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Review Article

Goat milk: Composition, health benefits, and product development

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Abstract

Goat milk is increasingly recognized as a functional food owing to its distinctive nutritional profile and health-promoting properties. It contains smaller fat globules, higher concentrations of medium-chain triglycerides, and lower αs1-casein than cow milk, which improves digestibility and reduces allergenicity. It is also a rich source of minerals, vitamins, and oligosaccharides that resemble those in human milk, supporting bone development, immune function, and gut microbiota modulation. In addition, bioactive peptides released during digestion, fermentation, or enzymatic hydrolysis exhibit antioxidant, antimicrobial, antihypertensive, and immunomodulatory effects. Traditionally consumed as cheese, yogurt, and fermented products, goat milk is increasingly used in the development of probiotic yogurts, infant formulas, fortified dairy beverages, and hydrolysed protein powders. Advances in processing technologies, including enzymatic hydrolysis, microencapsulation, and non-thermal technologies have further improved its stability, bioactivity, and consumer acceptance. However, its wider application remains limited by the need for clinical validation, large-scale production, and consumer acceptance outside traditional markets. Future research focusing on human trials, sustainable farming, and innovative product development is required to establish goat milk more firmly as a functional food.

Keywords: Bioactive peptides, Functional food, Goat milk, Health benefits, Product development

Highlights

- Goat milk - a nutrient dense and easily digestible functional food
- Rich in bioactive proteins, fatty acids, and minerals with therapeutic roles
- Clinical studies support benefits in allergy, gut health, and cardiometabolic wellness
- Innovative processing enhances bioactivity and product diversity
- Future research should focus on clinical validation and sustainable goat farming

INTRODUCTION

The global demand for functional foods has increased markedly over the past two decades, driven by heightened consumer awareness of the interrelationship between diet, health, and disease prevention. Functional foods, broadly defined as dietary components that confer health benefits beyond basic nutrition, are increasingly acknowledged as critical in the prevention and management of lifestyle-associated disorders such as obesity, diabetes mellitus, hypertension, cardiovascular disease, and neurodegenerative conditions (Granato et al., 2020; Verma et al., 2025). Among the wide spectrum of functional foods, dairy products occupy a prominent position owing to their intricate composition of bioactive constituents, including peptides, fatty acids, vitamins, minerals, and oligosaccharides. These compounds exert a range of physiological activities, encompassing antioxidant, antimicrobial, cardioprotective, and immunomodulatory effects (Nayik et al., 2019; Nayik et al., 2022).

Within the dairy sector, goat milk has emerged as a nutritionally and biochemically distinct alternative to cow milk. Although global production volumes are comparatively lower, goat milk contributes significantly to food and nutritional security in Mediterranean, Asian, and African regions where caprine farming forms a cornerstone of rural livelihoods (Prosser, 2021). According to Food and Agriculture Organization [FAO] (2024), global goat milk production reached 19.19 million metric tonnes, representing approximately 2.06% of total world milk output. The majority of production originates from Asia (56.49%), followed by Africa (23.26%), while the Americas (15.93%) and Europe (4.31%) contribute smaller proportions. Over recent decades, goat milk production has nearly doubled, reflecting sustained growth in demand for goat-derived dairy products. Goat milk displays several unique compositional traits, including smaller fat globules, higher concentrations

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of medium-chain triglycerides (MCTs), distinctive casein profiles, and a more bioavailable mineral fraction. Collectively, these features enhance digestibility, accelerate energy utilization, and reduce allergenicity, rendering goat milk a suitable option for individuals with cow milk protein allergy or intolerance (Gallier et al., 2020; Liao & Pant et al., 2024). Furthermore, recent analyses have highlighted its richness in bioavailable calcium, zinc, and selenium, which play pivotal roles in skeletal development, oxidative defence mechanisms, and immune function (Idamokoro et al., 2023).

Beyond its macronutrient and micronutrient composition, goat milk serves as a reservoir of bioactive molecules such as peptides, oligosaccharides, taurine, and sialic acid. These components contribute to diverse biological effects, including free radical scavenging, angiotensin-converting enzyme (ACE) inhibition, antimicrobial defence, modulation of intestinal microbiota, and neuroprotection (dos Santos et al., 2023). Advances in proteomics and molecular docking have recently enabled the identification of novel goat milk-derived peptides with potent antioxidant and antihypertensive activity (Ncube et al., 2025; Zhang et al., 2025). In parallel, goat milk oligosaccharides, which share structural similarities with human milk oligosaccharides, have been shown to promote the establishment of beneficial gut microbiota and provide anti-infective protection in infants (Leong et al., 2019).

In recent years, technological innovations have expanded the scope of goat milk utilization in the functional food industry. Approaches such as enzymatic hydrolysis, microencapsulation, high-pressure processing, and targeted nutrient fortification have significantly improved the bioavailability, stability, and bioactivity of its functional constituents (Nayik et al., 2021). These advances have facilitated the development of novel goat milk-based products, including probiotic yogurts, nutraceutical powders, infant formulas enriched with milk fat globule membrane (MFGM), and hydrolyzed peptide supplements (Gallier et al., 2020; Prosser, 2021). Notably, fermented goat milk products have demonstrated potential in ameliorating obesity and metabolic dysregulation, highlighting their therapeutic promise (Andrada et al., 2024).

This review synthesizes current knowledge on the composition, bioactive components, and health-promoting attributes of goat milk, with emphasis on recent developments in product innovation. It also explores the challenges and opportunities surrounding clinical validation, sustainable production, and industrial application, thereby underscoring the growing relevance of goat milk as a functional food in advancing global health and nutrition.

Nutritional and functional aspects of goat milk constituents

Goat milk is increasingly recognized as a nutritionally rich and biologically active food matrix, with compositional traits that distinguish it from cow and buffalo milk (Table 1). Its nutritional profile is dynamic, varying with factors such as breed, stage of lactation, feeding practices, and environmental conditions, which together influence its functional and technological properties (Yadav et al., 2016; Thompson et al., 2019; Hammam et al., 2021). Compared with other ruminant milks, goat milk offers superior digestibility, higher bioavailability of minerals, and unique bioactive components that

Table 1. Comparative composition of goat and cow milk (per 100 g)

Component	Goat Milk	Cow Milk	Key Functional Implication
Energy (kcal)	69	61	Slightly higher energy value supports growth and metabolism
Protein (g)	3.6	3.2	Rich in caseins and whey proteins; source of bioactive peptides
Fat (g)	4.1	3.4	Higher medium-chain triglycerides (MCTs) improve digestibility
Lactose (g)	4.5	4.8	Slightly lower lactose, suitable for lactose-sensitive individuals
Calcium (mg)	134	125	Enhanced bone health and mineral metabolism
Phosphorus (mg)	111	95	Essential for skeletal development
Potassium (mg)	204	150	Supports electrolyte balance and cardiovascular health
Vitamin A (µg)	57	46	Higher vitamin A contributes to immune and eye health
Vitamin B12 (µg)	0.07	0.45	Lower in goat milk, supplementation often needed
Fat globule size (µm)	2.0–2.5	3.0–4.5	Smaller globules enhance digestibility and bioavailability

(Data compiled from Organisation for Economic Co-operation and Development [OECD]/ Food and Agriculture Organization [FAO] (2025); recent dairy nutrition studies)

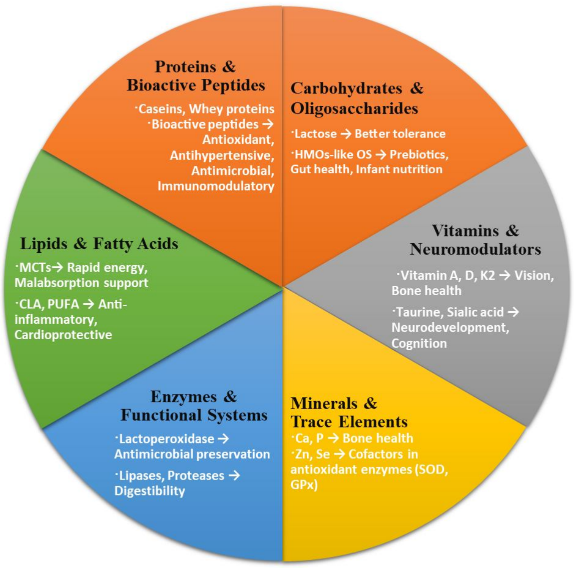

Fig. 1. Composition and functional roles of goat milk: The schematic highlights the major nutrient groups in goat milk proteins, lipids, carbohydrates, minerals, vitamins, and enzymes and their associated health benefits, including improved digestibility, antioxidant defence, cardioprotection, gut health, and neurodevelopment

support its role as both a staple food and a functional ingredient (Raynal-Ljutovac et al., 2008; Albenzio et al., 2021; Navamniraj et al., 2023). The key goat milk components and their health significances are highlighted in Fig. 1.

Protein and bioactive peptide: Proteins constitute approximately 3.4–3.9% of goat milk, with caseins representing 70–80% and whey proteins 20–25% of the total fraction (Nayik et al., 2021). A key differentiating feature is the low content of αs1-casein, which reduces allergenicity compared with bovine milk and contributes to better tolerance in individuals with cow milk protein allergy (Albenzio et al., 2021). Genetic polymorphisms in casein genes further affect coagulation, digestibility, and allergenic potential, influencing the technological properties of goat milk (Clark & García, 2017; Ma et al., 2024).

Upon digestion or enzymatic hydrolysis, caseins and whey proteins generate bioactive peptides with antihypertensive, antioxidant, antimicrobial, and immunomodulatory properties (Park & Nam, 2015; Moreno-Montoro et al., 2018; Muñoz-Salinas et al., 2022). Studies highlight that goat milk-derived peptides such as SLPQ, which not only inhibit angiotensin-converting enzyme (ACE) but also improve endothelial function and reduce vascular inflammation (Xing et al., 2024). Broader dairy peptide research also confirms roles in oxidative stress reduction, metabolic regulation, and anti-inflammatory activity, with new findings pointing to multifunctional peptides from goat whey identified through proteomics and molecular simulations (Koirala et al., 2023; Nielsen et al., 2024; Singh et al., 2024a; Kashung & Karuthapandian, 2025).

Whey proteins, including α-lactalbumin, β-lactoglobulin, lactoferrin, and immunoglobulins, play critical roles in immune defence, nutrient absorption, and gut development (Prosser, 2021; Al-Kaisy et al., 2023). Studies on fermented goat milk further demonstrate the release of antioxidant peptides with therapeutic potential, highlighting its role as a source of natural functional bioactives (Mahdi et al., 2018; Borges et al., 2025).

Functional lipid constituents: The lipid fraction of goat milk averages 4.1 g/100 mL and is notable for its abundance of medium-chain triglycerides (MCTs) such as caproic (C6:0), caprylic (C8:0), and capric (C10:0) fatty acids. These MCTs are rapidly metabolized, providing immediate energy and showing therapeutic relevance in the dietary management of malabsorption syndromes, metabolic disorders, and pediatric nutrition (Watanabe & Tsujino, 2022; Gosalvez-Tejada et al., 2023). Goat milk fat globules are also significantly smaller (2–2.5 μm) than those in cow milk, facilitating greater lipase accessibility and improved digestibility (Park et al., 2017; Stergiadis et al., 2019).

Beyond MCTs, goat milk provides conjugated linoleic acid (11.5 mg/100 g), monounsaturated fatty acids (23.4%), and polyunsaturated fatty acids (3.4%), which are associated with anti-inflammatory, anti-carcinogenic, and cardioprotective benefits (Cossignani et al., 2014; Amalfitano et al., 2024). Nutritional strategies such as supplementing goat diets with linseed or hempseed further enrich omega-3 PUFA and CLA concentrations, improving the nutraceutical potential of goat milk fat (Paszczyk, 2023; Cismileanu et al., 2024). Additionally, sphingolipids in goat milk are emerging as key bioactives linked to gut health and lipid metabolism regulation (Roy et al., 2020; Liao et al., 2024).

Carbohydrates and functional oligosaccharides: Carbohydrates constitute about 4.4–4.6% of goat milk, primarily as lactose. The slightly lower lactose concentration compared to cow milk makes goat milk better tolerated by individuals with mild lactose intolerance (Martín-Ortiz et al., 2019). More importantly, goat milk contains over 30 structurally diverse oligosaccharides (OS), many of which resemble human milk oligosaccharides (HMOs) (Lu et al., 2020; van der Toorn et al., 2023). Commonly reported OS include 32 - and 62 -sialyllactose, lacto-N-tetraose, lacto-N-neo-tetraose, galactosyllactose isomers, and small amounts of fucosylated compounds such as 22 - and 32 -fucosyllactose. These fucosylated and sialylated OS function as natural prebiotics by stimulating the growth of *Bifidobacterium* and *Lactobacillus*, while preventing pathogen adhesion (Martín-Ortiz et al., 2019; Leong et al., 2024). Recent *in vivo* studies also confirm that goat milk enriched with oligosaccharides beneficially modulates gut microbiota composition and increases short-chain fatty acid production, further strengthening its role in gastrointestinal health and metabolic regulation (Han et al., 2021). Their structural similarity to HMOs underpins the growing interest in goat milk as a superior base for infant formula development (Albenzio et al., 2016). Goat milk contains over 30 structurally diverse oligosaccharides (OS), many of which share remarkable structural similarity with human milk oligosaccharides (HMOs). These include fucosylated and sialylated OS, known for their role in shaping gut microbiota composition and promoting immune health (Martín-Ortiz et al., 2019; Lu et al., 2020). Acting as natural prebiotics, they selectively stimulate the growth of beneficial bacteria such as *Bifidobacterium* and *Lactobacillus*, while simultaneously impeding pathogen adhesion to intestinal epithelial cells (Wang et al., 2019; Leong et al., 2025). The metabolic by-products of these interactions particularly short-chain fatty acids, contribute to enhanced gut barrier integrity, modulation of inflammatory responses, and improved nutrient absorption.

Mineral bioavailability: Goat milk represents a naturally functional system that combines superior mineral bioavailability, antioxidant potential, and prebiotic activity, contributing to multiple aspects of human health. It is particularly rich in calcium (134 mg/100 g) and phosphorus (121 mg/100 g), which are vital for bone mineralization and structural development, while magnesium (15-18 mg/100 g) and potassium (204 mg/100 g) support neuromuscular coordination and cardiovascular stability (Navamniraj et al., 2023; Verma et al., 2025). Moreover, trace elements such as zinc (0.48 mg/100 g), copper (0.05 mg/100 g), and selenium serve as cofactors for crucial antioxidant enzymes superoxide dismutase (SOD) and glutathione peroxidase (GPx) that mitigate oxidative stress and maintain redox balance (Singh et al., 2019; Idamokoro et al., 2023; Amalfitano et al., 2024). The superior solubility of these minerals, coupled with their strong association with casein micelles and whey proteins, enhances their absorption and bioavailability, making goat milk an efficient dietary vehicle for preventing osteoporosis, rickets, and micronutrient deficiencies (Getaneh et al., 2016; Kapadiya et al.,2016).

Vitamins and neuromodulator compounds: Goat milk provides an appreciable supply of both fat- and water-soluble vitamins that contribute to essential physiological functions. Vitamin A supports immune regulation and visual health, while riboflavin (B_2) and niacin (B_3) are critical for energy metabolism (Hammam et al., 2021). It also contains vitamins D and K_2, which enhance calcium absorption and bone mineralization, playing a particularly important role in infants, children, and elderly populations (Albenzio et al., 2021). However, goat milk is relatively low in folate and vitamin B_{12}, which may predispose populations relying exclusively on it to megaloblasticanaemia unless dietary supplementation is provided (Alférez et al., 2015).

In addition to vitamins, goat milk contains several neuromodulatory bioactive compounds, including taurine, polyamines, nucleotides, and sialic acid. These molecules are implicated in neurological development, cognitive performance, and immune regulation (Verma et al., 2025). Importantly, sialic acid levels in goat milk vary across lactation, with concentrations peaking in early lactation, highlighting its critical role in neonatal nutrition (de Sousa et al., 2015). Experimental studies indicate that taurine and sialic acid supplementation enhances memory performance and exerts neuroprotective effects, underscoring goat milk's potential role in supporting cognitive health across different life stages (Safdar et al., 2020).

Enzymes: Goat milk naturally contains a variety of endogenous enzymes that contribute not only to digestion and nutrient utilization but also to its functional and antimicrobial properties. Among these, lipases (36 μM/min/100 mL) and esterases play a central role in hydrolyzing milk fat into free fatty acids, which improves lipid digestibility and enhances flavour development in fermented products such as cheese (Raynal-Ljutovac et al., 2008). The presence of proteases, including plasmin, influences protein degradation, casein micelle dynamics, and bioactive peptide release during storage and processing, thereby directly affecting both nutritional quality and functional activity (Albenzio et al., 2021).

The lactoperoxidase system (LPO) is particularly important as a natural antimicrobial barrier. This enzyme catalyzes the oxidation of thiocyanate in the presence of hydrogen peroxide, generating hypothiocyanite ions that inhibit a wide range of Gram-positive and Gram-negative bacteria (Ozhan et al., 2025). Such activity not only extends the shelf life of raw goat milk but also enhances its safety in regions where refrigeration is limited, making LPO activation a useful biopreservation strategy (Nayik et al., 2021). In addition, xanthine oxidase, an enzyme located in the milk fat globule membrane, exhibits antimicrobial activity through the production of reactive oxygen species and has been linked to modulation of gut microbiota and immune responses (Martín-Ortiz et al., 2019). Alkaline phosphatase (1100–1300 µg/100 ml) activity, traditionally used as an indicator of milk pasteurization efficiency, also plays a role in bone mineralization and phosphate metabolism (Amalfitano et al., 2024).

Collectively, these intrinsic enzyme systems highlight goat milk's multifunctional capacity: supporting digestion and bioactive peptide generation, improving flavour and texture in dairy products, and providing natural antimicrobial defences that enhance product safety and stability. The integration of these enzymatic properties into modern dairy processing strategies, including enzymatic activation, encapsulation, or controlled fermentation, presents promising opportunities for the development of value-added functional foods based on goat milk.

Health benefits of goat milk

The functional properties of goat milk arise from its distinctive nutritional and bioactive composition, which exerts positive effects across multiple physiological domains (Table 2). Evidence from in vitro assays, animal models, and human clinical trials supports its roles in digestive health, immune regulation, cardiometabolic balance, bone integrity, gut microbiota modulation, and neuroprotection (Kaskous & Pfaffl, 2025). Recent research also emphasizes its application in functional food development, including probiotic beverages, fermented products, infant formulas, and therapeutic nutraceuticals.

Digestibility and hypoallergenic properties: One of the most significant attributes of goat milk is its

Table 2. Health benefits of goat milk and associated bioactive components

Health Benefit	Key Bioactive Components	Supporting References
Improved Digestibility & Hypoallergenicity	Low αs1-casein, small fat globules, MCTs	Nayik et al. (2022); Benjamin-van Aalst et al. (2024)
Antioxidant Activity	Casein- and whey-derived peptides, lactoferrin, vitamins A & E, selenium	Ahmed et al. (2015); Moreno-Montoro et al. (2018); Haenlein and Park (2024)
Antimicrobial Activity	Lactoferrin, lysozyme, immunoglobulins, antimicrobial peptides	Al-Kaisy et al. (2023); dos Santos et al. (2023)
Cardiovascular & Metabolic Health	ACE-inhibitory peptides, CLA, PUFA, Mg, K	Qiao et al. (2022); Paszczyk (2023); Cismileanu et al. (2024); Nayik et al. (2021)
Gut Microbiota Modulation	Oligosaccharides, sialic acid, lactulose	Leong et al. (2019); van Leeuwen et al. (2020)
Bone Health / Mineralization	Calcium, phosphorus, vitamin D	Singh et al. (2021); Idamokoro et al. (2023).
Immune Modulation	Immunoglobulins, lactoferrin, peptides	Nayik et al. (2021)
Neuroprotective Effects	Sialic acid, taurine, antioxidant peptides	de Sousa et al. (2015); Kaura et al. (2022)
Anti-Inflammatory & Metabolic Regulation	CLA, bioactive fatty acids, oligosaccharides	Cismileanu et al. (2024); Martín-Ortiz et al. (2019), Leong et al. (2024)

superior digestibility and reduced allergenicity compared to bovine milk. Smaller fat globules and a higher proportion of medium-chain triglycerides (MCTs; C6:0–C10:0) support faster gastric emptying and efficient absorption (Nayik et al., 2022; Watanabe & Tsujino, 2022). The naturally lower αs1-casein content contributes to its hypoallergenic profile, making it suitable for infants, elderly populations, and individuals with cow milk protein intolerance (Benjamin-van Aalst et al., 2024). Clinical studies show that goat milk-based formulas (GMF) support normal growth and are well tolerated. A systematic review and meta-analysis confirmed that GMF is safe and nutritionally adequate (Jankiewicz et al., 2023), while a randomized controlled trial reported comparable growth and improved gastrointestinal comfort relative to cow milk formula (He et al., 2022). Real-world data further indicate reduced gastrointestinal symptoms in infants consuming GMF (Knipping et al., 2025). Also, Gallier et al. (2020) and Prosser (2021) evaluations confirmed that goat milk based infant formulas reduce gastrointestinal discomfort and colic compared to standard cow milk formulas, demonstrating tangible benefits in paediatric nutrition.

Antioxidant activity: Goat milk exhibits significant antioxidant properties, largely due to casein- and whey-derived peptides released during digestion, hydrolysis, or fermentation. These peptides act as free radical scavengers, metal chelators, and modulators of endogenous antioxidant enzymes. Additionally, micronutrients such as selenium, zinc, vitamin A, and vitamin E strengthen oxidative defence systems (Moreno-Montoro et al., 2018; Haenlein & Park, 2024). Emerging studies further show that probiotic fermented goat milk enriched with rice extract was shown to significantly boost antioxidant capacity and probiotic viability, suggesting novel product applications (Maleki et al., 2025).

Antimicrobial activity: Antimicrobial activity of goat milk is largely attributed to its innate immune proteins, including lactoferrin, lysozyme, immunoglobulins, and enzymatically generated peptides. These molecules work synergistically to inhibit bacterial growth and biofilm formation, offering protection against pathogens such as *Escherichia coli*, *Salmonella enterica*, and *Listeria monocytogenes*, while preserving beneficial gut microbiota (Al-Kaisy et al., 2023; dos Santos et al., 2023). Beyond antibacterial functions, goat milk protein hydrolysates also exhibit antifungal activity against spoilage fungi such as *Penicillium* spp., supporting their potential use in natural food preservation (Luz et al., 2020), while recent reviews further emphasize their antioxidant, antihypertensive, antimicrobial, and nutraceutical potential in functional food applications (Campos et al., 2022; Samtiya et al., 2022). Additionally, milk-derived proteins such as lactoferrin exhibit broad-spectrum antiviral activity by preventing viral attachment and entry into host cells, with evidence against enveloped viruses such as herpes simplex virus and rotavirus (Kell et al., 2020). Collectively, these findings suggest that goat milk and its bioactive fractions may serve as natural antimicrobial agents in both therapeutic and food industry contexts.

Cardiovascular and metabolic health: Cardiovascular and metabolic benefits are among the most intensively studied aspects of goat milk functionality. ACE-inhibitory peptides generated during proteolysis reduce blood pressure by interfering with the renin-angiotensin system (Qiao et al., 2022). Conjugated linoleic acid (CLA) and polyunsaturated fatty acids (PUFAs) improve lipid metabolism, lower LDL cholesterol, and enhance vascular function (Paszczyk, 2023; Cismileanu et al., 2024). Comparative analyses of goat, sheep, and cattle milk further confirm that goat milk exhibits superior antioxidant activity, higher digestibility, and more favourable microbial properties, which collectively support cardiometabolic health outcomes (Dauda et al., 2025). Additionally, potassium and magnesium present in goat milk contribute to vasodilation, regulation of blood pressure, and cardiovascular stability. Studies indicate that goat milk supplementation improves glucose metabolism and insulin sensitivity, suggesting its role in mitigating type 2 diabetes and metabolic syndrome (Verma et al., 2025). From a clinical perspective, dietary strategies incorporating goat milk and its bioactive components have been highlighted as promising adjuncts for managing cardiovascular conditions such as heart failure, owing to their effects on metabolic regulation, oxidative balance, and vascular function (Liao et al., 2024).

Gut microbiota modulation: Goat milk contains more than 30 structurally diverse oligosaccharides (OS), including fucosylated and sialylated forms analogous to human milk oligosaccharides (HMOs) (Chatziioannou et al., 2021). These compounds function as selective substrates that stimulate the growth of beneficial gut microbiota such as *Bifidobacterium* and *Lactobacillus* spp., thereby enhancing intestinal health and immune modulation. This modulation enhances gut barrier integrity, reduces gastrointestinal infections, and primes the immune system (Leong et al., 2019; Andrada et al., 2024). Sialic acid and lactulose in goat milk also support microbial diversity and intestinal health. Recent metabolomic studies indicate that goat milk-based infant formula enhances gut health by boosting intestinal immune function and SCFA production (Chen et al., 2024), and is associated with a lower incidence of gastrointestinal symptoms in infants compared to cow milk formulas (Knipping et al., 2025).

Bone health: The bone health benefits of goat milk are linked to its high bioavailability of calcium, phosphorus, and vitamin D, which synergistically enhance skeletal mineralization. Supplementation studies show that goat milk improves bone strength, reduces bone resorption, and increases bone mineral density in animal models of osteoporosis (Singh et al., 2021; Idamokoro et al., 2023). Clinical evidence also supports its role in preventing rickets and postmenopausal bone loss, particularly when combined with vitamin D-fortified formulations.

Immune modulation: Immune modulation is another significant benefit of goat milk. Immunoglobulins, lactoferrin, and peptides interact with immune cells to regulate innate and adaptive responses. These components suppress pro-inflammatory cytokines while stimulating macrophage and lymphocyte activity, enhancing overall immune resilience (Nayik et al., 2021). Recent trials with goat milk probiotics demonstrated reduced incidence of respiratory and gastrointestinal infections in children, highlighting its potential in functional immunonutrition (dos Santos et al., 2023). In addition, goat milk oligosaccharides (OS) contribute to immune regulation through modulation of the gut-immune axis. These OS selectively promote beneficial gut microbiota such as *Bifidobacterium* and *Lactobacillus*, leading to increased production of short-chain fatty acids that enhance intestinal barrier function, stimulate regulatory T cells, and reduce inflammatory cytokine expression (van der Toorn et al., 2023; Chen et al., 2024; Liu et al., 2025). This prebiotic-immunomodulatory interaction further strengthens systemic immunity and underscores the potential of goat milk as a natural source of functional immunonutrients.

Neuroprotective effects: Goat milk has shown promising neuroprotective potential due to its rich content of sialic acid, taurine, antioxidant peptides, and bioactive fatty acids, all of which play critical roles in neurodevelopment, synaptic plasticity, and protection against oxidative stress. Experimental studies demonstrated that goat milk supplementation enhances memory performance, reduces oxidative damage, lowers acetylcholinesterase activity, and increases glutathione levels in the brain, thereby reversing age- and drug-induced cognitive impairments (Safdar et al., 2020; Kaura et al., 2022). Fermented goat milk products, enriched with lactopeptides, have been reported to improve systemic antioxidant capacity and protect against oxidative damage, which may contribute to cognitive resilience during aging (Moreno-Fernández et al., 2019). Moreover, recent work in rodent models of autism spectrum disorder revealed that goat milk supplementation improved social behaviour, reduced neuroinflammation, and normalized neurotransmitter imbalances, underscoring its potential role in supporting neurodevelopment (Al-Dossari et al., 2023).

Anti-inflammatory and metabolic regulation: Goat milk demonstrates significant anti-inflammatory and metabolic regulatory properties, primarily linked to its content of conjugated linoleic acid (CLA), polyunsaturated fatty acids, and other bioactive lipids. These compounds attenuate inflammation by downregulating pro-inflammatory cytokines and mediators, while simultaneously improving lipid metabolism through reductions in LDL cholesterol and increases in HDL levels. They also contribute to better glucose utilization and insulin sensitivity, thereby supporting energy balance and reducing the risk of metabolic dysfunction. Collectively, these effects counteract chronic low-grade inflammation, a key driver of obesity, type 2 diabetes, and metabolic syndrome. Recent evidence reinforces this functional role: Cismileanu et al. (2024) reported that goat dairy products enriched with healthy fatty acids improved lipid metabolism and anti-inflammatory outcomes; Andrada et al. (2024) highlighted the role of fermented goat milk as a promising functional food in obesity management; and Petrella et al. (2024) demonstrated that goat milk supplementation enhanced mitochondrial oxidative capacity and reduced systemic inflammation in animal models. Together, these findings substantiate the growing consensus that goat milk and its derivatives may serve as effective dietary interventions for preventing and managing metabolic disorders.

Product development from goat milk

Goat milk has historically been integral to the diets of Mediterranean, Asian, and African populations, primarily in the form of cheeses, yogurts, and fermented beverages. These traditional products are valued for their unique sensory attributes and enhanced digestibility, conferred largely by medium-chain fatty acids and favourable mineral and vitamin profiles compared to cow milk. Recent advances in food technology and a growing consumer preference for functional and health-oriented products have expanded the application of goat milk to include functional dairy foods, nutraceuticals, fortified products, and novel beverages. This section explores the development of goat milk-based products across traditional and innovative categories. Various goat milk products, grouped into different categories and their functional attributes are summarized in Table 3.

Traditional products: Cheese and fermented dairy products remain the cornerstone of goat milk utilization. Goat cheeses, ranging from fresh to aged varieties, are globally appreciated for their distinctive sensory characteristics, which are closely linked to their fatty acid profile and regional production practices. Compared to cow milk cheese, goat milk varieties often exhibit enhanced digestibility due to higher levels of medium-chain triglycerides (MCTs) and lower αs1-casein content. Studies also highlight the release of bioactive peptides during ripening, including ACE-inhibitory sequences with cardiovascular benefits (Tilocca et al., 2022; Moises et al., 2024; Qiao et al., 2022). Similarly, fermented goat milk beverages such as yogurt, kefir, laban, and amasi play a dual role: providing probiotic organisms and delivering metabolites such as short-chain fatty acids that improve cholesterol metabolism and exert anti-inflammatory activity (Chen et al., 2023; Grujovic et al., 2024). These traditional products thus serve as both cultural heritage foods and functional dietary components.

Recent technological studies have further broadened the diversity of traditional products. For example, ultrafiltration-assisted manufacture of Halloumi-type cheese improved protein retention, meltability, microstructure, and sensory performance, particularly in formulations with elevated fat content (Deshwal et al., 2020). Similarly, investigations on goat-milk mozzarella demonstrated that different acidulants markedly influence meltability, rheology, colour attributes, and textural parameters, although overall sensory quality remained acceptable across formulations (Verma et al., 2022).

Functional dairy foods: The transition from traditional to functional dairy products has been driven by consumer demand for foods that promote gut health,

Table 3. Goat milk-based products and their functional properties

Product Type	Example Products	Functional Properties	References
Traditional dairy	Cheese (fresh, semi-hard, aged), yogurt, kefir, laban	Improved digestibility, unique sensory profile, probiotic potential	Park et al. (2017); Tilocca et al. (2022); Moises et al. (2024)
Functional dairy	Probiotic yogurt, infant formula, fortified dairy foods	Gut health, immune modulation, hypoallergenicity, improved microbiota	Brown (2024); Jankiewicz et al. (2023); Monareng et al.(2025)
Nutraceuticals	Hydrolyzed protein powders, encapsulated peptides, nutraceutical beverages	Antioxidant, antihypertensive (ACE inhibition), antimicrobial, cholesterol-lowering	Moreno-Montoro et al. (2018); Al-Kaisy et al. (2023); Grujovic et al. (2024)
Fortified products	Omega-3 enriched milk, vitamin- and mineral-fortified formulations, biofortified milk	Enhanced nutritional value, cardiovascular protection, bone health, elderly nutrition	Paszczyk (2023); Cismileanu et al. (2024)
Beverages	Probiotic drinks, synbiotic beverages, goat milk-plant extract blends	Synergistic gut and metabolic benefits, antioxidant and anti-inflammatory roles	Chen et al.(2023); Grujovic et al.(2024); Monareng et al. (2025)

immunity, and allergy reduction (Yangilar, 2013). Goat milk yogurt enriched with *Lactobacillus* and *Bifidobacterium* demonstrates improved probiotic survival under gastrointestinal stress compared with bovine milk matrices, offering an efficient vehicle for probiotic delivery (Monareng et al., 2025). Another rapidly expanding application is infant formula, where goat milk is valued for its oligosaccharide profile, which is structurally similar to human milk oligosaccharides (HMOs). These compounds promote *Bifidobacterium* colonization in the infant gut, reduce the risk of cow milk protein allergy, and enhance digestibility (Prosser, 2021; Jankiewicz et al., 2023). Recent advances in bioproduction techniques are also enabling the scalable synthesis of goat milk oligosaccharide analogs, expanding opportunities for developing next-generation infant formulas and functional beverages (Ranjith et al., 2025). Fortified goat milk products are additionally gaining momentum, with formulations enriched in omega-3 fatty acids, conjugated linoleic acid (CLA), vitamins, and selenium being explored for cardiovascular and metabolic health benefits, particularly in elderly populations where osteoporosis and immune decline are prevalent (Cismileanu et al., 2024). Additionally, incorporation of fruit and vegetable purees such as pineapple, carrot, and papaya enhanced antioxidant properties, viscosity, colour characteristics, and sensory performance while maintaining high probiotic viability during storage (Singh et al., 2024b). Such puree-enriched fermented products also showed improved stability during refrigeration and retained desirable textural attributes, highlighting their potential as naturally fortified functional dairy formulations (Singh et al., 2025).

Nutraceuticals and bioactive peptide products: A key area of innovation is the extraction and application of bioactive peptides and proteins from goat milk. Enzymatic hydrolysis generates hydrolyzed protein powders enriched with ACE-inhibitory, antioxidant, and antimicrobial peptides, offering targeted benefits for hypertension and oxidative stress management (Mahdi et al., 2018; Moreno-Montoro et al., 2018). Advances in proteomic techniques, such as shotgun proteomics and molecular simulations, have further identified multifunctional peptides in goat whey, demonstrating potential applications in peptide-based functional nutraceuticals (Singh et al., 2024a).

To ensure efficacy, encapsulation technologies-including microencapsulation, nanoencapsulation, and lipid-based carriers are increasingly employed to stabilize these bioactives and improve their delivery. Such encapsulated products are entering the nutraceutical market in the form of powders, capsules, and beverages (Grujoviæ et al., 2024). Additionally, goat milk serves as a base for functional drinks enriched with hydrolysates, probiotics, or plant polyphenols such as catechins and moringa extracts, producing synergistic antioxidant, hypocholesterolemic, and immunomodulatory effects (Tilocca et al., 2022; Monareng et al., 2025).

Fortified products: Goat milk fortification strategies are expanding its utility as a preventive health food. Omega-3 enrichment through feeding strategies such as linseed and hempseed supplementation enhances the anti-inflammatory profile of goat milk fats, while vitamin D and selenium fortification contributes to bone health and antioxidant defence (Verma et al., 2024). Biofortification approaches such as feeding goats selenium-rich forage or algae are now being investigated as sustainable methods to naturally elevate the nutraceutical value of milk (Paszczyk, 2023). Such approaches highlight the synergy between animal nutrition and human functional food development.

Goat milk-based beverages: Goat milk beverages have become an important category for delivering functional ingredients in an accessible format. Probiotic kefir and yogurt-based drinks enhance microbiota diversity and immune modulation, while synbiotic formulations combine natural oligosaccharides with probiotic cultures to optimize gut health outcomes. Nutraceutical beverages that incorporate goat milk hydrolysates with plant-derived extracts such as ginger, turmeric, and moringa are also under development, showing potential in modulating oxidative stress, inflammation, and metabolic disorders (Grujovic et al., 2024). This category demonstrates the versatility of goat milk in responding to modern consumer preferences for convenient, multifunctional products.

Emerging technologies in goat milk processing

The successful translation of goat milk into functional and nutraceutical products depends heavily on advances in processing technologies. Enzymatic hydrolysis and fermentation remain central to bioactive peptide release and probiotic enhancement (Moreno-Montoro et al., 2018; Chen et al., 2023). High-pressure processing (HPP) preserves thermolabile nutrients while ensuring microbial safety (Monareng et al., 2025), whereas membrane filtration allows concentration of proteins and oligosaccharides (Moises et al., 2024). Ultrasonication has emerged as a useful tool for improving homogenization, enhancing probiotic survival, and enabling nanoencapsulation (Nayik et al., 2021). Cold plasma technology, a sustainable non-thermal process, has shown promise in microbial inactivation while preserving bioactive integrity, thereby extending shelf life (Abbas et al., 2024). Looking forward, 3D food printing is being explored for its potential to transform goat milk proteins into nutraceutical gels and personalized nutrition solutions (dos Santos et al., 2023). These technologies not only expand the functional repertoire of goat milk but also align with global trends toward sustainability, personalization, and innovation in food systems.

Future prospects and challenges

Goat milk holds considerable promise as a globally recognized functional food, but its expansion into mainstream markets requires overcoming several hurdles. The foremost challenge is the clinical validation of its health benefits, since most available data are derived from laboratory and animal studies rather than large-scale human trials. Without rigorous evidence, substantiating health claims and achieving regulatory approval will remain difficult. At the same time, technological innovation provides strong opportunities: advances in enzymatic hydrolysis, fermentation, and encapsulation can optimize the release and delivery of bioactives, while non-thermal techniques such as high-pressure processing, ultrasonication, and cold plasma enhance microbial safety and nutrient preservation. Sustainability also adds to the promise of goat milk, as goats thrive in marginal environments with relatively low resource input, making them integral to climate-smart livestock systems. However, scaling production for industrial use raises concerns about supply chain management, quality standardization, and cost-effectiveness.

Another critical factor is consumer perception. Despite its cultural acceptance in many regions, goat milk remains less popular globally due to its distinct flavour and limited familiarity compared to cow milk. Product diversification through flavoured beverages, fortified powders, and blended formulations combined with education campaigns may improve acceptance. Looking forward, the integration of goat milk into personalized nutrition represents an exciting frontier. With the help of modern technologies and omics-based approaches, tailored formulations could be developed to address specific health needs such as cardiovascular health, bone integrity, and gut microbiota balance. In essence, the future success of goat milk as a functional food will rely on harmonizing scientific validation, technological innovation, sustainable practices, consumer awareness, and precision nutrition.

Conclusion

Goat milk stands out as a promising functional food owing to its unique nutritional profile, bioactive components, and adaptability to both traditional and modern product development. Its application spans from cheeses and yogurts to nutraceutical powders, fortified formulations, and functional beverages, highlighting its versatility. While significant progress has been made in understanding its health-promoting properties, further clinical validation is essential to support health claims and strengthen its global acceptance. Advances in processing and preservation technologies, coupled with sustainable production practices, will be key to unlocking its full potential. Equally important are consumer education and innovative product diversification, which can overcome barriers of perception and flavour. Taken together, goat milk has the capacity to contribute meaningfully to nutrition, health promotion, and the expanding functional food market worldwide.

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