-Saharan Africa's drylands. *Nat. Food*, 3: 523-531.
31. Wudil, A.H., M. Usman, J. Rosak-Szyrocka, L. Pilař and M. Boye, 2022. Reversing years for global food security: A review of the food security situation in Sub-Saharan Africa (SSA). *Int. J. Environ. Res. Public Health*, Vol. 19. 10.3390/ijerph192214836.
32. Willett, W., J. Rockström, B. Loken, M. Springmann and T. Lang *et al.*, 2019. Food in the anthropocene: The EAT-Lancet commission on healthy diets from sustainable food systems. *Lancet*, 393: 447-492.
33. Clark, M.A., M. Springmann, J. Hill and D. Tilman, 2019. Multiple health and environmental impacts of foods. *Proc. Natl. Acad. Sci. U.S.A.*, 116: 23357-23362.
34. Crippa, M., E. Solazzo, D. Guizzardi, F. Monforti-Ferrario, F.N. Tubiello and A. Leip, 2021. Food systems are responsible for a third of global anthropogenic GHG emissions. *Nat. Food*, 2: 198-209.
35. Xu, X., P. Sharma, S. Shu, T.S. Lin and P. Ciais *et al.*, 2021. Global greenhouse gas emissions from animal-based foods are twice those of plant-based foods. *Nat. Food*, 2: 724-732.
36. Kishore, A., B. Pal and P. Sarkar, 2024. Camelids for sustainability: A socio-economic perspective. *Asian J. Environ. Ecol.*, 23: 53-72.
37. Arain, M.A., H.M. Salman, M. Ali, G.B. Khaskheli, G.S. Barham, I.B. Marghazani and S. Ahmed, 2024. A review on camel milk composition, techno-functional properties and processing constraints. *Food Sci. Anim. Resour.*, 44: 739-757.
38. Hassan, R.A., I.E.M. El Zubeir and S.A. Babiker, 2007. Effect of pasteurization of raw camel milk and storage temperature on the chemical composition of fermented camel milk. *Int. J. Dairy Sci.*, 2: 166-171.
39. Al Haj, O.A. and H.A. Al Kanhal, 2010. Compositional, technological and nutritional aspects of dromedary camel milk. *Int. Dairy J.*, 20: 811-821.
40. Elagamy, E.I., 2000. Effect of heat treatment on camel milk proteins with respect to antimicrobial factors: A comparison with cows' and buffalo milk proteins. *Food Chem.*, 68: 227-232.
41. Rankin, S.A., A. Christiansen, W. Lee, D.S. Banavara and A. Lopez-Hernandez, 2010. *Invited review*: The application of alkaline phosphatase assays for the validation of milk product pasteurization. *J. Dairy Sci.*, 93: 5538-5551.
42. Lorenzen, P.C., R. Wernery, B. Johnson, S. Jose and U. Wernery, 2011. Evaluation of indigenous enzyme activities in raw and pasteurised camel milk. *Small Ruminant Res.*, 97: 79-82.

43. Konuspayeva, G. and B. Faye, 2021. Recent advances in camel milk processing. *Animals*, Vol. 11. 10.3390/ani11041045.
44. Tayefi-Nasrabadi, H., M.A. Hoseinpour-Fayzi and M. Mohasseli, 2011. Effect of heat treatment on lactoperoxidase activity in camel milk: A comparison with bovine lactoperoxidase. *Small Ruminant Res.*, 99: 187-190.
45. Abd El-Aziz, M., J.M. Kassem, F.M. Aasem and H.M. Abbas, 2022. Physicochemical properties and health benefits of camel milk and its applications in dairy products: A review. *Egypt. J. Chem.*, 65: 101-118.
46. Brezovečki, A., M. Čagalj, Z.F. Dermić, N. Mikulec, D.B. Ljoljić and N. Antunac, 2015. Camel milk and milk products. *Mljekarstvo*, 62: 81-90.
47. Ayyash, M., A. Abdalla, B. Abu-Jdayil, T. Huppertz and R. Bhaskaracharya *et al.*, 2022. Rheological properties of fermented milk from heated and high pressure-treated camel milk and bovine milk. *LWT*, Vol. 156. 10.1016/j.lwt.2021.113029.
48. Patel, D., S. Pinto and M. Pal, 2022. A comprehensive review on the properties of camel milk and milk products. *Int. J. Food Sci. Agric.*, 6: 200-207.
49. Berhe, T., E. Seifu, R. Ipsen, M.Y. Kurtu and E.B. Hansen, 2017. Processing challenges and opportunities of camel dairy products. *Int. J. Food Sci.*, Vol. 2017. 10.1155/2017/9061757.
50. Hashim, I.B., A.H. Khalil and H. Habib, 2009. Quality and acceptability of a set-type yogurt made from camel milk. *J. Dairy Sci.*, 92: 857-862.
51. Desouky, M.M., 2020. Improving the texture properties of camels' milk. *Egypt. J. Food Sci.*, 48: 89-99.
52. Jrad, Z., O. Oussaief, S. Zaidi, T. Khorchani and H. El-Hatmi, 2021. Co-fermentation process strongly affect the nutritional, texture, syneresis, fatty acids and aromatic compounds of dromedary UF-yogurt. *J. Food Sci. Technol.*, 58: 1727-1739.
53. Bulca, S., F. Umut and A. Koç, 2022. The influence of microbial transglutaminase on camel milk yogurt. *LWT*, Vol. 160. 10.1016/j.lwt.2022.113339.
54. Algonaiman, R. and H.F. Alharbi, 2023. Development of fermented camel milk incorporating oats and Sukkari date palm fruit: Nutritional, physicochemical, functional, and organoleptic attributes. *Fermentation*, Vol. 9. 10.3390/fermentation9100864.
55. Hailu, Y., E.B. Hansen, E. Seifu, M. Eshetu and M.A. Petersen *et al.*, 2018. Rheological and sensory properties and aroma compounds formed during ripening of soft brined cheese made from camel milk. *Int. Dairy J.*, 81: 122-130.
56. Bekele, B., 2022. Innovative Approach of Cheese Making from Camel Milk: A Review. In: *Current Issues and Advances in the Dairy Industry*, Ibrahim, S.A. and M.R. Bronze (Eds.), IntechOpen, London, United Kingdom, ISBN: 978-1-83768-093-1.
57. Baig, D., L. Sabikhi, Y. Khetra and P.A. Shelke, 2022. Technological challenges in production of camel milk cheese and ways to overcome them-A review. *Int. Dairy J.*, Vol. 129. 10.1016/j.idairyj.2022.105344.
58. Bathmanathan, R., Y.A.C. Yahya, M.M. Yusoff and J. Vejayan, 2019. Utilizing coagulant plants in the development of functional dairy foods and beverages: A mini review. *J. Biol. Sci.*, 19: 259-271.
59. Nicosia, F.D., I. Puglisi, A. Pino, A. Baglieri and R. La Cava *et al.*, 2022. An easy and cheap kiwi-based preparation as vegetable milk coagulant: Preliminary study at the laboratory scale. *Foods*, Vol. 11. 10.3390/foods11152255.
60. Shah, M.A., S.A. Mir and M.A. Paray, 2014. Plant proteases as milk-clotting enzymes in cheesemaking: A review. *Dairy Sci. Technol.*, 94: 5-16.
61. Hailu, Y., E. Seifu and Z. Yilma, 2014. Physicochemical properties and consumer acceptability of soft unripened cheese made from camel milk using crude extract of ginger (*Zingiber officinale*) as coagulant. *Afr. J. Food Sci.*, 8: 87-91.
62. Fguiri, I., M. Atigui, A. Sboui, A. Samira and C. Marzougui *et al.*, 2021. Camel milk-clotting using plant extracts as a substitute to commercial rennet. *J. Chem.*, Vol. 2021. 10.1155/2021/6680246.
63. Aider, M., 2021. Potential applications of ficin in the production of traditional cheeses and protein hydrolysates. *JDS Commun.*, 2: 233-237.
64. Mbye, M., H. Mohamed, Abdul Raziq and A. Kamal-Eldin, 2021. The effects of camel chymosin and *Withania coagulans* extract on camel and bovine milk cheeses. *Sci. Rep.*, Vol. 11. 10.1038/s41598-021-92797-6.
65. Sboui, A., I. Fguiri, A. Omrani, A. Rahali, M. Dbara and T. Khorchani, 2025. Production and characterization of camel milk cheese made using chicken gizzard inner lining extract as coagulant. *Processes*, Vol. 13. 10.3390/pr13020519.
66. Benkerroum, N., M. Dehhaoui, A. El Fayq and R. Tlaiha, 2011. The effect of concentration of chymosin on the yield and sensory properties of camel cheese and on its microbiological quality. *Int. J. Dairy Technol.*, 64: 232-239.
67. Derar, A.W.M.A. and I.E.M. El Zubeir, 2016. Effect of fortifying camel milk with sheep milk on the processing properties, chemical composition and acceptability of cheeses. *J. Food Sci. Eng.*, 6: 215-226.
68. Habtegebriel, H. and S. Admassu, 2016. Optimization of the production process of soft cheese from camel milk using linear programming technique. *Food Sci. Qual. Manage.*, 49: 35-41.
69. Sulieman, A.M.E., S.M. Siddig and Z.A. Salih, 2016. Microbiological characteristics and sensory evaluation of white cheese produced by using camel milk and mixture of camel and cow milk. *J. Microbiol. Res.*, 6: 8-13.

70. Siddig, S.M., A.M.E. Sulieman, Z.A. Salih and A.A. Abdelmuhsin, 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.
71. Soltani, N., H. Qiu, M. Aleksic, Y. Glinka and F. Zhao *et al.*, 2011. GABA exerts protective and regenerative effects on islet beta cells and reverses diabetes. *Proc. Natl. Acad. Sci. USA.*, 108: 11692-11697.
72. Konuspayeva, G., B. Camier, N. Aleilawi, M. Al-Shumeimyri and K. Al-Hammad *et al.*, 2017. Manufacture of dry- and brine-salted soft camel cheeses for the camel dairy industry. *Int. J. Dairy Technol.*, 70: 92-101.
73. Walle, T., M. Yusuf, R. Ipsen, Y. Hailu and M. Eshetu, 2017. Coagulation and preparation of soft unripened cheese from camel milk using camel chymosin. *East Afr. J. Sci.*, 11: 99-106.
74. Abdalla, A., B. Abu-Jdayil, S. AlMadhani, F. Hamed, A. Kamal-Eldin, T. Huppertz and M. Ayyash, 2022. Low-fat akawi cheese made from bovine-camel milk blends: Rheological properties and microstructural characteristics. *J. Dairy Sci.*, 105: 4843-4856.
75. Baig, D., L. Sabikhi, Y. Khetra and D. Kumar, 2022. Effect of casein to fat ratio of camel milk on solids losses in cheese whey and their recovery in camel milk cheese. *Int. Dairy J.*, Vol. 124. 10.1016/j.idairyj.2021.105185.
76. Mbye, M., M. Ayyash, B. Abu-Jdayil and A. Kamal-Eldin, 2022. The texture of camel milk cheese: Effects of milk composition, coagulants, and processing conditions. *Front. Nutr.*, Vol. 9. 10.3389/fnut.2022.868320.
77. Ishag, H.I.J. and I.E.M. El Zubeir, 2022. Processing and some physico-chemical properties of white cheese made from camel milk using *Capparis decidua* fruits extract as a coagulant. *J. Nutr. Food Process.*, Vol. 5. 10.31579/2637-8914/096.
78. Fguiri, I., A. Sboui, M. Atigui, S. Arroum and N. Ayeb *et al.*, 2023. Camel milk curd properties: Application of a kiwi juice as a coagulant. *Asian J. Dairy Food Res.*, 42: 14-19.
79. Setyawardani, T., J. Sumarmono and H. Dwiyantri, 2022. Preliminary investigation on the processability of low-fat herbal cheese manufactured with the addition of moringa, *Bidara*, and bay leaves extracts. *IOP Conf. Ser.: Earth Environ. Sci.*, Vol. 1012. 10.1088/1755-1315/1012/1/012081.