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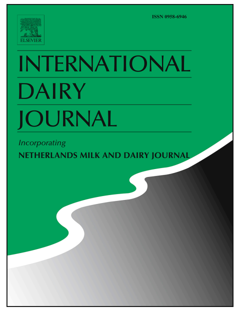

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ABSTRACT

Functional foods derived from milk are essential for human health, including fermented milk, dairy beverages, cheeses, and dairy sweets. The nutritional composition of different milk sources varies, impacting the qualities of resultant functional foods. Goat milk has health-promoting compounds, including calcium, medium-chain fatty acids, and α-casein. Sheep milk has significant amounts of vitamins A, C, thiamine, and folic acid. Buffalo milk is regarded as a nearly complete food item in the human diet and provides greater levels of α- and κ-casein relative to bovine milk. Mare and donkey milk is rich in carbohydrates and proteins, with low-fat contents, making it a suitable dietary option. Camel milk is rich in calcium, potassium, vitamin A, and the absence of β-lactoglobulin, a major allergy compared with bovine milk. This review highlights the nutritional properties of non-bovine milk sources, which could be potentially used in the dairy industry similar to that of bovine milk.

Contents

1. Introduction

Functional foods have considerably gained interest in the human diet around the globe. Those obtained from bovine and non-bovine milk products, including fermented milk, cheese, dairy beverages, and dairy sweets, are essential for human nutrition, such as fatty acids or amino acids. Milk and dairy products have been excellent sources of nutritious and energetic food and have contributed to human consumption for centuries. Several published articles recently state that over six billion people consume milk and its products, most of whom are in developing countries (Priyanka, Sheoran, & Ganguly, 2017; Visioli & Strata, 2014). Milk covers a considerable part of offspring's nutritional and physiological needs since its products are reservoirs of helpful bacteria called prebiotics, which contribute to gut health (Aljutaily et al., 2020; Dimitrellou et al., 2019). The majority of milk produced, sold, and consumed globally comes from cows, making it the principal milk (Deshwal, Tiwari, & Kadyan, 2021).

Although bovine milk is high in carbohydrates, lipids, proteins, water, vitamins, and minerals, recent concerns about climate change, floods, and cattle disease treatments have prompted a search for non-bovine milk to diversify global demand. Thus, milk obtained from non-bovines such as goats, sheep, buffalo, mares, and camel are great candidates for alternative, resilient milk options (Ranadheera, Naumovski, & Ajlouni, 2018). The production of non-bovine milk is limited and primarily known in Asia and Africa. It has been reported that about 150 million people produce non-bovine milk and significantly contribute to family revenue sources while providing a solid option for food security in these regions (Tsakalidou & Papadimitriou, 2016). A recent report indicated that non-bovine milk production had reached 133 million tons per year, which covers more than 17% of the total production (Ranadheera et al., 2019). The increased rate of milk production of small mammalian groups is evidence of the availability and market demand for non-bovine milk. For instance, an investigation from the years 2000 to 2019 showed a rapid increase in milk from these minor mammalian species, mainly goat (48.91%), sheep (46.31%), and camel (70.87%), when compared with cow milk (Popescu, Marcuta, Marcuta, & Tindeche, 2021). The milk and its products from these animals are remarkably similar to cow milk functional, nutritional, chemical composition, and physiological properties (Deshwal et al., 2021).

Goat milk and its products are most appreciated due to its easy digestibility, higher nutritional properties such as casein (83%, w/w), fat (3.5%, w/w), protein (3.3%, w/w), and less allergenicity linked to the inferior amount of β- lactoglobulin and α_{S1}-casein compared with bovine milk (Kiełczewska, Ambroziak, Krzykowska, & Aljewicz, 2021). In addition, goat milk contains a short chain of fatty acids (66.9%, w/w), which contribute to treating some physio-pathology disorders (Kiełczewska et al., 2021).

The primary goal of sheep farming in developing countries is not economic gain but rather the security of a living. In developing nations, milking sheep is still a relatively new, yet formulations made from sheep milk will be crucial in promoting human health in the new era of functional foods. The demand for sheep milk for the production of its various fermented and non-fermented products like cheese, yoghurt, sweet milk, and ice cream is in constant growth owing to its nutritional value, biological activities, and chemical content like proteins (5.6%, w/w), fat (6.4%, w/w), higher contents of vitamins, and minerals (0.9%, w/w) compared with bovine milk (Balthazar et al., 2017b).

Moreover, the global production and consumption of buffalo milk and products are undeniably well-known in India, Pakistan, Egypt, China, and Nepal. They are increasing in other parts of the globe (Arora & Khetra, 2017). Buffalo milk and its products offer various nutritional, medicinal, and therapeutic properties since they are a source of proteins (4.7%, w/w), fat (6.7%, w/w), folate (60 μg L^{-1}), calcium (205 mg 100 mL^{-1}) content compared with cow milk (Abesinghe et al., 2020). Many artisanal fermented dairy products from buffalo milk contain an essential reservoir of probiotics, providing health benefits to consumers. These products are predominantly distributed in different forms and names in Southeast and Central Asian countries (Kondybayev, Loiseau, Achir, Mestres, & Konuspayeva, 2021).

Although mare milk and its products have limited commercial and industrial perspectives, they have gained an essential reputation in some Asian and African countries where they have been used for thousands of years due to their use in folk medicine to treat numerous physiological diseases and anti-fatigue effect (Hsu et al., 2021; Navrátilová, Borkovcová, Kaniová, Dluhošová, & Zachovalová, 2020). In addition, the use and consumption of mare milk and its derived products in human nutrition in some European countries have recently proven their therapeutic and functional properties. It has been reported that 30 million people globally commonly consume mare milk and products (Karav, Salcedo, Frese, & Barile, 2018; Pieszka et al., 2016). The production per volume of mare milk and its chemical composition are lower than other ruminants (Kaskous & Pfaffl, 2022). However, it contains numerous vitamins such as A (0.06 mg L^{-1}) and E (0.08 mg L^{-1}), minerals, proteins, caseins, less fat, a high amount of lactose and whey proteins, and a significant number of lysozymes (Kaskous & Pfaffl, 2022; Navrátilová et al., 2020). Donkey milk has long been known for its medicinal characteristics, and it has been used to treat wounds and ailments such as bronchitis, asthma, joint discomfort, and gastritis (Martini, Altomonte, Licitra, & Salari, 2018). It is now accessible as a commercial product to aid babies, persons with cows' milk protein allergies, and the elderly (Karami & Akbari-Adergani, 2019).

Among non-bovine milk sources, camel milk constitutes an essential source of milk for the people living in the regions where camels are reared (Muthukumaran, Mudgil, Baba, Ayoub, & Maqsood, 2022). Recent studies on camel milk and its products indicated several biological and functional properties, including anti-cancerous, anti-diabetic, cholesterol-lowering, ACE-inhibitory, and hypo-allergenic activities (Gammoh et al., 2020; Muthukumaran et al., 2022; Redha, Valizadenia, Siddiqui, & Maqsood, 2022). Camel milk and its fermented products have been widely consumed by African, Middle East, and Southwest Asian people. Camel milk and its products have recently shown increased attention in Western countries because of their high nutritional value and biological, functional, and therapeutic properties (Aqib et al., 2019; Khatoon & Najam, 2017). Camel milk possesses proteins (2.55%, w/w), fat (2.72%, w/w), minerals (0.87%, w/w), vitamins such as A (0.1 mg L^{-1}), E (0.56 mg L^{-1}), and C (37.4 mg L^{-1}), and lower content of β-casein and β-lactoglobulin free (Galali & Al-Dmoor, 2019; Kaskous & Pfaffl, 2017).

Overall, there is a need to promote other minor milk-producing animals as an alternative source of milk for bovine milk. The main target of this review is to elucidate the nutritional composition, bioactivities, and functional properties of selected non-bovine-based milk and its products.

2. Goat milk

2.1. Overview of quantity and production

The early report estimated the goat population to increase by around 69% in 1991–2014, with total milk production of about 80% in 1991–2013 (Popescu et al., 2021). Among the producing countries of goat milk, only precise data on the total production of goat milk was obtained from the Middle East (Syria, Lebanon, and Jordan), accounting for 3.1 million goats generating 161 thousand tons of milk, and Europe (Greece) estimated at six million goats producing 680 thousand tons of milk have been documented (Kondyli, Katsiari, &

Voutsinas, 2007). Nowadays, due to advanced analytical tools and controlled manufacturing processes, goat milk is characterised by its various components. It is considered high-quality milk in preparing infant milk-based food and some population segments with particular needs and as a substitution for cow milk (Haenlein, 2004; Park, Haenlein, & Wendorff, 2006; Prosser, 2021).

2.2. Physical and chemical composition

The physical parameters such as moisture contents, titratable acidity, pH, total soluble solids, and specific gravity determination are crucial in food-borne pathogens prevention and preservation (Table 1). The analysis of goat milk indicated a moisture content of 86.23–90.23% (w/w), pH value of 5.05–6.72, titratable acidity (0.12–0.15), total soluble solid of 12.7–12.97% (w/w), and a specific gravity of 1.63–1.83 mPa S (Mayer & Fiechter, 2012; Roman, Vojtech, Sarka, & Kvetoslava, 2015). A comparative study on some physical properties of goat, ewe, and cow milk showed a lower titratable acidity and pH in goat milk than in ewe milk. In contrast, the total solid of goat milk was found to be greater than that of cow milk (Sağdıç, Dönmez, & Demirci, 2004).

The density of goat milk at 15 °C is 1.027 to 1.040 and expresses a pH of 6.5 to 6.7. Specific heat was observed, which is 0.93, and the freezing point of goat milk was regarded as –0.55 °C. Other sources define goat's milk as a liquid that contains between 77% and 80% water and 20–23% total solids. The total solids typically have 3–3.5% (w/w) fat with 3–3.5% w/w protein and 4–6% (w/w) carbohydrates like lactose and vital minerals like calcium (Salvador-Morales et al., 2006). Egyptian goats' milk has a viscosity of 0.002 Pa s (Hadjichambis et al., 2008) and 0.001 Pa s for Indian goat milk, compared with 0.001 Pa s for cow milk. Goat milk has a slightly lower natural acidity of 0.16% than cow milk (0.17–

0.18%). Compared with cow milk, goat milk has less alcoholic stability, precipitated by the addition of 44% ethanol, while 70% for cow milk. It has a slightly higher freezing point than cow milk, –0.543 °C, while –0.564 °C for cow milk. However, specific gravity was 1.0263–1.0335 compared with 0.1320 for cow milk (Mahmood & Usman, 2010). According to Mayer & Fiechter (2012), mean values obtained for all goat breeds in Austria for the entire season were followed by pH 6.55 and –0.549 °C freezing point dip sheep and goat milk lipids with different physicochemical properties than cow milk (Jooyandeh & Aberoumand, 2010).

2.3. Nutritional properties

Goat milk contains less total casein (2.5%, w/w) but more significant non-protein nitrogen than the cow counterpart (Table 2). In goat milk, α_{S2}-casein (α_{S2}-CN), κ-casein (κ-CN), β-lactoglobulin (β-Lg), β-casein (β-CN), and α-lactalbumin (α-La) are the principal proteins present. The main casein portion in goat milk is β-casein, while the main casein fraction in cow milk is α_{S1}-casein (Park, 2010). Goat milk fat varies in concentration between breeds, ranging from 2.45 to 7.76% (w/w). This research found the average fat globule diameters for cow, buffalo, and sheep milk as 4.55, 5.92, and 3.30 µm, respectively, whereas that for goat milk is 3.49 µm (Haenlein & Caccese, 1984). Although more minor levels of inositol have been found in goat milk, lactose is the most abundant free carbohydrate discovered in goat milk. Lactose concentration found in goats' milk is typically between 0.2 and 0.5% lower than in milk from cows.

When compared with human milk, the concentration of Mg and Ca were generally higher, K and Na were comparable, while the concentration of Fe, Cu, and Zn was lower (Bilandžić et al., 2014). Zinc, magnesium, and potassium were present in the most significant amounts in goat milk, with values of 0.69, 7.3, and 183.60 mg 100 mL^{-1}, correspondingly

(Table 3). Moreover, goat milk has the most significant levels of K and Mn compared with sheep and cow milk (Park, 2000).

Goat milk has enough vitamin A and niacin, providing infants with excesses of thiamine, pantothenate, and riboflavin (Table 4). It is important to remember that both goat (1.5 mg 100 mL^{-1}) and cows' milk (2.1 mg 100 mL^{-1}) are similarly low in vitamin C; due to this, it is necessary to complement the diet with additional nutritional sources of these vitamins. The amount of folic acid in goat milk is only 20% as much as in cow milk. It is also reported that the folic acid bioavailability in goat milk is lesser than in cow or human milk; therefore, to avoid anaemia in infants, goat milk should be supplemented with folic acid for infants (Ahmed, Elahi, Salariya, & Rashid, 2014).

2.4. Potential products

Several milk products have been formulated using goat milk in the Middle Eastern and European regions (Albenzio et al., 2006). Among these products with various names according to the localities, including fresh milk, soft cheese, semi-soft cheese, yoghurt, fermented milk, sweetened milk, ice cream, pasteurised milk, and milk powder have been developed based on traditional and novel techniques (El Balaa & Marie, 2008; Sert & Mercan, 2022). Goat cheese has a higher percentage of protein (16.01–17.45%, w/w) and fat (24–25.5%, w/w) compared with goat milk, ice cream and yoghurt, as shown in Table 1. Cheese with various types is arguably the most dominant product obtained from goat milk owing to its sensorial and nutritional value (Kondyli, Pappa, & Svarnas, 2016). Goat cheese whey contains oligosaccharide, which is used to assess the fermentation potential probiotics. For instance, Oliveira et al. (2012) evaluated in-vitro digestion using batch culture at 37 °C with human excrement under anaerobic conditions. The study showed that goat milk whey stimulated the growth of gut microbiota, which impacted human health. Oligosaccharides in goat milk showed a preventive effect in premature infant intestines against *Candida albican* damage and invasion (Gonia et al., 2015). The bio-accessible fragment of peptides liberated via in vitro gastrointestinal digestion of fermented goat milk showed a dialysable fraction of peptides with antioxidant α_{S1}-casein, antihypertensive α_{S2}-casein, antibacterial α_{S2}-casein, and ACE inhibitory activity (Moreno-Montoro et al., 2018).

According to Park, Juárez, Ramos, and Haenlein (2007), the poor consistency of curd created during goat milk coagulation is advantageous for human digestion but reduces cheese output. This comportment is further persuaded by inorganic phosphorus and calcium in goat milk, poorer solvation, and inferior heat stability with more effortless casein loss in cow milk (Al-Saadi, Shaker, & Ustunol, 2014). Moschopoulou et al. (2018) investigated the syneresis of yoghurts made from semi-skimmed sheep, cow, and goat milk. According to their findings, the yoghurt manufactured with goat milk has maximum water retention capacity because fat globule membrane material increases yoghurt gels. Furthermore, goat milk is an excellent platform for developing comprehensive and unique health-promoting functional food products such as incorporating prebiotics or probiotic bacteria (Silanikove, Leitner, Merin, & Prosser, 2010).

3. Sheep milk

3.1. Overview of quantity and production

In 2020, world production of whole fresh sheep milk was estimated at 10.62 million tons. Since selling and consuming sheep milk in liquid form is rare (Tamime, Wszolek, Božanić, & Özer, 2011), various dairy products, including yoghurt, ayran, butter, ice cream, kefir, cheese, and sheep milk powder, are made from this type of milk. Several studies focusing on the compositional characteristics of mammalian milk have shown that sheep milk has the best composition and could be used as a relevant alternative to human breast milk (Mohapatra, Shinde, & Singh, 2019). Since milk is secreted to ensure the nutrition and protection of the newborn, beyond its known nutritional aspects, it contains various bioactive ingredients that induce health benefits. Owing to its content of bioactive components, sheep milk is considered one of the most critical functional food products in the world (Mohapatra et al., 2019).

3.2. Physical and chemical composition

The physical characteristics of sheep milk are given in Table 5. Sheep milk is distinguished from other milk by its physical characteristics. The sheep milk density (1.03) is higher than camel milk (1.02). According to Wendorff and Haenlein (2017), sheep milk has a better viscosity, refractive index, titratable acidity, and lower freezing point than cow and goat milk. The superior viscosity of sheep milk can also be attributed to a significant water-holding capacity through hydrogen bonding in the milk proteins. The average freezing point of sheep milk is about –0.57 °C. Previous studies demonstrated that a freezing point of –27 °C is necessary to preserve the protein stability of sheep milk for up to 12 months in a storage (Balthazar et al., 2017a).

3.3. Nutritional properties

Sheep milk provides 5.7% (w/w) protein, 115.7 Kcal L^{-1}, 7% (w/w) fat, and 4.7% (w/w) lactose, as shown in Tables 2 and 5 (Fantuz, Salimei, & Papademas, 2016). In addition to significant amounts of total solids (protein and fat) and many other nutrients in sheep milk, sheep milk provides a more substantial percentage of these primary nutrients than goat and cow milk. Compared with cow milk (2.8%, w/w), sheep milk contains a greater concentration of casein (4.4%, w/w) and bigger casein micelle size, affecting its renneting characteristics and coagulation time. When the divalent (higher valence) ions are bound by casein, which is a chelator of those minerals, the resulting mineral concentration is more significant in sheep milk than in cow, camel, and goat milk due to the high content of casein in sheep milk (Silanikove, Leitner, & Merin, 2016). Sheep milk has the most significant number of caseins (CNs) in it (76–83% of total proteins), and they are also found in most cheeses made from sheep milk. Four kinds of polypeptide chains (α_{S1}-CN, β-CN, α_{S2}-CN, and κ-CN) are included in the term "casein." About 17–22% of the total proteins found in sheep milk are whey proteins, including β-lactoglobulin (β-Lg) and α-lactalbumin (α-La). Low quantities of serum albumin, immunoglobulins, and protease-peptones are existent (Ramos & Juarez, 2003). Both sheep and goat milk contain a significant concentration of fat globules that are smaller than cow milk; the globule diameters of sheep and goat milk average out to be 3.6 and 3.0μm respectively, while cow milk has globule diameters average 4.0μm (Balthazar et al., 2017a; Gantner, Mijić, Baban, Škrtić, & Turalija, 2015). Milk from sheep and cows has approximately the same amount of lactose. Thus, lactose in sheep milk is 22% of the total solids, unlike cow milk, where lactose is 33% of the entire solids (Ramos & Juarez, 2003).

Sheep milk contains around 0.9% (w/w) minerals. Calcium (181.7 mg 100 mL^{-1}) and phosphorus are critical to nutritional purposes and their role in maintaining the stability of casein micelles and, consequently, in the behaviour of the caseins throughout milk processing. Trace components, such as zinc (0.58 mg 100 mL^{-1}) and iron (0.08 mg 100 mL^{-1}), are the most plentiful (Table 3). Sheep milk has more significant amounts of most vitamins, as shown in Table 4 (except vitamin D and biotin, which are lower, and folic acid, which is equivalent to cow milk). Riboflavin (0.38 mg 100 mL^{-1}) levels in sheep milk are higher than in other animal milk, including cow, goat, and buffalo milk (Balthazar et al., 2017a). Retinol (146 IU) is the only form of vitamin A in sheep's milk since all the dietary β-carotene is transformed into this form. Vitamin E has three formats (β-, α-, and γ-tocopherols). However, α-tocopherol is the most common form (Balthazar et al., 2017a).

3.4. Potential products

Due to its higher total solid content (18%, w/w), sheep milk is more suitable for producing yoghurt and cheese than other milk (Barłowska, Szwajkowska, Litwińczuk, & Król, 2011; Mohapatra et al., 2019). These two dairy products, from sheep milk, are the most popular. Cheese is the leading dairy product in the sheep milk processing (Pirisi, Comunian, Urgeghe, & Scintu, 2011). For instance, approximately 95% of the annual sheep milk production in the United States is processed into cheese (Milani & Wendorff, 2011). In 2016, the world production of sheep milk cheese was approximately 0.7 million tons against 0.06 million tons of butter and ghee (Mohapatra et al., 2019), for about 10 million tons of milk produced in the same year. The high yield could explain this due to sheep milk's higher solid content, particularly proteins and fats. Sheep milk would be preferred because it is more profitable for cheese production than other milk. In the Mediterranean basin, with 66% of the world’s sheep milk production, most sheep milk cheese fabrication is protected by the EC regulation (Pandya & Ghodke, 2007; Pirisi et al., 2011). The milk from ewes and its dairy products, including probiotics, prebiotics, and symbiotics, have unique properties. Yoghurt is the most famous dairy product in the world. It is usually made from sheep milk without adding milk powder or stabilisers (Milani & Wendorff, 2011). Sultan, Huma, Butt, and Shahid (2017), reported that sheep milk yoghurt displayed higher antioxidant activity than buffalo, cow, and goat milk yoghurt. Compared with cow, goat, and buffalo milk yoghurts, sheep milk yoghurt has less syneresis and high gel strength (Wendorff & Haenlein, 2017). Due to its high-fat content, one would expect a significant amount of butter and fat-based milk products made from sheep's milk. According to the literature, most of the butter and milk fat-based products (dhan, yayik, nehre butter, and ghee, etc.) made from sheep milk are still derived from traditional processes.

Sheep milk ice cream is one of the most attractive and popular functional foods for consumers worldwide (Bahram-Parvar, 2015). Prebiotics (inulin or fructooligosaccharide) substituting sheep milk fat to produce sheep milk ice cream showed high consistency, hardness, and viscoelasticity. Yet, it was also creamier and brighter than whole sheep milk ice cream (Balthazar et al., 2017c). Various flavour compounds of dairy products, especially those with high-fat content, are derived from milk fatty acids. Overall, appropriate measures must be taken to avoid lipase activity, which can significantly affect the sensory characteristics of dairy goods.

4. Buffalo milk

4.1. Overview of quantity and production

Buffalo milk is the world's second most popular milk after cow milk, accounting for more than 12% of global milk production. India produces approximately 70% of whole buffalo milk. In the recent decade, global milk output has increased, with buffalo milk production coming in second after bovine milk (El-Salam, Mohamed, & El-Shibiny, 2011). Buffaloes provide about half of the milk processed by organised dairies in India (Han et al., 2007). The swamp buffalo has long been viewed as a working animal, particularly in China and other Far Eastern rice-growing countries (Ahmad, Anjum, Huma, Sameen, & Zahoor, 2013).

4.2. Physical and chemical composition

The moisture (83.2–87%, w/w), total solids (10–16.5%, w/w), specific gravity (1.03–1.07), pH (6.75), ash (0.72–0.81%, w/w), and titratable acidity (0.13–0.9) of buffalo milk is presented in Table 6. The viscosity (0.003–0.004 Pa s) and total solid of buffalo milk are greater than cow milk (Imran, Khan, Hassan, & Khan, 2008). Baloch et al. (2019) conducted a study on buffalo milk; specific gravity, total solids, pH, acidity, and conductivity were higher than in camel milk. In their research, Ahmed et al. (2014), observed that the physical and chemical properties of yoghurt obtained from buffalo milk significantly changed after fermentation due to the enhanced activity of starter culture with time, which increased its nutritional properties and made it more easily digestible.

4.3. Nutritional properties

Buffalo milk provides protein (4.7–3.57%, w/w), fat (6.7–7.5%, w/w), lactose (4.4–4.86 g L^{-1}), and 114.9 Kcal L^{-1}, as indicated in Tables 2 and 6 (Fantuz et al., 2016). Buffalo milk had greater levels of κ-casein and α_{S2}-CN relative to cow milk. The buffalo milk whey protein concentration was comparable with cow milk, β-LG makes up most of the whey protein content. Therefore, β-LG is the main protein (>50% of total whey) (El-Salam et al., 2011). These studies discovered that buffalo milk has more giant fat globules (FG) (5μm) in contrast to other ruminants (Zotos & Bampidis, 2014). In buffalo milk, the average FG size (measured using the microscopic technique) was 4.07 μm, which was more significant than the average size in cow, goat, and sheep milk, which is 3.16, 2.57, and 3.02 μm, respectively. Generally, buffalo comprises two distinct proteins: whey proteins (WP) and caseins (CN). α_{S1}-CN, β-CN, α_{S2}-CN, and κ-CN are the primary constituents of caseins, and these molecules are known to have genetic polymorphisms and posttranslational modifications, such as glycosylation and phosphorylation. β-Lactoglobulin (β-Lg) and α-lactalbumin (α-La) are the two main whey proteins, which also have genetic variations. Also included in the whey fraction are large quantities of blood serum albumin (BSA) and immunoglobulins as well as smaller amounts of still significant lactoferrin, proteins, and lactoperoxidase, which are commercially accessible (Pandya & Haenlein, 2009). Whey proteins, including β-Lg, which include sulphur amino acid content that seems to bind mutagenic heterocyclic amines with carcinogenic attributes, are protective in animal models against cancer development when given orally (Sousa et al., 2012). The buffalo casein peptide fraction showed antimicrobial properties towards *Escherichia coli* NCDC134, *Bacillus cereus*, and *Kluveromyces* (Pandya & Haenlein, 2009).

Several tests were completed on the anti-mould activity of buffalo and cow lactoferrin (LF). They were tested against four mould strains (*Aspergillus niger, Penicillium roquefortii, Rhizopus oryzae, and P. camemberti*). The lowest inhibitory concentrations for buffalo and cow LF were 25–75 and 25–125 μg mL^{-1}, respectively (Pandya & Haenlein, 2009). This study examined the antifungal properties of buffalo LF against five different strains of yeast (*Kluveromyces marxianus* NCDC39, *Rhodotorula glutinis* NCDC 51, *Saccharomyces cerevisiae* NCDC 47, and *Candida guillermondi* NCDC44). Buffalo LF was shown to have the tiniest effective inhibitory concentration of 25 to 250μg mL^{-1}. In contrast to yeast cultures, *Rhodotorula glutinis* NCDC 51 was most sensitive to buffalo LF, *Asp. niger* NCDC 267 was the most sensitive mould to buffalo and cow LF, and mould maturation was suppressed (Pandya & Haenlein, 2009). Overall, buffalo caseins, lactoferrin, and whey proteins have the potential for antibacterial, anti-mould, and anti-fungal activity.

As identified in many studies, buffalo milk has a high concentration of calcium (Table 3), which is 1.5 times that of cow milk. In contrast, Argentine buffalo milk had a calcium level similar to cow milk (Ménard et al., 2010; Pinares-Patiño et al., 2007). The presence of fifteen elements (Zn, Mn, Co, Fe, Cr, Cu, Sn, Pb, B, Cd, Br, Se, Ni, As, and Rb) in buffalo milk has been reported in different studies (El-Salam et al., 2011; Garau, Manis, Scano, & Caboni, 2021). However, Fe, Zn, and Cu contents of buffalo milk have expected particular attention, while the other trace components were described in a few studies (El-Salam et al., 2011). However, only vitamin A was found in buffalo milk (Table 4). Because of physiological and environmental variables and the sensitivity of the measurement techniques, the published data on the vitamin A (35.5–117.6 mg L^{-1}) concentration in buffalo milk varies.

4.4. Potential products

Buffalo milk is a suitable raw material for manufacturing traditional and modern buffalo dairy products. Buffalo milk is more valuable in nutritious elements than cow milk, making it preferable in many Asia food cultures (Patil, Khedkar, Chavan, & Patil, 2016). Various buffalo products have been produced and consumed in many countries, especially South-East Asia. Since ancient times, these dairies have been made by fermentation to extend their shelf life, enriching them with valuable microorganisms and adding value to the perishable milk (Abesinghe et al., 2020). For example, different types of cheese (domiati, mozzarella, queso blanco, Cheddar), acid-coagulated (paneer), clarified butter fat (butter and ghee), creamy yoghurt, sour yoghurt (dadih), and sweetened milk are widely produced in India, Sri Lanka, and Philippines (Arnold, Rajagukguk, & Gramza-Michałowska, 2021;

Malik & Sheenam, 2015; Pandey et al., 2019). Buffalo milk is mainly used in the manufacture of several varieties of cheese. Modern fermentation processes using a starter culture and suitable technologies have been developed to add value to buffalo milk. Buffalo cheese (22.43%, w/w protein and 29.75%, w/w, fat) and paneer (19.68–20.34%, w/w, protein and 23.7–24.3%, w/w, fat) contain higher amounts of protein and fat than buffalo milk and yoghurt (Table 6).

Probiotic buffalo milk-based beverages, probiotic buffalo yoghurt, and probiotic buffalo curd are commercially available (Abesinghe et al., 2020). The worldwide buffalo milk production is estimated to be 127.34 million tons annually. The global production of buffalo milk is more abundant in Asia (98.1%), followed by Africa (1.7%) and Europe (0.2%); India is the biggest producer. The bio-accessibility of some compounds in milk is crucial to maintaining human health and preventing the onset of some chronic pathologies. Buffalo milk is rich in bioactive molecules, including bioactive peptides, antioxidant compounds, and minerals that play a tremendous role in the human body after drinking a bottle of an immense role in the human body after drinking milk (Basilicata et al., 2018). Bioactive peptides are well-known molecules implied in many physiological functions, namely in gastrointestinal, cardiovascular, immune, and endocrine (Zenezini Chiozzi et al., 2016). Basilicata et al. (2018) demonstrated the bioavailability of biopeptides after in vitro simulated gastrointestinal digestion of buffalo milk; their results showed various potential bioactive peptides that inhibit some chronic disease activities.

Roy, Hussain, Prasad, and Khetra (2021) investigated the quality attributes (flavour, body and texture, colour, and appearance) of buffalo milk ice cream enriched with high protein; the findings revealed that the panellist most liked the sample with 80% proteins. A comparative study of raw and pasteurised cow and buffalo milk conducted by Khan et al. (2017) showed that panellists appreciated the colour and flavour of buffalo milk compared with cow milk. The paneer prepared from buffalo milk using different coagulants had a significant appearance (from soft to hard) and similar white colour properties (Dongare & Syed, 2018). An organoleptic assessment, including smell, colour, taste (acidity), and texture of buffalo, cow, and goat yoghurt prepared using different starter culture cultures conducted by Ahmed et al. (2014) revealed that buffalo yoghurt scored the best results compared with cow and goat yoghurt.

5. Equid milk

5.1. Mare milk

5.1.1. Overview of quantity and production

Mare milk was recently studied as an alternative to cow milk and allergic control formulas for youngsters in Italy. Mare milk cures various human diseases, including hepatitis, chronic ulcers, and tuberculosis. This concept of mare milk's medicinal benefit and hypoallergenic to humans is likely based on the fact that horse milk configuration is frequently thought to be similar to human milk (Svahn, Feldl, Räihä, Koletzko, & Axelsson, 2002). Early use of mare milk in Central Asian countries has been observed, and the use of milk recognised it as a dairy animal (Salimei & Park, 2017). Due to its high nutritional value, it has been used to substitute cow milk for children who are allergic.

5.1.2. Physical and chemical composition

The evaluation of moisture contents (97.8–98.8%, w/w), total solid (9.47%, w/w), and titratable acidity (0.4–0.76) of mare’s milk and products have demonstrated their importance in milk storage, shelf life, acceptance, and physicochemical and nutritional properties (Table

7). Arabian mare milk was assigned an electrical conductivity of 3.56 mS cm^{-1}, a viscosity of 2.83 mPa s, and a freezing point of –0.55 °C (Hachana, Nasraoui, Frija, & Fortina, 2022). Mare milk has been reported to have low electrical conductivity, viscosity, and titratable acidity. On the other hand, the density, osmotic pressure, specific gravity, and freezing point remain the same. Teichert et al. (2021) investigated some physical properties of the mare milk Polish cold blood breed. The authors indicated that mare milk had a freezing point of – 0.55 °C and a viscosity of 3.05 mPa s, higher than the Arabian mare milk.

5.1.3. Nutritional properties

Human and mare's milk are equivalent in crude protein and lactose. Compared with cow milk (3.7%, w/w), mare milk has a fat content of 1.21% (w/w), while the human milk content is 3.64% (w/w) (Jastrzębska, Wadas, Daszkiewicz, & Pietrzak-Fiećko, 2017). In contrast to the other fat, which has more triglycerides, this fat has fewer triglycerides. However, it is more potent in free fatty acids (FFAs) and phospholipids. Based on Sheng and Fang (2009), mare milk has primarily medium-chain fatty acids, while human milk has more long-chain fatty acids. On the other hand, cow milk has a higher concentration of short-chain fatty acids. Mare milk has more than 20% more whey protein than cow milk, reaching about 40%, while human milk has the most whey protein at 52%. Caseins are present in the most significant quantity in cow's milk. Mare milk represents a good source of nutrition for humans than cow milk because of its high amount of whey protein and exogenous amino acids (Pieszka et al., 2016).

There are significant variations in the mineral composition of cow, mare, and human milk: many of these minerals are more excellent in mare milk than in human milk, but considerably lower than in cow milk (Table 3). According to Claeys et al. (2014), cow milk has approximately 50% more calcium and almost twice as much phosphorus and potassium as mare milk, while horse milk contains about two times as much calcium and phosphorus as human milk. Calcium consumption in human and mare milk is more beneficial when compared with cow milk, according to the calcium: phosphorus ratio. All the kinds of milk studied had low levels of microelements.

Several variables, such as the relative concentration of other milk components, may influence the bioavailability of milk minerals. Furthermore, lactation and feeding routines are essential aspects of a mare content of vitamins and other features (Claeys et al., 2014). Milk from mare has many vitamins and minerals, including vitamins A, K_2, C, D_3, B_2, B_3, E, B_1, B_6, and B_{12}. It is also known to include nicotinic, pantothenic, and folic acids. Except for vitamin C, the number of other vitamins found in milk from cows and mares is not vastly different (Table 4) (Salamon, Salamon, Csapó-Kiss, & Csapó, 2009). Compared with cow milk, the vitamin content in mare milk is considerably higher. This nutritional value is attributed to the vitamin's ability to resist oxidation and its anti-inflammatory effects. By 1.5 months after foaling, mare milk has 17.2 mg L^{-1} vitamin C content, then decreases to 12.87 mg L^{-1} (Claeys et al., 2014). A comparable amount of vitamin A is found in mare (0.4 mg L^{-1}) and cow milk (126 IU). However, human milk had higher vitamin A concentrations (190 IU) concentrations than mare milk. β-Carotene supplementation for mares has been shown to enhance the amount of this vitamin in colostrum and milk (Kuhl et al., 2012). However, compared with human milk, mare milk had higher vitamin D (4.93 μg L^{-1}) levels (Pieszka et al., 2015).

5.1.4. Potential products

Several types of mare milk products (fermented and non-fermented) have been proposed in Asian and newly in Europe countries, including yoghurt and curd for children's food (Kondybayev et al., 2021; Yakunin, Sinyavskiy, & Ibraimov, 2017), cheese, lactic and alcoholic beverages (qymyz, koumiss), and fresh milk (Kondybayev et al., 2018). Koumiss has a significant percentage of protein (2–2.5%, w/w) and fat (1–1.3%, w/w) (Table 7). In the recent report of the Food and Agriculture Organisation of the United Nations (FAO) released in 2017, 60 million mares have been inventoried. Among the biggest mare milk producer countries (Mongoly, Russia, China, Kazakhstan), only Mongolian production is estimated at 8 million litres, and its main fermented product (airag) has been reported by Cais-Sokolińska, Wójtowski, and Pikul (2016) and Park et al. (2006). Mare milk is thought to have a soft flavour, weak body, and creamy texture due to lower short-chain fat content (Kondybayev et al., 2021). The prize tradition fermented beverage from mare milk, known as qymyz proper to nomadic people in central Asia, has been documented to contain an intense and distinctive odour and taste; this unique aroma of qymyz is the consequence of the interaction of volatile acids, fusel alcohols, lactic acid, ethyl alcohol and other constituents produced during fermentation (Kondybayev et al., 2021; Uniacke-Lowe, 2011).

5.2. Donkey milk

5.2.1. Overview of quantity and production

Upper-class people consumed donkey milk in the 19th century, while poor families stored it for a sick kid or an elderly relative (Aspri, Economou, & Papademas, 2017). Donkey milk began to be utilised frequently to feed infants in maternity facilities. Additionally, donkey milk was promoted until the turn of the 20^{th} century for use in nourishing elderly people, sick people, children, and orphans. Along with the rediscovery of its potential health benefits, donkey milk has recently gained popularity in various Asian and European nations and Europe, particularly in Croatia, France, Hungary, Italy, the Netherlands, and Serbia

(Martini, Altomonte, Tricò, Lapenta, & Salari, 2021). China produces a lot of donkey meat and milk, and the donkey business has grown significantly important throughout rural China.

5.2.2. Physical and chemical composition

The total solid (8.8–11.7%, w/w) and pH (7–7.2) value of donkey milk is presented in Table 7. Donkey milk has a much greater freezing point of (–0.510 °C) than goat milk (–0.555 °C) or bovine milk (–0.520 °C), which can be attributed to its lower dry matter content (Aroua et al., 2018). According to their findings, donkey milk has a nearly neutral pH (7.09), whereas cow and goat milk have pH values of 6.65 and 6.5, respectively. According to Salimei et al. (2004), the higher pH of donkey milk is due to decreased casein and phosphate levels. The pH of donkey milk does not alter appreciably during lactation (Aspri, Souroullas, Ioannou, & Papademas, 2019). The increase in pH value at later stages of lactation is most likely related to a drop in casein level and an increase in urea content in the milk. The average particle size of donkey milk is 355 nm, which provides information about colloidal systems and is smaller than that of bovine and goat milk (Madhusudan et al., 2017). Donkey milk density at 20 °C is 1.029, while cow milk density is 1.032 (Chiavari, Coloretti, Nanni, Sorrentino, & Grazia, 2005).

5.2.3. Nutritional properties

The lactose (5.8–7.4%, w/w), protein (1.5–1.8%,w/w), and fat (0.3–1.8%, w/w) of donkey milk are demonstrated in Table 7. Human (1.42%) and donkey milk both have an average amount of total protein that is quite comparable with that of cows' milk (3.3%) (Martini, Altomonte, & Salari, 2014). Furthermore, not only is the overall number of proteins identical in human and donkey milk, but so is the profile of the protein fractions. Human and donkey milk, for example, have casein concentrations of approximately 0.4% and 0.64–

1.03% of milk, respectively, but total protein and casein fractions are abundant in ruminants. The total casein concentration of cow milk is 2.8% (w/w) on average, more than three times that of donkey milk (Ragona et al., 2016). Minerals are widely known for their relevance in human nutrition since they are essential for growth and skeletal structure development. Donkey milk mineral and trace element is remarkably similar to human milk, except that donkey milk has more significant amounts of calcium (33–114 mg 100 mL^{-1}) and phosphorus (32–65 mg 100 mL^{-1}). However, the Ca-P ratio is similar (Table 3).

Table 4 shows the vitamin levels in donkey milk. Vitamin B12 (cobalamin), crucial for maintaining healthy nerve cells and aiding in the production of DNA and RNA, is found in significantly higher concentrations than in bovine and human milk. Other B-complex vitamins, except for niacin, such as thiamine and riboflavin, are also more significant than human milk (Aspri et al., 2014). Compared with bovine and human milk, donkey milk contains fewer vitamins A, and E. Donkey milk total vitamin C content is the recommended daily dose of vitamin C for children aged 6 to 12 months (Gubic et al., 2014).

5.2.4. Potential products

A yoghurt-style product made from donkey milk without additives is achievable with the inclusion of other milk in a limited amount, and it may be well welcomed in the market due to its sensory features (Tsakali et al., 2018). Although the price of donkey milk is much greater than that of other animal milk, people are prepared to pay extra to benefit from its unique features. Donkey milk is available in various forms, including liquid milk, fermented products (with increased peptide content and a bioavailable calcium supply), freeze-dried powders, and spray-dried powders (Derdak et al., 2020). Donkey milk is a significant component in the manufacturing of high-quality dairy products. Donkey milk lysozyme is also employed in the food sector because of its stability and resilience to different technical procedures such as thermic treatment and digestive tract conditions such as acid pH and gastrointestinal enzymes (Ozturkoglu-Budak, 2018).

Because of its low fat and casein concentration, donkey milk forms a soft gel throughout the cheesemaking process. Several research studies have addressed this issue, for example, by adding MTGase—a microbial transglutaminase that can improve curd texture without affecting moisture, proteins, lipids, or cheese output (D'Alessandro, Martemucci, Loizzo, & Faccia 2019). Donkey milk might thus be added to the new generation of fermented milk beverages, such as koumiss made from mare milk, allowing for an efficient combination of the beneficial characteristics of the raw ingredients with probiotic lactic acid bacteria (Derdak et al., 2020). Other items such as ice cream, cookies, cakes, sweets, and liqueurs have been produced from pasteurised donkey milk throughout the years, and its technological application has been successfully tried in hard cheese manufacture, adding to dairy industry innovation.

6. Camel milk

6.1. Overview of quantity and production

For centuries, ancient peoples used camels, including dromedary and Bactrian, for milking and transportation, especially in Africa, the Middle East, Asia, and India. Some studies on camel milk and its products showed unique content of macro and microelements, similar to that of cow milk (El-Agamy, 2006). It has been determined that camel milk β-casein and lactalbumin of whey protein are pure and identical to human milk (Ali et al., 2019). The global production of camel milk is estimated to be 5.4 million tons, and Somalia represents the most significant production (Kgaudi, Seifu, & Teketay, 2018).

6.2. Physical and chemical composition

The physical properties such as specific gravity, moisture content, total solids, pH, and titratable acidity characterisation of camel milk and its products by some scientists in milk and dairy foodstuffs fields have made significant progress in milk storage and shelf-life parameters determination, ingredients choices in milk fortification (Table 8). The Bactrian camel milk has a lower pH (6.3–6.57) value and higher titratable acidity (0.17–0.2) than dromedary camel milk. However, the density (1.02–1.03) of Bactrian and dromedary camel milk insignificantly differ.

In contrast, Chinese bactrian camel milk was assigned a density of 1.029 to 1.030, a viscosity of 6.79 to 8.27 mPa s, and an electrical conductivity of 0.380 to 0.547 mS cm^{-1} (El-Agamy, Nawar, Shamsia, Awad, & Haenlein, 2009; Zhao, Bai, & Niu, 2015). The total solids of camel milk, especially bactrian camel, have been reported to range from 13.07 to 15.54% (w/w), which was higher than that of dromedary camel milk, 9.41 to 14.3% (w/w) (Kamal, Salama, & El Saied, 2007; Konuspayeva, Faye, & Loiseau, 2009; Park et al., 2006). The acidity of camel milk increased rapidly and remained stable for an extended period when kept at room temperature compared with the milk from other ruminant bovine milk. This phenomenon may be probably due to the content of antimicrobial constituents lysozyme, lactoferrin, and immunoglobulins (El-Agamy, 2009; Konuspayeva et al., 2010).

6.3. Nutritional properties

The proteins included in camel milk are essential for many activities (Zibaee, Yousefi, Taghipour, Kiani, & Noras, 2015). Bactrian camel and dromedary camel milk do not contain β-lactoglobulins, much like human milk. Camel milk is dominated by α-lactalbumin, comprising about 25% of the total whey proteins in cow milk (Rahmeh, Alomirah, Akbar, & Sidhu, 2019). The number of amino acids in camel milk is high except for lysine, threonine, glycine, and valine. Camel milk is a good source of linoleic acid and unsaturated fatty acids, making it healthy and nutritious (Zibaee et al., 2015).

The micronutrient components of camel milk are shown in Table 3. Although the phosphorus content of the Najdi camel milk was comparable with the mean value of Egyptian camel milk, the calcium and magnesium levels were significantly lower (Egyptian camel milk, mg 100 mL^{-1}: Ca, 196.5; P, 62.6; Mg, 21.0) (Ahmed, Awad, & Fahmy, 1977; Konuspayeva, Faye, & Bengoumi, 2022). However, in the other case, the calcium level of Najdi camel milk was more significant, and its phosphorus content was lower than those of Adal camel milk of Ethiopia (Ca, 40 mg 100 mL^{-1}; P, 138 mg 100 mL^{-1}) (Knoess, 1977). Calcium, phosphorus, and magnesium were all present in Najdi camel milk at almost equal concentrations as cow milk. Najdi camel milk sodium and potassium concentrations were above cow milk (Sawaya, Khalil, Al-Shalhat, & Al-Mohammad, 1984). The sodium and phosphorus in dromedary camel milk are closely connected to seasonal temperature and water consumed (Yagil & Etzion, 1980). Table 4 shows the vitamins in Najdi camel milk. The mean value of the vitamin A content of the milk obtained was lower than that reported by Ahmed et al. (1977), who found it to be 129.62 IU 100 mL^{-1} for Egyptian camel milk and lower than that reported by Khan & Appanna (1967), who found it to be 7.57 μg mL^{-1} for Bactrian camel milk. Also, Dromedary camel milk had a lower vitamin A concentration than cow milk (159 IU 100 mL^{-1}) (Sawaya et al., 1984).

6.4. Potential products

Various types of camels' milk and products, comprising yoghurt, soft cheese, fresh milk, and newly ice cream, sweetened milk, butter, shubat milk tea, pasteurised milk, camel milk powder, and milk soap, have been acknowledged in these mentioned regions and some European countries (Baig, Sabikhi, Khetra, & Kumar, 2022; He et al., 2012). Fermented camel milk products are significant worldwide as they have therapeutic and functional properties. These fermented products have a different name, such as gariss, chal, dhannan, arkhi, shmeen, and airag worldwide. Camel soft white cheese, a valuable and emerging product, has been recently introduced in European countries as a new breakfast ingredient (Baig et al., 2022). In addition, fermented camel milk possesses high ACE-inhibitory activity compared with fresh camel milk and ruminant milk (Ali et al., 2019; Solanki & Hati, 2018).

Among the entire camel producer regions reported Africa remains at the top, accounting for 80% of the world camel population. Under harsh conditions, camels can generate more milk than ruminants for more extended periods of production of camel milk per lactation period between 8 to 18 months is estimated to be about 1000 to 2000 L of milk, in which the daily milk production under good feed and husbandry practices is reported to be 3 to 10 kg (Farah, Mollet, Younan, & Dahir, 2007). Camel milk may be the milk of the 21st century owing to its excellent therapeutic, nutritional, and functional properties, immune system preventive and restorative compared with other bovine and non-bovine milk products. For example, bioactive peptides in camel milk proteins indicated many preventive and curative effects of microbial infection and have been reported to reinforce the immune system (Ali et al., 2019; Redha et al., 2022). The yield of bioactive peptides after the administration of camel milk showed hypoglycemic, hypoallergic, immune tonic, anti-microbial, and anti-carcinogenic factors (Al-Shamsi, Mudgil, Hassan, & Maqsood, 2018).

Camel milk has provided a variety of new dairy products, including pasteurised milk, butter, flavoured milk, cheese, yoghurt, and milk for tea (Al-Saleh, Metwalli, & Ismail, 2011;

Muthukumaran et al., 2022; Park, 2009). Cheese from camel milk showed a significant amount of protein (11.12–17.49%, w/w) and fat (17.99–20.91%, w/w) compared with other camel products (ice cream and yoghurt) (Table 8). Pasteurised camel milk (shelf life of 10 days at 4 °C) is now the most popular product in several countries, such as Mauritania (Park, 2009). These countries make pasteurised camel milk on a big scale. Furthermore, in raw and fermented milk, lactic acid bacteria (LAB) are the predominant population; they produce a variety of antimicrobial substances, including organic acids and hydrogen peroxide, bacteriocins, and antifungal peptides, and are essential to the fermentation of food (Khalesi, Salami, Moslehishad, Winterburn, & Moosavi-Movahedi, 2017; Nagyzbekkyzy et al., 2020). For the continued development of useful camel-milk-derived products, isolating and characterising the resident LAB in raw and fermented camel milk is crucial.

Camel milk yoghurt is a probiotic that may have therapeutic benefits, depending on the number of doses (Kumar et al., 2016). The lower viable probiotic levels in final fermented camel milk are estimated to be around 10^6–10^7 cfu g^{-1}. *Lactobacillus casei* isolated from fermented camel milk developed a new bacteriocin with remarkable heat and pH stability, purified, and described recently (Lü, Hu, Dang, & Liu, 2014). This could be extended in the presence of particular items, such as soybeans. Even with several types of stabilisers, the consistency of the texture of camel milk yoghurt has not improved (Al-Zoreky & Al-Otaibi, 2015). The fermentation process of camel bio-yoghurt takes longer than that used to make buffalo milk yoghurt (Ereifej, Alu'datt, AlKhalidy, Alli, & Rababah, 2011). Compared with camel milk alone, yoghurt made from camel and sheep milk mixtures showed higher protein, total solids, and fat for better satisfaction (Ibrahem & El Zubeir, 2016).

For many years, camel milk and fermented products have promoted bone construction in infants and the healing of various internal diseases (Lü et al., 2014). Antithrombotic, antigenotoxic, antimicrobial, antioxidative, antihypertensive activity, anticytotoxic, antihypertensive, immunomodulatory, anti-inflammatory, hypoglycaemic, hypoallergenic, and anthelmintic activity were demonstrated in these products (Abdalla et al., 2015; Alhaider, Abdel Gader, Almeshaal, & Saraswati, 2014; Alimi et al., 2016; Nagy, Skidmore, & Juhasz, 2013; Osman, Samir, Orabi, & Zolnikov, 2014; Salwa & Lina, 2010).

7. Consumers' behaviour, market conditions, and international regulations on non-bovine sources of milk and their products

Utami (2014) reported that consumers frequently bought raw goat milk or its processed goods, although only a few people rarely did in Malang East Java, Indonesia. Most customers commonly desired fresh goat milk or its processed goods since they had larger families and understood the value of this food's accessibility, variety, and low cost. Contrarily, those with high levels of education concerned about the importance of money, the availability of cow milk and its products, and people who believe that fresh goat milk and the processed goods made from it are exceptional delicacies may only sometimes buy these foods. Vargas-Bello-Pérez et al. (2022) demonstrated that consumers liked both sheep and goat goods (49.4%); it was noted that in Bangladesh, Mexico, and Denmark, more than 50% of consumers preferred goat dairy products. Fresh and mature cheeses were the most popular goods. In Chile, mature cheese was the most popular commodity; fresh cheese was favoured in Mexico, Italy, Greece, and Denmark. In Bangladesh, more than 30% of respondents reported observing the consumption of dairy products from small ruminants, in contrast to the rest of the world. Because they are unfamiliar with them, many people in Mexico do not eat dairy products made from sheep or goats. Limited market accessibility was also a factor in Bangladesh, Mexico, and Chile, where non-consumption occurred. Cazacu et al. (2014)

described that the popularity of buffalo milk products has increased in Greece because of its rich flavour and advantageous health properties.

Additionally, product knowledge, nutritional benefits, attitudes, and social contacts all benefit residents of the greater Thessaloniki area's inclination to purchase buffalo milk products. According to Kondybayev et al. (2021), mare milk consumption is growing in Central Asia because it has a nutritional profile similar to human milk but different from cow milk. Ismail et al. (2022) reported that 60% of participants were frequent drinkers of camel milk in the United Arab Emirates, and yoghurt and flavour milk were the most popular camel milk products, followed by fresh milk. Most customers (57%) consumed less than one cup of camel milk daily. Customers of camel milk preferred it to other types of milk because of its high nutritious value (66%) and high therapeutic value (39%).

As the dairy sector rules were created for cows, it was challenging for goat milk producers to obtain permits in the 1980s (Miller & Lu, 2019). The "Guidelines for the Production and Regulation of Quality Dairy Goat Milk" were released by the Dairy Practices Council in 2006 after years of campaigning and numerous scientific studies, allowing the industry to grow within a regulatory framework. The national and international standards for cow and goat milk differ significantly. While milk from healthy goats will test far higher than the minimum somatic cell count (SCC) of 750,000 cells mL^{-1} required for "Grade A" (best quality) cow milk set in 1991 in the US. As a result, goat milk was allowed to contain an SCC of 1 million cells mL^{-1} under the 2006 Guidelines. To enable more producers to market "Grade A" goat milk, which sells for a premium price, this was increased to 1.5 million somatic cells mL^{-1} in 2009. Fluid goat milk must meet national Food and Drug Administration standards for a minimum of 3.25% (w/v) fat and 8.25% (w/v) milk solids, including minerals, lactose, and protein (Miller & Lu, 2019).

8. Conclusions

Nowadays, several milk types have been used in functional meals for ages due to their composition, which provides a better environment for probiotic bacteria, including bifidobacterial and lactic acid bacteria, than dietary supplements. Mammal milk is a rich supply of carbohydrates for probiotic bacteria, swiftly digested and transformed into lactic acid and other metabolites. As a result, many products rely heavily on probiotics and prebiotics to achieve “functional” status. Little research has been done to estimate milk type of physical qualities. Functional food, including prebiotics and probiotics, provided a new market segment that aims for customer recognition and acceptance. At some points, milk type is also a big concern when adopting milk for functional benefits. Camel milk thermal characteristics and pH sensitivity should be considered while processing and analysing camel milk products. Mare milk was recently studied as a substitute for cow milk and allergic control formulas for youngsters.

Furthermore, in the advanced era, we need to pay more attention to precious species while focusing research on frequently used mammal species and their milk. There is a dire need to focus on milk and milk products, bioactivity, and health aspects of yak, zebu-brahma, mithun, reindeer, and sow-type mammal species. There is comprehensive data on yak, whereas reindeer and sow data needed to be more adequate, and no data on zebu milk were found. Mithun is the most neglected mammal species, as no data have been investigated. At the same time, some researchers have tried their best to solely compare calcium, phosphorus, and other minerals content with cow and buffalo species. Lastly, a vast range of research focus must be to carry out nutritional aspects of such neglected species so that in the race for the best healthy non-bovine sources, we can enhance dietary benefits, which may lead to discoveries in functional foods.

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Table 1

Physicochemical and nutritional properties of goat milk and products.

Product	Moisture (%, w/w)	Total solids (%, w/w)	Specific gravity (density)	pH	Ash (%, w/w)	Lactose (%, w/w)	Protein (%, w/w)	Fat (%, w/w)	Titratable acidity	Reference
Milk	86.23–90.23	12.07–12.97	1.634–1.831	5.05–6.72	0.7–0.82	4.00–4.79	2.20–3.4	2.25–4.08	0.12–0.15	Ahmed et al., 2014; Haenlein, 2004; Park et al., 2006
Pasteurised milk	83.04–88.6	12.01–12.36	1.01–1.03	4.99–6.58	0.8–0.86	3.76–4.64	3.15–3.29	3.75–3.80	0.17–0.20	Ranadheera et al., 2019; Roman et al., 2015
Cheese	54.56–55.91	40.2–40.9	–	4.6–4.89	1.60–1.74	–	16.01–17.45	24–25.50	2.16–2.27	Kondyli et al., 2016
Ice cream	–	37.50–38.56	–	6.61–6.65	1.27–1.29	–	4.41–4.46	9.50–9.67	0.16–0.19	Park, 2010
Yoghurt	82.23	11.5–17.7	–	4.85	0.82–1.02	–	3.47–3.99	1.18–6.50	0.72	Alqahtani et al., 2021

Table 2

Casein, calorie, viscosity, surface tension, refractive index, freezing point, and conductivity of selected milk types. [a]

Properties	Goat	Sheep	Buffalo	Mare	Camel	Donkey	Cow	Human	Reference
Casein (%, w/v)	2.5	4.4	3.46	ND	ND	0.64–1.03	2.8	0.4	Fantuz et al., 2016
Calorie (Kcal L^{-1})	76	115.7	114.9	480	ND	ND	69	ND	Fantuz et al., 2016; Jastrzębska et al., 2017
Viscosity (Pa s)	0.002	0.003–0.004	0.002	0.003	0.002	ND	0.002	ND	Yakunin et al., 2017
Surface tension (Dynes cm^{-1})	52.0	44.94–48.70	55.4	ND	58.39	ND	44.94–48.70	ND	Ahmad et al., 2013
Refractive index	1.450	1.349–1.350	1.345	ND	1.342	ND	1.451	ND	Cais–Sokolińska et al., 2016
Freezing point (−°C)	0.56	0.570	0.526	0.522	0.518	ND	0.530–0.570	ND	Mohapatra et al., 2019
Conductivity (Ω^{-1} cm^{-1})	0.0043–0.0139	0.0038	0.00467	0.00394	0.0061	ND	0.0040–0.0055	ND	Yakunin et al., 2017

[a] Abbreviation: ND, not determined.

Table 3

The mineral content of selected milk types. [a]

Mineral (mg 100 mL^{-1})	Human	Cow	Mare	Goat	Sheep	Buffalo	Donkey	Camel	Reference
Ca	27.6	119.8	92.9	130.4	181.7	159.6–166.2	33–114	106	Sawaya et al., 1984
Mg	3.80	12.6	8.1	7.3	12.5	17.7–18.8	4–8.3	12	Pietrzak–Fiećko & Kamelska–Sadowska, 2020
K	71.3	147.9	87.1	183.6	178.6	102.3–108.8	24–74.7	156	El–Salam et al., 2011
Na	15.9	49.3	17.4	35.9	52.1	39.0–42.3	10–26.8	69	Pietrzak–Fiećko & Kamelska–Sadowska, 2020
Fe	0.20	0.08	0.19	0.07	0.08	ND	0.04–0.27	0.26	El–Salam et al., 2011
Zn	0.64	0.62	0.21	0.69	0.58	ND	0.12–0.31	0.44	Pietrzak–Fiećko & Kamelska–Sadowska, 2020
P	14	11.9	ND	ND	ND	118.8–120.6	32–65	63	El–Salam et al. 2011

[a] Abbreviation: ND, not determined.

Table 4

Vitamin content of selected milk types. [a]

Vitamin	Goat	Cow	Human	Sheep	Buffalo	Mare	Donkey	Camel
Vitamin A (IU)	185	126	190	146	35.5–117.6 mg L^{-1}	0.403 mg L^{-1}	0.02 mg L^{-1}	500
Vitamin D (IU)	2.1	2.0	2.2	0.18	ND	4.93 μg L^{-1}		ND
Vitamin E (mg L^{-1})	ND	ND	ND	ND	38.0–136.3	1.13	0.06	ND
Thiamine (mg 100 mL^{-1})	0.068	0.045	0.017	68	ND	20–40 μg L^{-1}	0.41 mg L^{-1}	0.330 mg L^{-1}
Riboflavin (mg 100 mL^{-1})	0.21	0.16	0.04	0.38	ND	10–37 μg L^{-1}	0.7 mg L^{-1}	0.416 mg L^{-1}
Niacin (mg 100 mL^{-1})	0.27	0.08	0.17	0.42	ND	ND	0.75 mg L^{-1}	0.0015 mg L^{-1}
Pantothenic acid (mg 100 mL^{-1})	0.31	0.32	0.20	0.41	ND	277–300 μg L^{-1}	ND	0.88 mg L^{-1}
Vitamin B6 (mg 100 mL^{-1})	0.046	0.042	0.011	ND	ND	30 μg L^{-1}	ND	0.523 mg L^{-1}
Folic acid (mg 100 mL^{-1})	1.0	5.0	5.5	5.0	ND	0.13 μg L^{-1}	ND	ND
Biotin (mg 100 mL^{-1})	1.5	2.0	0.4	0.92	ND	ND	ND	ND
Vitamin B12 (mg 100 mL^{-1})	0.07	0.4	0.03	0.71	ND	ND	1.1 mg L^{-1}	0.0015 mg L^{-1}
Vitamin C (mg 100 mL^{-1})	1.5	2.1	4.3	4.16	ND	ND	3.4–5.1 mg L^{-1}	23.7 mg L^{-1}
Choline (mg 100 mL^{-1})	15	14	9	ND	ND	ND	ND	ND

[a] Abbreviation: ND, not determined. Data from El–Salam et al. (2011), Jastrzębska et al. (2017), Sawaya et al. (1984).

Table 5

Physicochemical and nutritional properties of sheep, cow, and human milk. [a]

Product	Moisture (%, w/v)	Total solids (%, w/v)	Specific gravity (Density)	pH	Ash (%, w/v)	Lactose (%, w/v)	Protein (%, w/v)	Fat (%, w/v)	Titratable acidity	Reference
Sheep	ND	18.50	1.035–1.038	6.51–6.85	ND	4.7	5.7	7.0	0.22–0.25	Mohapatra et al., 2019
Cow	ND	13.80	1.023–1.040	6.65–6.71	ND	4.8	3.3	3.7	0.15–0.18	Fantuz et al., 2016; Jastrzębska et al., 2017
Human	ND	ND	ND	ND	ND	6.71	1.42	3.64	–	Fantuz et al., 2016; Jastrzębska et al., 2017

[a] Abbreviation: ND, not determined.

Table 6

Physicochemical and nutritional properties of buffalo milk and products. [a]

Product	Moisture (%, w/w)	Total solids (%, w/w)	Specific gravity (Density)	pH	Ash (%, w/w)	Lactose (g L^{-1})	Protein (%, w/w)	Fat (%, w/w)	Titratable acidity	Reference
Milk	83.2–87	10–16.5	1.03–1.07	6.75	0.72–0.81	4.4–4.86	4.7–3.57	6.7–7.5	0.13–0.9	Ahmed et al., 2014
Cheese	45–60	59.28	ND	5.9	ND	ND	22.43	29.75	0.15	Asif et al., 2021
Butter	ND	88.86	ND	6.9	ND	ND	1.46	86.00	0.12	Ahmed et al., 2014
Paneer	47.2–48.3	ND	ND	ND	1.1–1.23	2.15–2.54	19.68–20.34	23.7–24.3	ND	Asif et al., 2021
Yoghurt	83.54–85–37	15.78–19.14	ND	4.53–4.89	0.72–0.89	ND	3.20–3.93	6.05–7.80	0.74–0.79	Ahmed et al., 2014

[a] Abbreviation: ND, not determined.

Table 7

Physicochemical and nutritional properties of mares' and donkey milk and products. [a]

Product	Moisture (% w/w)	Total solids (% w/w)	Specific gravity (Density)	pH	Ash (% w/w)	Lactose (% w/w)	Protein (% w/w)	Fat (% w/w)	Titratable acidity	References
Mare milk	97.8–98.8	9.47	ND	4.51–7.32	0.5	5.6–7.2	1.4–3.2	0.3–4.2	0.4–0.76	Claeys et al., 2014; Polidori & Vincenzetti, 2019
Koumiss	80–90	ND	ND	ND	0.4–0.7	4.5–5.5	2–2.5	1–1.3	0.6–1.2	Claeys et al., 2014; Polidori & Vincenzetti, 2019
Donkey milk	ND	8.8–11.7	ND	7–7.2	0.3–0.5	5.8–7.4	1.5–1.8	0.3–1.8	ND	Polidori et al., 2009

[a] Abbreviation: ND, not determined.

Table 8

Physicochemical and nutritional properties of camel milk and products. [a]

Product	Moisture (%, w/w)	Total solids (%, w/w)	Specific gravity (Density)	pH	Ash (%, w/w)	Lactose (%, w/w)	Protein (%, w/w)	Fat (%, w/w)	Titratable acidity	Reference
BC milk	86.33–88.5	13.07–15.54	1.029–1.030	6.30–6.57	0.66–0.94	4.23–5.20	3.33–4.45	4.83–6.67	0.17–0.20	Bekele et al. 2019; El–Agamy et al., 2009
DC milk	85.5–90.66	9.41–14.30	1.028–1.038	6.40–6.77	0.60–0.94	2.56–5.80	2.00–4.60	2.35–5.5	0.13–0.15	Kamal et al., 2007; Zhao et al., 2015
Ice cream	11.38–19.36	ND	ND	ND	1.48–1.86	ND	1.67–2.40	0.10–0.23	ND	Bekele et al., 2019; El–Agamy et al., 2009
Yoghurt	83.40	14.6–16.83	ND	4.30–4.66	1.13	ND	3.14–3.45	3.12–3.19	0.5–0.81	Kamal et al., 2007; Zhao et al., 2015
Cheese	55.64–58.84	34.76–43.44	ND	4.54–5.20	1.27–2.40	2.53–4.00	11.12–17.49	17.99–20.91	0.59–1.09	Bekele et al., 2019; El–Agamy et al., 2009

[a] Abbreviations: BC, Bactrian camel; DC, dromedary camel; ND, not determined.

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

None