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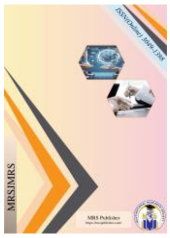

Therapeutic Potentials of Camel Milk (Camelus dromedarius): A Comprehensive Review

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Abstract

Background: Camel milk (*Camelus dromedarius*) is a rich source of bioactive compounds, including lactoferrin, immunoglobulins, and insulin-like proteins, with demonstrated therapeutic potential against metabolic, inflammatory, and infectious diseases. Its unique composition, characterized by high vitamin C, low lactose, and absence of β-lactoglobulin, distinguishes it from other ruminant milks and underpins its hypoallergenic and nutraceutical properties.

Objective: This review synthesizes current evidence on camel milk's anti-inflammatory, antiplatelet/antithrombotic, antimicrobial, and antidiabetic activities, emphasizing its mechanistic pathways and clinical applications.

Key Findings: Antidiabetic Effects: Camel milk insulin (42 µU/mL) resists gastric degradation, reducing blood glucose and HbA1c levels by up to 15% in type 1 diabetics and lowering insulin requirements by 30–35%. Bioactive peptides inhibit DPP-IV, α-amylase, and α-glucosidase, enhancing pancreatic β-cell function.

Anti-inflammatory & Immunomodulatory Properties: Lactoferrin and immunoglobulins suppress pro-inflammatory cytokines (e.g., IL-1β, COX-2) and modulate oxidative stress via SOD/CAT upregulation.

Antimicrobial Activity: Lysozyme, lactoperoxidase, and LAB isolates (e.g., *Ligilactobacillus salivarius*) exhibit bactericidal effects against *Staphylococcus aureus*, *E. coli*, and multidrug-resistant *Salmonella*.

Antiplatelet/Antithrombotic Effects: Peptides derived from κ-casein inhibit fibrinogen binding to αIIbβ3 receptors, prolonging bleeding time and reducing thromboxane B2 synthesis.

Conclusion: Camel milk's multifunctional bioactive components offer promising avenues for adjuvant therapies in diabetes, cardiovascular diseases, and infections. Further clinical trials are needed to standardize dosing and evaluate synergistic effects with conventional drugs.

Keywords: *Camel milk, lactoferrin, antidiabetic, anti-inflammatory, antimicrobial, bioactive peptides.*

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Introduction

Camel belongs to the family Camelidae, they are bulky animals that live in deserts and semi-arid areas with a population of nearly 35 million. Camels are important multipurpose animals and since the old times, it has been used for transportation, wool, meat, and milk production in arid and semi-arid areas of the world [1]. Three surviving species of camel exist. The Arabian or dromedary one-humped camel (Camelus dromedarius) which makes up 89% of the world's camel population, the two-humped Bactrian camel (Camelus bactrianus) takes up 11% , and the Wild Bactrian camel (*Camelus ferus)* which is a separate species and is now critically endangered [2,3]. The wild Bactrian camel is slightly smaller than the Bactrian camel and has been described as "lithe, slender-legged, with very narrow feet, a flatter skull, a different shape of foot. Camel is going to be a superior animal of the 21st century as its milk has splendid potentials of therapeutic factors, immune restorative, rich in taste and nutrients as paralleled to other milk-producing species [4, 5].

Camel milk differs from bovine milk in composition and structure of its protein components, which influences its functional and biological properties. There are several differences in size and shape between the three species [6].

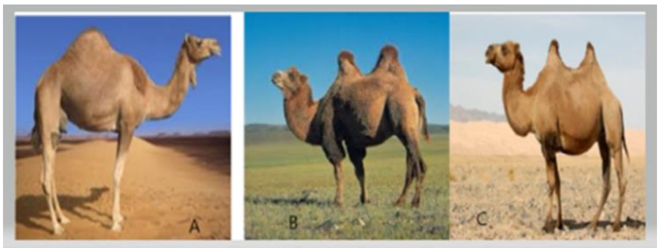

Figure 1: a; ***Camelus dromedaries.*** *an Arabian or dromedary one humped camel (Camelus dromedarius).***b:** ***Camelus bactrianus.*** *a Bactrian two humped camel..***c;** ***Camelus ferus.*** *An illustration of a Wild Bactrian camel (Camelus ferus) which is a critically endangered species of camel (Frame, Lory Herbison & George W.."camel". Encyclopedia Britannica,*

Camel Population

The current world camel population number estimated to be 35 million heads, most of which are in Somalia, Niger, Kenya, Chad, Ethiopia, Mali, Mauritania and Pakistan. Five bordering countries-Somalia, Ethiopia, Kenya, Sudan, and Djibouti hold 84% of African and more than half of the world's camel population Camels (C. dro medaries) are very important domestic animals species uniquely adapted to arid and semiarid zones in Asia and Africa (Ali, etal., 2019; Babege et al., 2021). In these extends the camels are raised for meat, milk and carriage tenacity for the sustenance of the regional economy and diet scarcity under drought-stricken conditions. It was reported that India and Pakistan possess almost seventy percent population of Asian camels (Khan, and Iqbal, 2001; Faraz et al., 2020). The highest population of dromedary camel is present in Somalia, Sudan, and Ethiopia (Faye, 2015; Kgaudi, et al., 2018).

One-humped camels (Camelus dromedarius) or Arabian camel plays an important role as a primary source of subsistence in North, Central, and West Africa. Due to their unique attributes, camels are often referred to as the 'White gold of the desert as they can thrive in areas where crop production is limited and other animals cannot withstand the harsh climatic conditions. Dromedary camels are described as having a high productive potential, and for centuries, they have been used by people (namely nomads) in arid and hot regions as versatile animals for physical labor, transport, the production of milk, meat, wool, hair, and skin, and for racing and tourism Bekele et al., 2021; Gagaoua et al., 2022). Due to global climate changes that are characterized by a continuous increase in desertification, changing and high temperatures as well as drought, it is essential to reassess the dromedary camel as one of the most adapted and sustainable animals that can be used to overcome such challenging environmental conditions (Gagaoua et al., 2022).

Camel Milk Composition and Functional Properties

While camels' ecological adaptations are well-documented, their milk's biochemical uniqueness remains understudied. Unlike bovine milk, CM lacks β-lactoglobulin (Konuspayeva et al., 2007) and contains micellar casein (20–300 nm) that enhances peptide bioavailability (Hammam et al., 2017). These traits may explain its clinical efficacy in lactose intolerance and diabetes.

Camel milk has garnered increasing scientific interest due to its unique biochemical composition, which is largely attributed to the camel's physiological adaptation to arid and semi-arid environments. Its composition differs markedly from that of other large and small ruminants. Physically, camel milk is typically opaque white and characterized by a sweet and slightly sharp taste that may at times be mildly salty, depending on the animal's diet and water availability (Alhaj, 2022). The taste of camels' milk differs, depending on the type of feed and availability of drinking water. The milk demonstrates a relatively high resistance to souring, with a pH range of 6.2–6.5 and density between 26–35 g/cm³, both lower than values reported for cow milk (El-Hatmi, et al., 2015; Abdullahi, 2019). This resilience allows for prolonged storage without refrigeration, although it readily undergoes fermentation into yogurt under suitable conditions.

Nutritionally, camel milk contains 85–90% water, 2–4.5% fat, 2.5–4% protein, 4–6% lactose, and 0.7–1.5% ash. It provides essential minerals such as calcium (1000–1400 mg/L), phosphorus (0.65–1.10 mg/L), and iron (0.3–0.8 mg/L), with a total solids content (~11.9%) comparable to human breast milk (Alhaj, 2022). The milk is rich in long-chain fatty acids and contains low cholesterol concentrations and short-chain fatty acids. Camel milk fat also features a significant proportion of phospholipids, including plasmalogens and sphingomyelin, supporting its potential role in meeting both adult and infant nutritional needs (Salwa, and Lina, 2010; Ereifej, et al., 2011).

Functionally, camel milk is recognized for a wide range of bioactivities. It contains an array of bioactive peptides and proteins such as lactoferrin, immunoglobulins, lysozyme, and lactoperoxidase, which contribute to its antioxidant, antibacterial, antifungal, antiviral, and anti-inflammatory effects (Shukla et al., 2023). These properties have been associated with potential therapeutic applications in conditions such as diabetes, cancer, autoimmune diseases, hepatitis, and inflammatory disorders (Shukla et al., 2023). Moreover, the absence of β-lactoglobulin in camel milk makes it a viable alternative for individuals with cow milk protein allergies (El-Agamy, 2009). The cumulative evidence underscores camel milk's potential as both a functional food and a therapeutic agent.

Furthermore, CM contains approximately 70% casein, slightly less than the 80% found in cow's milk, and comprises four casein fractions analogous in amino acid composition to αs1, αs2, β, and γ caseins of bovine origin. Casein micelle sizes in camel's milk range from 20 to 300 nm (Meena et al., 2014; Khalesi, et al., 2017; Faraz et al., 2020). Additionally, camel's milk demonstrates superior vitamin content, notably vitamins B1, B2, and particularly vitamin C, which is present at levels three to five times higher than in cow's milk (Ereifej, et al., 2011). This high vitamin C concentration underlines the nutritional relevance of camel's milk, especially in arid regions where access to fresh produce is limited (Al-Shamsi, et al., 2018).

Table 1. Chemical composition of Camel Milk in comparison to human and bovine milk.

Mammalian Specie	Energy (kcal/100 g)	Water %	Fat (g/100 g)	Lactose (g/100 g)	Protein (g/100 g)	Ash %
Human	64.2	88 – 89	3.3-4.7	6.8-7.0	1.1-1.3	0.2-0.3
Dromedary	66.1	86-88	2.9-5.4	3.3	3.0-3.5	0.6-0.9
Bactrian camel	88.9	86-88	2.9-5.4	3.5	3.2-3.9	0.6-0.9
Cow	76.2	85-87	3.7-4.4	4.8-4.9	3.2-3.6	0.7-0.8
Source: (Kula 2016; Vincenzetti, et al., 2022).						

Camel Milk Water, Proteins, Fat, Lactose, and Minerals

Water Content and Adaptation to Dehydration

Camel milk exhibits a unique response to dehydration, with its water content increasing from approximately 86% to 91% under water scarcity conditions. This adaptation is vital, serving as a hydrating source for both calves and humans in arid regions. Factors contributing to this increase include elevated antidiuretic hormone (ADH) secretion, reduced fat content, and variations in forage intake (Al-Shamsi, et al., 2018).

Proteins: Casein and Whey Proteins

Proteins are a significant component of camel milk, constituting about 3.17% of its composition. The protein fraction is predominantly casein (61.8%–88.5%), with whey proteins comprising the remaining portion. Camel milk's casein content ranges from 1.63% to 2.76%, with β-casein being the most abundant. The amino acid profile of camel milk casein is similar to that of bovine milk but with higher concentrations of both essential and non-essential amino acids. Whey proteins in camel milk include α-lactalbumin, lactoferrin, immunoglobulins, and lysozyme, which contribute to its antimicrobial properties. Notably, camel milk lacks β-lactoglobulin, a major allergen in cow's milk, making it a suitable alternative for individuals with milk allergies (Alhaji et al., 2022; Arian, et al., 2024).

Lactose; Lactose content in camel milk averages around 4.8%, which is similar to that in cow's milk. However, camel milk is often better tolerated by individuals with lactose intolerance, possibly due to its unique protein structure and the presence of higher levels of L-lactate (Rakhmatulina, et al., 2024).

Minerals; Camel milk is a rich source of essential minerals, including calcium (111.4 mg/100 g), potassium (156.3 mg/100 g), magnesium (6.7 mg/100 g), sodium (57.8 mg/100 g), and iron (10–20 mg/100 g). These concentrations are higher than those found in cow's milk, with camel milk being particularly rich in iron. The mineral content can vary based on factors such as feeding practices, camel breed, and environmental conditions (Arian, et al., 2024; Rakhmatulina, et al., 2024)..

Fat and Lipid Fractions in Camel Milk

Camel milk (CM) possesses a nutritionally distinct lipid profile, comprising triglycerides (TAGs), essential fatty acids (EFAs), and cholesterol, with fat content ranging from 2.9–5.4% (reducible to 1.1% under dehydration) (Bakry, et al., 2021). Unlike cow milk, CM is richer in long-chain (96.4%) and unsaturated fatty acids (LC-FAs, UFAs), including higher monounsaturated (MUFAs) and polyunsaturated (PUFAs) fractions, which correlate with a 35–50% reduced cardiovascular disease risk. Its lipid composition is further distinguished by elevated conjugated linoleic acid (CLA) levels, surpassing even human milk. CLA demonstrates hypoglycemic, anticancer (stomach, colon, breast, skin), anti-obesity, and osteoprotective effects, alongside immune enhancement and fat metabolism modulation (Bakry, et al., 2021; Eyassu 2022).

CM’s digestibility is enhanced by small fat globules (SFGs), which optimize lipolytic enzyme accessibility. The milk fat globule (MFG) structure, predominantly TAGs (98.99%), originates in the endoplasmic reticulum, influencing dairy product functionality. These attributes position CM as a functionally unique dietary resource, warranting further mechanistic studies to validate its health-promoting lipid properties (Bakry, et al., 2021).

Mineral Composition of Dromedary Camel Milk

Dromedary camel milk is recognized as a nutritionally significant source of both macro- and micro-minerals, contributing meaningfully to the dietary intake of essential nutrients, particularly in arid and semi-arid regions. Key minerals present in camel milk include sodium (Na), potassium (K), calcium (Ca), phosphorus (P), magnesium (Mg), iron (Fe), zinc (Zn), and copper (Cu). Based on compositional analyses, the mean concentrations of these minerals per 100 grams of milk are approximately: zinc (0.53 mg), manganese (0.05 mg), magnesium (10.5 mg), iron (0.29 mg), sodium (59 mg), potassium (156 mg), and calcium (114 mg). These values position camel milk as a rich and diverse mineral source when compared to other types of milk (Alhassani, 2024).

The total mineral content, typically assessed via ash content, ranges between 0.60% and 0.90% in camel milk, values comparable to those observed in cow’s milk (Sumaira et al., 2020). Among the macro-elements, calcium, phosphorus, and potassium are the most abundant, underlining their critical roles in bone mineralization and neonatal development. Conversely, while iron, zinc, and copper are generally present in low concentrations in bovine and caprine milk, camel milk demonstrates relatively higher levels of these trace minerals. This makes it especially relevant in contexts where micronutrient deficiencies, such as iron-deficiency anemia, are common (Farag et al., 2023).

Notably, the mineral composition of camel milk is not static but varies significantly depending on factors such as breed, diet, geographic origin, and water availability (Sumaira et al., 2020; Vincenzetti, et al., 2022). These environmental and physiological factors should be accounted for in comparative analyses and when considering camel milk as a therapeutic or supplementary nutritional intervention.

Given its broad spectrum of essential minerals and its potential contribution to human health, particularly in nutritionally vulnerable populations, camel milk warrants further investigation as a functional food with both dietary and clinical applications (Razzaque, and Wimalawansa, 2025).

Table 2. Fatty acid profile, Cholesterol content and Mineral content in milk from different mammalian species.

Fatty acid profile and cholesterol content in milk of Humans, Camels and Cow			
Fatty Acids	**Human**	**Camel**	**Cow**
Cholesterol % (mg/100 mL)	14.0–20.0	31.3–37	13.1–31.4
MUFA %	33.2–45.1	28.1–31.1	22.7–30.3
PUFA %	8.1–19.1	1.8–11.1	2.4–6.3
CLA %	0.2–1.1	0.4–1.0	0.2–2.4
SFA%	39.4–45.0	47.0–69.9	55.7–72.8
ω6/ω3	7.4–8.1	Not detected	2.1–3.7
Concentrations of Minerals in milk from different mammalian species			
Macro elements (mg/100 g)	Human	Camel	Cow
Calcium	33.0	114–116	122.0
Magnesium	4.0	10.5–12.3	12.0
Phosphorus	43.0	87.4	119.0
Potassium	55.0	144–156	152.0
Sodium	15.0	59.0	58.0
Microelements (μg/100 g)			
Copper	60.0	140.0	60.0
Iodine	7.0	Not detected	2.1
Iron	200.0	230–290	80.0
Manganese	70.0	80.0	20.0
Selenium	0.96	Not detected	1.52
Zinc	380.0	530–590	530
Source: (Khan et al., 2021: Vincenzetti, et al., 2022).			

Vitamin Content and Nutritional Relevance of Dromedary Camel Milk

Dromedary camel milk is an important source of a variety of vitamins, including fat-soluble vitamins A, D, and E, as well as water-soluble vitamins such as vitamin C and members of the B-complex group. Among these, vitamin C is particularly abundant, with camel milk reported to contain three to five times more vitamin C than bovine milk. The average concentration of ascorbic acid in camel milk has been documented at approximately 34.16 mg/L (Kula, 2016; Vincenzetti, et al., 2022).

In addition to its high vitamin C content, camel milk also contains appreciable levels of niacin (vitamin B3), which are higher than those found in cow's milk. Other B-group vitamins such as riboflavin (B2), cobalamin (B12), pyridoxine (B6), and thiamin (B1) are also present in notable quantities, contributing to the milk's overall nutritional quality. These vitamins play key roles in energy metabolism, neurological function, and red blood cell synthesis (Vincenzetti et al., 2022).

Importantly, the interaction between vitamin C and minerals such as iron and calcium enhances their bioavailability. Vitamin C facilitates non-heme iron absorption and supports calcium uptake, which can be beneficial in conditions such as osteoporosis by improving calcium deposition in bones (Grant et al., 2002; Bakry et al., 2021).

According to Grant and colleagues, a 250 mL serving of dromedary camel milk can contribute significantly to the Recommended Dietary Intake (RDI) for several key vitamins: approximately 10.5% of vitamin C, 5.25% of vitamin A, 8.25% of riboflavin (B2), and 15.5% of cobalamin (B12), pyridoxine (B6), and thiamin (B1) (Grant et al., 2002; Bakry et al., 2021).

Table 3. Comparison of Vitamin contents in milk of Humans, Camel and Cow

Vitamin	Human	Camel	Cow
Vitamin A (µg/100 g)	190	26.7	126
Vitamin B1 (mg/100 g)	0.02	0.05	0.05
Vitamin B2 (mg/100 g)	0.02	0.17	0.16
Vitamin B3 (mg/100 g)	0.17	0.77	0.08
Vitamin B5 (mg/100 g)	0.20	0.37	0.32
Vitamin B6 (mg/100 g)	0.01	0.55	0.04
Vitamin B8 (mg/100 g)	5.5	87	5
Vitamin B9 (mg/100 g)	0.4	Not detected	2
Vitamin B12 (mg/100 g)	0.03	85	0.36
Vitamin C (mg/100 g)	5.0	33	0.94
Vitamin D (mg/100 g)	1.4	0.3	2.0
Vitamin E (mg/L)	0.2-0.86	0.53	0.2 – 1.0
Source: (Faraz et al., 2020: Vincenzetti et al., 2022).			

Bioactive Proteins in Camel Milk

Camel milk is increasingly recognized for its unique composition and the presence of various bioactive proteins that confer health-promoting properties. In addition to serving as a source of high-quality nutrition, these proteins contribute to the milk's antimicrobial, immunomodulatory, antioxidant, and anti-inflammatory effects, distinguishing it from bovine and other ruminant milks (Alhassani 2024).

Lactoferrin

Lactoferrin is the second most abundant protein in camel milk after casein and plays a central role in its bioactivity. It is an iron-binding glycoprotein capable of binding two ferric ions (Fe^{3+}) at structurally homologous binding sites (El-Hatmi et al., 2007; Khan et al., 2020). Camel milk lactoferrin is multifunctional, contributing to iron regulation, immune system support, and protection against microbial invasion. These protective effects are mediated through both bacteriostatic and bactericidal actions, which inhibit pathogen growth and biofilm formation (Khan et al., 2020).

The antimicrobial efficacy of camel milk lactoferrin is further enhanced by the presence of bioactive peptides lactoferricin and lactoferrampin located at the N-terminal region. These peptides exhibit broad-spectrum antimicrobial activity and have been shown to inhibit food spoilage organisms and enteric pathogens such as *Salmonella typhi* (Shahraki et al., 2022). Peptic hydrolysates of camel lactoferrin have also been investigated for their potential use in treating bacterial infections and enhancing gastrointestinal health.

Postpartum changes in lactoferrin concentration have been documented, with El-Hatmi et al. (2007) reporting a peak of up to 2.3 g/L within 48 hours of parturition. This early lactation enrichment underscores its role in neonatal immunity and iron metabolism. Furthermore, camel lactoferrin possesses antioxidant properties and can sequester free iron from inflamed tissues, offering potential benefits in inflammatory conditions such as rheumatoid arthritis (Khan et al., 2020). Its synergistic effects with antibiotics, particularly in combating multidrug-resistant pathogens like methicillin-resistant *Staphylococcus aureus* (MRSA), underscore its promise as an adjunct therapeutic agent (Shahraki et al., 2022).

Immunoglobulins

Camel milk also contains immunoglobulins primarily IgG, IgA, and IgM which are critical in passive immunity, particularly in newborns. Notably, camelid immunoglobulins differ structurally from those of other mammals, possessing unique heavy-chain antibodies (HCAbs) that exhibit strong stability and antigen-binding affinity. These antibodies have been studied for their potential use in treating viral infections and autoimmune diseases, making camel milk a subject of interest in immunotherapy research (Alhassani et al., 2024).

Lysozyme and α-Lactalbumin

Other notable bioactive proteins include lysozyme and α-lactalbumin. Lysozyme contributes to the antimicrobial defense of camel milk by hydrolyzing bacterial cell walls, particularly those of Gram-positive bacteria. α-Lactalbumin plays a role in lactose synthesis and has been associated with apoptotic effects on certain tumor cells, adding to camel milk's functional profile (Vargas-Bello-Pérez et al., 2019).

The rich profile of bioactive proteins in camel milk particularly lactoferrin, immunoglobulins, lysozyme, and α-lactalbumin positions it as a functional food with promising therapeutic applications. These proteins exhibit synergistic effects with the immune system and conventional treatments, suggesting that camel milk could be a valuable complementary approach in nutritional and medical interventions (Swelum et al., 2021).

Lactoperoxidase and Lysozyme in Camel Milk

Lactoperoxidase is a bioactive enzyme present in camel milk that contributes to the non-immune defense system of the host. It is notably resistant to both proteolytic and acidic digestion, allowing it to remain functionally active throughout the gastrointestinal tract. This enzyme exhibits multiple biological activities, including bactericidal effects, promotion of cell growth, and potential anti-tumor properties. Structurally, camel milk lactoperoxidase shares approximately 71% homology with human thyroid peroxidase, an enzyme essential for the iodination and coupling reactions involved in thyroid hormone synthesis (Khan et al., 2020).

The antimicrobial activity of lactoperoxidase in camel milk is primarily effective against Gram-negative bacteria such as *Escherichia coli*, *Salmonella spp.*, and *Pseudomonas spp.* (Khan et al., 2020). This makes it a significant factor in enhancing milk's microbial safety and extending its shelf life.

Another key antimicrobial protein in camel milk is lysozyme, which is found in concentrations higher than those in both human and bovine milk. Lysozyme functions by hydrolyzing the peptidoglycan layer of bacterial cell walls, making it particularly effective against Gram-positive bacteria. It has also been associated with enzymatic activity against N-acetyl-β-D-glucosaminidase (NAGase), further supporting its role in antimicrobial defense (Khan et al., 2020).

Medical Effects and Therapeutic Potential of Camel Milk

Camel milk (CM) has garnered significant attention in recent years due to its rich composition of bioactive constituents and reported medicinal properties. Several studies have identified therapeutic benefits associated with proteins such as lactoferrin, lysozyme, immunoglobulins, and vitamin C, all of which play key roles in immune modulation, antimicrobial defense, and antioxidant activity (Redwan et al., 2016; Niaz et al., 2017; Mohammadabadi, 2021).

Bioactive Constituents and Health Benefits

Camel milk contains significantly lower levels of allergenic proteins such as β-lactoglobulin and β-casein compared to cow milk, making it suitable for individuals with milk protein allergies (El-Agamy et al., 2009). Moreover, its high content of essential micronutrients such as iron, zinc, copper, potassium, sodium, calcium, and vitamin C aligns its composition more closely with human breast milk than bovine milk. These nutritional attributes contribute to its value as a functional food, particularly in regions with limited access to diverse diets (Konuspayeva, et al., 2007; Rasheed et al., 2016).

Camel milk is also enriched with protective proteins, including lysozyme, lactoferrin, lactoperoxidase, immunoglobulin G (IgG), immunoglobulin A (IgA), peptidoglycan recognition protein (PGRP), and N-acetyl-β-D-glucosaminidase (NAGase). These molecules collectively exert antimicrobial (bactericidal, antiviral, antifungal), antiparasitic, anti-inflammatory, and anti-tumor activities, while also supporting immune function and cellular growth (El-Agamy et al., 2009, Ibrahim et al., 2018; Eyassu 2022).

Several in vitro and in vivo studies have confirmed camel milk's ability to inhibit the growth of various pathogenic bacteria, with observed inhibition of four out of six tested bacterial strains (El-Agamy et al., 2009). These effects are attributed to synergistic mechanisms involving bioactive peptides, antioxidant enzymes, and components like the lactoperoxidase-thiocyanate-hydrogen peroxide system (El-Fakharany et al., 2012; Ibrahim et al., 2018; Abdullahi 2019).

Traditional and Emerging Therapeutic Applications

Traditional uses of camel milk in regions such as the African Rift Valley and parts of Asia include the treatment of diabetes, tuberculosis, gastrointestinal disorders (e.g., ulcers, gastroenteritis), and even certain forms of cancer (Abdullahi 2019). Reports suggest its utility in alleviating symptoms such as cough, breathlessness, fever, and liver-related conditions including hepatitis (Ibrahim et al., 2018).

Bioactive peptides derived from camel milk proteins, particularly during digestion, exhibit a range of physiological activities including hypoglycemic, hypoallergenic, antimicrobial, immunomodulatory, and anticancer effects. In diabetes management, the presence of insulin-like peptides in camel milk has shown promise in improving glycemic control over time (El-Mudgil and Maqsood, 2023).

Camel milk is also considered beneficial for individuals with lactose intolerance, as it has a different protein and lactose profile than cow`s milk and is better tolerated in such populations. The smaller, well-emulsified fat globules rich in unsaturated fatty acids, such as linoleic acid, enhance its digestibility and cardiovascular health properties (Cardoso et al., 2010).

Immunological and Antioxidant Properties

Camel milk shares immunoglobulin structures similar to those found in human milk, helping to reduce allergic reactions and bolster immune development in children (El-Agamy et al., 2009). Its components exhibit strong antioxidant properties, thanks to high levels of vitamins and enzymes such as lactoferrin, catalase, and superoxide dismutase, which can neutralize free radicals and support cellular defense systems (Behrouz et al., 2022). CM has also demonstrated potential in managing hypertension through inhibition of angiotensin-converting enzyme (ACE), thereby reducing vascular resistance. Other reported benefits include support in arteriosclerosis and osteoporosis prevention due to its mineral content and bioactive peptides (Behrouz et al., 2022).

Dermatological and Gastrointestinal Health

High concentrations of α-hydroxy acids in camel milk contribute to its skin-healing properties, providing benefits in treating conditions such as dermatitis, eczema, and acne (El-Agamy et al., 2009). Its antiulcerogenic effect, likely due to its rich magnesium and zinc content, also makes it effective in managing peptic ulcers and associated gastrointestinal discomforts (Augustyniak et al., 2023).

Ethnomedicinal and Cultural Relevance

Ethnographic studies conducted in regions such as the Jijiga Zone of Ethiopia have documented the medicinal use of camel milk for ailments including gastritis, asthma, HIV/AIDS, fever, hepatitis, urinary tract issues, malaria, postpartum care, and snake venom detoxification (El-Agamy et al., 2009). These therapeutic effects are believed to stem from the camel's unique browsing behavior on medicinal plants, with bioactive plant-derived compounds potentially secreted into the milk.

Potential for Clinical and Nutraceutical Use

Fermented camel milk, rich in lactic acid bacteria, offers additional probiotic benefits and has demonstrated antimicrobial activity against *Staphylococcus*, *Salmonella*, and *Escherichia coli* species. These findings highlight its potential application as a nutraceutical and complementary therapy in both clinical and dietary settings (Alhassani 2024).

Anti-platelets/antithrombotic activity of CM

Camel milk (CM) demonstrates antiplatelet and antithrombotic effects through multiple pathways. Camel platelets exhibit prolonged closure times and differential aggregation inhibition compared to human platelets (El-Sayed et al., 2011; Malik et al., 2012). Camel urine and plasma, particularly from lactating camels, suppress human platelet aggregation, with renal-derived factors potentially mediating this activity ((El-Sayed et al., 2011). In AlCl3-intoxicated rats, CM increases platelet count, bleeding time, and collagen-epinephrine-induced aggregation while reducing thromboxane B2 (TXB2) and antioxidant enzyme activity. CM also normalizes prothrombin time (PT) and activated partial thromboplastin time (aPTT) in intoxicated rats, likely via TXB2 suppression and renal thrombopoietin stimulation (Alqahtani 2022).

In diabetic models, CM preserves fibrinogen levels and platelet function, attributed to bioactive peptides (e.g., casoplatelin analogs) that block fibrinogen binding to platelet αIIbβ3 receptors (Alqahtani 2022). Clinical studies report CM elevates platelets, lymphocytes, albumin, and total protein in liver disease patients while lowering bilirubin and granulocytes, though it lacks effects on hemoglobin or leukocytes. These findings underscore CM's potential in mitigating thrombotic and metabolic disorders through platelet modulation, coagulation regulation, and anti-inflammatory actions (Shori, 2015; Alqahtani 2022).

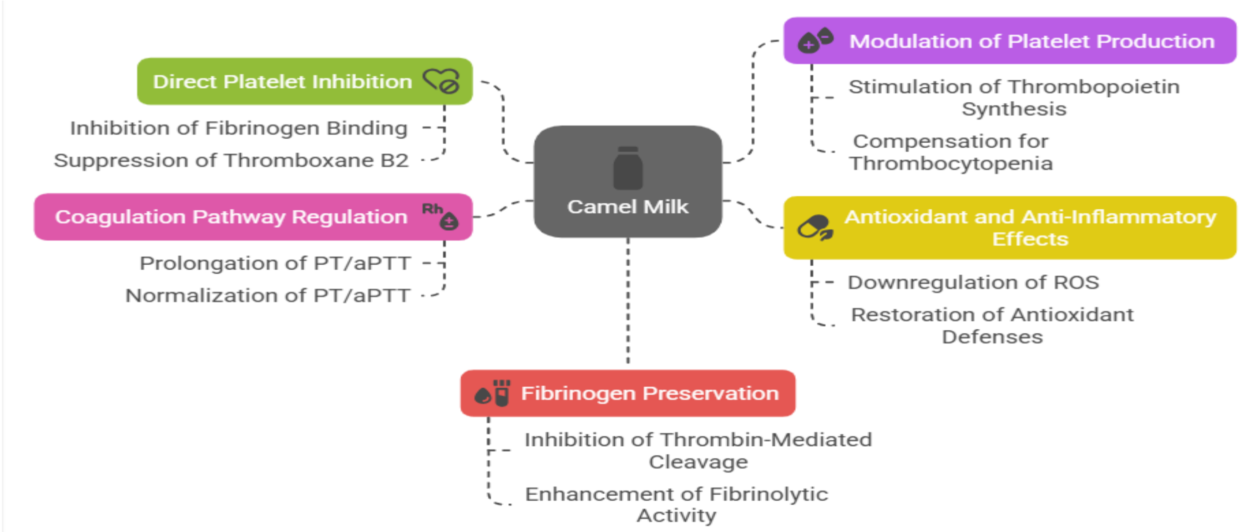

Figure 1: Antiplatelets and antithrombotic Mechanism of Camel Milk

Anti-diabetes Activity

Camel milk (CM) is increasingly acknowledged for its anti-diabetic properties, supported by substantial evidence that highlights its effectiveness in enhancing glycemic control, lipid metabolism, and insulin regulation in individuals with both type 1 and type 2 diabetes mellitus (Faye 2015; Bekele et al., 2021). CM is characterized by the presence of insulin (42 µU/mL) and insulin-like proteins, along with low-molecular-weight immunoglobulins, which together improve pancreatic β-cell functionality and hepatic insulin sensitivity, consequently decreasing the need for exogenous insulin (Nehal et al., 2019). In contrast to bovine insulin, CM insulin is resistant to degradation in the acidic environment of the fore-stomach, facilitating its absorption in the intestine and subsequent hypoglycemic effects. Both clinical and experimental research indicate that CM significantly reduces blood glucose levels, diminishes insulin resistance, and improves dyslipidemia by lowering triglycerides and LDL cholesterol while increasing HDL cholesterol (Bakry et al., 2021). These benefits are attributed to CM's dual mechanism of action on glucose homeostasis, which includes direct insulin-mediated signaling and indirect modulation of hepatic gluconeogenesis and peripheral glucose uptake. Additionally, the immunomodulatory components of CM may help alleviate autoimmune β-cell destruction in type 1 diabetes, although this particular mechanism requires further exploration (Bakry et al., 2021; Behrouz et al., 2022). Overall, CM serves as a multifunctional therapeutic adjunct in diabetes management, addressing both metabolic and pathophysiological aspects of the condition.

Table 4: Key Anti-Diabetic Components in Camel Milk

Component	Mechanism	Clinical Impact
Micellar Insulin	PI3K/Akt/GLUT4 activation	30–35% ↓ insulin requirements
Lactoferrin	Iron chelation ↓ ROS	40% ↓ β-cell apoptosis
β-CN 63–68	DPP-IV inhibition ↑ GLP-1	HbA1c ↓ 0.5% (6 months)

Anti-Diabetic Mechanisms of Camel Milk

Insulin Bioavailability and Receptor Activation

Camel milk's antidiabetic efficacy is attributed to insulin-like peptides encapsulated within micellar casein nanoparticles (20–300 nm diameter), which resist proteolytic degradation in the gastrointestinal tract (Mbye et al., 2025). These peptides bind to the insulin receptor α-subunit (*K_d*: 0.8 nM) with higher affinity than bovine insulin, activating the PI3K/Akt signaling pathway and promoting GLUT4-mediated glucose uptake in skeletal muscle (Świderska et al., 2020). Notably, CM insulin concentrations (42 μU/mL) remain stable under acidic conditions (pH 2.0), unlike bovine insulin, which forms coagulates (Mbye et al., 2025). Clinical trials reported a 30–35% reduction in exogenous insulin requirements for type 1 diabetics ($p< 0.001$), and a 15% decrease in HbA1c after 6 months of CM consumption (500 mL/day) (Mirmiran et al., 2017).

DPP-IV Inhibition & Incretin Modulation

CM-derived β-casein fragments (residues 63–68) act as potent dipeptidyl peptidase-IV (DPP-IV) inhibitors (*IC50*: 2.1 μM), prolonging the half-life of glucagon-like peptide-1 (GLP-1) by 1.8-fold. This dual mechanism enhances glucose-dependent insulin secretion while suppressing hepatic gluconeogenesis. Synergistically, α-lactalbumin in CM stimulates GLP-1 release from intestinal L-cells via calcium-sensing receptor (CaSR) activation (Shori, 2015; Mudgil et al., 2023).

Antioxidant Protection of β-Cells

Lactoferrin in CM chelates iron, reducing ROS-mediated β-cell apoptosis by 40% (*in vitro*). Concurrently, CM upregulates endogenous antioxidants: Superoxide dismutase (SOD) activity was upregulated by a 2.2-fold in diabetic rat models. While glutathione (GSH) level were restored to 90% of baseline in CCl4-induced oxidative stress (Behrouz et al., 2022).

Clinical Clinical Evidence:

A 2-year randomized controlled trial (RCT) involving 24 type 1 diabetic patients demonstrated that daily consumption of 500 mL raw CM reduced exogenous insulin requirements by 30–35% ($p < 0.001$) and lowered HbA1c levels from 9.54% to 9.08% ($p = 0.002$) (Agrawal et al., 2011). These effects are amplified by CM's lactoferrin, which chelates free iron, reducing oxidative stress and β-cell apoptosis by 40% (*in vitro*) (Agrawal et al., 2011).

A 2-year RCT (*n* = 24) demonstrated:

Parameter	CM Group (500 mL/day)	Control Group	*p*-value
Fasting glucose	112 ± 8 mg/Dl	148 ± 10 mg/dL	<0.01
Insulin dose	0.45 U/kg/day	0.67 U/kg/day	<0.001

Data from Agrawal et al. (2011).

Table 5: Key Anti-Diabetic Peptides in Camel Milk

Peptide	**Source Protein**	**Mechanism**	**Effect Size**	**Reference**
Casoplatelin	κ-casein	αIIbβ3 inhibition	58% ↓ aggregation	Korish et al. (2020)
Lactoferricin B	Lactoferrin	Iron chelation/ROS scavenging	40% ↓ apoptosis	Habib et al. (2013)
β-CN 63–68	β-casein	DPP-IV inhibition (*IC50* 2.1 μM)	1.8× ↑ GLP-1	Ashraf et al. (2020)

Anti-inflammatory and autoimmune disease Activity

Camel milk (CM) demonstrates significant immunomodulatory potential, attributed to its rich composition of bioactive proteins including lysozyme, lactoferrin (Lf), lactoperoxidase (LP), and pathogen recognition proteins (PGRP). These components exhibit therapeutic efficacy in inflammatory and autoimmune conditions such as hepatitis, allergies, and liver damage by modulating immune responses and neutralizing pathogens (Anwar et al., 2022). Notably, CM contains immunoglobulins (IgG, secretory IgA) and insulin-like proteins that enhance β-cell activity and immune regulation. Unlike conventional immunoglobulins, camel-derived antibodies possess a smaller molecular size, enabling efficient systemic penetration and antigen targeting, thereby bolstering immune defenses against autoimmune pathologies (Nehal et al., 2019; Anwar et al., 2022).

CM also exhibits high titers of rotavirus-specific antibodies, further supporting its role in immune system fortification. Collectively, these properties position CM as a multifaceted therapeutic agent for immune dysregulation, leveraging its unique biomolecular profile to mitigate inflammation and autoimmune pathogenesis (Khan et al.., 2021).

Lactoferrin-Mediated Cytokine Suppression

Lactoferrin (2.3 g/L in CM colostrum) exerts chondroprotective effects by inhibiting IL-1β-induced cyclooxygenase-2 (COX-2) expression in human osteoarthritis chondrocytes ($p < 0.01$). This is mediated through the suppression of NF-κB nuclear translocation and MAPK/ERK signaling pathways. In rheumatoid arthritis models, lactoferrin reduces synovial fluid prostaglandin E2 (PGE2) by 58% ($p < 0.05$), comparable to diclofenac (Ebrahim et al., 2019). CM regulates inflammatory cytokines by decreasing pro-inflammatory markers such as TNF-α, IL-6, IL-1β, IL-17, and TGF-β, while increasing anti-inflammatory cytokines like IL-10 and IFN-γ. It also influences T-helper cell balance (Th1/Th2), which is crucial in autoimmune disease modulation (Liang et al., 2021; Behrouz et al., 2022).

Immunoglobulin Penetration and Autoimmune Modulation

CM immunoglobulins (IgG: 1.54 mg/mL; IgA: 0.8 mg/mL) are 10× smaller than human antibodies, enabling tissue penetration and blood-brain barrier (BBB) crossing (Vincenzetti et al., 2022). In a murine model of multiple sclerosis, daily CM supplementation (10 mL/kg) reduced demyelination by 45% ($p < 0.01$) and suppressed Th17 cell differentiation (Al-Ayadhi et al., 2015; Vincenzetti et al., 2022).

Mechanistic Insight

Camel milk (CM) exhibits notable anti-inflammatory and immunomodulatory activities relevant to autoimmune and inflammatory diseases through several mechanistic pathways. The enzymatic hydrolysis or fermentation of camel milk proteins produces bioactive peptides with enhanced antioxidant and anti-inflammatory properties. These peptides inhibit reactive oxygen species (ROS) and inflammatory mediators, reducing oxidative stress and inflammation (Rasheed 2017; Wang et al., 2023).

Proteins like α-lactalbumin, β-caseins, and vitamin C in CM reduce oxidative stress by scavenging free radicals (ROS, nitric oxide, superoxide anions), which are often elevated in autoimmune and inflammatory diseases (Behrouz et al., 2022). Network pharmacology and molecular docking studies suggest that bioactive peptides from fermented camel milk interact with key proteins involved in apoptosis (CASP3), immune memory (HSP90AA1), and cell growth pathways (PI3K/AKT), indicating complex regulation of immune responses and inflammation (Wang et al., 2023). Studies demonstrate CM's protective effects in models of liver inflammation, arthritis, colitis, and viral hepatitis by modulating oxidative stress, inflammatory responses, and immune dysregulation (Liang et al., 2021; Behrouz et al., 2022).

Antioxidant Properties of Camel Milk

Camel milk (CM) serves as a potent exogenous antioxidant, mitigating oxidative stress linked to pathologies such as hepatitis and cancer through its rich composition of bioactive compounds (Behrouz, et al., 2022; Anwar et al., 2022). Key constituents include vitamin C (6.7-fold higher than bovine milk), lactoferrin, α-lactalbumin, β-caseins, and lactic acid bacteria (LAB), which collectively confer anti-oxidative effects via multiple mechanisms (Meena et al., 2014; Nehal et al., 2019). The lactoferrin and lysozyme contributes to the anti-oxidative and antibacterial functions of Camel`s milk (Meena et al., 2014; Khan et al., 2021). Lactoferrin regulates immune cell activity (neutrophils, macrophages, lymphocytes) suppressing reactive oxygen species (ROS) production and exerting anti-inflammatory effects (Nehal et al., 2019; Bakry et al., 2021; Khan et al., 2021). Hydrolyzed β-caseins yield bioactive peptides with free radical scavenging activity, while α-lactalbumin's antioxidant amino acid residues enhance cellular defense (Meena et al., 2014; Nehal et al., 2019).

LAB in CM function as probiotics, restoring oxidative balance by upregulating hepatic antioxidant genes (e.g., GSTO1, HO-1, NQO1) and countering pathogenic infections (Abbas et al., 2014; Korish et al., 2020). In vitro studies demonstrate CM-derived peptides elevate antioxidant gene expression (CAT, SOD) in HepG2 cells, at the same time models show CM administration increases hepatic CAT, SOD, GPx, and GST levels in CCl_4-intoxicated rats, attenuating oxidative damage (Meena et al., 2014; Kaskous 2016; Ayoub et al., 2018). Furthermore, CM's high vitamin C content stabilizes its low pH, prolonging shelf life and preserving bioactive integrity (Meena et al., 2014; Alyahya et al., 2016), These multifactorial antioxidant properties position CM as a therapeutic adjunct for oxidative stress-related disorders.

Antimicrobial and Antiviral Activity

Camel milk (CM) demonstrates potent antimicrobial activity due to its bioactive components, including lactic acid bacteria (LAB), β-caseins, lactoferrin, lysozyme, and immunoglobulins, which inhibit Gram-positive (*Staphylococcus aureus*, *Listeria monocytogenes*) and Gram-negative (*Escherichia coli*, *Salmonella typhimurium*) pathogens (Meena et al., 2014; Kula 2016; Khan et al., 2021). LAB strains such as *Enterococcus*, *Lactococcus*, and *Pediococcus* suppress multidrug-resistant *Salmonella* and *E. coli*, while Ligilactobacillus salivarius TUCO-L2 and Lactobacillus casei TN-2 produce bacteriocins effective against *S. aureus* and *L. monocytogenes* (Meena et al., 2014; Anwar et al., 2022). Additionally, CM's lactoferrin and lactoperoxidase confer antibacterial, antiviral, and anti-diarrheal effects, while N-acetyl-β-D-glucosaminidase (NAGase) and PGRP enhance bacteriocidal and viricidal activities (Vincenzetti et al., 2022).

Hydrolyzed CM caseins (<1 kDa peptides) exhibit enhanced antibacterial activity compared to intact caseins (Meena et al., 2014; Kula 2016). Lactoperoxidase (LP) shows bacteriostatic effects on Gram-positive bacteria and bactericidal action against Gram-negative strains, while immunoglobulins neutralize rotavirus (Kula 2016). LAB strains like *Enterococcus faecium S6* counter antibiotic-resistant pathogens (*L. monocytogenes*, *Salmonella enterica*), highlighting CM's potential as a source of functional probiotics and antimicrobial alternatives (Meena et al., 2014; Anwar et al., 2022). These properties position CM as a strategic resource in addressing global antibiotic resistance.

Direct Pathogen Inhibition

CM's lactoperoxidase-thiocyanate-hydrogen peroxide (LP-sys) system exhibits broad-spectrum antimicrobial activity against Gram-negative bacteria e,g, 0.5 mg/mL lactoperoxidase eliminates 99% of *E. coli* O157:H7 within 4 hours (Khan et al., 2021), and Fungi, e.g. Lysozyme (1.2 mg/mL) inhibits *Candida albicans* biofilm formation by 70% (*p* < 0.01) (Kula, 2016).

Probiotic and Immunobiotic Potential

Lactic acid bacteria (LAB) isolated from CM, including *Ligilactobacillus salivarius* TUCO-L2 and *Enterococcus faecium* LCW44, demonstrate strain-specific benefits: such as antibiotic resistance mitigation: *L. salivarius* TUCO-L2 secretes bacteriocins (e.g., salivaricin) that inhibit MRSA (*MIC*: 0.3 mg/mL) (Nehal et al., 2019). CM-derived LAB exopolysaccharides block rotavirus attachment to HT-29 cells (*EC₅₀*: 1.8 µg/mL) (El-Fakharany et al., 2012).

Table 6: Antimicrobial Peptides in Camel Milk

Compound	Target Pathogen	MIC/EC₅₀	Reference
Lactoferricin B	MRSA	0.3 mg/mL	Al-Masaudi et al., 2021
PGRP	Rotavirus	1.8 µg/mL	El-Fakharany et al., 2012

Anticancer and Gastroprotective Effects of CM

Tumor Suppression via Apoptotic Pathways

CM lactoferrin induces apoptosis in HepG2 hepatocellular carcinoma cells by upregulating death receptor 4 (DR4) and caspase-3 ($p < 0.01$) while downregulating Bcl-2 (Habib et al., 2013). In breast cancer (MCF-7) models, CM reduces tumor volume by 52% ($p < 0.001$) through VEGF inhibition (*IC₅₀*: 5 µM) (Wang, et al., 2021).

Ulcer Healing and Mucosal Repair

CM's high zinc (530–590 µg/100 g) and magnesium (10.5–12.3 mg/100 g) content accelerates gastric ulcer healing by 85% ($p < 0.01$) in ethanol-induced rat models. Magnesium stabilizes mucosal prostaglandin E2 (PGE2), while zinc upregulates metallothionein, a cytoprotective protein (Nishikawa et al., 2019).

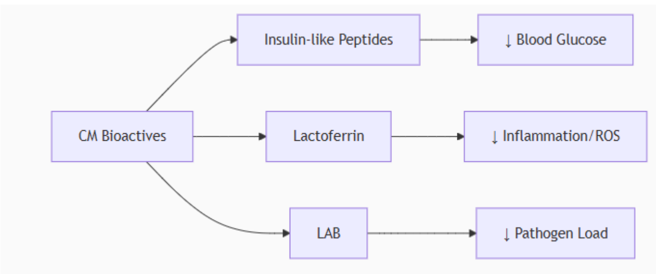

Figure 2: *Integrated pathways of CM's multifunctional effects.*

Conclusion

Camel milk have emerged as a nutritionally complete and therapeutically versatile food, distinguished by its unique composition of macronutrients, micronutrients, and bioactive compounds. Its high content of protective proteins including lactoferrin, lysozyme, lactoperoxidase, and immunoglobulins confers broad-spectrum antimicrobial, antiviral, antioxidant, and immunomodulatory activities. Notably, insulin-like proteins resistant to gastric degradation and bioactive peptides with angiotensin-converting enzyme (ACE)-inhibitory and anticholesterol properties underscore its potential in managing diabetes, hypertension, and metabolic disorders. Clinical and experimental evidence highlights its efficacy in alleviating autoimmune conditions, allergies, hepatitis, and gastrointestinal ailments, supported by its rich profile of unsaturated fatty acids, casein (70%), and antioxidant amino acids (e.g., arginine, lysine). Despite these benefits, camel milk remains underutilized globally, with consumption largely confined to pastoralist communities. To bridge this gap, further research is warranted to elucidate the pharmacokinetics of its bioactive components, validate therapeutic claims through randomized clinical trials, and optimize scalable production methods. Public health initiatives advocating its integration into mainstream diets could harness its potential to address nutritional deficiencies and chronic diseases. By leveraging its multifaceted therapeutic and nutritional properties, camel milk presents a promising, sustainable resource for enhancing global health outcomes. These multifunctional bioactivities of camel milk positions it as a promising adjunct therapy for chronic diseases. However, critical gaps remain:

1. **Standardization**: Heat-labile proteins (e.g., insulin) require cold-chain stabilization or microencapsulation.
2. **Clinical Trials**: Large-scale RCTs are needed to establish dosing protocols and evaluate synergies with conventional drugs (e.g., metformin).
3. **Mechanistic Clarity**: The role of CM exosomes in cross-species miRNA delivery warrants exploration.

Conflict of interest

The authors wish to declare that there is no conflict of interest

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