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Prospective nutritional, therapeutic, and dietary benefits of camel milk making it a viable option for human consumption: Current state of scientific knowledge

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ABSTRACT

For over five thousand years, people in Asia and Africa have known about the health benefits of camel milk. Thus, it is used not only as a food source but also as a medicine. The similarities between camel milk and human milk have been scientifically proven. Camel milk is unique among ruminant milk because it is high in vitamins C and E and low in sugar and cholesterol. Still, it contains a wide variety of beneficial minerals (including sodium, potassium, iron, copper, zinc, and magnesium), besides being rich in several nutrients, including monounsaturated and polyunsaturated fatty acids, serum albumin, lactoferrin, immunoglobulins, lysozyme and the hormone insulin. Because of these components, many medical professionals now recommend camel milk as a treatment for various human ailments. It has been demonstrated to be effective in treating gastrointestinal issues, Type 1 diabetes, and food allergies. As a bonus, camel milk has been utilized to cure autism, lower cholesterol, prevent psoriasis, heal inflammation, aid tuberculosis patients, boost the body's natural defences, and impede the spread of cancer

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cells. Those who have problems digesting lactose may still be able to tolerate it. Conversely, camel milk can also help reduce an excessively high bilirubin, globulin, and granulocyte count. Drinking camel milk does not affect the erythrocyte sedimentation rate, hemoglobin concentration, and leukocyte count. The proteins in camel milk have an adequate ratio of critical amino acids. Immunoglobulins, which fight disease, are contained inside, and their small size allows antigens to penetrate and boosts the immune system's efficacy. This article highlights the health benefits and medicinal uses of camel milk.

1 Introduction

Allergy to cow's milk is the most frequent food allergy among newborns and toddlers. Medical crises involving patients with anaphylaxis or severe allergic reactions to this dairy source require the administration of adrenaline (epinephrine). This risk factor for functional gastrointestinal diseases can be mitigated, however, if an alternative is found to cow milk for feeding children and new-borns and one such important alternative is camel milk (Yadav et al. 2015; Yassin et al. 2015; Chandran et al. 2021; Muthukumaran et al. 2022; Patange et al. 2022a; Patange et al. 2022b; Krishnan et al. 2023). Regarding nutritional value, camel milk resembles human milk and is superior to cow milk (Lejaniya et al. 2021a; Lejaniya et al. 2021b; Ho et al. 2022).

Camels prefer dry, hot climates with little available flora. Camels are raised in nations with sizable desert areas for a wide range of purposes, including but not limited to food, transportation, clothing, cosmetics, and even human consumption. There are roughly 29 million camels in the globe, with the vast majority being dromedary (*Camelus dromedarius*) camels (Bakry et al. 2021; Islam et al. 2022). The majority of the world's supply of fresh whole camel milk comes from Africa, while Asia accounts for the rest. Figure 1 shows a breakdown of the major camel milk-producing countries and their global production profiles. Nutritionally, camel milk is superior to bovine milk, and its composition is the same as human milk; hence it is often used as a stand-in for human milk when the latter is unavailable (Kumar et al. 2016). In recent years, camel milk's potential as a dairy alternative to cow, sheep, buffalo, donkey, and mare milk has garnered much attention. It has been shown that the immunoglobulins (Igs) found in camel milk help alleviate the symptoms of cow milk protein allergy in 2-6% of children and new-borns (Jilo and Tegegne 2016; Muthukumaran et al. 2022). A

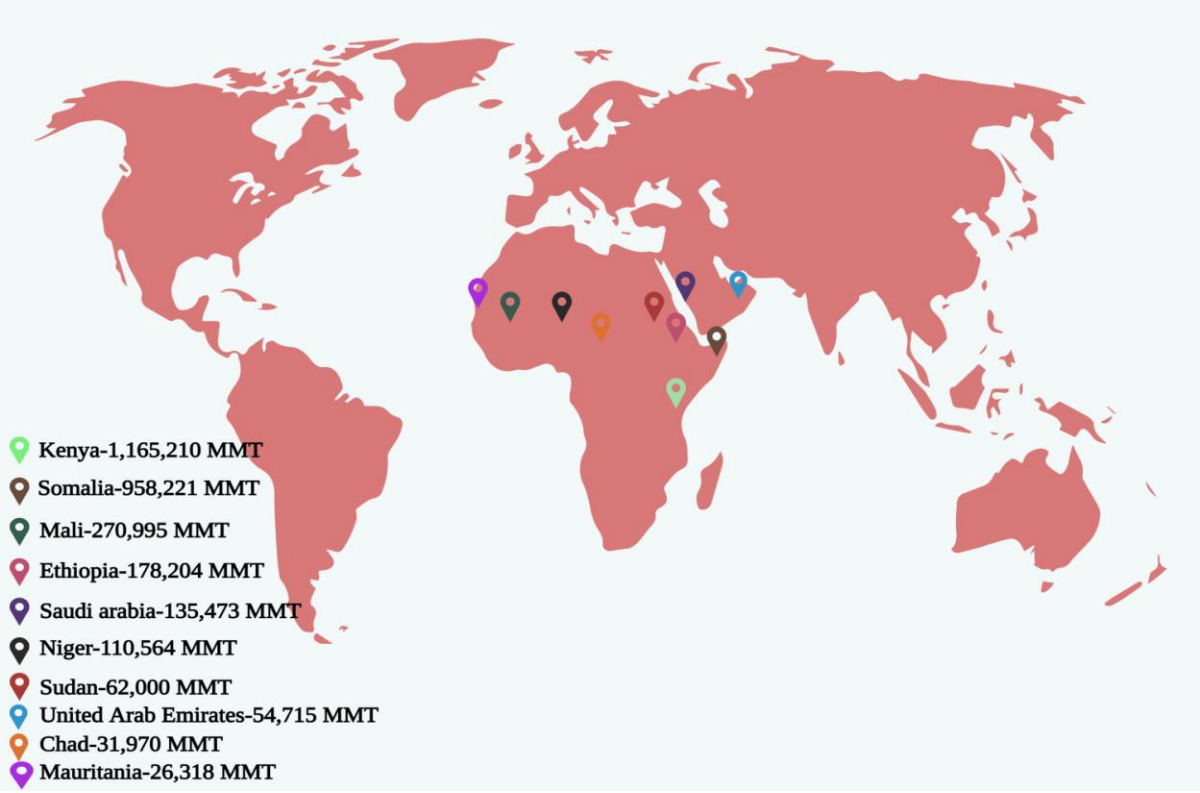

Figure 1 Examining the global situation of camel milk production (Designed with Biorender premium software; https://app.biorender.com/)

lack of beta-lactoglobulin and plenty of alpha-lactalbumin give camel milk an antiallergenic quality comparable to human breast milk (Mohammadabadi and Faraz 2021). Camel milk's high levels of antioxidants and antimicrobials make it useful for a wide variety of medical purposes, including the prevention of gastrointestinal illness, the management of diabetes, psoriasis, and hepatitis C and B, the improvement of immune system function, the suppression of cancer cell growth, and the treatment of tuberculosis (Kuala 2016; Faraz 2020; Bakry et al. 2021).

There are many bioactive peptides and protective enzymes in camel milk, and these compounds are responsible for their medicinal, antibacterial, and antioxidant properties (Yadav et al. 2015). In addition to its excellent nutrient and mineral makeup, camel milk also contains protective proteins with potential health benefits, including lactoperoxidase, lysozyme, lactoferrin and immunoglobulins. Even those who have digestive issues with lactose may be able to tolerate it (Kuala, 2016; Khalesi et al. 2017). Contrarily, drinking camel milk can reduce a high bilirubin, globulin, or granulocyte count. There was no correlation between camel milk consumption and changes in erythrocyte sedimentation rate, hemoglobin content, or leukocyte count. Proteins in camel milk contain a good amount of each essential amino acid. Disease-fighting immunoglobulins are stored within, and their diminutive size makes it easier for antigens to enter the body and trigger an immune response (Jilo and Tegegne 2016; Mohammadabadi and Faraz 2021; Muthukumaran et al. 2022; Seifu 2023). The current article looked at camel milk's health and therapeutic benefits, which are more relevant to developing a commercially viable product.

2 Nutritional profile and chemical composition of camel milk

Researchers found that camel milk had a less consistent composition than other milk types, such as bovine milk. Many factors, including the camel's breed, age, and the number of calves birthed, may account for the reported variations in camel milk composition. These include analytical measuring methodologies, geographic regions, feeding conditions, and sample origin. Camel milk composition is most strongly influenced by its place of origin and the time of year (Khalesi et al. 2017; Hailu et al. 2016; Sakandar et al. 2018). According to research by Konuspayeva et al. (2008), camels in East Africa produce milk with a higher lipid content than their counterparts in Africa and Western Asia. Camel milk contains between 87% and 90% water. Total solids in camel milk were shown to be inversely proportional to the amount of water consumed by the camels.

2.1 Milk fats

Camel milk fat content varies from 1.25 to 4.55%, depending on the camel's diet, lactation stage, breed, time of year, and other environmental factors. Camel milk fat is the most nutrient-dense source of unsaturated fatty acids of any animal fat. This may be the primary cause of camel milk fat's waxy consistency (Faraz 2020; Bakry et al. 2021). Fat from dromedary camels contained more long-chain fatty acids than fat from cows. Compared to bovine milk, the beta-carotene content of camel milk is lower. Camel milk fat might be less vibrant because it contains less of the antioxidant carotene (Hailu et al. 2016; Sakandar et al. 2018; Solanki and Hati 2018; Sumaira et al. 2020).

2.2 Milk proteins

The protein content in camel milk is 2.15–4.90%. Whey protein is higher in camel milk than cow milk, although casein quantity is the same. Camel milk has the best whey-to-casein ratio. Because of this, camel milk's coagulum may be less solid than cow milk (Yassin et al. 2015). Of the total proteins (1.63-2.76%) in a glass of camel milk, 52-87% are casein. Beta-casein is 65%, compared to 36% in bovine milk. Comparatively, only around 13% of the total casein in bovine milk is beta-casein, while camel milk has about 3.47 % (Sumaira et al. 2020; Kumar et al. 2021; Seifu 2023). About 20 to 25% of milk's protein comes from whey proteins, which comprise 0.63 to 0.80%. The primary whey protein in camel milk is alpha-lactalbumin rather than beta-lactoglobulin. Serum albumin, immunoglobulins, peptidoglycan recognition protein, and lactoferrin are other camel milk whey proteins. Cathepsin D and chymotrypsin A are also found in whey protein (Faraz 2020; Chandran et al. 2020; Benmeziane–Derradji 2021; Swelum et al. 2021; Muthukumaran et al. 2022).

2.3 Lactose

Camel milk primarily comprises lactose sugar, with concentrations ranging from 3.30 percent to 5.80 percent. Camel milk’s wide-ranging lactose content may be mainly due to the variety of desert flora camel feeds upon. To satisfy their physiological needs for salts, camels commonly consume halophilic plants like Salosa, Acacia, and Artiplex. However, throughout time, the lactose concentration was found to be slightly different in several dromedary breeds around the world. The human digestive system easily absorbs sugar from milk (lactose). Camel milk's 3.5 to 4.5% lactose concentration is remarkably consistent between seasons and across hydrated and dehydrated environments (Sumaira et al. 2020; Seifu 2023).

2.4 Vitamins

Niacin and vitamin C are higher in camel milk than in cow milk. B1, B2, folic acid, and pantothenic acid are lacking in camel milk, although B6 and B12 are present. Compared to bovine milk, camel milk has 100–380 g/L of vitamin A (Yadav et al. 2015; Seifu 2023). Camel milk (250 mL) provides 15.5% of an adult's daily

Table 1 Camel milk's nutritional composition compared to those of other mammals, including humans

Nutrients	Camel milk	Cow milk	Goat Milk	Donkey milk	Sheep milk	Human milk
Fat (g/100mL)	4.5	3.5	3.5	0.3-1.8	6.1	3.4
Protein (g/100mL)	3.5	3.4	3.3	1.3-1.8	6.21	1.1
Lactose (g/100mL)	4.4	4.5	4.1	5.8-7.4	4.8	6.5
Minerals (g/100mL)	0.7	0.7	0.86	0.3-0.5	5.5	0.21
Solids-not-fat (g/100mL)	8.6	9.1	8.75	9.018	10.33	8.9
Total solids (g/100mL)	16.89	13.12	13.2	8.8-11.7	18.75	12.75
Cholesterol (mg/100g)	34.5	5	11	8.6	27	14
Calcium (g/100mL)	1.43	1.20	1.34	6.89	2.00	3.20
Phosphorus (g/100mL)	1.16	1.3	1.08	1.596	0.15	0.13
Saturated fatty acids (g/100mL)	51.9	67.73	70.42	67.6	65.17	46.60
Monounsaturated fatty acids (g/100mL)	39.60	27.3	25.67	15.80	24.29	43.55
Polyunsaturated fatty acids (g/100mL)	8.46	5.25	4.08	16.60	2.45	9.85
Water (%)	87-90	87	82.46-89.05	92.5	80.62	87.5

Sources: Yadav et al. (2015); Jilo and Tegegne (2016); Kumar et al. (2016); Abrhaley and Leta (2018); Faraz (2020); Sumaira et al. (2020); Bakry et al. (2021); Mohammadabadi and Faraz (2021)

recommended intake of cyanocobalamin, 10.50% of ascorbic acid, thiamine, and pyridoxine, 8.25% of riboflavin (B2), and 5.25% of vitamin A (Gul et al. 2015; Benmeziane–Derradji 2021; Muthukumaran et al. 2022).

2.5 Minerals

Camel milk has a mineral concentration between 0.60% and 0.90%. Zinc, iron, copper, and manganese are all present in higher concentrations in camel milk than in bovine milk. Like cow milk, camel milk has high concentrations of other essential minerals: calcium, magnesium, phosphorus, sodium, and potassium. Camel milk is rich in chloride because camels eat Atriplex and Acacia, which are generally high in salt (Ahamad et al. 2017; Sakandar et al. 2018; Solanki and Hati 2018). Another possible explanation for camel milk's salty flavour is that the milk of dehydrated camels has a higher chloride concentration due to a decrease in main milk components. Camel milk has a more elevated calcium-to-phosphorus ratio of 1.5:1 compared to 1.29:1 for cow's milk and 2.1:1 for human's milk. Because cow milk-based infant formula includes a lot of phosphates, which can cause hyperphosphatemia and low serum calcium, it is essential to keep the two in check (Gul et al. 2015; Sumaira et al. 2020; Bakry et al. 2021; Benmeziane–Derradji 2021; Seifu 2023).

2.6 A comparison of camel and cow milk

The physiology of camels and ruminants are very different, and so is the content of their milk. The fat in the milk is entirely homogenized polyunsaturated fatty acids, which gives the milk its characteristic smooth white appearance. Even though it contains 4.8% lactose, lactose intolerant people have no trouble digesting this milk sugar. Specific gravity-wise, camel milk is lighter than bovine milk (Mullaicharam 2014; Jilo and Tegegne 2016; Mohammadabadi and Faraz 2021; Saleena et al. 2022a; Saleena et al. 2022b). Table 1 provides the chemical makeup of camel milk compared to the milk of other ruminants and humans. Camel milk is distinct from the milk of other ruminants because it is low in protein, high in vitamin C, low in cholesterol, and high in minerals (sodium, potassium, iron, zinc, and magnesium) (Hailu et al. 2016; Sakandar et al. 2018; Bakry et al. 2021; Benmeziane–Derradji 2021). Camel milk had far more trace minerals than cow's milk. Cow milk provides more vitamins A, E, and B1 than camel milk. Alpha-carotene is absent from camel milk. Camels produce two to three times more vitamin C than cows (Kumar et al. 2016; Muthukumaran et al. 2022; Seifu 2023).

3 Potential healthful and therapeutic benefits of camel milk

Camel milk affects human cuisine, medicine, and nutrition, as depicted in Figure 2.

3.1 Immune-boosting potential of camel milk

Studies have revealed that drinking camel milk can boost one's immune system. Serum from camels has a unique group of immunoglobulins structurally distinct from other types of antibodies (Hailu et al. 2016; Sakandar et al. 2018). The milk

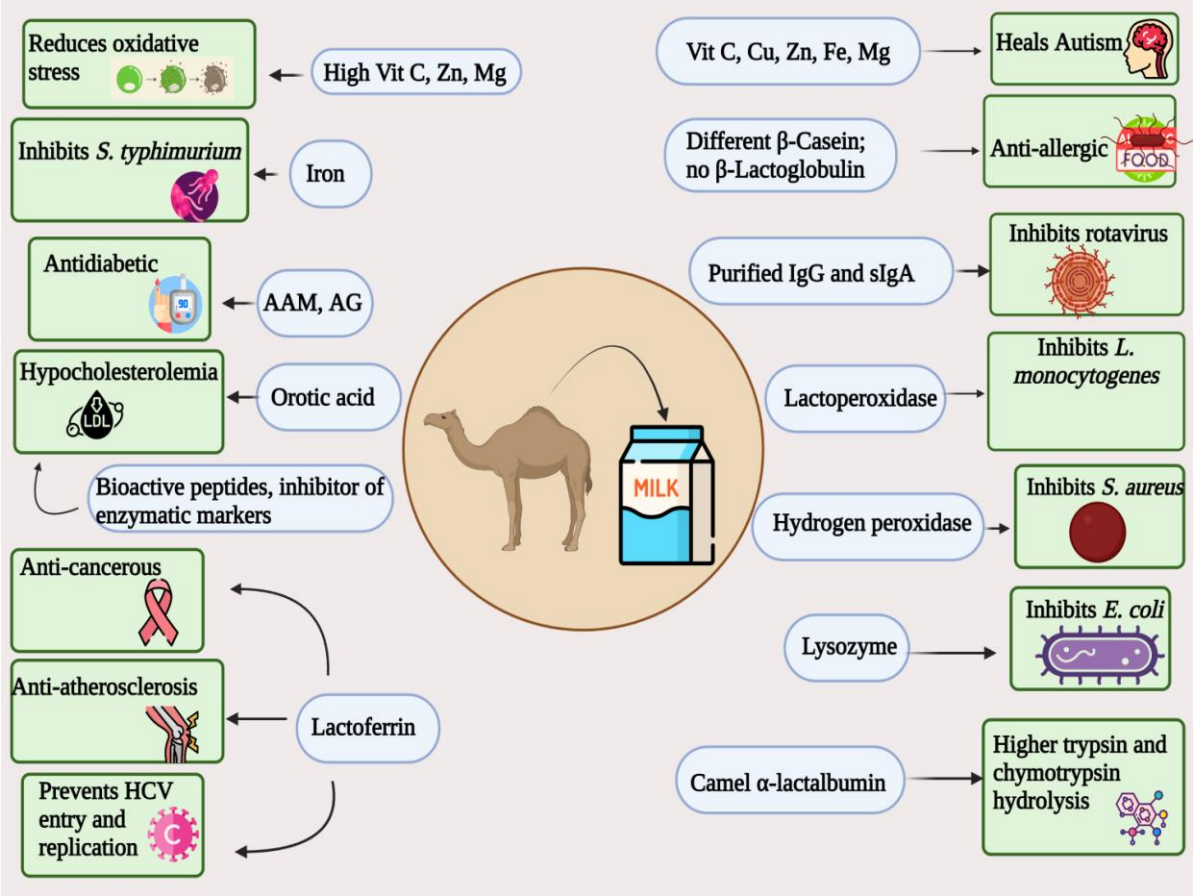

Figure 2 Camel milk has significant dietary, medicinal, and nutritional ramifications for humans
(Designed with Biorender premium software; https://app.biorender.com/)

proteins were shown to contain distinct structures, unlike those in cow or human milk, according to research by El-Agamy et al. (2009). In light of these findings, it may be important to account for the immunological differences between camel and cow's milk proteins when considering nutritional, physiological, and clinical considerations. As a result, when humans consume camel milk, the immune system will operate better. A stronger immune system means the human body will be healthier and less vulnerable to infection from bacteria and viruses. Immunoglobulins (Ig) unique to camels have been found in camel milk. These immunoglobulins have the same basic structure as their human counterparts but are just a tenth as large. So, unlike human immunoglobulins, these can identify and penetrate foreign illnesses, allowing the immune system to destroy them (Levy et al. 2013; Faraz 2020; Mohammadabadi and Faraz 2021; Seifu 2023).

Camel milk, compared to other types of milk, is richer in certain immune-boosting proteins. Camels' milk is rich in peptidoglycan recognition protein (PGRP). It has both antibacterial and immune-boosting properties for the host. Compared to lactoferrin found in cow's and goat's milk, camel's lactoferrin is more bioactive (Zhao et al. 2015; Chandran and Radhakrishnan 2019; Chandran et al. 2020). Antimicrobial and anti-invasion properties are provided by lactoferrin. One component of the body's innate immunological defences is an enzyme known as lysozyme, which attacks explicitly gram-positive bacteria (Chandran and Radhakrishnan 2019; Sumaira et al. 2020; Patange et al. 2021a). Lactoperoxidase kills gram-negative bacteria like *Escherichia coli* and Salmonella. The antibacterial enzyme N-acetyl-beta-D-glucosamidase in human milk in roughly the same concentrations (Ahamad et al. 2017).

3.2 Anti-microbial potential of camel milk

Camels' milk contains antimicrobial compounds such as hydrogen peroxide, lysozyme, lactoperoxidase, lactoferrin, and immunoglobulins. *Listeria monocytogenes*, *Staphylococcus aureus*, *E. coli*, and *Salmonella typhimurium* are susceptible to camel milk's antibacterial properties (Solanki and Hati 2018; Mohammadabadi and Faraz 2021; Seifu 2023). One possible explanation for camel milk's antimicrobial properties is that it contains lactoperoxidase, hydrogen peroxide, and lysozyme.

Lactoferrin in camel milk suppressed *S. typhimurium* growth by binding iron and rendering it inaccessible to the bacteria (Mullaicharam 2014; Hailu et al. 2016; Ahamad et al. 2017; Chandran and Rahakrishnan 2019).

Rotaviruses cause most cases of non-bacterial gastroenteritis in newborns. Camel milk and colostrum were shown to have the highest anti-rotavirus activity. Raw camel milk appears to suppress human rotavirus. These results shed light on why camel herders have used camel milk as a treatment for diarrhea (Yasin et al. 2015). Elbarbary et al. (2014) revealed that camel and bovine whey proteins might be used to fight the virus. They also found goat milk has the second-best anti-rotaviral efficacy after desert camel milk whey proteins in treating rotavirus infection in mice. Shubat, a Kazakh fermented camel milk drink, inhibits orthomyxoviruses and paramyxoviruses (El-Fakharany et al. 2008). Shubat's antiviral properties may stem from the lactic acid bacteria and yeasts that contributed to its production and its metabolic by-products, including sialic conjugates (Faraz, 2020). Redwan and Tabll (2007) investigated whether or not camel milk proteins may prevent the hepatitis C virus (HCV) from entering and replicating inside cells. Camel lactoferrin blocked HCV entrance and replication in human peripheral blood mononuclear cells and human hepatoma HepG2 cell lines in vitro.

3.3 Anti-cancer potential of camel milk

Drinking a mixture of camel milk and camel pee (the "drinking cure") has been shown in multiple tests to prevent cancer growth. Successful single-dose testing in mice has prompted researchers to proceed with human studies. A high success rate in treating blood cancer (leukemia) was found. The medicine shows promise as a treatment for various cancers, including those of the lung, liver, and breast (Gul et al. 2015; Zhao et al. 2015; Mohammadabadi and Faraz 2021). Korashy et al. (2012) discovered that camel milk reduced HepG2 and MCF7 cell proliferation via oxidative stress-mediated mechanisms and death receptor stimulation. The extrinsic and intrinsic apoptotic pathways were activated by camel milk, which the researchers believe is responsible for reducing survival and proliferation in HepG2 and MCF7 cells. For the first time, camel milk lactoferrin was tested for its ability to prevent DNA damage, free radical generation, and HCT-116 cell growth in vitro.

3.4 Camel milk for diet and milk allergy

It has been documented by Shabo and Yagil (2005) that food allergies in children are frequently life-threatening and can cause anaphylactic reactions. Consumption of bovine milk and milk derivatives is particularly problematic for those sensitive to milk proteins. Anaphylaxis is a potentially fatal reaction brought on by some types of food allergies. Allergic reactions can be broken down into three broad categories. In the first category, symptoms, including hives, facial swelling, and anaphylaxis, can appear as soon as 45 minutes after ingesting cow's milk. Symptoms like weakness, nausea, and diarrhea appear after 45 minutes to 20 hours with the second type. The third kind is delayed and includes reactions in the skin, lungs, and intestines. The life-threatening allergic reaction known as anaphylaxis can strike any system in the body (including the skin, respiratory system, digestive system, and cardiovascular system) and can spread quickly. Many children develop milk allergies because cow's milk contains beta-lactoglobulin and beta-casein, two potent allergens (Kumar et al. 2021; Muthukumaran et al. 2022).

Children with food allergies have been helped by drinking camel milk. Milk and dairy products are well-documented allergens (Zhao et al. 2015). There do not appear to be any immunological cross-reactions between the proteins in camel milk and bovine milk, as evidenced by research by El-Agamy et al. (2009). Restani et al. (1999) and El-Agamy et al. (2009) found that cow's milk-allergic children's IgE only unreacted with camel milk. This can be traced back to the underlying evolutionary distinctions between camels and ruminants.

Camel milk has the following qualities, which make its proteins very effective for preventing and treating food allergies. Camel milk lacks beta-lactoglobulin. Camel milk beta-casein is unusual. Like human breast milk, Camel milk includes immunoglobulins that reduce newborn allergic responses and promote food digestion (Restani et al. 2009; Solanki and Hati 2018; Kumar et al. 2021).

Shabo et al. (2005) examined how camel milk helped eight children with life-threatening reactions to other foods. For two weeks, the kids were fed nothing but camel milk. Within 24 hours of starting treatment, the youngsters would have shown considerable improvement, and within four days, all of their problems would have vanished. All eight cases improved immediately, and the youngsters could digest more meals (Faraz 2020). It is thought that the immunoglobulins in camel milk help alleviate allergy symptoms in kids. Kaskous (2009) found the same finding in his research. Thirty-five youngsters (23 boys and 12 girls) between the ages of 4 and 126 months were used. Camel milk treats food-allergic youngsters 80% of the time. Camel's milk works for kids with cow's milk allergies (Bakry et al. 2021; Benmeziane–Derradji 2021). The lack of immunological resemblance between camel and bovine milk proteins can be critical nutritional determinant for children allergic to cow milk, according to El-Agamy et al. (2009). The data suggests that more research is needed to confirm that camel milk helps treat allergies.

3.5 Potential of camel milk against gastro-intestinal disorders

Camel milk's abundant anti-inflammatory proteins have been proven to help with stomach pain. As a result of its vitamin-rich and mono-

and polyunsaturated fatty acid-rich makeup, glucose metabolism is enhanced. Further research revealed that the protein in fermented camel milk is more accessible to break down due to the abundance of Angiotensin I-converting enzyme (ACE) (Solanki and Hati 2018). There have been recent studies on the benefits of camel milk for the digestive system, and the results have shown that even youngsters who experience 20 episodes of diarrhea per day can be treated by drinking camel milk. Since camel milk is high in antibodies that combat rotavirus, it can be given to young infants who have developed diarrhea due to eating contaminated food (Sumaira et al. 2020; Muthukumaran et al. 2022).

3.6 Anti-aging potential of camel milk

Camel milk produces antioxidant and ACE-inhibiting peptides, according to Jilo and Tegegne (2016). Camel milk's strong vitamin C content maintains collagen, which fights ageing. Camel milk's vitamin C content gives it anti-inflammatory and tissue-protective properties. Vitamin C is a powerful antioxidant and vital water-soluble vitamin. Vitamin C is needed to build collagen, providing skin with suppleness and strength. Collagen is a protein that aids in the maintenance of healthy skin, cartilage, and joints (Salami et al. 2011; Sakandar et al. 2018). Repair is aided by vitamin C because it increases the skin's structural support and resilience. Antioxidant vitamin C helps prevent premature ageing and skin dryness caused by free radicals. Furthermore, lactoferrin, a protein capable of chelating iron, is more abundant in camel milk. People with Arthritis see improvement due to this protein's ability to clear excess free iron from their joints (Mihic et al. 2016; Bakry et al. 2021). Alpha-lactalbumin and beta-casein in camel milk suppress or slow the generation of reactive oxygen species, peroxyl and hydroxyl radicals, superoxide anions and nitric oxide (Behrouz et al. 2022).

3.7 Potential of camel milk against autoimmune disorders

In autoimmune illnesses, B lymphocytes produce antibodies that wrongly target self-antigens (tissues of the body) rather than foreign antigens. There are times when these autoantibodies can cause tissue damage or dysfunction. The symptoms of autoimmune disorders might vary widely. For instance, in multiple sclerosis, the immune system attacks the brain; Crohn's disease attacks the digestive system. However, in other disorders like systemic lupus erythematosus (SLE), different organs and tissues may be afflicted in different people. Although a person with an autoimmune disease may appear to be in good health, they will likely need ongoing treatment and monitoring for the rest of their lives. Few autoimmune illnesses can be treated or "eliminated" with therapy at present. With the proper treatment, many patients with these disorders can lead normal lives (Roda et al. 2020).

Camel milk has been shown through years of study to be effective in managing and in some cases curing autoimmune disorders. Camel milk's ability to effectively manage autoimmune illnesses is grounded in its multiple therapeutic benefits (Faraz 2020; Benmeziane–Derradji 2021). It has been reported by El-Agamy et al. (2009) that tiny immunoglobulins can be transferred from camel milk into human blood due to the camel's superior immune system. Due to the presence of immunoglobulins in camel milk throughout lactation, it can be used as an effective aid in the fight against autoimmune illnesses and the resulting sadness. Due to their diminutive size, camel immunoglobulins are readily available in camel milk to treat autoimmune disorders (Sumaira et al. 2020). In contrast to other mammals, camels have an incredible immune system, as Faraz (2020) detailed. Human antibodies fall into five categories: IgG, IgM, IgA, IgD, and IgE. Monomers, the smallest possible form of an antibody, take the shape of a "Y," and include IgG, IgD, and IgE. IgM is a pentamer, while IgA is a dimer. Two heavy chains and two light chains make up a monomer's total number of four glycoprotein chains. Immunoglobulins are large molecules that have trouble penetrating antigens. On the other hand, Camel immunoglobulins are small and lack short chains, making them effective against antigens (Mihic et al. 2016; Solanki and Hati 2018; Sumaira et al. 2020; Benmeziane–Derradji 2021).

According to Muyldermans et al. (2001), the size of the antibodies represents a pivotal setback in advancing human immunotherapy. Antibodies with a larger size will miss their mark. Antibodies in camels are a tenth the size of those in humans (natural nanobodies). Camel milk immunoglobulins can access and interact with active sites, allowing them to penetrate dense tissues in search of antigens because of their minimal complexity, high affinity, and specificity. The most important consideration is that standard treatments for autoimmune illnesses rely on suppressing the immune system, whereas camel milk immunoglobulins stimulate the immune system and restore its health (Faraz 2020).

3.8 Anti-diabetic potential of camel milk

The use of camel milk in the treatment of diabetes has been documented. The metabolic disorder known as diabetes mellitus leads to elevated blood sugar levels. Type 1 diabetes develops when the body stops producing enough insulin. The beta cells are responsible for making insulin die off in the pancreas. Classical insulin-deficient diabetes typically appears in early infancy or adolescence (Shori 2015; Benmeziane–Derradji 2021). Some scientists have hypothesized that the autoimmune death of human Langerhans islets cells, and consequently Type-1 diabetes, was started by a cross-reaction with cow's milk proteins. Research on diabetic rats also shows that after 30 days of drinking camel milk, the animals' blood sugar levels return to normal, while research on diabetic rabbits shows that camel milk is more successful than solitary insulin treatment and prevents the produced oxidative stress. Alloxan-induced diabetic dogs had a similar outcome (Levy et al. 2013; Yassin et al. 2015).

El-Sayed et al. (2011) observed that camel milk significantly reduced insulin needs. After 12 weeks of treatment, daily insulin doses can be reduced by as much as 66% (20 units/day), according to a study of 50 patients with Type 1 diabetes conducted in Yemen. The study's authors attribute these results to camel milk and insulin. This research has also demonstrated that camel milk helps diabetic rats' kidneys and liver.

Compared to bovine milk, camels' milk has significantly higher amounts of insulin (58.67±2.01 UL vs 17.01±0.96 UL) plus insulin-like growth factor-I (which is not degraded in the stomach) than cow's milk. Only camel milk makes it through the stomach acid and into the small intestine, where it can be absorbed. When given orally to diabetic individuals, insulin is typically ineffective. However, camel milk may provide an exception (Muthukumaran et al. 2022). Camel milk insulin has a unique feature that facilitates its uptake into circulation and reduces resistance to proteolysis, making it a superior alternative to insulin from other sources. Nanoparticles (lipid vesicles) enclosing camel insulin facilitate its absorption by the body and subsequent distribution (Sumaira et al. 2020). Camel milk's ability to fight diabetes stems from its non-fatal extra nutrients. Camel insulin can discriminate and circumvent mucosal barriers on its way to the bloodstream; however, this is not reflected in its sequencing or predicted digestion pattern (Al Kanhal 2010; Kumar et al. 2016).

The beta cells in the pancreas can benefit from camel milk's insulin-like action, regulatory, and immunomodulatory properties (Sumaira et al. 2020). Camel milk reduces insulin demand, blood glucose levels, diabetic sequelae like liver and renal illness, high cholesterol, low oxidative stress, and slow wound healing, according to Shori (2015). It appears that more research on the efficacy of camel milk as a diabetes treatment is required. Consumption of camel milk has shown positive effects in tests of people with lactose intolerance, and 23 out of 25 patients reported a positive reaction to the beverage. Hence, those who have a lactose intolerance should know that camel milk is a possibility (Mihic et al. 2016; Solanki and Hati 2018).

Patients with lactose intolerance may find camel milk easy to digest, as stated by Mullaicharam (2014). Camel milk has a higher percentage of the amino acid L-Lactate than cow milk, which is rich in the fatty acid D-Lactate, which may explain why camel milk consumption leads to a decreased incidence of lactose intolerance.

3.9 Inhibiting effect of camel milk on angiotensin I-converting enzyme

Many dietary proteins, including milk proteins, include blood pressure-lowering ACE-inhibitory peptides. Also present in fermented camel milk are the peptides as mentioned above. Probiotic bacteria's ability to hydrolyze milk protein components has been shown to increase the number of peptides and free amino acids, both of which are required to develop probiotic bacteria (Bakry et al. 2021). ACE-inhibitory peptides in camel milk have been isolated using *Lactobacillus helveticus* 130B4, and the sequence is documented to be Ala-Ile-Pro-Pro-Lys-Lys-Asn-Gln-Asp (Abrhaley and Leta 2018; Benmeziane–Derradji 2021; Muthukumaran et al. 2022).

3.10 Defending against hepatitis C and B using camel milk

There is currently no cure for the hepatitis C virus (HCV), despite its widespread distribution. Egyptian patients frequently rely on traditional treatments, such as lactoferrin protein-rich camel milk, to treat their illnesses (Redwan and Tabll 2007). In place of the primary biotechnology treatment used to treat HCV infection, camel milk has taken place because of its slightly higher lactoferrin concentrations. Camel milk IgGs recognized HCV peptides with a substantial titer, unlike human IgGs, which did not. Independent researchers corroborated this. In addition, camel milk boosts the cellular immune response in chronic hepatitis B patients, which inhibits viral DNA replication and supports healing (Abrhaley and Leta 2018; Ibrahim et al. 2018; Bakry et al. 2021).

3.11 Blood cholesterol-lowering effects of camel milk

Blood cholesterol levels are considered a key risk factor for cardiovascular disease. Research in mice shows that lowering cholesterol levels is one of the side effects of consuming fermented camel milk. Although the exact mechanism by which camel milk reduces cholesterol levels in rats and humans is unknown, several hypotheses have been proposed. Orotic acid, a nucleic acid intermediary, and bioactive peptides from camel milk decrease cholesterol (Abrhaley and Leta 2018; Benmeziane–Derradji 2021; Bakry et al. 2021). The cholesterol levels of obese male Wistar rats were dramatically reduced when fed camel milk fermented with red quinoa flour (Al-Anazi et al. 2022).

3.12 Camel milk against heavy metal toxicity

Camel milk's antioxidant vitamins, magnesium, and zinc may lessen cadmium's effects on red blood cells by reducing free radicals and oxidative stress. Total erythrocytes, haemoglobin, and haematocrit increased following 30 days of camel milk consumption, mitigating aluminum's adverse effects. In lead acetate-poisoned rats, camel milk restored hepatic enzyme function (Hailu et al. 2016; Ahamad et al. 2017; Abrhaley and Leta 2018). Camel milk protects male albino rats from lead acetate and fipronil's hepatotoxic and nephrotoxic effects (Abdel-Mobdy et al. 2023). Al-Asmari et al. (2017) observed that camel milk reduced oxidative stress and inflammation to protect and regenerate hepatocyte membranes. After radiation exposure, camel milk improved rats' liver function, alanine, aspartate, and glutathione levels.

3.13 Cosmetic values of camel milk and its application in skin disease treatment

The presence of alpha-hydroxyl acids in camel milk gives it a cosmetic effect, making it great for reducing the appearance of wrinkles and fine lines. By dissolving carbohydrates, which are typically employed to bind skin cells together, alpha-hydroxyl acids facilitate the removal of the horny, dead skin layer (epidermis). New, more pliable and transparent cells can be revealed with this method. As alpha-hydroxyl acids reduce the thickness of the skin's outermost layer—the epidermis—while simultaneously increasing the thickness of the skin's thicker, deeper layer—the dermis—they help get rid of wrinkles, age spots, and dry skin. It has also been found that the liposomes found in camel milk can be used as a possible anti-ageing cosmetic ingredient (Hailu et al. 2016; Mihic et al. 2016). Essential vitamins and minerals for skin health are found in the component. Lanolin and other emollients in milk relax and soothe the skin, treating acne, psoriasis, eczema and dermatitis and preserving a healthy and appealing appearance. In addition, the alpha-hydroxyl acids found in camel milk help soften the skin, keep it supple and smooth, and even work to reduce the appearance of fine lines and wrinkles (Khalesi et al. 2017).

An experiment using 40% raw camel milk for topical application yielded good results. Camel milk crème was applied twice daily for four weeks to 20 patients (10 men and 10 women) with mild to moderate psoriasis. The patients' ages ranged from 6 to 72 years. Those affected felt cooler and experienced less itching and pain. There was a notable improvement in the skin's redness and dryness (Yadav et al. 2015).

3.14 Camel milk for tuberculosis sufferers

Mycobacterium, typically *Mycobacterium tuberculosis*, is the causative agent in most tuberculosis cases. People with low incomes are disproportionately affected by tuberculosis, a chronic disease that causes severe weight loss. A person infected with tuberculosis bacillus is at a higher risk of contracting other diseases because the bacillus weakens the body's immune defence mechanism (Gul et al. 2015). World Health Organization (WHO) estimates that between 16 and 20 million people worldwide have tuberculosis, with an additional 7 million to 8 million new cases diagnosed yearly (Mohammadabadi and Faraz 2021).

Mycobacterium bacteria may develop resistance to therapy if the patient does not take their medication as directed. Due to this, the medicine is no longer effective against the bacterium. Multidrug-resistant tuberculosis (MDR-TB) describes cases in which the germs have developed resistance to multiple anti-tuberculosis medications. Multidrug-resistant tuberculosis is rising as an endemic infection in developing and developed nations. There is an immediate need for novel methods of identifying and treating tuberculosis patients, as the disease has emerged as a major threat to public health (Mohammadabadi and Faraz 2021; Muthukumaran et al. 2022).

Indian researchers have shown that individuals with MDR-TB who consume camel milk show statistically and clinically substantial improvements in their symptom observed values. As a result, in the experimental group, camel milk was given as a dietary supplement to each participant at a rate of 1 litre per day. No more coughing, sputtering, or chest pain was experienced. The group given camel milk as a supplement reported greater hunger and weight gain. Improvements in patients who drank more camel milk have not yet been studied to determine if and how they will persist (Yadav et al. 2015; Yassin et al. 2015).

Alwan and Farhuni (2000) reported that camel milk effectively treats TB, especially in patients with MDR-TB. Mal et al. (2000) examined camel milk's multidrug resistance benefits. Fourteen male patients with tuberculosis for an average of seven years without therapy were split into two groups, T1 and T0, with eight and six patients, respectively. At 1 kg per day, raw camel milk was added to the diets of the T1 patients, while dairy milk was provided to the T0 patients for a full ten weeks. Both groups were fed regularly and were given essentially identical care. Clinical signs and symptoms, bacterial counts, radiographic images, hemoglobin levels, immunoglobulin titers, results of the mantoux test, and body weight were documented before and after the trial. The experiment concluded that camel milk supplementation was beneficial for tuberculosis patients. According to research by Mal et al. (2000), camel milk may help boost the immune system since it includes protective proteins. Camel milk proteins have antimicrobial characteristics that kill the Mycobacterium bacteria that cause tuberculosis (Bakry et al. 2021).

3.15 Anti-autism benefits of camel milk

The opioid peptides are blamed for supporting autism. The pathophysiology of autism may involve an overabundance of endogenous or exogenous opioid peptides, such as those produced from dietary (cow's milk) proteins. Some patients have an insufficient intestinal metabolization of casein proteins. Therefore, casein-derived short neuroactive peptides like beta-casomorphins are generated. Beta-casomorphin has been suspected of being an autistic risk factor (Hailu et al. 2016; Ahamad et al. 2017).

As an immunological disorder, autism typically affects the digestive tract rather than the brain. Intestinal responses start with diarrhea and a loss of appetite. Camel milk has been shown to have a therapeutic impact on autism because it lacks the two caseins found in cow milk linked to autistic symptoms (Ismail et al. 2022). Shabo and Yagil (2005) and Yagil (2013) found that camel milk

was effective in treating autism in the following situations: After 40 days of consuming camel milk, the autistic symptoms of a 4-year-old girl completely vanished; A 30-day course of camel milk therapy cured autism in a boy aged 15; Those aged 21 were found to be calmer and less destructive after drinking camel milk for two weeks in a facility for autistic youngsters. Children under 10 years reaped the most significant benefits, while those aged 15 and up also saw significant improvements.

In terms of the outcomes observed, camel milk considerably enhanced clinical measures of autism severity. Al-Ayadhi and Elamin's (2013) study on the impact of camel milk on oxidative stress in autistic children provided conclusive evidence that milk has a significant role in improving the behaviour of autistic children by decreasing oxidative stress. Wernery et al. (2012) found similar benefits for autistic children after giving them camel milk, including improved social functioning, reduced hyperactivity, increased alertness, and regular bowel routines.

3.16 Treatment for Crohn's disease using camel milk

Crohn's disease, often called Crohn syndrome or regional enteritis, is an inflammatory bowel illness that can manifest in a broad range of ways throughout the gastrointestinal tract, from the mouth to the genitourinary system. However, it can also create issues outside the digestive system, such as fatigue, arthritis, eye inflammation, skin rashes, and lack of attention, in addition to the usual symptoms of abdominal discomfort, diarrhoea, vomiting, or weight loss. Crohn's disease develops in those genetically predisposed to it due to an interplay between environmental, immunological, and bacterial factors. A chronic inflammatory condition develops as a result, with the immune system mistakenly attacking the gastrointestinal tract in response to microbial antigens.

Mycobacterium avium subspecies paratuberculosis (MAP) is transmitted through cow milk and is resistant to pasteurization. An autoimmune reaction occurs once MAP penetrates the mucosa as saprophytes and becomes active only when the host is under extreme stress. Crohn's disease is incurable, and even remission may not be sustainable. In cases where remission is achievable, medicines, lifestyle and nutritional adjustments, changes in eating patterns (eating smaller quantities more often), stress reduction, moderate activity, and exercise can be used to avoid relapse and manage symptoms (Ibrahim et al. 2018; Benmeziane–Derradji 2021; Muthukumaran et al. 2022). According to Shabo et al. (2008), camel milk is an excellent treatment for Crohn's disease. Camel milk's potent bactericide properties combined with peptidoglycan recognition protein (PGRP) have a rapid and beneficial effect on the healing process because this bacterium is in the family that causes tuberculosis. Immunoglobulins can restore the immune system to normalcy (Hailu et al. 2016; Sakandar et al. 2018).

4 Functionality of camel milk's bioactive peptides

Short protein fragments (2-30 amino acids) having biological activity can be formed naturally by digestion or manufactured in the lab by food processing, fermentation, or enzymatic hydrolysis. Milk proteins may provide bioactive peptides for food preservation and wellness. These peptides have antioxidant, angiotensin-converting enzyme-inhibiting, antithrombotic, antibacterial, immunomodulatory, ion-binding, and opioid-antagonist properties (Al Kanhal 2010; Ibrahim et al. 2018; Benmeziane–Derradji 2021). Kumar et al. (2016) looked into the digestion of camel beta-lactalbumin with enzymes and its antioxidant properties. Camel alpha-lactalbumin is more susceptible to hydrolysis by trypsin and chymotrypsin but less so by pepsin than bovine alpha-lactalbumin. Due to their different structures and amino acid sequences, camel alpha-lactalbumin and bovine alpha-lactalbumin had different levels of antioxidant activity (Salami et al. 2011; Mullaicharam 2014; Hailu et al. 2016). Khalesi et al. (2017) found that digestive enzymes boosted camel whole casein and beta-casein's antioxidant and ACE-inhibitory effects. Hydrolysis with pepsin alone, as well as pepsin followed by trypsinolysis and chymotrypsinolysis, revealed strong ACE-inhibitory actions in both camel whole casein and beta-casein. Hydrolysis of camel beta-casein with chymotrypsin revealed strong antioxidant action (Ibrahim et al. 2018).

Jrad et al. (2014a) and Jrad et al. (2014b) examined how sequential in vitro hydrolysis by pepsin and pancreatin affected camel milk casein's free radical-scavenging activity. They found that the casein peptides outperformed other scavengers. Peptide fractions from fermented bovine and camel milk were investigated for ACE-inhibitory and antioxidant activities. Camels produce more ACE-inhibiting and antioxidant milk than cows. The 5–10 kDa peptide fractions are the best radical scavengers in fermented milk. TEAC values for 5-10 kDa peptides in fermented bovine and camel milk were 110.41-745.35 M and 844.08-1737.88 M, respectively.

5 Availability of camel milk

Before going on the markets in Gulf countries, this camel milk undergoes a 15-second pasteurization process at 74°C. According to Dubai municipal regulations, pasteurized camel milk's shelf life is limited to 5 days. Pasteurized camel milk has been demonstrated to keep well in the lab for up to 15 days when refrigerated. Milk (produced by Natural Product Company) and milk powder (from camel milk) are two of the camel-related products sold in the Indian market by Sara International company (Yadav et al. 2015; Ismail et al. 2022). Several components in camel milk were shown to be more heat resistant than those in cow milk, as shown by research by Wernery (2006). When heated from room temperature to 72°C for 5 minutes, the value of many vitamins and hormones in raw milk was reduced by only 5 to 8%. One possible way to tell if camel milk has been pasteurized is to test it for the gamma-

glutamyl transaminase (GGT) enzyme. Camel milk retains its alkaline phosphatase (ALP) indicator enzyme, whereas cow milk's ALP is destroyed at 72°C during pasteurization. According to Wernery (2006), GGT is eliminated in camel milk between 10 and 20 minutes after being heated to 72°C, making it an ideal heat inactivation component.

6 Challenges and opportunities

Considering escalating issues like climate change and shortage of food, the sustainable food sector that produces nutritious camel milk with multiple health benefits may turn out to be a meal of the future. While camel milk output has increased, only a small fraction of the milk produced is consumed (Mullaicharam 2014; Hailu et al. 2016). Recent research has looked at the challenges the technology presents to turn it into various items with monetary worth (Ismail et al. 2022; Muthukumaran et al. 2022). To improve upon the current technologies, based on the processing of bovine milk solely, extensive research into the basic chemical makeup of the components of camel milk is required. More study into processing and preservation methods for camel milk is warranted to increase its global availability and acceptance. Further research into the chemistry of camel milk proteins and the modifications those proteins undergo as a result of various processing methods is, without a doubt, warranted. These alterations greatly aid the development of new camel milk products (Sumaira et al. 2020). Camel milk is an underutilized dairy supply, and the food industry may take advantage of this by processing it so that people can enjoy the health advantages. Sustainable camel milk production and strategies for preserving and diversifying processed camel milk products are also required for products generated from camel milk to be competitive in international markets. Camel milk has been praised for its purported health benefits, but further studies are needed to support these claims. This proof can help the food and pharmaceutical industries see the potential of camel milk for creating new functional and nutraceutical products (Muthukumaran et al. 2022).

Conclusions

Regarding both macro- and micronutrient content, camel milk is an excellent food choice. Camel milk's chemistry shifts with the lactation cycle, the camel's breed, and the time of year. The unique chemical composition of camel milk limits its adaptability and reduces its organoleptic appeal. Fermentation, in particular, appears to be a practical and generally accepted method for transforming camel milk into a valuable product. Antimicrobial properties in camel milk and its by-products may be due to lysozyme and lactoferrin, two milk components, and a large diversity of beneficial microorganisms. Bioactive peptides are thought to be responsible for the anti-diabetic properties of camel milk. Several enzymatic markers are inhibited in *in-vitro* experiments, and *in-vivo* research has identified other processes implicated in camel milk's antidiabetic characteristics. Researchers have shown that the proteins in camel milk have anticancer properties (whey, lactoferrin and casein). More comprehensive research into camel's therapeutic potential is required to substantiate the growing interest in the animal.

Given the abundance of bioactive compounds found in camel milk, it is used in treating various severe ailments in various regions of the world. Camel milk has been used to cure different conditions, including gastrointestinal illnesses, hepatitis B and C, diabetes, autism, psoriasis, food allergies, high blood cholesterol, immune system boosting, cancer, tuberculosis, etc. There has been a recent uptick in the number of peer-reviewed studies emphasizing the unique healing properties of camel milk. The biological elements in camel milk can even help the patient, but only if it is ingested raw and without any pathogens shortly after it has been produced. It is possible that this milk will also be made available following a thorough machine milking.

Camel milk and other camel products are a healthy food option for persons living in dry or semiarid climates. Camel milk output has risen recently and is associated with increasing consumer demand. Camel milk has been found to have various unique qualities that set it apart from milk from other animals, such as bovine milk. According to certain investigations, the health benefits associated with drinking either fresh or fermented camel milk may differ depending on the presence or absence of bioactive components. More studies are needed to confirm these purported health advantages of camel milk and boost its popularity.

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