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Summary

Camel's milk is an important part of staple diet in several parts of the world, particularly in the arid and semi-arid zones. The nutraceutical and therapeutic properties of camel milk are associated with its unique compositional and biomolecular characteristics that provide particular health benefits to the consumer depending on their bioactive properties. Camel milk is being used for the treatment of various ailments, since time immemorial, and the scientific evidences also support that the camel milk possesses antiallergic, anti-ulcerogenic, antibacterial, antiviral, antiparasitic, antihyperglycemic, anticholesterolemic, antihypertensive, anticancerous effects etc. Camel's milk is rich in health-beneficial substances, such as bioactive peptides, lactoferrin, micro-minerals, antioxidant vitamins, polyunsaturated fatty acids, etc. These substances could help in the treatment of some important human diseases like autism, tuberculosis, asthma, gastrointestinal diseases, and jaundice. A higher concentration of insulin has proven therapeutic efficacy against type1 diabetes. Correlation and validation of biomolecules having pharmaceutical properties will pave the way for camel milk as a nutraceutical adjuvant in many human ailments.

Introduction

Modern-day camel regains its importance due to its recognition as 'Diary Camel' that manufactures 'White Gold' for the desert. The milk is a staple food for desert nomad tribes and it plays an essential role in their survival during long journeys in the desert and in periods of scarcity/natural calamities, e.g. continuous years of drought and scarcity. Camel milk and milk products are good source of nutrition and income for people living in dessert. Concurrently, camel has gained its importance due to its dairy traits and milk production potential. It serves as a biomedicine for potential therapeutic application in many health problems throughout the world.

Camel milk is originally an asset of camel nomadic societies such as the Bedouin of Arabia, the Somali, Gabbra, Rendille and Afar in the Horn of Africa, the Tuareg in the Sahara, the Baluch in Pakistan, the Raika and Fakirani Jat in India and many others. Rebari community believes “It is ordained by Lord Shiva to take care of camels, never harm it or kill it or sell its milk”. Over the years, use of camel milk, which has been restricted to few communities raising camel is now being outreached because of its bio-functional/nutraceutical properties.

Camel milk: Physical and organoleptic attributes

Camel milk is generally opaque white and low in carotene, has a sweet and sharp taste, but sometimes can also be salty. The taste generally depends on the type of fodder and availability of drinking water (Sahoo, 2020). It is less viscous than bovine milk (Khaskheli et al., 2005) and its viscosity at 20°C is 1.72 mPa.s compared to bovine milk 2.04 mPa.s (Kherouatou et al., 2003). The water content in camel milk varies from 87 to 91% and an inverse relationship exists between total solids in camel milk and water intake by the camel (Haddadin et al., 2008; Khalesi et al., 2017). The shelf-life of raw camel milk is 8-9 h at 37 °C and more than a week at 4-6 °C (Singh and Sahoo, 2021). Lactoperoxidase system in fresh camel milk is found to be effective in preserving raw camel milk up to 18-20 h at 37°C (Raghvendar et al., 2001; 2004; 2006a). The pH of fresh camel milk ranges from 6.4 to 6.7 and the density from 1.026 to 1.035, and both are lower than the bovine milk. Compared to cow's milk, camel's milk sours very slowly and can be kept longer without refrigeration (Farah, 2011). It remains stable for a longer time at room temperature compared with milk from other animals, e.g. bovine milk took 3 h to turn sour (to reach a pH of 5.7) at 30 °C, while camel milk took longer time of 8 h to reach a pH of 5.8 at the same temperature. According to Mal and Pathak (2010), pure and milk diluted with water (1:1) can be stored for 8 and 10 h, respectively, at room temperature. In another observation, bovine milk took 48 h to completely turn sour and coagulate, whereas camel milk turned sour after 5 days and did not coagulate over 7 days at 30 °C, as did bovine milk (Yagil et al., 1984). Pasteurized camel milk can last for more than 10 days at 4 °C (Wernery, 2008; Ansari et al., 2020). The heat coagulation time (HCT) of camel milk is found lowest at pH 6.0 and highest at pH 6.8 and then stable after pH 7.2 to 7.6 (Raghvendar et al., 2006a). The freezing point is between -0.57 °C and -0.61 °C.

Continually, the demand for camel milk and meat products have been augmented both locally and globally with products ranging from milk and its derivatives to nutraceuticals and therapeutics and extending to beauty products and essentials. Most of the camel milk is consumed as fresh milk. It is a unique source of nutrients and supports nearly 30% of the annual calorie in the diet of pastoral community (Farah et al., 1993). Now-a-days, pasteurized camel milk is the principal processed product that can be kept refrigerated (4°C) for 10 days. Besides, various new dairy products such as, flavoured milk, lassie, butter, yogurt, cheese, chocolate, ghee, ice-cream, kulfi, peda, kheer, etc have been processed (Fig. 1) with different organoleptic properties and long-term storage capacity for augmenting consumer acceptability and marketing so as to reach out people who need mining its nutraceutical properties. Various other natural products are also

tried and prescribed as therapeutic aid to control the progression of diseases and metabolic disorders.

Fig. 1. Different camel milk processed products

Chemical constituents

Camel milk is popularly referred as 'The White Gold of the Desert'. There are considerable compositional differences in milk from camel and other species (Table 1),

Table 1. Composition of milk in different animal species

Constituents	Camel	Cattle	Buffalo	Sheep	Goat	Human
Nutrient composition (g/100 g)						
Fat	2.8	4.0	7.0	6.5	3.5	4.0
Protein	3.3	3.5	5.2	5.3	3.7	2.7
Lactose	3.8	4.8	4.8	4.8	4.5	5.1
Minerals	0.79	0.71	0.98	0.93	0.78	0.31
Solids-not-fat	7.7	9.0	11.0	11.0	9.0	8.1
Total solids	10.5	13.0	18.0	17.5	12.5	12.1
Special characteristics						
Insulin (U/L)	58.7	17.0	16.2	30.0	35.3	60.2
Lactoferin (mg/L)	220	110	332	70	120	200
Lysozyme (mg/mL)	288	13	60	80	23	400
Cholesterol (mg/dL)	3.40	14.0	55.0	52.0	21.0	20.0
Immunoglobulin G (mg/mL)	1.64	0.67	0.63	0.55	0.70	0.86
Saturated fatty acids (g/100g)	2.40	2.45	3.75	3.70	2.09	1.80
Monounsaturated fatty acids (g/100g)	1.40	1.40	2.50	2.40	1.26	1.60
Polyunsaturated fatty acids (g/100g)	0.50	0.13	0.22	0.22	0.09	0.50

Source: Khalesi et al., 2017; Singh et al., 2017; Sahoo, 2020,2021; Swelum et al., 2021

Therapeutic/functional attributes

The unique properties of camel milk make it an important health promoter having nutraceutical value and used in different parts of the world for supportive treatment of various diseases such as diabetes, jaundice, hypertension, tuberculosis, cancer, asthma, dropsy and leishmaniasis or kala-azar, etc. (Sahoo, 2020). Camel milk is also recommended to be consumed by children who are allergic to human/bovine and other non-bovine milk. Ayurveda has referred medicinal value of camel milk under the classification of "Dugdha Varga" (Milk Classification). Primarily, human health benefits caught the eyes of scientific community, policy planners and it was publicized through press and media. This paved way to define standards for camel milk so that trade could be initiated. Due to increase in awareness and approval by the Food Safety and Security Standards of India (FSSAI) in 2016 (fat-2% min; SNF 6% min), progressive entrepreneurs and farmers have initiated trade of Camel milk. Presently, over 20 entrepreneurs from Rajasthan and Gujarat are engaged in processing and marketing of milk.

Camel milk has superior nutritional quality and purported medicinal properties against a range of human illnesses including antidiabetic, anti-autistic, anti-microbial, antihypertensive, anticarcinogenic, anticholesterolemic, antioxidant, anti-inflammatory, hypoallergenic, hepatoprotective and immune boosting effects. Traditionally, many communities consume milk to improve health and vigour. The claimed therapeutic property of camel milk is attributed to its possession of various bioactive compounds as well as generation of bioactive peptides from intact proteins during digestion and/or fermentation of the milk. Some of the human-health benefits of camel milk are summarized below.

Human health benefits

- **Diabetes** in people occurs in two forms Type-1 and Type-2, and camel milk has been used for the management of **Type-1 diabetes** due to presence of insulin/insulin like substances in the milk. Significant glycaemic control was observed in patients receiving camel milk 500 ml daily. Recently, it has also showed beneficial effect in the management of Type-2 diabetes.
- **Tuberculosis**, a chronic and debilitating disease of humans responds to camel milk as nutraceutical adjuvant. The therapeutic role is contributed by presence of high quantities of antimicrobial components in camel milk. Its consumption has been shown beneficial effects as it increases appetite, live weight gain, contents of haemoglobin, Zinc, Iron; reduces TLC and ESR.
- **Autism** is an autoimmune disease is caused due to formation of casomorphin a powerful opioid by breakdown of casein causing typical

cognitive and behavioural symptoms. Use of camel milk therapy has helped to improve Health/ Cognitive/ Behavioural parameters as Autism Treatment Evaluation Checklist (ATEC) scores improved in all categories of affected children. Observations on use of "Camel milk therapy" have proved to be useful in children.

- **Antioxidant properties** in the camel milk are due to presence of substantial quantities of Vitamin C, Lysozyme and it is also rich source of Lysine which shows antioxidant property.
- **Antiallergenic properties**: Whey proteins are the main component which constitutes 20-25% of total proteins. Whey proteins of bovine milk contains β-lactalbumin 50% whereas α-lactalbumin is the second component (25%) whereas in camel milk β-lactalbumin is deficient and α-lactalbumin is the major component due to which allergies due to milk are not observed.
- **Anti-cancer** properties of camel milk can be attributed to comparatively higher antioxidant, angiotensin-converting-enzyme (ACE)-inhibition and antiproliferative activity of fermented camel milk and its bioactive peptides.
- **Gut-health**: Camel milk contains highest concentration of lactoferrin among bovine, caprine and human milk. It is also suitable for people who are **lactose intolerant** and is a natural **probiotic drink** that promotes the growth of healthy bacteria in the gut.
- **Skin-health**: The antioxidant properties of camel milk has protective activity on skin tissue against free radicals and heals skin issues; wrinkles and dryness and its α-hydroxyl acid acts as anti-aging.
- **Antimicrobial/ Antioxidant/ Immune-modulator** properties of whey-protein are attributed to substantial quantities of serum albumin, lactoferrin, immunoglobulin and peptoglycan recognition protein. The lactoferrin content of camel colostrum and whole milk is high and it also poses antimicrobial properties and beneficial role in various biological functions.

Role in various biological functions

Camel milk is unique, the most significant being no milk-lactoglobulin as in human milk. The distinctive feature of camel milk is its minimal allergic effects due to a lower concentration β-lactoglobulin and α-casein (Sahoo, 2020). But it has high concentration (mg/mL) of α-lactalbumin (2.01), lactoferrin (1.74) and serum albumin (0.46). Among caseins, β-casein is in high concentration (12.78 mg/mL) followed by α-casein (2.89) and κ-casein (1.67). The presence of larger casein micelles and smaller fat globules provides camel milk a diverse colloidal structure that imparts special biological activities of protective and not-allergenic milk proteins, lysozyme, lactoferrin, lactoperoxidase and antiviral activities (Sakandar et al., 2018). When camel milk is consumed and digested, the produced peptides start to

act as natural antioxidants and ACE-inhibitors and thereby play an important role as a natural source of anti hypertensive agents (Salami et al., 2011). The disease-fighting immunoglobulin are smaller in size that allows its penetration and augment the mechanism of immunity. The ability to reduce the increased levels of bilirubin, globulin and granulocytes through consumption of camel milk has also been recognized. It has higher amount of lipid micelles than the bovine milk that enhances the body's defence against free radicals and displays higher antioxidant activity due to distinctive whey proteins with high content of antioxidant amino acids (cysteine, methionine, tryptophan, tyrosine and phenylalanine). Camel milk has been reported to successfully stabilize diabetes because of the presence of insulin-like protein, which enhances the interaction with insulin receptors thereby controlling hyperglycemia in type 1 diabetes (Agrawal et al., 2005; Singh et al., 2017; Sahoo, 2020). There is multiple potential role of camel milk bioactive peptides to demonstrate as antimicrobial, antiviral, immunomodulatory, anti-inflammatory, anti-oxidative and anti-hypertensive activities (Al Kanhal, 2010; Khatoon and Najam, 2017). The camel milk lactoperoxidase is found bacteriostatic against the Gram-positive strains and bactericidal against Gram-negative cultures (El-Agamy et al., 1992).

Camel milk has balanced nutrients and exerts array of biological activities that modulates digestion, nutrient absorption and metabolism, growth and development and resistance to various diseases. Several reports have demonstrated bio-functional and potential therapeutic properties viz. antidiabetic, wound healing, remedy against hepatitis C (HCV) infection, managing autism cure, antihypertensive and hypoallergenic effect (Sahoo, 2020). The hypoallergenic effect is attributed to the presence of immunoglobins and its protein (free of β-lactoglobulin) profile and thus serves as a good alternative for people with cow milk allergy. Recent updates on major bio-functionalities of camel milk and its protein hydrolysates include immunomodulatory, antimicrobial, antiviral, anticytotoxic, antioxidant, antiradical, angiotensin-converting enzyme inhibitory, anticancer, anti-inflammatory, hepatoprotective and as counteractive agent reducing the harmful effects of toxins. On similar line, camel milk is also effective in treating inflammation of the digestive system, as observed in Cohn's disease (Rosenheck et al., 2012). The principal bioactive components that modulates health-beneficial properties are protective proteins (lactoferrin, lysozyme, and immunoglobulins), minerals (Zn and Mg), vitamins (C and E), antioxidant enzymes (glutathione peroxidase and superoxide dismutase) and the bioactive peptides derived from camel milk proteins (Khatoon and Najam, 2017). The camel milk has

potential therapeutic effects in neurological disorders such as autism, Parkinson's, and seizures (Al-Ayadhi and Elamin, 2013; Singh et al., 2017) duly supported by antioxidant activity of casein and high content of vitamins C, A and E. The antipathogenic properties of camel milk have also been investigated to substitute for drugs and hence to overcome drug resistance. Whole camel milk showed significant dose-dependent in vitro anthelmintic activity against *Haemonchus contortus* as ascertained by worm motility and egg hatching inhibition compared to cow, ewe and goat milk due to higher contents of protective protein (lactoferrin) and vitamin C (Alimi et al., 2016). It has beneficial action on chronic liver patients, in chronic fatigue and provides a powerful protector system to fight against debilitating diseases (Singh et al., 2017). Ayyash et al. (2018) reported comparatively higher anti-cancer properties in camel milk than bovine milk due to its antiproliferative activity and specific cytotoxicity on cancer cells. Compared to milk from other animal species, camel milk gets easily hydrolysed and the children receiving camel milk have shown improved motor skills, joint coordination, language, cognition, improvements in behaviour and diets including skin health (Sahoo, 2020). It is used in arid rural communities of Asia and Africa as a biomedicine to cure several other health issues like tuberculosis, asthma, gastroenteritis, oedema, neurological disorders, etc.

Bioactive properties in processed and fermented camel milk

Camel milk differs markedly from bovine milk in terms of structural and functional properties of the milk components, and composition of individual proteins and its colloidal structures. These differences present challenges for processing camel milk into products. Moreover, surplus camel milk is generally processed into naturally fermented products. Camel milk is less readily converted into butter, cheese, and yogurt, but is known for its health-promoting properties and a lot of research has been performed to explore and characterize these properties (Sahoo, 2021). The protein composition and colloidal structure of camel milk differs from cow milk. It is characterized by absence of β-lactoglobulin, low κ-casein content, high proportion of β-casein, larger casein micelles and smaller fat globules. These differences lead to the difficulty of making dairy products from camel milk using the same technologies as for bovine milk. Some of the challenges of camel milk processing include poor stability of the milk during UHT treatment, impaired rennetability, formation of weak and fragile curd during coagulation, longer fermentation time, and low thermal stability of the milk during drying (Seifu, 2022, 2023). Despite these difficulties, it has now become possible to produce a range of commercial and traditional dairy products from camel milk, viz. pasteurized milk, fermented milk, cheese, powder, or other products.

Whey protein

The main components of whey proteins in camel milk and colostrum were similar to that in bovine, except for the lack in β-lactoglobulin (El-Hatmi et al., 2007). It is composed of numerous soluble proteins, but also has indigenous proteases such as chymotrypsin A and cathepsin D. In addition to their high nutritional value, these whey proteins have unique characteristics, including physical, chemical, physiological, functional, and technological features that are useful in the food application. Whey proteins are more heat stable in camel milk compared to cow and buffalo (Mohamed et al., 2022). Camel milk proteins have useful bioactive peptides with diverse functional properties, which can be exploited by fusing milk proteins into different nourishments and this will certainly open a new market for camel milk for use in various human foods and medicaments. Camel milk has comparatively higher functional contribution to human health as a result of the unique composition of caseins and whey proteins [serum albumin, α-lactalbumin, lactoferrin, peptidoglycan recognition protein short variant (PGRP-S), and immunoglobulins G (IgG) with the different variants IgG1, IgG2, and IgG3] (Hailu et al., 2016).

Protein hydrolysate

The hydrolysis of camel's milk proteins leads to the formation of bioactive peptides, which affect major organ systems of the body and impart physiological functions to these systems. Kumar et al. (2016) reported that camel milk casein hydrolysates could be fractioned to get specific molecular weight peptides, but for food application or direct human consumption, use of whole hydrolysates could be more beneficial with regards to its functionalities and cost of production. Proteases such as Alcalase, α-Chymotrypsin produced peptides with higher biological activity as compared to Papain. Camel milk casein may thus be used as natural source of food protein to produce hydrolysates with higher antioxidant and antimicrobial activities. This will further encourage the use of camel milk caseins and derived peptides for direct human consumption and as ingredient in nutraceutical and pharmaceuticals for enhancing its functionalities and shelf-life.

Fermented products

The fermentation process is commonly used for the preservation of food, which is a traditional ancestral method all over the world consisting of transformation of lactose into lactic acid by the natural microflora in milk dominated by lactic bacteria and, in some cases, by yeasts. Several strains of conventional lactic acid bacteria (LAB) have been tested such as *Lactobacillus bulgaricus*, *L. acidophilus*, *L. casei*, *Streptococcus*

thermophilus and *Bifidobacteria* (Konuspayeva and Faye, 2021). Soleymanzadeh et al. (2016) compared fermentation of camel and bovine milk by LAB isolated from the Iranian traditional dairy product (Chal) and found higher antioxidant activity of fermented camel milk. Similarly, Sharma et al. (2021) have screened the milk of Indian camel breeds like Mewari, Bikaneri, Kachchi and Jaisalmeri and found *L. lactis*, *Enterococcus lactis* and *L. plantarum* to have potential probiotic effects and has recommended as a substitute of functional food, synthetic food and industrial curd formulation with in the shortest span (240 min at 28–32 °C). The fermented beverages are generally differently named in various parts of the world, but some of the most common products are yogurt, cheese, whey, probiotic drink, etc. Cheese production from camel milk using recombinant camel chymosin helps in coagulating camel milk, but the extent of its hydrolysis depends on several factors like acidification, pH, calcium and gelation time (Baig et al., 2022). Use of starter culture (type and level), application of heat treatment, addition of rennet (type and level), calcium chloride level and standardisation of casein/fat ratio significantly affect the quality and yield of camel milk cheese and hence needs optimisation in rennet coagulation time, texture, yield and quality of the product. Effect of cooking temperature, salting level and pressing duration also significantly affect the quality of cheese during ripening and require detailed investigation.

Fermented camel milk seems to be a good dairy product with high sensory quality. In addition, its biological activities are enhanced by the fermentation process, e.g. whey protein concentrate, which promises higher bio-functionalities (Singh et al., 2013; Solanki and Hati, 2018; Singh and Sahoo, 2021). Thus, the therapeutic values of camel milk offer an extra advantage for its utilization in production of different functional food products (Muthukumaran et al., 2023). Therefore, efforts should be made at all stages, from rearing of camel, milking, milk quality assessment, packaging and transport through cold chain to reach every corner of the country for management of diseases like diabetes, autism, milk allergies etc. At the same time, hygienic milk production needs to be ensured with camel health care to ensure better quality. Freeze drying is recommended that preserves its quality and is therefore considered the best process of making milk powder for packaging, transportation and marketing from the production site to distant consumers. These approaches will certainly help to utilize milk for commercial purposes and help to improve livelihood of the people engaged in the chain. Chocolates prepared from camel milk by NRCC, AMUL, ADVIK Foods and other processing units form India are finding way in the consumer chain.

Camel milk in infant milk formula

Infant milk formula (IMF) can be defined as a product composed of milk nutrients along with other ingredients that are essential for the infant growth, that helps in meeting the infant's nutritional requirement until they reach the age where they can consume complimentary foods. Therefore, the manufacturers try to mimic the nutritional profile of mother milk in the IMF while avoiding any factors which might be detrimental to infant's health and growth. Compared to bovine milk, camel milk is closer to mother milk and the peculiarities, viz. absence of -lactoglubulins, presence of smaller immunoglobulins, concentration of low fat with smaller fat globules, richness in vitamin C, Ca, Zn, Mn, Fe, electrolytes (Sahoo, 2021) may play a greater role in enriching the formula with lesser adverse effect. Diluted skimmed camel milk is being used by nomads in the deserts of Egypt, Sudan, Mauritania, Kenya, China, Kazakhstan for feeding their babies and thus camel milk might be a promising new protein source for children allergic to cow milk protein (El-Agamy et al., 2009). The camel milk fat globule membrane has health-promoting effects like anti-adhesion and anti-bacterial properties, which makes it suitable for people who are allergic to cow's milk. It is also rich in phospholipids, especially plasmalogens and sphingomyelin that helps to meet daily nutritional requirements of adults and infants (Raghvendar and Sahoo, 2021). It is postulated that transforming growth factor (TGF-β2) in breast milk may modulate class II molecule expression on intestinal epithelial cells until the neonate is capable of handling the antigens to which it is exposed after weaning (El-Agamy et al., 2009). Therefore, camel milk derived TGF-β can be exploited in functional foods for the infant or during therapies for specific intestinal diseases. Mudgil et al. (2022) observed enhanced protein digestibility with camel milk infant formula fortified with 10% whey protein. Since, camel milk is close to human milk and is important for its nutritional properties, non-food allergy, medicinal value and therapeutic applications, it seems promising in design and formulation of new products IMF with significant health-promoting benefits.

Conclusion

There is no second thought that camel milk has unique therapeutic potential, but non-existing of proper pricing and market-chain deter its potential to reach the needy people. Establishment of village and regional 'Milk-Cooperatives' would play a significant role in launching a processing unit nearby the pooled collection unit and infuse in to the marketing-chain with proper packaging and pricing for the reach of consumers. Camel milk could soon become the new super food due to its high nutritional and

therapeutic value. Now, the country has renewed its focus on improving dairy production system from both bovine and non-bovine species with emphasis on upgradation of native animal germplasm. Technical innovations for an optimal pasteurization protecting quality and biological functionality of non-bovine milk, development of controlled fermentation protocol, standardized technology suitable for cheese making and improvements in processes for the supply of a high-quality milk powder are among the challenges of research and development.

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