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EXPLORING THE NUTRITIONAL AND BIOCHEMICAL PROPERTIES OF BACTRIAN CAMEL MILK: INSIGHTS INTO FUNCTIONAL FOODS AND MEDICAL APPLICATIONS

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ABSTRACT

Bactrian camel (*Camelus bactrianus*) milk (BCM) has gained attention for its rich nutrients and unique biochemical properties. This review summarises its key nutritional components—proteins, fats, vitamins and minerals and its biochemical traits like antioxidant and immune-modulating effects. By examining current literature, we discuss its health benefits, disease prevention potential and role as a functional food. The review also highlights current research and suggests future studies to maximise its dietary and therapeutic benefits.

Key words: Bactrian camel milk, biochemical properties, functional foods, medical applications, nutritional components

Milk from the Bactrian camel (*Camelus bactrianus*) has attracted considerable scholarly attention due to its distinctive nutritional and biochemical characteristics. In contrast to conventional dairy products, Bactrian camel milk (BCM) is characterised by a higher protein content, reduced fat levels and a diverse array of vitamins and minerals, rendering it a promising alternative for various dietary requirements (He *et al,* 2019; Zhong *et al,* 2025; Jiao *et al,* 2025; Huang *et al,* 2024). Research indicates that this milk contains essential amino acids and fatty acids vital for human health. Notably, the primary fatty acids present in BCM are palmitic, oleic and stearic acids, with a significant proportion of long-chain fatty acids that may confer health benefits, such as enhanced cardiovascular health and improved metabolic functions (He *et al,* 2019; Zhong *et al,* 2025; Jiao *et al,* 2025; Huang *et al,* 2024; Pan *et al,* 2024). Additionally, the unique composition of BCM makes it suitable for individuals with lactose intolerance, as it contains lower lactose levels compared to cow's milk, thereby offering a viable option for those who experience discomfort with traditional dairy products (Pan *et al,* 2024; Du *et al,* 2025).

The biochemical attributes of BCM extend beyond its nutritional composition, exhibiting significant antioxidant properties that are crucial in mitigating oxidative stress and inflammation within the body. Empirical evidence suggests that the antioxidant capacity of BCM surpasses that of other types of milk, potentially contributing to its health-enhancing effects (He *et al,* 2019; Zhong *et al,* 2025; Jiao *et al,* 2025; Du *et al,* 2025). This antioxidant activity is ascribed to various bioactive compounds present in the milk, which are instrumental in modulating immune responses and safeguarding cellular integrity. Furthermore, the presence of distinctive proteins, such as αs2-casein, highlights the potential of BCM as a functional food (Zhong *et al,* 2025; Du *et al,* 2025; Pauciullo *et al,* 2023). These proteins not only enhance the nutritional quality of the milk but also improve its applicability in food processing and product development.

In the realm of medical applications, has demonstrated potential across various therapeutic domains, notably including anti-inflammatory, antidiabetic and anticancer effects. Its bioactive constituents have been associated with the modulation of gut microbiota, a factor essential for maintaining overall health and preventing chronic diseases (Seyiti *et al,* 2024). The potential of BCM to function as a functional food in managing conditions such as diabetes and obesity is particularly significant, as it may aid in the regulation of blood

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glucose levels and lipid profiles. Furthermore, the milk's immunomodulatory properties may confer advantages in bolstering the body's defenses against infections and diseases (Iacobucci *et al,* 2019).

In summary, the investigation into the nutritional and biochemical properties of BCM highlights its considerable potential as both a functional food and a medical resource. The distinctive composition and associated health benefits of this milk underscore its value for dietary and therapeutic applications. Future research should aim to elucidate the mechanisms underlying its bioactive properties and explore its applications across diverse health contexts, thereby advancing its role in the fields of functional food science and medicine.

Nutritional Composition of BCM

Bactrian camel milk is increasingly acknowledged for its distinctive nutritional composition, which offers significant benefits to populations residing in arid regions (Zhong *et al,* 2025; Huang *et al,* 2024). This milk is distinguished by its elevated levels of essential nutrients, including proteins, fats, vitamins and minerals. Research indicates that BCM is rich in a variety of bioactive compounds, enhancing its value as a dietary component (He *et al,* 2019; Zhong *et al,* 2025; Jiao *et al,* 2025). The nutritional composition of BCM can vary considerably due to factors such as geographical location, breed and feeding practices, all of which can impact its overall nutritional quality (He *et al,* 2019; Razuan *et al,* 2025).

The protein content of BCM is remarkably high, constituting approximately 3.5 to 4.0% of its overall composition. The primary proteins present are caseins and whey proteins, with caseins accounting for roughly 80% of the total protein content. The amino acid profile of BCM proteins is enriched with essential amino acids, which are vital for human health and development (Guo *et al,* 2023; Ma *et al,* 2025). Notably, BCM contains elevated levels of specific amino acids, such as lysine and methionine, compared to cow's milk, thereby enhancing its nutritional value (Zhong *et al,* 2025; Huang *et al,* 2024; Ma *et al,* 2025). These proteins also demonstrate functional properties, including emulsification and foaming, which are advantageous in food processing applications (Ma *et al,* 2025). Furthermore, BCM proteins have been linked to various health benefits, such as anti-inflammatory and antimicrobial properties, making them a subject of interest in the research of functional foods (Guo *et al,* 2023; Ma *et al,* 2025).

The fatty acid composition of BCM represents a significant element of its nutritional profile. Notably, it contains a higher proportion of unsaturated fatty acids, specifically monounsaturated and polyunsaturated fatty acids, in comparison to cow's milk. Prominent fatty acids in BCM include oleic acid, linoleic acid and palmitic acid (Chu *et al,* 2014). The presence of these fatty acids is linked to various health benefits, such as enhanced cardiovascular health and anti-inflammatory effects. Research suggests that the distinctive fatty acid profile of BCM may contribute to its potential therapeutic properties, particularly in the management of conditions such as diabetes and obesity (Zhong *et al,* 2025; Jiao *et al,* 2025; Du *et al,* 2025). Additionally, the fatty acids in BCM are believed to facilitate the absorption of fat-soluble vitamins, thereby enhancing overall nutrient bioavailability (Chuluunbat *et al,* 2014; Zhan *et al,* 2023).

Bactrian camel milk is a substantial source of essential vitamins and minerals. It contains notable quantities of vitamins A, B, C, D and E, which are crucial for various physiological functions, including immune response, vision and skin health (Zhong *et al,* 2025; Jiao *et al,* 2025; Du *et al,* 2025). The mineral profile is equally noteworthy, featuring elevated levels of calcium, magnesium, potassium and zinc, all of which are vital for bone health and metabolic processes (Zhong *et al,* 2025; Jiao *et al,* 2025). Research indicates that the mineral composition of BCM may vary according to the animal's diet and environmental conditions; however, it consistently serves as a valuable source of these nutrients (Huang *et al,* 2024). The bioavailability of minerals in BCM is enhanced by the presence of specific proteins that facilitate their absorption in the human body. This distinctive combination of vitamins and minerals renders BCM a nutritious option for augmenting dietary intake and promoting overall health (Razuan *et al,* 2025; Guo *et al,* 2023).

Biochemical Characteristics of BCM

Empirical studies have demonstrated that BCM contains elevated levels of specific fatty acids, including palmitic acid, oleic acid and stearic acid, in comparison to other milk types, which may confer various health benefits (He *et al,* 2019; Pan *et al,* 2024). Additionally, the milk is characterised by a unique amino acid profile, with leucine, lysine and valine being predominant, which are essential for protein synthesis and overall health (Pan *et al,* 2024). There are certain differences in the specific nutritional

composition between BCM and dromedary camel milk (DCM) (see Table 1 for details). This distinctive composition not only renders BCM an essential dietary resource for desert populations but also positions it as a functional food with potential therapeutic applications (Zhong *et al,* 2025; Jiao *et al,* 2025; Du *et al,* 2025).

The antioxidant properties of BCM are of significant academic interest due to their potential implications for health promotion and disease prevention (Zhong *et al,* 2025; Jiao *et al,* 2025; Du *et al,* 2025). Empirical studies have demonstrated that BCM possesses substantial antioxidant activity, which is primarily attributed to its rich composition of bioactive compounds, including vitamins, minerals and specific peptides (Jiao *et al,* 2025; Huang *et al,* 2024). Notably, the total antioxidant capacity (T-AOC) and the activity of antioxidant enzymes, such as superoxide dismutase (SOD) and catalase, have been observed to vary with the parity of lactating camels (Du *et al,* 2025). This variation suggests that the antioxidant profile of the BCM is subject to modulation by physiological factors (Jiao *et al,* 2025; Du *et al,* 2025). The underlying mechanisms of the antioxidant effects of BCM involve the scavenging of reactive oxygen species (ROS) and the modulation of redox signaling pathways, which are essential for cellular protection against oxidative stress (Jiao *et al,* 2025; Pan *et al,* 2024). This antioxidant activity not only underscores the health benefits of the BCM but also highlights its potential as a therapeutic agent in the management of conditions related to oxidative stress (Fig 1).

In addition to its antioxidant properties, BCM has been extensively studied for its immunomodulatory effects. Research suggests that components within BCM can enhance immune responses and modulate inflammation, positioning it as a promising candidate for therapeutic applications in autoimmune diseases and other inflammatory conditions (Jiao *et al,* 2025). For example, BCM has been demonstrated to influence immune cell activity, promoting a balanced immune response that may aid in the management of chronic inflammatory diseases (Huang *et al,* 2024). The immunomodulatory effects are believed to be mediated by various bioactive molecules present in the BCM, such as immunoglobulins and lactoferrin, which can enhance the body's defense mechanisms against pathogens and mitigate the severity of inflammatory responses (Chuluunbat *et al,* 2014). Additionally, it enhances the efficacy of chemotherapeutic agents, such as cisplatin, in a synergistic manner. Anti-cancer mechanism is to mediate the proliferation and apoptosis of cancer cells by relying on JNK signaling pathway, MAPK signaling pathway and NFkB signaling pathway, thereby playing an anti-cancer role (Jiao *et al,* 2025; Du *et al,* 2025) (Fig 2). This aspect of BCM highlights its potential as a functional food that not only provides nutritional benefits but also supports immune health.

In addition to its antioxidant and immunomodulatory characteristics, BCM demonstrates significant antimicrobial activity, thereby enhancing its functional profile. Research has shown that BCM inherently possesses antibacterial properties, largely due to the presence of specific proteins and peptides that inhibit the proliferation of various pathogens, including bacteria and viruses (Pan *et al,* 2024). For instance, lactoferrin in BCM has been demonstrated to exert antimicrobial effects by sequestering iron, thus depriving bacteria of this vital nutrient and inhibiting their growth (Huang *et al,* 2024). Furthermore, the distinctive fatty acid composition of camel milk may further contribute to its antimicrobial efficacy, positioning it as a potential natural preservative in food applications (Ma *et al,* 2022). This antimicrobial activity not only improves the safety and shelf-life of the milk but also supports its utilisation in traditional medicine and as a functional food in modern diets. Even the bioactive substances of BCM regulate the intestinal microbiota and its metabolites through metabolites and regulate various tissues and organs throughout the body through the "microbial-gut-x" axis (Jiao *et al,* 2025; Du *et al,* 2025) (Fig 3).

Application of BCM in functional foods

BCM has been identified to contain bioactive compounds with anti-inflammatory, antidiabetic and lipid-lowering properties, further augmenting its potential as a functional food (Seyiti *et al,* 2024). The presence of unique fatty acids, such as long-chain fatty acids, contributes to its health benefits, including enhanced cardiovascular health (He *et al,* 2019). Additionally, studies have highlighted the antioxidant properties of BCM, indicating its potential to mitigate oxidative stress, which is associated with various chronic diseases (Du *et al,* 2025). Overall, the nutritional profile and bioactivity of BCM position it as a promising candidate for dietary supplementation, appealing to health-conscious consumers and individuals seeking alternative nutritional sources. BCM has garnered significant attention for its potential health benefits, particularly among specific populations such as

Table 1. Comparative Analysis of Nutritional Components in Camel and Bovine Milk.

Nutritional Parameter	Bactrian Camel Milk (BC)	Dromedary Camel Milk (DC)	Bovine Milk (Cow)	Comparative Advantage (BC vs DC/Cow)	References
Macronutrients					
Total Solids (%)	14.2–17.5	10.8	12.4	+29%↑ DC / +18%↑ Cow	[Cefalu *et al*, 2004; Seyiti *et al*, 2024]
Protein (%)	3.6–4.8	3.2	3.4	+34%↑ DC / +23%↑ Cow	[Seyiti *et al*, 2024]
Fat (%)	3.4–7.4	3.1	3.7	+48%↑ DC / +24%↑ Cow	[Cefalu *et al*, 2004; Seyiti *et al*, 2024]
Lactose (%)	4.6–6.2	3.8	4.7	+32%↑ DC / +17%↑ Cow	[Seyiti *et al*, 2024; Miao *et al*, 2023]
Ash (%)	0.7–0.9	0.7	0.6	+14%↑ DC / +33%↑ Cow	[Seyiti *et al*, 2024]
Minerals (mg/kg)					
Sodium (Na)	552–720	474	319	+34%↑ DC / +126%↑ Cow	[Seyiti *et al*, 2024; Almasri *et al*, 2024]
Phosphorus (P)	1068–1168	946	901	+19%↑ DC / +25%↑ Cow	[Seyiti *et al*, 2024]
Calcium (Ca)	1442–1809	1299	1137	+23%↑ DC / +37%↑ Cow	[Seyiti *et al*, 2024]
Potassium (K)	1244–1910	1732	1418	DC: +10% / BC: +35%↑ Cow	[Seyiti *et al*, 2024]
Vitamins (mg/kg)					
Vitamin C (VC)	28.2–42.3	33	15	+28%↑ DC / +182%↑ Cow	[Cefalu *et al*, 2004; Seyiti *et al*, 2024]
Vitamin A (VA)	0.5–1.1	0.3	0.4	+267%↑ DC / +175%↑ Cow	[Seyiti *et al*, 2024]
Vitamin E (VE)	1.4–2.7	0.02	1	+134×↑ DC / +170%↑ Cow	[Seyiti *et al*, 2024]
Functional Characteristics					
β-Casein Proportion	65%	45%	30%	Enhanced digestibility & absorption	[Xiao *et al*, 2022]
Lactoferrin (mg/L)	3.2	2.1	0.1	15× higher antimicrobial activity	[Xiao *et al*, 2022; Zhang *et al*, 2005; Chen *et al*, 2024]

Table 2. The Effects of BCM on Different Types of Diabetes Mellitus.

Type of Diabetes	Research Findings	Recommended Dosage	References
Type 1 Diabetes	Significant reduction in fasting blood sugar (FBS) and glycated haemoglobin (HbA1c)	500 mL/day for 3 months	(Seyiti *et al*, 2024; Jiao *et al*, 2025)
	Decreased insulin injection dosage (~37%)		
	Improved diabetic nephropathy (reduced microalbuminuria)		
Type 2 Diabetes	Reduced fasting blood glucose and plasma insulin levels	500 mL/day for 2-3 months	(Seyiti *et al*, 2024; Jiao *et al*, 2025; Pan *et al*, 2024)
	Improved lipid profile (TG, TC)		
	Some inconsistent findings, potentially due to small sample sizes		

individuals with lactose intolerance. In contrast to cow's milk, BCM contains reduced levels of lactose, thereby rendering it more suitable for those who experience discomfort from lactose ingestion (Seyiti *et al*, 2024). Empirical studies have demonstrated that lactose-intolerant individuals can consume BCM without experiencing the gastrointestinal disturbances commonly associated with lactose-containing dairy products (Seyiti *et al*, 2024). Furthermore, the distinct protein composition of BCM, including casein variants that differ from those found in cow's milk, may enhance its digestibility and acceptance among lactose-intolerant consumers (Jiao *et al*, 2025). Beyond lactose intolerance, BCM

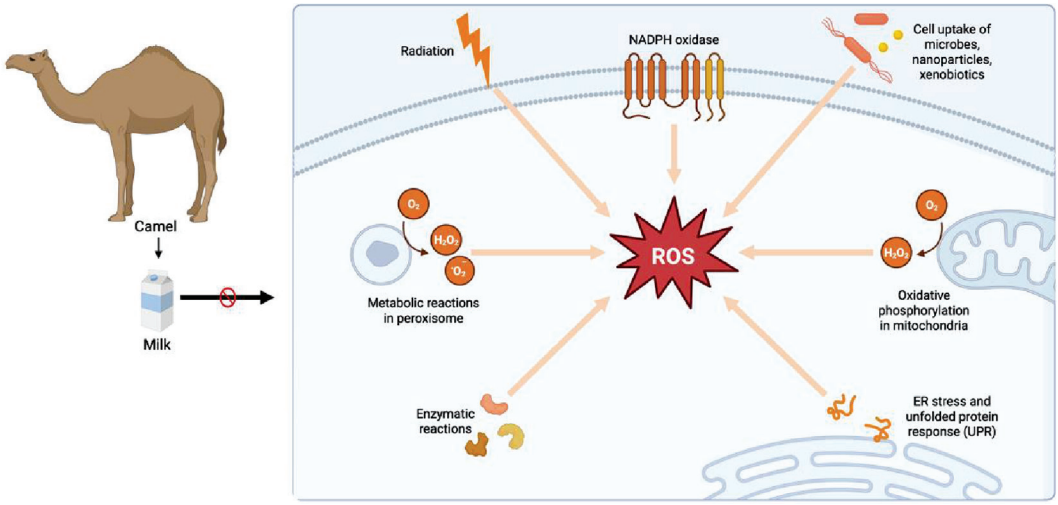

Fig 1. The main antioxidant mechanism of BCM.

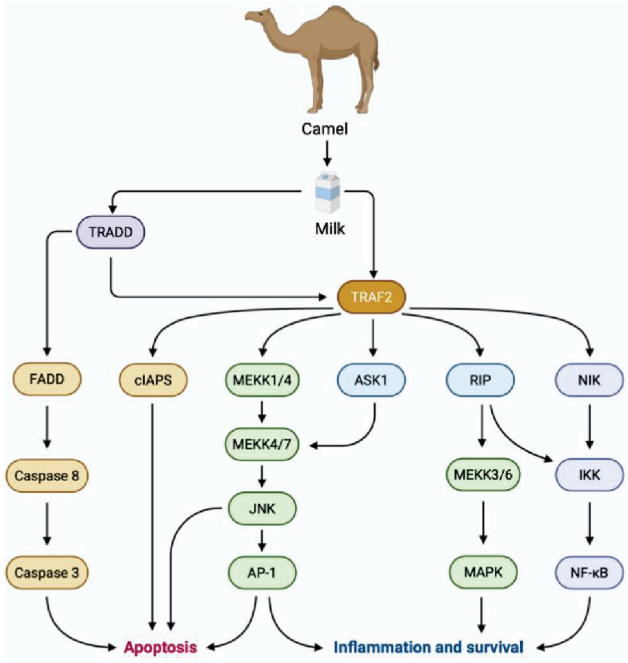

Fig 2. Anticancer mechanism of the active ingredient in BCM.

has been investigated for its potential advantages in other vulnerable groups, including children and the elderly, who may benefit from easily digestible nutritional sources (Pan *et al,* 2024; Du *et al,* 2025). The anti-inflammatory and immunomodulatory properties of BCM further increase its attractiveness for individuals with compromised immune systems or chronic inflammatory conditions (Seyiti *et al,* 2024). Thus, BCM presents a viable alternative for those in need of dairy substitutes, offering both nutritional benefits and enhanced digestibility.

Medical Applications of BCM

Recent clinical research has underscored the potential of BCM as a preventive medicines. Empirical studies have indicated that regular consumption of BCM can result in significant enhancements in various health parameters, such as lipid profiles, glycemic control and inflammatory markers (Seyiti *et al,* 2024). Furthermore, the lipid profile of BCM, characterised by a higher proportion of unsaturated fatty acids, contributes to its lipid-lowering effects, which can alleviate cardiovascular risks (Seyiti *et al,* 2024). Study concentrating on diabetic patients demonstrated that individuals who incorporated BCM into their diet achieved superior glycemic control compared to those who did not (Seyiti *et al,* 2024; Jiao *et al,* 2025; Pan *et al,* 2024) (Table 2). Furthermore, the anti-inflammatory properties of BCM may play a role in preventing chronic diseases by reducing systemic inflammation, a common underlying factor in many chronic conditions (Ma *et al,* 2022). BCM is abundant in immunoglobulins, lactoferrin and other bioactive components that can enhance immune responses and provide protection against infections (Huang *et al,* 2024). This multifaceted approach to disease prevention underscores the importance of BCM as a potential medications in the context of chronic disease management. At present, there are some "camel milk therapy" used in clinical practice for patients with chronic diseases and diabetes (Pan *et al,* 2024). These attributes suggest that BCM could serve as a complementary therapy for patients with immune system disorders, potentially enhancing their quality of life and improving clinical outcomes. Moreover, the distinctive composition of BCM, establishes it as a preventive medicines that can be integrated into therapeutic guidelines for diverse populations, particularly those at risk for chronic diseases (Seyiti *et al,* 2024) (Fig 4). The growing body of evidence supporting the health benefits of BCM underscores

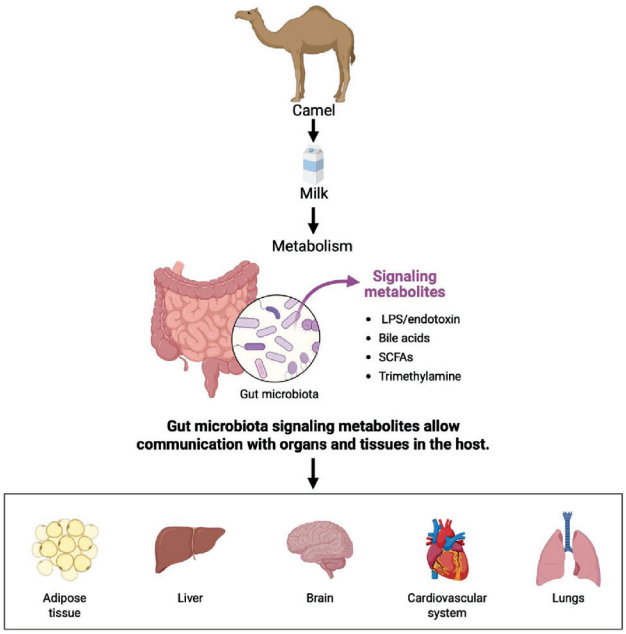

Fig 3. BCM and its metabolites regulate organ function through the "microbial-gut-x" axis.

its potential as a valuable addition to preventive medicines research and dietary practices, paving the way for future studies and applications in clinical nutrition.

Future Research Directions and Challenges

The domain of BCM research is undergoing rapid advancement, offering numerous opportunities for further investigation and addressing existing challenges. As interest in BCM continues to expand, particularly due to its distinctive nutritional and bioactive properties, future research endeavors should concentrate on several critical areas to enhance our comprehension and application of this valuable resource. Investigating the nutritional components of BCM is essential for elucidating its health benefits and potential applications in dietary interventions.

The processing and product development of BCM are essential for optimising its nutritional benefits and market potential. Due to its unique composition, BCM necessitates specific processing techniques to maintain its bioactive properties while ensuring food safety and quality (Du *et al,* 2025). Research suggests that traditional methods, such as fermentation, can enhance the probiotic content of BCM, thereby establishing it as a valuable functional food product (Seyiti *et al,* 2024). Furthermore, contemporary processing techniques, including pasteurisation and ultrafiltration, have been investigated to extend the shelf life and safety of BCM without compromising its nutritional integrity

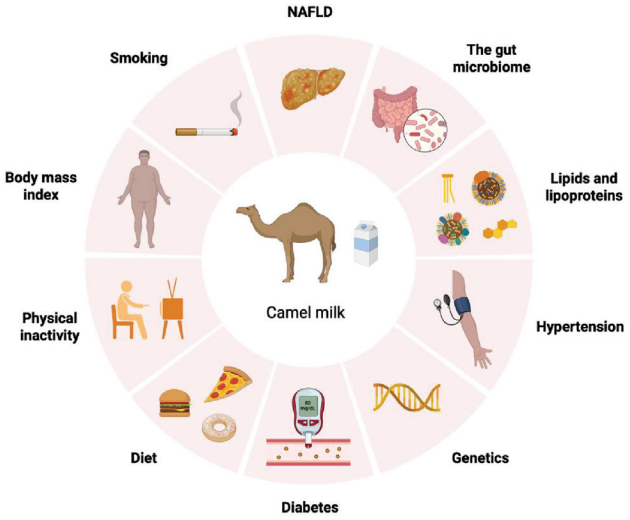

Fig 4. Summary of the beneficial regulatory effects of BCM on chronic diseases.

(Wang *et al,* 2024). The exploration of diverse BCM-based products, such as cheese, yogurt and powdered milk, has broadened its applications within the food industry (Seyiti *et al,* 2024). Moreover, the economic potential of BCM in China is considerable, as it aligns with the increasing consumer demand for functional foods and natural health products (Seyiti *et al,* 2024). As research continues to unveil the health benefits and processing innovations associated with BCM, the market for BCM products is expected to expand, offering new opportunities for both producers and consumers. Future research should aim to conduct comprehensive analyses of these components, exploring how geographic and environmental factors influence the nutritional quality of BCM. Such studies could lead to the development of targeted nutritional strategies that leverage the unique properties of BCM for specific health outcomes.

To effectively translate the promising findings from BCM research into practical applications, it is imperative to conduct rigorous clinical trials. Preliminary studies have suggested potential health benefits of BCM, such as its anti-inflammatory and antidiabetic properties; however, these claims necessitate validation through well-designed clinical trials (Seyiti *et al,* 2024). Specifically, the role of BCM in managing conditions like lactose intolerance and its potential as a functional food should be assessed across diverse populations. Additionally, research should focus on investigating the safety and efficacy of BCM consumption among various demographic groups, including children and the elderly, who may derive significant nutritional benefits. Establishing a robust evidence base through clinical trials will not only enhance the credibility of BCM as a health-

promoting food but also facilitate its inclusion in dietary guidelines and recommendations. The effective integration of BCM into the market is contingent upon strategic promotion and consumer acceptance. Despite its nutritional benefits, BCM remains underutilised compared to cow's milk, primarily due to limited consumer awareness and prevailing misconceptions regarding its taste and health benefits (Seyiti *et al,* 2024). Future research should prioritise understanding consumer perceptions and identifying barriers to acceptance, thereby informing targeted marketing strategies. Educational campaigns that emphasise the unique health benefits of BCM, coupled with sensory evaluations aimed at enhancing taste profiles, could significantly boost consumer interest. Furthermore, the development of innovative products, such as fortified or flavoured BCM, may appeal to a wider audience. Collaborating with health professionals and utilising social media platforms for outreach can further promote BCM as a functional food, ultimately increasing its market presence and consumer demand.

Conclusion

This review consolidates the primary nutritional elements and bioactive properties of BCM, highlighting its prospective benefits for health enhancement and disease prevention. Although its nutritional benefits are well-documented, the primary challenge is to reconcile diverse research outcomes with practical applications. This requires a balanced approach that integrates clinical research with consumer perspectives, ensuring that the development of BCM products is consistent with both scientific validation and market demands. Educating consumers about the unique benefits of BCM, coupled with initiatives to improve production and distribution channels, will be instrumental in promoting broader acceptance within the health-conscious market. Collaboration among researchers, healthcare professionals and food industry stakeholders will be crucial in navigating the complexities of this emerging field.

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Conflict of interest

The authors declare that they have no conflict of interest.

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