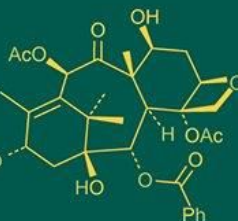
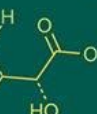
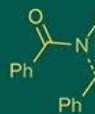


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Non-bovine milk as emerging functional dairy sources: Nutritional composition, bioactive components and health benefits

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Abstract

One of the first and most complete natural foods taken by humans, milk contains vital nutrients and bioactive substances that promote immunity, growth, and general health. Although cow milk is the most popular dairy product in the world, milk from non-bovine animals like goats, sheep, camels, mares, and donkeys is receiving more attention. These alternative milks have unique nutritional compositions and physicochemical characteristics that may provide certain health advantages. When compared to bovine milk, non-bovine milk frequently has better digestibility, distinct bioactive peptides, higher concentrations of specific vitamins and minerals, and less allergenicity. Their potential use in the treatment of diseases such as lactose intolerance, diabetes, hypertension, oxidative stress, and immunological disorders have been highlighted by research. Furthermore, new processing techniques are being investigated to improve these milks' functional qualities, safety, and quality. This review highlights the growing significance of non-bovine milk as a functional food and a prospective substitute for traditional dairy sources by summarizing its nutritional makeup, medicinal qualities, and technological developments.

Keywords: Non-bovine milk, Goat milk, Camel milk, bioactive compounds, functional foods, therapeutic properties

Introduction

Mammals are introduced to food for the first time through milk. In addition to its well-known nutritional benefits, milk contains a variety of biological substances that are involved in the immune system, bone health, and gut flora, all of which are critical for overall health and wellness. However, the usage of milk from other animals has diminished in favor of specialty conventional dairy goods. No species consumes milk beyond infancy or consumes milk from another species, with the exception of humans (and companion animals that are fed by humans) (*Cow's Milk: A Cruel and Unhealthy Product* | PETA, 2022). Since the earliest times milk is considered to be primary foods which was produced as an "alternative" product basically for health and cultural reasons. Deer, donkey, and mare milk are not widely consumed or traded, but they have significant cultural importance in certain communities (Vadher *et al.*, 2025) [52]. Recently, milk from non-bovine sources has been the focus of extensive research activities owing to its vast potential and health benefits. Milk consumed by humans have brought itself into consideration for its physico-chemical characteristics that further become the basis for the functional properties leading to subsequent technological advancements such as utility, yield, structure, and stability) and sensory properties as well as the valorisation of milk and its products for targeted consumers

Traditional sources of milk: cow milk

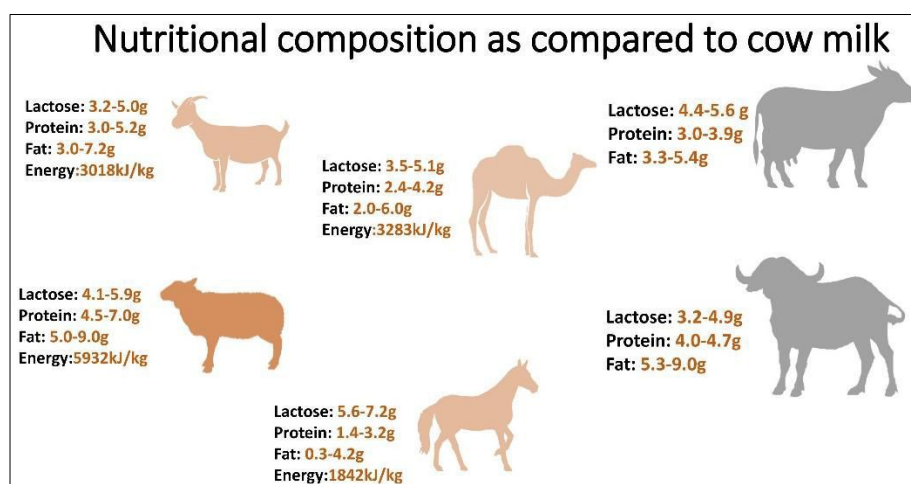
Cow milk has been a crucial component of human diet for more than 8000 years. Milk is a key component of dietary requirements in many nations since it includes numerous critical elements. Cow milk had a clear "support of farmers and national economy" ladder, with "domestic, regional product" as the first step (Haas *et al.*, 2019) [17].

Rise of non-bovine milk animal milk options

Modern human food and lifestyle changes are becoming a problem in developing countries, leading to a myriad of illnesses. Bioactive foods are therefore essential in the present spectrum of human health. Functional dairy foods are now essential under the heading of food and nutrition security (Mohapatra *et al.*, 2019) [35]. Cow milk is under increased scrutiny due to its environmental impact and ethical considerations concerning animal welfare (Haas *et al.*, 2019) [17]. Still, non-bovine milk produced in non-western countries by nearly 150 million milk producers is a significant source of family income apart from providing nutrition and food security (Tsakalidou, & Papadimitriou, 2016). India has an amazing diversity for source of milk. It is usually thought that milk, is mainly in terms of cow milk, followed by buffalo milk. But there are also these three sources namely- "Shecago". As the abbreviation expands, it refers to "Sheep-Camel-Goat" milk. (*Cow's Milk: A Cruel and Unhealthy Product* | PETA, 2022) The consumption of non-bovine milk in many regions date back to thousands of years as an old tradition, with the consumption of goat and

sheep milk in the Arabian Peninsula and Mediterranean region (Ahlem & Sghaier, 2026) [1], as well as in European and Asian countries as well; camel milk in the Arabian Peninsula and Mongolia (Rakhmatulina *et al.*, 2024) [42]. Mare milk popular in Northern China, Mongolia, and Kazakhstan (Toishimanov *et al.*, 2025) [51]; and deer milk (although not much available) in the north of Europe and Russia being common practice (Kanetkar *et al.*, 2025) [24]. Various non-bovine animals, including goats, sheep, camels, mares, and reindeer, have milk that is thought to have various therapeutic benefits for human health, although little attention has been paid to these species. Their milk is distinguished by a significant number of immunoglobulins, immunological proteins, lactose, functionally active lipids, peptides, nucleotides, oligosaccharides, and metabolites (Li *et al.*, 2025) [29]. Additionally, the milk possesses distinct chemical and microbiological qualities that can be used to benefit human health.

Nutritional composition of milk from different species



Goat milk is richer in vitamin A, vitamin B1, vitamin B2, vitamin B5, calcium, phosphorous, zinc, potassium, and selenium than cow milk (Saikia *et al.*, 2022) [47]. The key features of camel milk in comparison to bovine milk are the higher amount of minerals (Ca, Fe, Mg, Cu, and Zn), vitamins (A, B2, E, and C), and antimicrobial components (immunoglobulins, lactoferrin, and lysozyme), and lower amount of fat and cholesterol (Deshwal *et al.*, 2020) [57]. Camel milk has a higher vitamin C content, which is about three to five times as high as compared to bovine milk (Ho *et al.*, 2022) [19]. Sheep milk is characterized by high energy value of 5932 kJ/kg whereas that of cow, buffalo, camel, goat and human are 3169-3730 kJ/kg 3450 kJ/kg 3283 kJ/kg, 3018 kJ/kg and 2407 kJ/kg respectively. The donkey milk is characterized by lowest energy value of -1842 to 2051 kJ/kg (Meena *et al.*, 2014) [33].

Digestibility

There exists a variability in the fat digestion from milk of different species. This has been checked using *in vitro* digestion models. Among the different milk samples, it was found that the size of fat globules decreased from buffalo to cow then goat fat globules and least in size is of camel fat globules. Owing to this size consideration the digestibility of fat increased in order of camel being highest followed by goat, cow and lastly being buffalo (Meena *et al.*, 2014) [33].

Camel and goat milk fat has the highest fat digestibility because of the small size of fat globules on the completion of fat digestion (Park, 2007; Yadav *et al.*, 2015) [58, 59]. Furthermore, goat milk fat's smaller width (3.2-3.6 μ m) and higher concentration of short to medium-chain fatty acids (MCFA) are responsible for its ease of digestion. These properties also make goat milk fat an advantageous treatment for metabolic diseases, anaemia, cholesterol issues, and low mineral bone density (Kielczewska *et al.*, 2020) [60]. Digestibility of goat milk proteins is found to be better than of the bovine milk proteins due to difference in casein molecules, which lead to it formation of softer curd in the stomach during acidification, that are efficiently digested by proteases (Park, 2007) [58]. The horse, and donkey milk are known to form very weak or fragile curds or flocs when acidified in stomach upon action of rennet and thus are expected to form soft breakable curd like formation in the stomach, in comparison with cattle milk, due to the lower casein content (Iannella, 2015) [21]. As casein micelles and fat globules in milk from cattle and non-cattle differ in content and structure, they are expected to behave differently in the digestive system, which might have an impact on the kinetics of digestion and the bioavailability of nutrients (Pérez *et al.*, 2024) [40]. The results that have been published for the casein micelle properties within the same species exhibit a considerable degree of variance, which

may be caused by variations in the analytical techniques employed (Roy *et al.*, 2020) ^[45].

Benefits of these nutritious alternative

Lactose intolerance: A clinical disease known as lactose intolerance is defined by symptoms linked to lactose malabsorption. This may be brought on by decreased or absent lactase activity or diminished or missing lactase production (Hassan & Elkhedir, 2026) ^[18]. Abdominal discomfort, bloating, gas, diarrhoea and, in rare cases, constipation), borborygmi, nausea, and vomiting are typical symptoms of lactose intolerance. They often start around an hour after consuming lactose-containing meals, although they can occasionally show up earlier or later. (Cangemi *et al.*, 2021) ^[4]. Goat's milk contains less lactose content as compared to cow's milk, which is considered to be beneficial in those that are lactose intolerant due to lack of lactase enzyme (Kumar *et al.*, 2016) ^[27]. Compared with ruminant milk, donkey milk presents high lactose content, therefore resulting as inadequate for people suffering from lactose intolerance (Madhusudan *et al.*, 2017) ^[31]. Cardoso *et al.* (2017) ^[61] concluded that the use of camel's milk could be an option for patient's intolerant to lactose and who, therefore, cannot take cow's milk.

Anti-allergic potential

A persistent immune-mediated reaction to the proteins in cow's milk is known as a cow's milk allergy (CMA). One of the most prevalent food allergies in children due to beta-lactoglobulin, a milk protein found in cow milk. Cow's milk allergy (CMA), an IgE-mediated hypersensitivity response, often manifests symptoms minutes to two hours after consumption (Sayed *et al.*, 2026) ^[49]. When exposed to a protein from cow's milk, mast cells degranulate and release mediators, including histamine, as a result of IgE antibodies binding to the protein. Urticaria, throat tightness, respiratory symptoms like coughing and wheezing, gastrointestinal symptoms like nausea, vomiting, and diarrhoea, and cardiovascular symptoms like dizziness, disorientation, and hypotension are some of the symptoms that result from this (Padilla *et al.*, 2025) ^[38]. Human allergies are mostly brought on by the milk protein beta-lactoglobulin, it has little prevalence in camel milk, however, means that it does not present a concern for those who are allergic or allergic-sensitive (Saha *et al.*, 2018) ^[46]. Goat milk (GM) has gained much attention due to its higher nutritional value, better digestibility, and less allergenicity than cow milk owing to the lower content of α s1-casein and β -lactoglobulins. (Kielczewska *et al.*, 2020) ^[60]. Camel milk is preferred over bovine milk due to its non-allergenicity which is attributed to the lower amount of α s1-casein and absence of β -lactoglobulin in camel milk (Deshwal *et al.*, 2021) ^[9]. With a complete protein content of 1.5-1.8 g/100g, donkey milk has a composition that is practically identical to that of human milk. For newborns, allergic to the proteins in cow's milk, donkey milk may be used as a substitute milk source. It has been seen that donkey milk is accepted by 90% of newborns with various food sensitivities therefore, it is utilized as naturally hypoallergenic milk (Salimei & Fantuz, 2012).

Bioactive peptides

Specific protein fragments that have a favourable effect on bodily processes or situations and may eventually have an

impact on health are referred to as bioactive peptides (Luparelli *et al.*, 2025) ^[30]. These peptides can be produced under proteolytic circumstances, such as those in the gastrointestinal system or during food preparation, even though they are inactive within the sequence of the parent protein. These bioactive peptides may perform their function in the human body following digestion (Elisha *et al.*, 2025) ^[11]. Bioactive peptides have antibacterial, antioxidant, ACE inhibition, antihypertensive, and immunomodulatory actions in addition to their positive impacts on health. The active peptides were often generated during milk fermentation by microbial enzymes or by hydrolysis using specific proteases such as pepsin, trypsin, papain, or thermolysin (Guha *et al.*, 2021) ^[16].

Antidiabetic effect

The consumption of Camel milk for treating diabetes has been a traditional practice dating long back in camel-rich regions. In India, it has been found that there is significantly lower prevalence of diabetes in camel milk consuming regions when compared to other regions where it is not consumed (Agarwal *et al.*, 2007) ^[62]. It controls the blood glucose by some mechanisms including effect on insulin receptors activity, increasing of the signaling in the insulin-sensitive tissues, effect on the pancreatic beta-cells function and activation of GLUT4 in the cells (Agarwal *et al.*, 2007) ^[62]. Recently, camel milk has gained popularity owing to its anti-diabetic, anti-cancerous, and autism prevention ability (Deshwal *et al.*, 2020) ^[57]. The diabetes of type 1 and type 2 and gestational diabetes, may see improvement due to hypoglycaemic effects of camel milk (Ayoub *et al.*, 2018; Faraz, 2020). Daily drinking of camel milk may meet about 60% of the insulin in diabetic patients (Agarwal *et al.*, 2009) ^[63]. Nongonierma *et al.* (2017) ^[64] stated that camel milk protein hydrolysates included anti-diabetic peptides with dipeptidyl peptidase IV (DPP-IV) inhibitory action. Results showed that peptides that were supposed to be lacking from bovine milk hydrolysates potential and new DPP-IV inhibitory peptides actually present. The concentration of insulin in camel milk (32 μ U / mL) is high as compared to bovine milk (23 μ U / mL) and its regular consumption effectively maintains blood sugar levels (Saha *et al.*, 2018) ^[46]. In a recent study, Abou- Soliman *et al.* (2020) performed an *in vitro* digestion of Camel milk and found no insulin activity after 30 min of gastric digestion.

Antihypertensive effect

ACE-inhibitory peptides were also discovered in CM hydrolysates and fermented CM. Angiotensin I-converting enzyme (ACE) is a dipeptidyl carboxypeptidase that regulates blood pressure, and ACE inhibition results in a fall in blood pressure (Ho *et al.*, 2022) ^[19]. In another study by Alhaj *et al.* (2016) ^[65], peptides possessing ACE inhibitory activity were identified from camel milk fermented with two potent bacterial cultures namely, *L. helveticus* and *L. acidophilus*. Camel milk fermented with *L. helveticus* yielded stronger ACE-inhibitory activity than other strains (*L. acidophilus*). The peptides showed stability for up to 15 days of storage as revealed by the results of this study. The presence of ACE inhibitory peptides in casein and whey fractions of goat milk was evaluated by Ibrahim *et al.*, (2017) ^[66]. It was found that pepsin generated hydrolysates of whey and casein demonstrated significantly higher ACE inhibitory activities. There exists very limited research on

the bioactive peptides released from mare milk, but koumiss (fermented mare milk) has been shown to have ACE inhibitory activity. Goat milk also has higher monounsaturated and polyunsaturated fatty acids, and medium-chain triglycerides as compared to cow milk which are beneficial to human beings especially to the ones suffering from cardiovascular diseases (Kumar *et al.*, 2016) [27]

Potential immunological benefits

There is immense immunological potential of milk from various species. Firstly, Goat milk, it has been reported to contribute towards increasing platelet counts in patients suffering from various viral diseases like chikungunya and dengue fever (Kuniyal *et al.*, 2024) [28]. The exosomes of goat milk are found to show anti-viral property against Dengue virus by causing inhibition in replication of viral genome and maturation of viral particles. Exosomes are structurally membranous nano-structures of 30-150 nm secreted by various mammalian cells and therefore found in the various bodily fluids including blood, CSF, milk, and urine (Yenuganti *et al.*, 2022) [54]. It is well known that exosomes from milk are resistant to digestive process, and can cross the intestinal barrier, to reach different parts of the body without causing any cytotoxicity (Manca *et al.*, 2018) [32].

Sheep milk is considered to be superior to buffalo, cow, and goat milk. As it is the richest source of butyric acid (C4:0), Omega 3 fatty acid, CLA, and α -linolenic acid. Sheep milk has been found to be beneficial against various diseases such as coronary heart disease, cancer, and osteoporosis; also found to be stimulating the immune system (Djordjevic *et al.*, 2019) [10]. Sheep casein glycomacropeptide (CMP) has been demonstrated to possess antiplatelet aggregation properties (Guha *et al.*, 2021) [16]. Camel milk has been reported to show the following characteristics that is strong immunomodulatory, antiviral, antifungal, anti-hepatitis, antioxidative, antibacterial, hypoglycaemic activity and anti-cancerous properties. It also helps in prevention of aging and autoimmune diseases (Jilo and Tegegne, 2016) [67].

Antioxidative property

The status of oxidative stress is defined an imbalance between oxidants and antioxidants, due to the excess of oxidant activity not being neutralised by antioxidant capacity (Kiran *et al.*, 2023) [26]. Oxidation in sheep milk is naturally counter balanced by its constitutive antioxidant agents, e.g. whey proteins, antioxidant, enzymes (superoxidedismutase, catalase, glutathione, peroxidase), carotenoids, vitamins (C, E, A, D), lactoferrin, tocopherols, ascorbic acid etc (Caroprese *et al.*, 2019) [5]. In goat milk casein hydrolysate, a significant increase in free radical scavenging and iron chelation capacities were found (Redha *et al.*, 2022). Antioxidant and ACE inhibitory activity exhibiting peptides were isolated and purified from donkey milk (Zenezini *et al.*, 2019) [68]. Fractionated camel milk proteins hydrolyzed using pepsin revealed that both casein and whey proteins have the potential for being utilized as an ingredient in functional foods (Ibrahim *et al.*, 2018) [69].

Anti-autistic property

Autism is a neurodevelopment disorder. Though the cause of autism remains unknown, studies propose it to be related

to an increase in oxidative stress. Clinical studies have proved that with regular consumption of camel milk, children suffering from this problem showed significant improvement (Elshamy *et al.*, 2025) [12]. It is believed that camel milk can decrease oxidative stress by increasing antioxidant enzymes and non-enzymatic antioxidant molecules which greatly help in improving autistic behaviour in children. (Saha *et al.*, 2018) [46]. Camel milk therapy reported a remarkably positive effect on the autistic children behaviour. After two weeks consumption of camel milk, it was found that glutathione, myeloperoxidase, and superoxide dismutase (SOD) concentrations were found to improve significantly in the plasma of autistic children, which results in the control of stress due to reactive oxidative species (Ho *et al.*, 2022b) [19].

Anti-ageing property

Camel milk has anti-ageing effect due to the presence of alpha-hydroxyl acids which are known to plump the skin and smoothen fine lines. They also help in eliminating wrinkles, age spots and facial dryness. (Saha *et al.*, 2018) [46]. The extraordinary cosmetic and therapeutic properties of equine milk are widely known. Facts state that, that ancient privileged ladies like Cleopatra, Poppea and others used to take their baths in donkey's milk in order to keep their skin fresh and shiny (Cunsolo *et al.*, 2011) [7].

Calcium and bone health

The high lactose content of donkey milk also stimulates intestinal absorption of calcium, which is important for bone mineralization and the development of the nervous system in infants (Xu *et al.*, 2025) [55]. It has been documented by Vihan *et al.*, (2025) [53] that goat shows positive effects on the structural integrity and health of bone due to more bioavailability of calcium and phosphorus. A recent study stated that sheep milk consumption results in higher trabecular bone surface density and bone surface to volume ratio in growing rats compared to cow milk having equal total solids content. Therefore, it confirmed the better effects of sheep milk on human body (Mohapatra *et al.*, 2019) [35].

Some unique features of different non-bovine milk goat

milk: India has 148 million goats, producing about 7.59 million tonnes of milk. Due to lower production of milk per animal, it is primarily reared for household consumption. Goat is known as “cow of the poor people”. It has been the most reliable source of livelihood for people since its domestication from the Neolithic Age (Zervas & Tsiplakou, 2013) [56]. Although, India ranks first in goat milk production but its farming is mostly subsistence-oriented (Agnihotri & Rajkumar, 2007) [70]. There exists an organized market for goat milk which is especially in European regions, especially in France. The cheeses manufactured from goat milk in those regions is an artisanal activity and is very high in demand. Manufacturing cheese from goat milk is a specialized activity and is high in demand. The main products obtained from goat are meat, milk, and fibre. But the rearing of this animal is done primarily for meat with milk being an adjunct. Goat milk, although so rich in various properties, does not receive the ubiquitous popularity and acceptability because of being “strong, smelly, salty or sweet” (Park, 2017) [39]. Nevertheless, consumer preference for goat milk is gradually increasing due to the growing consumer

awareness about the nutraceutical and therapeutic properties of it. Goat milk contains a higher proportion of MCT which is, caproic (C6:0), caprylic (C8:0), and capric (C10:0), which are partly responsible for its characteristic “goaty” odour and flavour. Goat colostrum and milk are rich in polyamines; higher than in milk of other mammals (Nayik *et al.*, 2022) ^[36]. The oligosaccharides portion of goat milk have many functional properties such as antimicrobial, immune modulation, cell response modulation of intestinal epithelial cells, and provides nutrients for development of neonatal brain and also show probiotic properties (Lima *et al.*, 2018) ^[71].

Sheep milk

Sheep milk has a sweet, soft flavour and aroma with a rich creamy texture due to smaller size of fat globules, thus making it easy to digest (Park *et al.*, 2007) ^[58]. Sheep milk owing to its higher total solids content, has a higher, titratable acidity, refractive index, specific gravity, viscosity and lower freezing point as compared to cow milk (Haenlein and Wendorff, 2006) ^[72]. Sheep milk contains higher medium-chain triglycerides (MCT) and PUFA content than cow milk. Various products like fresh or soft-type processed products which includes, fluid milk, fermented milk, yogurt, ice-cream, butter, and soft cheeses can be prepared from sheep milk. Due to the limited production sheep milk and related products are more expensive than its contemporaries (Park *et al.*, 2007) ^[58]. Sheep milk is increasingly used for the production of different milk products like cheese, yoghurt, ice-cream, etc., and has economic value for countries bordering the Mediterranean Sea, sub-Saharan Africa, Middle East, and East and Southeast Asia (Balthazar *et al.*, 2017) ^[73]. Sheep milk products retain higher yield, superior product quality, and nutritional value due to a higher proportion of proteins (5.6%), fat (6.4%), minerals (0.9%), and essential vitamins compared to cow milk (Balthazar *et al.*, 2017) ^[73].

Camel milk

Camel in itself is a distinct animal among all creatures, which can survive in very harsh climatic conditions. Due to its longer lactation length of 14-16 months it produces milk round the year in much larger quantities (Mohammed *et al.*, 2025) ^[34]. Camel milk called “white gold of the desert” has much similarities to human milk, and is low in cholesterol and lactose content, and is high in mineral content such as sodium, potassium, magnesium, iron, copper, zinc and magnesium, vitamin C, lactoperoxidase, immunoglobulins, lactoferrin and lysozyme (Yadav *et al.*, 2015) ^[59]. The milk also contains a high concentration of anti-inflammatory proteins and insulin-like proteins which shows positive effects on health. Thus, camel milk finds its application in many health concerns including GIT disorders, diabetes, hypercholesterolemia cancer, autism, hepatitis C and B, low immunity, psoriasis and tuberculosis (Kaskous, 2016) ^[74]. The similarity to human milk is due to its approximately double β -casein content and approximately five times Igs as compared to cow milk (Hailu *et al.*, 2016) ^[75].

Equine milk: The mammary glands of equids have a low capacity i.e. maximum 2.5 L. A female gives between 0.5

and 1.3 litres of milk a day for about 6-7 months. Equine milk doesn't form cream very easily due to the small amount of cryoglobulin (agglutinins), it is a protein that adsorbs onto fat globules because of reduced temperature; and hence it retards the agglutination of globules together and also takes much longer time (O'Mahony & Fox, 2014) ^[76].

Donkey milk

Nowadays, consumer the interest of consumers in donkey milk is increasing in various parts of the world, due to its similarity in composition to human milk, and good palatability (Altomonte *et al.*, 2019) ^[2]. Hence, in Western countries, especially European countries, donkey dairies are emerging to produce an alternative milk source for human infants. The donkey milk contains less fat, protein, and inorganic salts but more lactose with a concentration closer to human milk (Tidona *et al.*, 2011) ^[50]. Lactose or milk sugar is a source of readily available energy source which makes the milk much sweeter, palatable, and acceptable to children. The pH of donkey milk, is neutral or slightly alkaline, probably due to low caseins and phosphates content (Pal *et al.*, 2018) ^[77]. Fat content is also found to be lesser in donkey milk than in cows, goats, and sheep milk (Martini *et al.*, 2013) ^[78]. Donkey milk also contains inherent preservatives such as lysozyme and lactoferrin (Khan *et al.*, 2024) ^[25]. Lysozyme in this species' milk is present in large amounts, ranging from 1- 4 mg/mL, and it is highly resistant to heat, acid and protease activity and may play a significant role in improved immune responses (Tidona *et al.*, 2011) ^[50]. It's lower fat content which makes it a good choice for cholesterol management. The fat content of donkey milk has been found to be almost negligible (Bhardwaj *et al.*, 2020) ^[79] and hence, the milk is sometimes termed as naturally defatted milk. The mammary secretions of donkey contain a human-like leptin at much closer levels compared to human milk (3.35 to 5.32 ng/mL) (Salimei & Fantuz, 2013) ^[48]. The bioactive peptides, like IGF-1, ghrelin, and triiodothyronine - are also found in donkey milk (Derdak *et al.*, 2020). It acts as a restorative agent for metabolic diseases therefore showing remedial value. It can be used in the cosmetics industry (Hosur *et al.*, 2025) ^[20]. It is regarded as the most expensive milk in the world owing to its low production and desirable properties. The valorisation of donkey milk yields high end products with tremendous potential, in the form of drinks for persons in sports because of its lower fat and cholesterol content.

Products from different breeds

There has been a surge in the past few years of the milk from non-bovine species and their products which have further attracted significant attention from the processing industries and researchers. This is being reflected by a sizable list of commercialized non-bovine milk such valuable and underutilized nutrient sources to explore their applicability in food formulations and export potent products. Namely: -Aadvik camel milk ghee, Aadvik goat milk ghee, Aadvik camel colostrum powder, Aadvik donkey milk soap, Aadvik camel milk soap, Amul camel milk, Yeshmita haran donkey milk, Aadvik donkey milk chocolate etc.



Challenges and limitations

Non-bovine milks are limited to specific locations and ecosystems worldwide.

Non-bovine milk faces four important challenges

1. how to improve the milk productivity, which is generally very low compared with that of cow,
2. how to get production concentrated in certain locations and regions, more integrated into markets,
3. how to support the development of different milk processing, and
4. how to increase the knowledge of, and better characterize, non-bovine milk (Faye & Konuspayeva, 2012) [15]

Technological interventions

Thermal processing methods such as pasteurization and UHT processing are universally employed to ensure milk consumption quality and processing safety. However, there are certain limitations linked with these intensive heat treatments like loss of nutrients, colour modifications, and flavour changes due to Maillard reaction which have led to an exploration of emerging technologies to produce wholesome milk products with better retention of nutrient, flavours and biological components (Deshwal *et al.*, 2021b) [9].

The notable novel methods assessed for processing non-bovine milk and milk products are mainly high-pressure processing (HPP), ultrasound processing (USP), irradiation (ultraviolet (UV-C) and gamma), microwave processing (MWP), and ohmic heating (OH). The major effects of these technologies in strengthening the quality and safety of non-bovine milk and milk products & some of the applications to pathogen and endospore inactivation, reduction in spoilage microflora, biogenic amines, and toxins (Deshwal *et al.*, 2021b) [9]. Cold plasma is generated at 30-60 °C under atmospheric or reduced pressure by partial or complete ionization of gas during electrical discharge, which consists of photons, ions, free electrons, and excited/unexcited atoms. The applications of cold plasma in the dairy industry have been comprehensively reviewed by Coutinho *et al.* (2018) [6]. Among non-bovine milks, cold plasma technique has been explored for goat milk only to be best of our knowledge, wherein MUFA and PUFA decreased

significantly with simultaneous increase of saturated fatty acids on gas phase plasma treatment (single electrode, 2.5 kV, 25 Hz, and argon gas input). Along with, unacceptable “burnt” and “ozone” flavour was observed, which was attributed to the generation of highly reactive species leading to initiation of free radical chain reaction (Juric *et al.*, 2018) [80]. Sonicated camel milk proteins had significantly higher antioxidant activity due to enhanced availability of aromatic amino acids and sulphur-containing amino acids accredited by the unfolding of proteins and subsequent exposure of antioxidant residues. Also, a significant increase in angiotensin-converting enzyme (ACE) inhibitory activity makes ultrasound processed CM components, a valuable alternative in functional food ingredients, to prevent hypertension. There are very few studies on the processing of Donkey milk using emerging technologies (Deshwal *et al.*, 2021) [9]. Emerging processing technologies, undoubtedly, hold immense potential in quality and safety improvement of milk of different species with minimal changes in nutritional and functional profiles of milk components. HPP, USP, and MWP are among the most employed emerging technologies in non-bovine milk and milk products.

Future prospects and investment opportunities

1. Non-bovine milk plays an important role in providing food security of consuming population and economic upliftment of people involved in its production
2. Non-bovine milk and milk products being nutritionally superior therefore have higher commercial value. Hence, identification of unique metabolites to be used as biomarkers for quality monitoring and adulteration is necessary
3. The development of NBM production systems (productivity, health prevention, and hygiene) will enable territorial development
4. Establish therapeutic value of non-bovine milk
5. NBM is frequently produced by underprivileged people in remote areas therefore develop dairy entrepreneurship and mini-dairies for non-bovine milk.

Conclusions

With the surge in alternative milk product consumption owing to health and environmental concerns. There is

evidence that milk from non-bovine origin may be an effective alternative for cow milk for the maintenance or even improvement of general health. Non-bovine milk is becoming more and more significant on a global scale, not only in terms of production but also in terms of cultural, economic, and ecological interest (better feed conversion efficiency). There should be increased research so that the medicinal use and consumer acceptance can be increased to further develop the market for Non- Bovine Milk.

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