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Camel milk: Nutritional composition, therapeutic properties, and benefits for human health

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ABSTRACT

Camel's milk is a widely consumed staple meal, especially in areas with dry and somewhat dry climates. Camel milk is rich in valuable ingredients, including lactoferrin and zinc, lactoactive peptides, and mono- and polyunsaturated fatty acids, which support optimal health. These compounds have the potential to effectively treat various prominent human illnesses, such as tuberculosis, asthma, gastrointestinal disorders, and jaundice. The composition of camel's milk is more varied than that of cow's milk. The composition of camel milk is primarily influenced by nutrition, breed, age, and lactation stage. The composition of camel's milk exhibits significant variation based on the geographical region and season. These whey proteins possess distinct physical, chemical, physiological, functional, and technological attributes that provide benefits in culinary uses and have high nutritional worth. Hydrolysis breaks down the proteins in camel's milk into bioactive peptides, which have physiological effects on the body's major organ systems. Camel milk, rich in essential fats, proteins, lactose, and minerals, positively impacts the treatment of diabetes, hepatitis C, and allergies and improves antioxidant enzyme levels in autistic children and tuberculosis patients. The review explores camel milk's therapeutic properties, nutritional composition, and implications for treating specific diseases and improving human healthcare.

Keywords: Camel milk, Nutritional composition, Therapeutic properties, Mental health.

Introduction

Many people, particularly those in the Middle East and Arabian Peninsula desert regions, rely extensively on camels for their livelihood (Kaskous, 2016; Amsidder *et al*., 2021). Camels possess the ability to adapt to different environments. Camels serve multiple purposes, including transportation, recreation, and providing meat and milk. This contributes to the economy and ensures that people have food access (Suliman *et al*., 2019; Swelum *et al*., 2020; Hakim *et al*., 2024). Based on the most recent data from the FAO, the global population of camels exceeds 29 million, with approximately 95% being dromedary (one-humped) camels (Sikkema *et al*., 2019).

Multiple factors, including breed, animal well-being, lactation phase, and housing conditions, impact the quantity of milk generated (Swelum *et al*., 2020). Despite the similarity in structure between camel udders and cow udders, camel milk production is lower and more inconsistent than cow milk. Enhancements in nutrition, water supply, and veterinary procedures can increase camel milk production (Felfoul *et al*. 2015; Swelum *et al*., 2021; Seifu, 2022). Millions of individuals worldwide consume milk daily because of its numerous nutritional advantages; in particular, milk has a crucial role in enhancing the growth of children's bones owing to its abundant concentration of calcium and vitamin D. Camel milk has proven benefits for older persons, particularly menopausal women, who are more susceptible to osteoporosis caused by insufficient calcium levels (Swelum *et al*., 2021). Milk production provides sustenance, income, and food stability to 150 million households globally, benefiting small-scale producers with prompt funding influx (FAO, 2012).

Camel milk's nutritional composition varies based on environmental conditions and fodder type. It contains high immunoglobulin, insulin, vitamins, and minerals, reducing protein, sugar, and cholesterol. Vitamins protect tissues (Hassani *et al*., 2022). In addition, it is superior in storage at room temperature and is crucial for newborn calves' growth and development, with its whey component containing more antimicrobial substances than bovine milk (Ho *et al*., 2022). Furthermore, it has a higher protein level than bovine milk due to its 21 essential amino acids. Casein makes up 52.07% of total proteins, while bovine milk has only 18 amino acids. Camel milk offers anti-hypersensitive,

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anti-diabetic, and anti-carcinogenic properties (Konuspayeva and Faye, 2021).

Camel milk is gaining recognition for its therapeutic benefits, including combating infections, cancer, and diabetes and providing energy for recovery. Human infectious disorders and gastrointestinal malignancies use it as an additional treatment (Swelum *et al*., 2021). This review investigates the therapeutic advantages of camel milk, emphasizing its diverse role in nutrition and medicine, and calls for further research and recognition of its importance in global health.

Chemical composition of camel milk

The camel milk color is usually white, and the taste is slightly salty, although there have been reports of salty camel milk (Abbas *et al*., 2013). The milk appears opaque, and the flavor is unique. The type of fodder and the availability of drinking water affect the taste of camel milk. Due to its lower density and increased buffering ability, it can withstand a pH of 4.95 (Gul *et al*., 2015). Several factors, including the physiological stage of the camel, nutritional circumstances, seasonal or physiological changes, and genetics, influence the composition of the milk produced by camels (Elkot *et al*., 2021). Omer and Eltinay (2008) state that camel milk comprises 97% water, 3.4% protein, 3.5% fat, 4.4% lactose, and 0.79% ash. Table 1 displays the milk components across various animal species. Figure 1 presents a schematic graphic that illustrates camel milk's chemical structure.

Water

Camel milk is primarily composed of water. Dehydrated camel milk has a greater amount of water compared to other forms of milk. When water is abundant, it has a water content of 86%, but it increases to 91% when it is scarce. Sisay and Awoke (2015) indicated that they can employ this method to replenish the body fluids of individuals and remove fluids from livestock in situations where access to clean water is not possible. The milk of a dehydrated camel contains a higher proportion of water due to an increase in antidiuretic hormone synthesis (Gebreyohanes and Assen, 2017).

Proteins

Proteins in camel milk vary in composition and properties, with casein being the predominant and plentiful protein, accounting for 3%–3.9% of the milk (El-Aziz *et al*., 2022). Based on (Konuspayeva and Faye, 2021), camel milk has a greater protein content, specifically casein, than human milk. In addition, camel milk has a lower amount of whey protein.

Dromedary camel milk contains a high concentration of casein, a substantial protein in camel milk. The αs1 casein and αs2 casein serve as the fundamental constituents. The absence of the αs1 casein fraction in human milk leads to symptoms related to milk protein allergies. The casein content in cow milk is 38.4%, while in buffalo milk, it is 30.22%, and β-casein constitutes 65% of casein (Gizachew *et al*., 2014; Mohamed *et al*., 2020). Camel milk contains whey protein, with dromedary camel milk containing 0.63%–0.80%. Lactoalbumin replaces lactoglobulin and makes up 50% of the whey protein in cow's milk (Lajnaf *et al*., 2023).

Camel milk contains the antioxidant protein lactoferrin (LF) at 0.22 mg/ml^{-1}, reaching its peak 2 days after delivery. This high concentration prevents the growth of bacteria and pathogens, making it a beneficial milk source (Ali *et al*., 2019a). Lactoperoxidase, a protein found in camel milk, has antibacterial, growth-promoting, and anticancer properties. Camel milk, rich in immunoglobulins, is highly effective against *Escherichia coli*, *Salmonella*, and *Pseudomonas*, making it easier to absorb into the nursing camel's digestive system (Shaban *et al*., 2023).

Fats

Daroma camel milk, sourced from dehydrated animals, has a lower % fat content of 1.1%, primarily PUFA and omega-3 FA, with lower average diameters in buffalo and camel milk (Amr and Farid, 2024). Enzymes degrade lipid droplets in milk derived from cows, goats, and camels. Camel milk exhibits more long-chain fatty acids than cow's milk (Arain *et al*., 2023). In addition, Konuspayeva *et al*. (2007) found that the cholesterol content in camel milk fat is greater (34.5 mg/100 g^{-1}) than the cholesterol content in bovine milk fat (25.63 mg/100 g^{-1}). Camel milk fat comprises elevated levels of carotene and short-chain fatty acids (SCFAs) compared to cow milk (El-Zahar *et al*., 2021). The milk fat globule membrane contains 95% cholesterol in the milk fat globule membrane. Cholesterol levels are higher in milk fat globule membranes with higher concentrations of smaller fat globules. Camel milk has more SCFA than cows, goats, sheep, and buffalo. It has 6–8 times more SCFA (Sumaira *et al*., 2020).

Carbohydrates

All milk species contain lactose, a disaccharide of glucose and galactose. The lactose concentration in dromedary camel milk varies from 3.3% to 5.8% (Bouhaddaoui *et al*., 2019), while it ranges from 4.8% to 4.9% in cow milk. Nevertheless, human milk has the highest lactose level (6.8%–7.0%) when comparing camel and cow milk (Al-Juboori *et al*., 2013). The oligosaccharides are important carbohydrates found in human milk. They comprise around 0.1%–1.0% of normal milk and 1.5%–2.3% of colostrum. Fucosylated oligosaccharides make around 35%–50% of the oligosaccharides in human milk, while sialylated oligosaccharides account for 12%–4%, and nonfucosylated oligosaccharides make 42%–55% (Donovan and Comstock, 2017).

Minerals

Total ash, which ranges from 0.6% to 0.9%, expresses the aggregate quantity of minerals in camel milk (El-Aziz *et al*., 2022). In addition, Konuspayeva *et al*. (2022) attributed the variation in mineral concentration

Table 1. Milk components between various animal species (Jilo, 2016).

Ingredient	Water%	Protein%	Fat%	Lactose%	Ash%
Camel	86–88	3.0–3.9	2.9–5.4	3.3–5.8	0.6–0.9
Cow	85–87	3.2–3.8	3.7–4.4	4.8–4.9	0.7–0.8
Buffalo	82–88	3.3–3.6	7.0–11.5	4.5–5.0	0.8–0.9
Sheep	79–82	5.6–6.7	6.9–8.6	4.3–4.8	0.9–0.1
Goat	87–88	2.9–3.7	4.0–4.5	3.6–4.2	0.8–0.9
Human	88–89	1.1–1.3	3.3–4.7	6.8–7.0	0.2–0.3

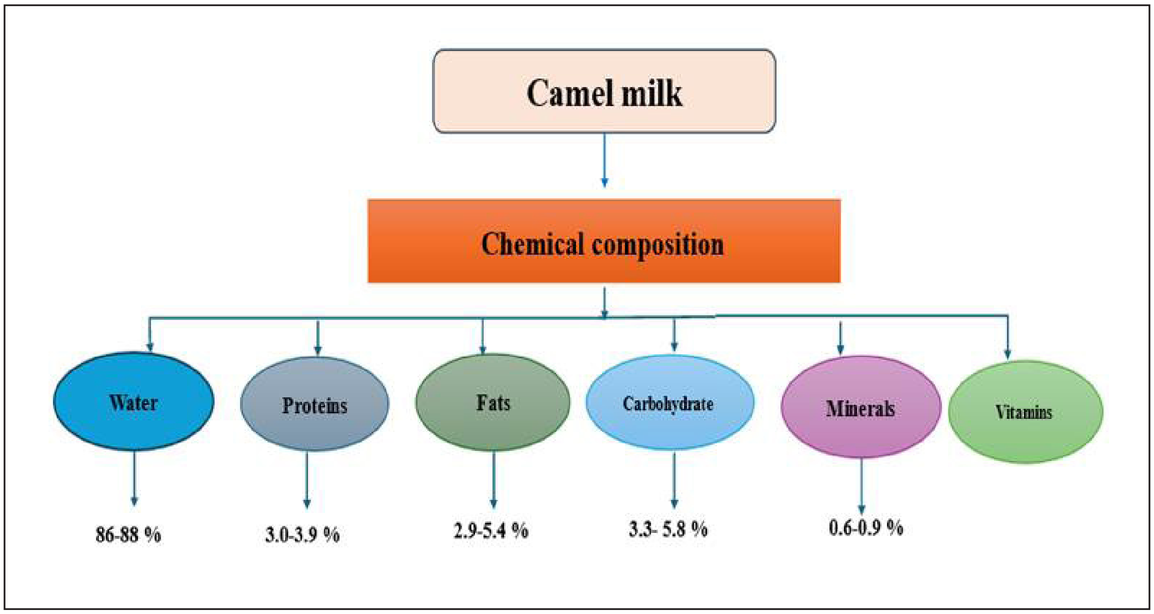

Fig. 1. Schematic diagram illustrating the composition of camel milk.

to disparities in diet, breed, and water consumption. Under comparable circumstances, milk from Bactrian camels has more minerals than milk from Dromedaries. The Ca, P, Na, K, and Mg levels in Bactrian camel milk are approximately 146.8, 134.1, 61.5, 167, and 9.9 mg/100 g, respectively. In dromedary camel milk, the concentrations of these elements are approximately 123.7, 85.2, 51.6, 143.5, and 12.6 mg/100 g (Koc and Atasever, 2016).

Camel milk is a significant source of Cl, mostly because camels consume plants such as Atriplex and Acacia (Wang *et al*., 2011). Camel milk has larger concentrations of Na, K, Fe, Cu, Zn, and manganese (Mn) compared to cow udder, although the levels of Mg, P, and Ca are comparable in both types (Singh *et al*., 2017; Swelum *et al*., 2021). Ho *et al*. (2022) found trace element concentrations in camel and human milk, with Fe, Zn, and Cu concentrations of 1.37, 2.19, and 0.44 mg/100 g, respectively. When contrasted with camel and cow milk, human milk includes the smallest levels of Ca, P, Fe, Zn, Na, K, and Mg. However, it has the highest Mn content (El-Aziz *et al*., 2022).

Vitamins

Animal milk contains vitamins and fats that are soluble in water. Camel milk stands out due to its exceptional abundance of vitamin C. Its vitamin C concentration is much higher, between 3.0 and 7.5 mg per 100 g, compared to cow's milk, which contains only 0.8–2 mg per 100 g. However, its vitamin C level is like that of human milk, which ranges from 1.19 to 7.84 mg per 100 g, with an average of 4.86 mg per 100 g (Bouhaddaoui *et al*., 2019). Similarly, camel milk demonstrated elevated concentrations of vitamin B1, B12, folic acid, and pantothenic acid compared to cow's milk (Ansari *et al*., 2024).

Furthermore, Qin *et al*. (2022) noted that the vitamin D level in Bactrian camel milk (640–692 IU/l) is greater than that in cow's milk (20–30 IU/l). Wang *et al*. (2011) found that camel milk has lower concentrations of vitamins B1 and B2, folic acid, and pantothenic acid but higher levels of vitamins B6 and B12. In addition, Faye *et al*. (2019) found that the levels of vitamins E, B6, and B1 in camel milk were comparable to those in cow's milk. Muthukumaran *et al*. (2023) found that camel milk contains fewer Vit A and E compared to cow's milk but more Vit C and B3 than cow's milk, with lower levels of B1, B2, B5, B12, and α-tocopherol.

Characteristics of Camel Milk

Taste and color

Camel milk is characterized by its opaque white color, typical milky smell, slight saltiness, and high acidity. The camel's diet and lactation stage primarily influence these properties (El-Aziz *et al*., 2022; Kishore *et al*., 2024). The reduction in key components of milk and the enhancement in Cl level in milk collected from dehydrated camels and their feed could contribute to the salty taste of camel milk (Konuspayeva *et al*., 2022; Laameche *et al*., 2024). The taste of camel milk may vary depending on the camel's habitat. The milk derived from camels indigenous to the American continent is characterized by its saccharine, mildly saline, and velvety consistency. The flavor of camel milk in the Middle East is reminiscent of hazelnuts (Galali and Al-Dmoor, 2019). Whey camel milk, after coagulation, reveals a white color, while whey caw milk has a greenish hue due to light dispersion caused by tiny fat globules and caseins (Sakandar *et al*., 2018; Arain *et al*., 2023). Figure 2 shows a schematic of camel milk's characteristics.

Acidity and pH

Camel milk has a pH ranging from 6.5 to 6.75, such as cow milk's pH range (6.4–6.8), but lower than human milk's one (6.75–7.42). The average pH of human milk is 7.09 (Alhaj *et al*., 2022). Camel milk exhibits an acidity level between 0.14% and 0.15%, like cow milk's acidity, specifically 0.15% (Karmaker *et al*., 2020; El-Aziz *et al*., 2022). According to Yogananda *et al*. (2014), the acidity concentration in fresh camel milk is approximately 0.13%–0.16%, marginally less than the average acidity content of 0.17% in cow milk. The acidity percentage in camel milk appears to vary depending on the breed. Abdullahi (2019) stated that the pH of camel milk falls within the lower range of 6.2–6.5 in comparison to cow's milk.

Heat stability

At high temperatures, camel milk exhibits lower thermal stability than cow milk. The inability to sterilize camel milk at a natural pH is due to the significant magnitude of the casein micelles and the absence of β-lactoglobulin (LG) and α-casein (CN) (Seifu, 2023). Also, Sakandar *et al*. (2018) state that CN and Ca significantly impact camel milk's thermal stability. At a temperature of 130°C, cow milk exhibits its highest heat stability level when the pH is 6.7 and its lowest level when the pH is 6.9. In contrast, camel milk does not demonstrate improved stability at a pH of 6.7 (Ho *et al*., 2022).

The primary issue with stored UHT camel milk is protein settling, which necessitates the use of certain chemicals to ensure its structural integrity. It optimized the thermal resistance of sterilizing camel milk at pH levels from 7.0 to 7.2, whereas the least heat stability was observed at pH levels from 6.5 to 6.8. High-temperature short-time methods can effectively pasteurize camel milk without any observable protein

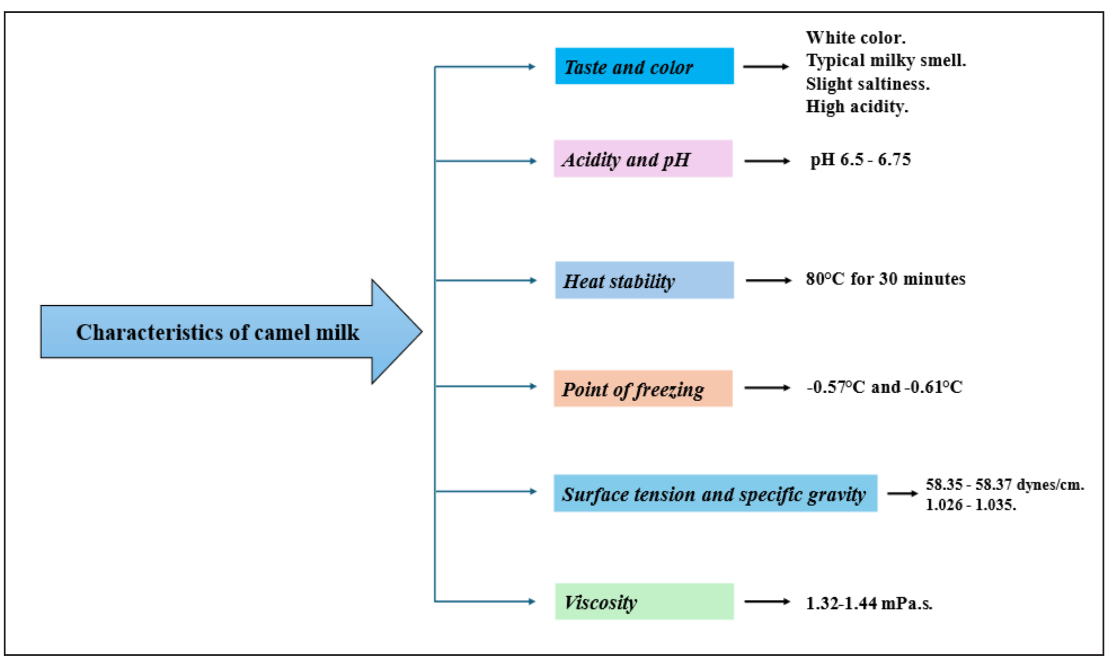

Fig. 2. A schematic that displays the properties of camel milk.

precipitation (Alhaj *et al*., 2022). Camel milk exhibited greater heat stability of whey proteins than cow milk (Mohamed *et al*., 2022; Saadi *et al*., 2024). When exposed to a temperature of 80 °C for 30 minutes, the denaturation of whey proteins in camel milk was found to be lower, at around 32%–35%, compared to cow milk whey proteins, which experienced denaturation of approximately 70%–75% (Lajnaf *et al*., 2023).

Point of freezing

Camel milk has a greater freezing point (−0.51°C) compared to cow milk (−0.53°C) because it contains a lower amount of milk solids nonfat content (Konuspayeva *et al*., 2023). In their study, Desouky (2021) reported that the freezing point of cow milk ranged from −0.57°C to −0.53°C. Conversely, a distinct investigation revealed that the cryoscopic point of camel milk lies within the interval of −0.57°C and −0.61°C, below the cryoscopic point of cow milk. Elevated salt or lactose levels in camel milk could account for its lower freezing point than cow milk (Arain *et al*., 2023; Konuspayeva *et al*., 2023). Studies show that camel milk's freezing point can be higher than cow milk, particularly in soluble components such as lactose and salts (Singh *et al*., 2017; El-Aziz *et al*., 2022).

Surface tension and specific gravity

The average specific gravity of camel milk is 1.029 and can range from 1.026 to 1.035, with variations observed among different breeds (Abdullahi, 2019; Mohamed-Elhassan and El Zubeir, 2024). The results for cow and human milk, which range from 1.026 to 1.034 (Karmaker *et al*., 2020), are comparable to these values. There is less information regarding the surface resistance levels of camel milk in contrast with cow milk. However, a study measured the mean surface tension of camel milk to be between 58.39 and 0.421 dynes/cm. Camel milk samples in the United Arab Emirates (UAE) exhibit surface tension ranging from 58.35 to 58.37 dynes/cm (El-Aziz *et al*., 2022). Furthermore, Wang *et al*. (2023) demonstrated that the surface tension of camel milk was greater than that of cow milk (42.3–52.1 dynes/cm) and human milk (47.73–1.50 dynes/cm). Lajnaf *et al*. (2023) attribute the difference in surface tension values in camel milk to the higher level of proteins and substances that are not polar.

Viscosity

The viscosity of camel milk falls within the 1.32–1.44-mPa range, which is the greatest compared to cow and human milk (Habtegebriel *et al*., 2020). Furthermore, Yoganandi *et al*. (2014) measured the viscosity of Indian camel milk to be 1.77 mPa, whereas they found the viscosity of cow's milk to be 1.54 mPa. Camel milk in the UAE was shown to have a viscosity ranging from 1.765 to 1.785 mPa at a temperature of 25°C. Tiny floccules, such as fat globules, are responsible for the elevated viscosity of camel milk (Arain *et al*., 2023). In addition, Seifu (2022) discovered that the viscosity of camel milk is 1.72 mPa, smaller than cow milk in terms of DM and amount under identical conditions (2.04 mPa). The divergent findings can be attributed to variations in husbandry practices, particularly about water provision.

The milk from heifers deprived of water for a few days was shown to be watered; this is likely to prevent the calf from experiencing dryness under drought conditions. The concentration of milk's components, pH level, temperature, and thermal history primarily determine its viscosity. The main factors determining milk's thickness are proteins and fats, present in smaller quantities in camel milk than in cow's milk (Habtegebriel *et al*., 2020).

The Therapeutic Effects of Camel Milk

Effects that protect the nervous system

Camel milk has therapeutic potential for neurological illnesses. A study using animal (rat) models found that camel milk exhibits anti-Parkinson action. Camel milk significantly reduced Parkinson's disease in animals compared to control and standard medication groups, causing mild degenerative changes in brain histopathology analysis (Seifu, 2022). Figure 3 shows a diagram explaining the healing advantages of camel milk.

In a separate investigation, Khatoon *et al*. (2015) and Behrouz *et al*. (2022) found that camel milk has antiseizure and neuroprotective properties, as demonstrated by inducing seizures in animals with strychnine and comparing its effects with diazepam. The administration of camel milk to mice resulted in antiseizure effects, characterized by a delay in the start of seizures, reduced convulsions duration, and a drop-in mortality rate compared to mice treated with distilled water. In mice treated with camel milk, the histological examination of the brain revealed a notable preservation of hippocampal neurons. Unlike animals treated alone with strychnine, these neurons appeared generally normal and healthy, with only minimal damage identified (Khatoon *et al*., 2015). Therefore, camel milk can serve as an alternate remedy for seizure disorders, effectively preventing the harmful effects of drugs and the development of drug resistance (Seifu, 2022). Table 2 provides a concise overview of camel milk's biological activity and primary mechanism of action.

Activities of antioxidants

Peptides from camel milk exhibit antioxidant characteristics, making them suitable for disease prevention (Ibrahim *et al*., 2018). The primary therapeutic benefits of camel milk, including its anticancer, hepatoprotective, and autism therapy properties, can be attributed to its antioxidant activity (Khatoon and Najam, 2017). Recently, Jrad *et al*. (2014) demonstrated that camel milk caseins can produce antioxidant peptides. They also observed that pepsin and pancreatin hydrolyze camel casein *in vitro*,

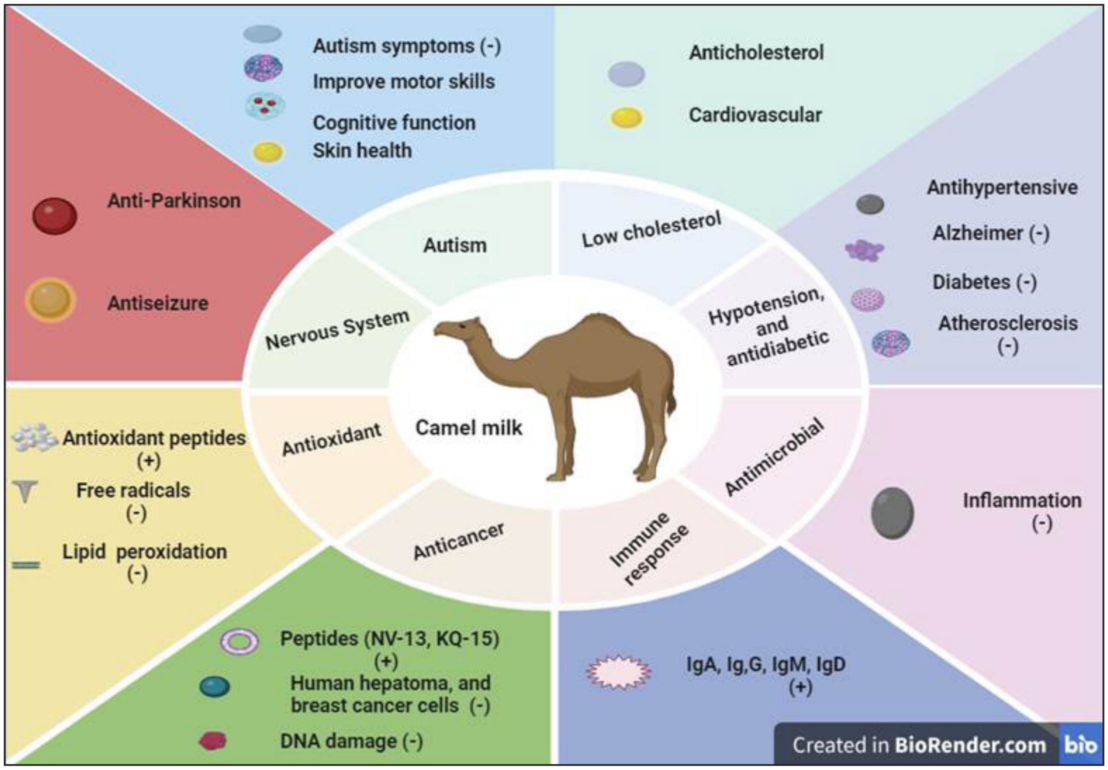

Fig. 3. Schematic illustrating the therapeutic benefits of camel milk.

exhibiting free radical scavenging action. Initially, milk-derived peptides remain inert as part of their parent proteins, but enzymatic hydrolysis transforms them into active forms and releases them. The peptides have free radical scavenging and metal ion chelation properties, and they can reduce lipid peroxidation. These effects are attributed to their enzyme hydrolysis activation. According to Behrouz *et al*. (2022), camel milk and its bioactive constituents can be therapeutically beneficial for conditions resulting from inflammation, oxidative stress, and immunological dysregulation.

Antitumor action

In addition, camel milk demonstrates anti-cancer properties. Homayouni-Tabrizi *et al*. (2016) showed that peptides derived from camel milk, such as NEDNHPGALGEPV (NV-13) and KVLPVPQQMVPYPRQ (KQ-15), are promising for treating oxidative stress disorders. In addition, Khan *et al*. (2021) discovered that camel milk effectively stopped human hepatoma and breast cancer cells from surviving and growing. It did this by starting both external and internal apoptotic pathways. Research has shown that camel milk LF can effectively hinder approximately 50% of colon cancer cells. It also leads to significant decreases in DNA damage (Muthukumaran *et al*., 2023), proliferation, viability, and migration of colorectal cancer cells (HCT 116). Furthermore, it activates autophagy, reducing breast cancer cells Michigan Cancer Foundation (MCF-7) (Krishnankutty *et al*., 2018; Muthukumaran *et al*., 2023).

Liver-protective impact

Camel milk has a hepatoprotective effect because of its antioxidant activity (Behrouz *et al*., 2022; Hassaneen *et al*., 2023). Furthermore, Abdel-Mobdy *et al*. (2023) found antioxidant properties in camel milk that can protect against drug-induced liver damage. The increased antioxidant properties of camel milk are attributed to its ability to chelate harmful substances and its high concentration of antioxidant amino acids (Ali *et al*., 2019b). The histopathological examination of liver tissues revealed that camel milk protects against alcohol-induced cellular damage compared to individuals who did not receive camel milk treatment (Shakeel *et al*., 2022).

Ming *et al*. (2021) found that camel milk can alleviate alcoholic liver damage by regulating inflammatory factors and correcting immune system dysfunctions. Hao *et al*. (2022) discovered that camel milk protects against chronic alcoholic liver illness in mice. It protects alcohol-induced intestinal dysfunction and lipid buildup and modulates oxidative stress and inflammatory cytokine release. This demonstrates camel milk's protective capacity against the harmful effects of alcohol on the liver.

Impact on autoimmune conditions

Camel milk can be a substitute therapeutic approach for treating autoimmune illnesses that may impact

Table 2. The biological properties and mechanisms of action of camel milk.

Application field	Mode of action	References
Nervous system	Camel milk has shown potential as a therapeutic alternative for neurological illnesses, with anti-Parkinson and antiseizure properties. Studies show that preserved hippocampal neurons prevent drug-related harm and develop drug resistance.	(Behrouz *et al*., 2022; Seifu, 2022)
Antioxidant	Camel milk caseins make antioxidant peptides that eliminate free radicals, bind metal ions, and lower lipid peroxidation.	(Ibrahim *et al*., 2018; Siddiqui *et al*., 2023)
Anticancer	Camel milk has anti-cancer properties, with peptides like NV-13 and KQ-15 promising for treating oxidative stress disorders, suppressing human hepatoma and breast cancer cells, and inhibiting DNA damage.	(Khan *et al*., 2021; Muthukumaran *et al*., 2023)
Immune response	Camel milk contains immunoglobulins, including IgG, IgM, IgA, and IgD, which can be used as natural nanobodies to treat autoimmune illnesses, such as tetanus toxin.	(Pedreáñez *et al*., 2021; Ho *et al*., 2022; Kocyigit *et al*., 2024)
Anti-inflammatory	Camel milk with dextran sodium sulfate can reduce inflammation and maintain gut microbiota, while fermented camel milk peptides are less inflammatory and more antioxidant.	(Dharmisthaben *et al*., 2021; He *et al*., 2022)
Antimicrobial	Camel milk contains antimicrobial agents, aiding in managing bacterial infections, accelerating recovery in drug-resistant tuberculosis patients, enhancing liver function in hepatitis C patients, and facilitating chronic hepatitis B recovery.	(Ho *et al*., 2022; Ansari *et al*., 2024)
Hypotension	Camel milk, rich in protein and antioxidants, contains bioactive peptides with antihypertensive properties, potentially preventing diseases such as Alzheimer's, diabetes, atherosclerosis, and cancer.	(Al-Anazi *et al*., 2022; Redha *et al*., 2022)
Low cholesterol	Camel milk, rich in bioactive peptides and orotic acid, has anti-cholesterolemic properties, potentially reducing heart conditions and lowering cancer, hypertension, and cardiovascular diseases.	
Antiallergenic	Camel milk, with its hypoallergenic properties, maybe a potential alternative for infants allergic to cow's milk, despite the amino acid differences between bovine and human milk, which can be challenging to digest.	(Berhe *et al*., 2022; Alharbi *et al*., 2022; Khalid *et al*., 2023)
Autism treatment	Camel milk, a rich source of antioxidants, has been proven to enhance children's behavior, reduce autism symptoms, and improve motor skills, cognitive function, and skin health.	(Behrouz *et al*., 2022; Kandeel and El-Deeb, 2022; Pal*et al*., 2024)
Antidiabetic	Camel milk, rich in insulin-like protein, has anti-diabetic properties, with recent studies showing its lactoferrin can combat hepatocarcinoma and HEK293 cells.	(Degen *et al*., 2019; Ashraf *et al*., 2021)

brain tissues and the gastrointestinal tract (Kocyigit *et al*., 2024). Researchers primarily attribute the value of camel milk in this context to its abundance of immunoglobulins, specifically IgG, IgM, IgA, and IgD, found in camel serum and camel milk (Swelum *et al*., 2021; Seifu, 2022).

Camel milk includes immunoglobulins significantly smaller than human antibodies, measuring only one-tenth of their size (Ho *et al*., 2022). The size of antibodies is a significant limitation in advancing immunotherapy, as larger antibodies struggle to effectively reach their intended target locations (Al-Numair *et al*., 2022).

Camelids produce small immunoglobulins that function as natural nanobodies. These nanobodies can be used as a novel medication delivery mechanism for treating autoimmune and neurological illnesses (Pedreáñez *et al*., 2021). Because they are small, have a simple structure, and are very attracted to specific antigens, camel milk antibodies can easily get into dense tissues, get to the active site, and bind to the antigen (Shabo and Yagil, 2005; Al-Numair *et al*., 2022). The camel IgG antibody completely blocks tetanus toxin and is known to be a better inhibitor of enzyme antigens (Ho *et al*., 2022).

Effect of anti-inflammatory

He *et al*. (2022) recently found that camel milk made with dextran sodium sulfate can reduce inflammation and keep the gut microbiota in mice with colitis in check. Therefore, we can utilize camel milk as a preventive against colonic inflammation. According to a study, camel milk can prevent the excessive production of inflammatory cytokines in the colon, reducing the inflammatory response (Kocyigit *et al*., 2024). It successfully controls the microbiota of the intestinal tract in mice with colon, which is improved by increasing the diversity of gut microbiota, stimulating the growth of helpful bacteria, and decreasing the population of harmful bacteria (He *et al*., 2022). As part of their study, Dharmisthaben *et al*. (2021) discovered that peptides made when lactic acid bacteria (specifically *Lactobacillus plantarum* KGL3A) ferment camel milk had properties that made it less inflammatory and more antioxidant. When these low molecular weight peptides were added to lipopolysaccharide-treated murine macrophages, they lowered the production of cytokines that cause inflammation.

Antimicrobial efficacy

Mehta *et al*. (2015) found that camel milk exhibits greater stability at ambient temperature than milk from other species. At a temperature of 30°C, bovine milk required 3 hours to become sour, reaching a pH of 5.7. In contrast, camel milk took 8 hours to attain a pH of 5.8 at a constant temperature. Camel's milk contains numerous antibiotics, including lysozyme, lactoperoxidase, LF, immunoglobulin, and bactericidal (Aqib *et al*., 2019), which is why it lasts longer and kills bacteria. Camel milk demonstrates antibacterial and antiviral properties against pathogenic pathogens such as *E. coli*, *Salmonella*, *Staphylococcus*, *Bacillus*, *Listeria monocytogenes*, and rotavirus (Ho *et al*., 2022). Camel milk's antimicrobial properties effectively manage disorders caused by bacterial infections, such as tuberculosis and Crohn's disease (Rakhmatulina *et al*., 2024). Consistent intake of camel milk led to accelerated clinical and radiological recovery in patients suffering from multiple drug-resistant tuberculosis (El-Aziz *et al*., 2022). In addition, Ansari *et al*. (2024) found that the higher levels of LF in camel milk than in cow milk contribute to its antiviral and antibacterial characteristics. Researchers found the average LF concentration in unprocessed milk from the dromedary camel to be between 0.209 and 0.131 mg/ml (Konuspayeva *et al*., 2007; Seifu, 2022). However, the quantity of LF found in cow milk varies according to different sources, ranging from 0.0767 to 0.022 mg/ml (El-Hatmi *et al*., 2006; Arzumanian *et al*., 2022).

A study revealed that administering camel milk as a supplement to patients with hepatitis C effectively improved liver function and blood parameters. Furthermore, state that camel LF inhibits the hepatitis C virus's function. Furthermore, studies have observed that camel LF exhibits stronger antiviral effects against the hepatitis C virus than humans, sheep, and bovine LF (Ali *et al*., 2019b). Furthermore, research has shown that camel milk can enhance the cellular immune response and facilitate the recovery of individuals suffering from chronic hepatitis B by impeding viral DNA reproduction (Khatoon and Najam, 2017).

Hypotensive effect

Research has revealed that camel milk contains bioactive peptides with many biological roles, including actions that help lower blood pressure (Ho *et al*., 2022). Several diseases, including Alzheimer's, diabetes, atherosclerosis, rheumatoid arthritis, and cancer, are caused by unregulated oxidative stress caused by an abundance of free radicals and other ROS within the cells of the body (Berhe *et al*., 2017). Therefore, utilizing bioactive peptides derived from milk proteins for their antioxidant properties is crucial for stopping radicals from forming or getting rid of existing ones (Ibrahim *et al*., 2018).

According to Swelum *et al*. (2021), camel milk is a very protein-rich substance with potential antibacterial, antioxidant, and angiotensin I-converting enzyme (ACE)-inhibitory properties. Akan (2021) showed that breaking down casein peptides from camel milk with enzymes increased their antioxidant and ACE-inhibitory effects. Most ACE-inhibitory and analgesic polypeptide components discovered in milk fermentation consisted primarily of peptides produced from CN as precursor molecules (Berhe *et al*., 2017). The considerably elevated concentration of β-CN in camel milk may provide an advantage. Lajnaf *et al*. (2023) discovered that camel milk α-lactalbumin and whey protein have higher digestibility, antibacterial activity, and antioxidant activity than other sources. Moslehishad *et al*. (2013a) noticed cultured camel milk showed higher ACE-inhibitory and antioxidant properties than bovine milk. The structural variations and increased proline concentration in the caseins of camel milk account for this difference.

Al-Anazi *et al*. (2022) discovered two new antioxidant peptides in camel milk, suggesting that calcium-rich fermented milk ACE-inhibitory peptides may lower blood pressure. Furthermore, Redha *et al*. (2022) discovered that bioactive peptides from camel milk, synthesized through enzymatic hydrolysis or fermentation, have more bioactive properties than intact proteins. These peptides possess features that include "antioxidant, anti-diabetic, anti-obesity, antihypertensive, antibacterial, antibiofilm, anticancer, anti-inflammatory, and anti-hemolytic effects."

Influence of low cholesterol

Obesity and high cholesterol are two serious issues that are becoming more and more prevalent. Numerous potentially fatal illnesses, such as cancer, hypertension, and cardiovascular diseases, are associated with them. The excellent anti-cholesterolemic characteristics of camel milk can lower the risk of heart conditions (Swelum *et al*., 2021). Also, fermented camel milk bioactive peptides significantly lower plasma cholesterol levels. Due to its established effect on reducing human cholesterol levels, its presence in camel milk may contribute to its hypocholesterolemic effect (Alharbi *et al*., 2022; Khalid *et al*., 2023). A study found that rats consuming fermented camel milk and garnish containing Bifidobacterium had lower LDL and plasma triglyceride levels (Swelum *et al*., 2021). In addition, El-Zahar *et al*. (2021) reported that *Bifidobacterium longum* BB536 has a stronger effect on dairy production than traditional yogurt culture, with camel milk and camel milk plus cow's milk having a more significant impact. Camel milk fermented with *B. longum* BB536 reduces dyslipidemia risk in obese rats, increases kidney function biomarkers, and reduces tissue damage (Singh *et al*., 2017). Furthermore, Alharbi *et al*. (2022) suggested that fermented camel milk, rich in ATB-5 strains, can lower cholesterol levels and improve liver and kidney functions, a significant health concern in Arab countries. Consuming fermented camel milk products further reduces cholesterol levels by interacting bioactive peptides with cholesterol.

Effect of antiallergenic

Infants with a bovine milk protein allergy experience a strong immunological reaction when they consume nonhuman milk, specifically bovine milk (Saad *et al*., 2020; Brandwein *et al*., 2024). Children commonly use cow's milk as a supplement or to replace human milk. Regrettably, a significant cause of food allergy, mainly affecting babies, is reactivity to proteins found in cow milk. Most children with bovine milk protein allergies produce antibodies mostly against β-LG and α-CN (Giannetti *et al*., 2021). Experimental studies show that camel milk has hypoallergenic properties, suggesting that it could be a potential alternative for children allergic to cow's milk, as supported by other scientific references. The amino acid differences between bovine and human milk pose a challenge in infant formulas, with β-CN being the predominant protein in human milk. Berhe *et al*. (2017) and Seifu (2022) observed elevated levels of β-CN, reduced levels of αs1-CN, and the absence of β-LG in camel milk. Therefore, this trend suggests a resemblance between camel and human milk. Ansari *et al*. (2024) suggested camel milk could be a viable protein alternative for youngsters unable to consume cow milk.

Treatment for autism

Autism spectrum disorder (ASD) is a persistent neurological condition marked by deficient communication and social interaction, usually appearing before the age of 3 (Nguyen *et al*., 2016). ASDs affect brain development and maturation. Autistic individuals produce casomorphine, a protein found in beta-casein and beta-lactoglobulin, which can cause opioid-induced brain injury, negatively impacting cognition and behavior (Al-Juboori *et al*., 2013). The presence of beta-casein and beta-lactoglobulin, which are present in cow's milk, causes clear indications in the brain. In contrast, casomorphine is synthesized, producing a highly potent opioid (Yagil, 2013). This medication may produce symptoms that resemble those exhibited by individuals with autism. According to Shabo *et al*. (2008), camel milk does not include caseins that produce casomorphine, so it does not cause any symptoms. Camel milk is rich in immunoglobulins, which are essential for the immune system's development and provide nutritional benefits for brain development. Several studies have established a correlation between camel milk consumption and a reduction in symptoms associated with autism (Sharma and Singh, 2014). Also, Agrawal *et al*. (2013) conducted research demonstrating that camel milk can reduce autism symptoms in children and improve many physical and cognitive capacities.

ASD increases the risk of "autoimmune, gastrointestinal, dysbiosis, and mental retardation," while oxidative stress contributes to neurological disorders such as "Alzheimer's, Parkinson's, schizophrenia, bipolar disorder, and autism" (Usui *et al*., 2023). Oxidative stress, caused by the overproduction of ROS, can lead to brain damage, strokes, and neurodegenerative illnesses, necessitating regulation of ROS generation for normal cellular processes (Olufunmilayo *et al*., 2023). Glutathione is recognized as a crucial antioxidant within cells, maintaining a favorable internal environment for normal cell function and survival and decreasing oxidative stress. Behrouz *et al*. (2022) indicated that utilizing camel milk caused a notable increase in the GSH ratio. This can be ascribed to the presence of antioxidant elements in camel milk, including Mg, Zn, Vit E, and C. Studies have proposed that the presence of high levels of Mg, Zn, and Vit E in camel milk may potentially enhance the formation of glutathione and enzymes. This, in turn, could reduce oxidative stress in individuals with autism (Mohammadabadi, 2020).

Indicated that camel milk may provide therapeutic properties for individuals with autism. Autism is a profound neurodevelopmental illness marked by deficits in the process involving verbal and nonverbal communication, imagination, reciprocal social engagement, and signs of developmental delay before the age of three (Hodges *et al*., 2020). Recent studies suggest camel milk may be a promising therapeutic intervention for autism, as it has shown positive effects on children's behavior (Laila and Halepoto, 2017). Administering camel milk led to notable improvements in the behavior of children diagnosed with autism. Consumption of camel milk by children with autism resulted in decreased autistic symptoms and enhanced motor skills, verbal abilities, cognitive function, joint coordination, and skin health (Hassani *et al*., 2022). Table 3 illustrates the results of studies utilizing human models.

Effect of antidiabetic

People in Asia and the Middle East have long used camel milk to treat and control diabetes. Degen *et al*. (2019) report that the Bedouin people, who are nomads, have traditionally used camel milk to treat diabetes mellitus.

Table 3. Results of studies utilizing human models.

Disorder	Population	Quantity	Results	References
Diabetes	Individuals aged 20–70 diagnosed with type 2 diabetes	250-ml pasteurized camel milk PO twice daily × 2 months	It increased HDL, decreased LDL, reduced total cholesterol and triglycerides, and controlled blood sugar levels.	Ejtahed *et al*. (2015)
	Patients are 17–20 years old and have type 1 diabetes.	500-ml/d camel milk × 16 weeks	It led to excellent blood sugar control, reduced total cholesterol and triglycerides, and improved HDL and LDL levels.	Mohamad *et al*. (2009)
	24 patients with type 1 diabetes	500-ml camel milk	It resulted in decreased insulin dosages, an increase in plasma insulin, and blood sugar management.	Agrawal *et al*. (2005)
	50 type 1 diabetic patients	intensive insulin therapy + 500-ml/d unpasteurized camel milk	Reduced anti-insulin antibodies (%), elevated BMI, elevated plasma insulin, and improved blood sugar regulation.	Agrawal *et al*. (2007)
	24 type 1 diabetic patients	500-ml/d camel milk	It resulted in decreased insulin dosages and anti-insulin antibodies (%), increased plasma insulin and BMI, and increased blood sugar control.	Agrawal *et al*. (2011)
Autism	Kids with ASD, ages (2–12)	Raw milk, 500 ml/ daily	Lower childhood autism rating scale, higher myeloperoxidase, glutathione, and superoxide dismutase levels.	Al-Ayadhi *et al*. (2013)
	Kids with ASD, ages (2–12)	Boiled milk, 500 ml/ daily	Higher myeloperoxidase levels, glutathione, and superoxide dismutase are associated with a lower childhood autism rating scale.	Al-Ayadhi *et al*. (2013)
	Children (2–12 years old) with ASD	Raw milk, 500 ml/ daily	Reduced childhood autism rating scale and thymus and activation-regulated chemokine.	Bashir *et al*. (2014)
	Children (2–12 years old) with ASD	Boiled milk, 500 ml/ daily	The rating scale for childhood autism has decreased, and the thymus and activation-regulated chemokine have also been affected.	Bashir *et al*. (2014)
	Age 4–21 years	--------	After using camel milk, there was an improvement.	Shabo *et al*. (2005)
	9-year-old	4-oz daily raw milk	Enhancement of conduct and motor coordination	Adams (2013)

ASD, autism spectrum disorder; HDL, high-density lipoprotein; LDL, low-density lipoprotein; BMI, body mass index.

Camel milk can successfully manage diabetes-related problems such as high cholesterol and deteriorating liver and kidney function, among others (Shori, 2015). Furthermore, Kilari *et al*. (2021) used streptozotocin-induced diabetic rats as a model to show that camel milk protein hydrolysates had antihyperglycemic, antihyperlipidemic, and antioxidant properties. In addition, Korish *et al*. (2020) reported that whole camel milk had antithrombotic (anticoagulant) properties, indicating that camel milk may benefit diabetes management. There are several reasons why camel milk has anti-diabetic properties. A plausible explanation could be that camel milk contains a protein like insulin, which attaches itself to insulin receptors and encourages insulin to interact with them (Ali *et al*., 2019a,b; Muthukumaran *et al*., 2022). Ayoub *et al*. (2018) state that the increased concentration of insulin (52 U/l) and insulin-like protein in camel milk contributes to its antidiabetic action.

Ashraf *et al*. (2021) indicate that camel whey protein and its hydrolyses, produced using pepsin, can augment the stimulation of human hormone receptors and signaling cascades, thereby increasing glucose absorption in cell line models. A recent study looked at how LF from camel milk works on insulin receptors (IR) in hepatocarcinoma and human embryonic kidney (HEK293) cells. They also looked at its pharmacology and signaling. The results showed that LF was bioactive toward IR function, which means that it may be a bioactive protein that makes camel milk good for people with diabetes (Anwar *et al*., 2022; Khan *et al*., 2022). This is because drinking camel milk helps the pancreatic β-cells grow back, which in turn helps the β-cells make and release insulin better (Aqib *et al*., 2019).

Another possible explanation for the characteristics of camel milk's antidiabetic qualities is its simple absorption into the bloodstream. Camel milk instantly goes through the stomach with its unique insulin and enters the duodenum for rapid absorption because it does not clot at the pH of the stomach. Kamal-Eldin *et al*. (2021) showed camel insulin lipid vesicles create nanoparticles, protecting them from proteolytic degradation and delivering them into the bloodstream through the stomach's mucosal barriers.

Effect of camel feeding diet on milk compositions and its properties

Camels are crucial dairy animals in semi-arid communities, providing high-quality protein, fatty acids, vitamins, and minerals (Faye, 2016). However, their production systems are shifting toward a semi-intensive approach, relying on feed supplements for nutrient requirements, especially during lactation (Faye, 2013). Camels face constraints such as low growth rate, seasonal breeding, long gestation, abortion, low milk production, diseases, and a high mortality rate of pre-weaning newborns and dams, hindering productivity and performance (El-Zubeir and Ehsan, 2010). However, camel's unique anatomy and physiology make them suitable for harsh environments, poor feeding, and water scarcity. However, unknown nutritional deficiencies during different seasons reduce performance and profitability, affecting glucose, protein, lipid, and mineral absorption (Moore *et al*., 2005). Seasons significantly impact grazing ruminants' health and productivity due to variations in feed availability and nutritive values. Winter is particularly stressful for camels, affecting milk yield and growth (Dwyer *et al*., 2016).

Trace and macro minerals are crucial for animal health and productivity, especially in camels. Deficit can cause pathological issues, metabolic defects, and infertility (El-Bahrawy and El-Hassanein, 2011; Faye and Bengoumi, 2018). Studies in semi-arid and arid areas often overlook factors affecting camels' mineral and nutritional status, such as seasons, age, breed, sex, and management risk factors (Osman and Al-Busadah, 2003). This information is crucial for developing supplementation programs to improve camel reproductive efficiency and quality (Abdelrahman *et al*., 2013).

Dereje *et al*. (2016) discovered that giving supplements to dromedary camels increased their milk yield, physicochemical quality, and fatty acid profile over 120 days. They found that browsing/grazing plus 0.75 led to better body weight gain, higher milk yield, and higher milk fat content. Consuming concentrate boosts propionic acid synthesis, a precursor for glucose, which in turn leads to lactose synthesis, resulting in increased milk volume in camels (Costa *et al*. 2009). Camel milk's composition and mineral content is mainly influenced by its water content (Haddadin *et al*., 2008). In addition, camel milk is influenced by other factors such as feeding conditions, camel breed, stage of lactation, age, and the number of calves (Zhang *et al*., 2005). Abdelrahman *et al*. (2022) indicated that the total mixed ratio supplementation improves nutritional milk value, protein percentage, and mineral status. It also increases blood serum concentrations of Co, Mn, and Zn, with high correlations with other minerals.

Challenges and perspectives

Historically, herdsmen were the only ones who drank camel milk, which had limited commercial value. Furthermore, Konuspayeva and Faye (2021) noted that camel milk remained unaltered, except for undergoing fermentation solely for preservation. The latest endeavor has focused on supplying camel milk to domestic and global markets (Faye, 2016). To get camel milk into the market for commercial purposes, it is necessary to establish national, regional, and international standards. Camel milk production should not adhere to the requirements set for cow's milk. It is critical to determine pasteurization conditions and indications. Camel milk pasteurization is inappropriate for inactivating alkaline phosphatase since it exhibits heat resistance (Rankin *et al*., 2010). The usefulness of lactoperoxidase as an indicator depends on how it feels when heated, which is important for its business value (Tayefi-Nasrabadi *et al*., 2011).

In addition, Lund *et al*. (2020) discovered that subjecting camel milk samples to heat treatments decreased flavor, texture, and overall acceptance ratings. Utilizing starter cultures and controlled fermentation techniques in raw camel milk could improve its sensory characteristics. However, spontaneous fermentation results in a diverse microflora environment, making it difficult to obtain consistent sensory products.

According to Ayyash *et al*. (2018), camel milk fermented with *Lactococcus lactis* KX881782 has therapeutic benefits such as lowering blood sugar, fighting free radicals, lowering blood pressure, and stopping cell growth. Consumption of probiotic-fermented camel milk is a significant commercial debate due to its potential health benefits. Probiotics in camel milk have a long shelf life and maintain optimal viability after fermentation. Raw camel milk and its fermented products can be a source of potential probiotic strains (Didar, 2019). However, selecting appropriate strains based on functional criteria is crucial to avoid undesirable products. As an example, fermentation with *Lactobacillus fermentum, Lactobacillus rhamnosus*, and *L. plantarum* PTCC 1058 produces bioactive peptides and sensory properties that are good (Moslehishad *et al*., 2013b).

Camel milk has potential health benefits for diseases such as diabetes, allergies, and cancer, while probiotic camel milk has been introduced for advanced health properties. Due to its resistance to harsh environmental conditions and lack of water, camel milk is an attractive investment opportunity.

Conclusion

Camel milk and its derivatives have gained significant global attention due to their exceptional nutritional profile and reported therapeutic benefits for various human health conditions. Although the bulk composition of camel milk bears similarities to that of bovine and other domesticated animals' milk, its distinct properties make it behave differently in terms of processing and product development. One of the key features of camel milk is its high iron and vitamin C content, which not only enhances its nutritional value but also makes it a viable option for individuals with lactose intolerance. In addition, camel milk's long shelf life and its substantial levels of insulin-like protein have been linked to its therapeutic potential, particularly in managing conditions such as diabetes. Unlike bovine milk, camel milk lacks β-lactoglobulin, a protein often associated with milk allergies, making it a better alternative for those with sensitivities. Moreover, camel milk contains a wide range of bioactive peptides that significantly contribute to its biological value, offering benefits such as enhanced digestibility, better nutritional quality, and health-promoting effects. The hypoglycemic properties of camel milk further underscore its role in managing and controlling diabetes, making it a valuable dietary component for people with this condition. Overall, camel milk stands out as a functional food with promising applications in human health, meriting further research and development to harness its potential fully.

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