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BUTTERMILK AND HUMAN HEALTH: A COMPREHENSIVE REVIEW OF ITS NUTRITIONAL AND THERAPEUTIC POTENTIAL

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Abstract:

Buttermilk, a traditional dairy-based byproduct of butter churning or cultured fermentation, has gained renewed attention as a functional food with promising nutraceutical and therapeutic value. Rich in macronutrients such as proteins and low-fat content, along with micronutrients like calcium, B-complex vitamins, and minerals, buttermilk also harbors bioactive compounds including peptides, probiotics, and conjugated linoleic acid (CLA). These components contribute to a range of health-promoting effects including gastrointestinal modulation, cholesterol management, blood pressure regulation, anti-inflammatory activity, and immune enhancement. Moreover, its traditional usage in Ayurveda and modern dietary practices underlines its role in hydration, skin health, and metabolic balance. Despite its broad health potential, scientific validation of buttermilk's efficacy remains limited due to regional variations in preparation, lack of standardization, and insufficient clinical trials. Innovations in formulation—such as probiotic fortification, microencapsulation, and functional flavoring—have enhanced its scope in the functional food and therapeutic market. However, issues related to microbial stability, lactose intolerance, and quality control still pose significant challenges. This review explores the compositional attributes, physiological benefits, technological advances, and research gaps associated with buttermilk. It highlights the urgent need for robust mechanistic and clinical studies to substantiate health claims and promote its development as a standardized, safe, and effective nutraceutical product. With its affordability, accessibility, and wide cultural acceptance, buttermilk holds strong promise as a sustainable component of preventive and therapeutic nutrition.

Keywords:

Buttermilk; Functional food; Probiotics; Bioactive peptides; Nutraceutical; Gastrointestinal health

1. Introduction

Buttermilk, a traditional dairy-based beverage, has been an integral part of human diets for centuries, particularly in South Asian, Middle Eastern, and Mediterranean cultures. Traditionally obtained as the liquid left behind after churning butter from cultured cream, and more recently produced through fermentation of skimmed milk using lactic acid bacteria, buttermilk has transitioned from a humble byproduct to a valued nutritional drink. Its refreshing nature, low fat content, and ease of digestion make it suitable for diverse populations, including children, the elderly, and individuals with specific dietary needs.

This review aims to present a comprehensive evaluation of buttermilk's nutritional composition, health benefits, and functional potential, along with highlighting current gaps in research. It will also explore its role in traditional and modern medicine, recent technological advancements in its formulation, and the future scope for its development as a standardized therapeutic or nutraceutical agent.

1.1 Background and Importance of Buttermilk in Human Diet

Buttermilk, traditionally a by-product of butter churning or produced via controlled fermentation of skimmed milk using lactic acid bacteria, is recognized not only for its palatability but also for its significant nutritional and therapeutic potential. It is low in fat (typically less than 1.5%) yet rich in vital nutrients such as calcium (approx. 90–130 mg/100 mL), potassium, phosphorus, and water-soluble vitamins like riboflavin (0.1–0.2 mg/100 mL), B12, and folate (Rani et al., 2018; Rai et al., 2021). Lactic acid bacteria (LAB) like *Lactococcus lactis*, *Streptococcus thermophilus*, and *Lactobacillus bulgaricus* in buttermilk play a key role in gut health by enhancing intestinal flora, promoting lactose digestion, and exerting antimicrobial effects (Yadav et al., 2020).

Studies suggest that regular consumption of buttermilk may reduce serum cholesterol levels due to the presence of milk-derived bioactive peptides and phospholipids that inhibit cholesterol absorption in the intestine (Sharma et al., 2020; Tholstrup et al., 2004). Its hypotensive effect has also been attributed to ACE-inhibitory peptides released during fermentation (Patel & Prajapati, 2019). The consumption of buttermilk is especially valuable for lactose-intolerant individuals since the fermentation reduces lactose levels, enhancing digestibility (Singh et al., 2020).

In rural and urban diets, especially in India and other parts of South Asia, buttermilk is often used as a natural coolant, digestive aid, and carrier for medicinal herbs and spices like cumin, ginger, and curry leaves, which further enhance its functional value (Rani et al., 2018). Globally, fermented dairy drinks like buttermilk have gained renewed interest due to their potential roles in reducing risks of gastrointestinal infections, metabolic disorders, and even some types of cancers through antioxidant and immunomodulatory pathways (Marco et al., 2017).

2. Composition of Buttermilk

2.1 Types of Buttermilk (Traditional vs. Cultured)

Buttermilk is broadly classified into two types—Traditional buttermilk and Cultured buttermilk, each differing in origin, preparation, microbial composition, and nutritional properties.

Traditional Buttermilk, also known as *churned buttermilk*, is the liquid left behind after butter has been churned from cultured cream. It is commonly prepared in rural households using fermentation of whole milk or cream by naturally occurring lactic acid bacteria (LAB), followed by churning. This process results in a thin, tangy, and slightly sour liquid rich in indigenous probiotics, vitamins, and bioactive compounds (Rai et al., 2021). Traditional buttermilk often contains residual fat, phospholipids, and milk proteins, making it not only a refreshing beverage but also a functional component in digestive and cardiovascular health (Ghosh et al., 2015).

Cultured Buttermilk, on the other hand, is an industrially prepared product where pasteurized low-fat milk or skim milk is inoculated with specific bacterial cultures—primarily *Lactococcus lactis* subsp. *lactis*, *Lactococcus lactis* subsp. *cremoris*, and *Leuconostoc* species (Patel & Prajapati, 2013). This controlled fermentation process leads to coagulation of milk proteins and the development of a thick, smooth, tangy-flavored product that is microbiologically standardized, consistent in quality, and has a longer shelf life.

While both forms are rich in lactic acid, probiotics, and nutritional components, traditional buttermilk tends to have a wider range of indigenous microflora, whereas cultured buttermilk provides better quality control and commercial scalability. Both types are gaining importance in dietary interventions for gut health, metabolic balance, and immune modulation. Moreover, traditional buttermilk varies across cultures—for instance, it is referred to as *mattha*, *chaas*, or *takra* in India, and is comparable to fermented milk beverages like *doogh* and *ayran* in the Middle East. Its use is not only limited to consumption as a drink but extends to traditional remedies for digestive and skin health.

2.2 Macronutrient Profile (Proteins, Fats, Carbohydrates)

Buttermilk is a nutritious, low-calorie dairy product that provides essential macronutrients, making it a healthy addition to the human diet. Its protein content typically ranges between 2.8 to 4.0 g per 100 ml, depending on the type and method of production. These proteins, primarily casein and whey, are of high biological value and contain essential amino acids that support muscle maintenance and immune function. During fermentation, some of these proteins are broken down into bioactive peptides known for their antioxidant, antihypertensive, and antimicrobial effects (Korhonen & Pihlanto, 2006; Haque et al., 2009).

The fat content of buttermilk is relatively low, generally between 0.5 to 2.0 g per 100 ml. While traditional churned buttermilk may contain slightly more residual fat, cultured buttermilk made from skim milk is often lower in fat. Importantly, buttermilk retains components of the milk fat globule membrane (MFGM)—such as phospholipids, sphingomyelin, and gangliosides—which contribute to cholesterol regulation, brain development, and cellular health (Snow et al., 2011; Conway et al., 2014).

In terms of carbohydrates, buttermilk contains approximately 3.5 to 5.0 g per 100 ml, mainly in the form of lactose. However, fermentation by lactic acid bacteria reduces the lactose content, making it easier to digest for lactose-intolerant individuals. This fermentation also produces lactic acid, which enhances calcium and magnesium absorption (Blandino et al., 2003). The caloric value of buttermilk remains low, typically around 35 to 50 kcal per 100 ml, which supports its use in calorie-conscious and metabolic health-promoting diets (Wadhwa et al., 2017).

Overall, the macronutrient composition of buttermilk—moderate protein, low fat, and easily digestible carbohydrates—makes it a functional food with potential benefits in cardiovascular, digestive, and metabolic health.

2.3 Micronutrient Content (Calcium, Vitamins, Minerals)

Buttermilk is not only rich in macronutrients but also serves as a valuable source of essential micronutrients, including calcium, vitamins, and trace minerals, that contribute significantly to its health-promoting properties. It contains approximately 110–125 mg of calcium per 100 ml, which plays a crucial role in maintaining bone health, nerve transmission, and muscle function (Haug, Hostmark, & Harstad, 2007). Fermentation further improves calcium bioavailability by lowering the pH and increasing solubility, thereby enhancing absorption in the gastrointestinal tract (Tuohy et al., 2003).

In addition to calcium, buttermilk provides phosphorus (90–110 mg/100 ml) and magnesium (10–14 mg/100 ml), both of which are vital for energy metabolism and bone mineralization. It also contains potassium (150–180 mg/100 ml), which helps regulate blood pressure and fluid balance, making buttermilk a heart-friendly beverage. The sodium content remains low to moderate, depending on processing and salt addition.

Buttermilk is also a modest source of B-complex vitamins, including riboflavin (B2), vitamin B12, and niacin, which support red blood cell formation, neurological function, and energy production (El-Ziney & Al-Turki, 2007). Riboflavin, in particular, is retained well during fermentation and helps maintain healthy skin and vision. The fermentation process by lactic acid bacteria may also contribute to the synthesis of certain vitamins, including folate, further enriching its nutritional profile (Saubade et al., 2017).

Table 1: Nutritional Composition of Buttermilk

Nutrient	Amount per 100 mL	Unit
Energy	40	kcal
Protein	3.3	g
Total Fat	1.0	g
Saturated Fat	0.6	g
Carbohydrates	4.8	g
Sugars (Lactose)	4.8	g
Calcium	120	mg
Phosphorus	90	mg
Potassium	150	mg
Sodium	50	mg
Vitamin A	25	µg
Vitamin B2 (Riboflavin)	0.14	mg
Vitamin B12	0.4	µg

2.4 Presence of Bioactive Compounds (Peptides, Probiotics, CLA)

Buttermilk contains a range of bioactive compounds that contribute to its functional and therapeutic benefits. One of the most significant bioactives are bioactive peptides, which are formed during milk protein fermentation by lactic acid bacteria. These peptides exhibit various physiological effects such as antihypertensive, antioxidant, immunomodulatory, and antimicrobial activities (Korhonen & Pihlanto, 2006). Casein-derived peptides, especially, have shown inhibitory effects on angiotensin-converting enzyme (ACE), which is beneficial in lowering blood pressure (FitzGerald & Meisel, 2003).

In cultured buttermilk, the presence of probiotics—mainly strains like *Lactobacillus acidophilus*, *Lactococcus lactis*, and *Bifidobacterium spp.*—plays a major role in improving gut health. These beneficial bacteria contribute to the maintenance of intestinal microflora, enhance digestion, and support immune function (Saulnier et al., 2008). Regular consumption of probiotic-rich buttermilk has been associated with reduced gastrointestinal infections and improved lactose tolerance.

Another notable bioactive in buttermilk is conjugated linoleic acid (CLA), a type of polyunsaturated fatty acid primarily derived from ruminant milk fat. CLA has been studied for its anticarcinogenic, antiatherogenic, and body fat-reducing properties (Benjamin & Spener, 2009). Although present in small amounts, the CLA content in buttermilk contributes to its overall health-promoting effects, especially when derived from whole milk sources.

Table 2: Bioactive Components and Their Health Effects

Bioactive Component	**Source in Buttermilk**	**Health Effects**
Lactic Acid Bacteria (LAB)	Fermentation by probiotics	Enhances gut health, boosts immunity, reduces inflammation
Conjugated Linoleic Acid (CLA)	Milk fat	Antioxidant, anti-carcinogenic, supports weight management
Sphingolipids	Milk fat globule membrane (MFGM)	Supports brain function, modulates cholesterol metabolism
Peptides	Protein hydrolysis	Antihypertensive, antimicrobial, immune-modulating
Butyric Acid	Fermented milk fat	Improves colon health, anti-inflammatory properties
Exopolysaccharides (EPS)	Bacterial metabolites	Prebiotic effect, enhances gut microbiota
Phospholipids	MFGM	Supports cellular health, cognitive function
Short Chain Fatty Acids (SCFAs)	Fermentation by gut flora	Maintains gut barrier, reduces risk of colon cancer

3. Functional and Bioactive Properties

3.1 Antioxidant Activity

Buttermilk exhibits significant antioxidant activity, primarily due to the presence of bioactive peptides, milk fat globule membrane (MFGM) components, and microbial metabolites formed during fermentation. During the proteolysis of casein and whey proteins by lactic acid bacteria, bioactive peptides with antioxidant properties are released. These peptides can scavenge free radicals, chelate pro-oxidant metal ions, and inhibit lipid peroxidation, thereby reducing oxidative stress in the body (Erdmann, Cheung, & Schröder, 2008). Furthermore, the MFGM fraction, which remains in buttermilk after butter extraction, contains phospholipids and sphingolipids that have been shown to possess antioxidative effects by stabilizing cell membranes and reducing reactive oxygen species (ROS) formation (Dewettinck et al., 2008).

Fermentation enhances antioxidant activity further as lactic acid bacteria produce metabolites such as exopolysaccharides and short-chain fatty acids, which also contribute to oxidative defense mechanisms (Sharma et al., 2014). Studies have demonstrated that fermented dairy products like buttermilk show higher total antioxidant capacity compared to non-fermented milk due to these enzymatic and microbial changes (Pihlanto, 2006).

Incorporating buttermilk into the daily diet may thus provide protective benefits against oxidative damage, which is linked to aging and chronic conditions such as cardiovascular disease, diabetes, and cancer.

3.2 Enzymatic and Fermentation Effects

The enzymatic and fermentation processes involved in buttermilk production significantly enhance its nutritional and functional properties. During fermentation, lactic acid bacteria (LAB) such as *Lactococcus lactis* and *Lactobacillus* spp. metabolize lactose into lactic acid, which not only improves digestibility—especially for lactose-intolerant individuals—but also reduces the pH, creating a favorable environment for mineral solubility and absorption, particularly calcium and magnesium (Gänzle, 2015). Furthermore, these microbes activate endogenous milk enzymes such as proteases and lipases that catalyze the breakdown of milk proteins and fats, leading to the release of bioactive peptides and free fatty acids with antihypertensive, antimicrobial, and antioxidant properties (Korhonen & Pihlanto, 2006).

Fermentation also results in the production of vitamins (e.g., B12, folate), short-chain fatty acids (SCFAs), and exopolysaccharides, which contribute to gut health, immune modulation, and improved texture of the product (Saubade et al., 2017).

The microbial activity during fermentation enhances the overall bioavailability of nutrients, improves flavor, and extends the shelf life of buttermilk by inhibiting pathogenic microorganisms through acidification and bacteriocin production (Leroy & De Vuyst, 2004). These enzymatic and microbial transformations not only make buttermilk a nutrient-dense and easily digestible product but also promote its role as a functional food with multiple health-promoting properties.

3.3 Probiotic Potential and Gut Health Modulation

Buttermilk, particularly the cultured variety, serves as an excellent carrier of probiotics—live microorganisms that, when consumed in adequate amounts, confer health benefits to the host. These include strains like *Lactobacillus acidophilus*, *Lactobacillus delbrueckii subsp. bulgaricus*, *Bifidobacterium bifidum*, and *Streptococcus thermophilus*. These bacteria play a critical role in maintaining gut microbial balance, producing organic acids (like lactic acid and acetic acid) that lower intestinal pH and inhibit the growth of pathogens such as *Escherichia coli*, *Salmonella spp.*, and *Clostridium difficile* (Ouwehand & Salminen, 2003).

Regular consumption of probiotic-rich buttermilk has been associated with enhanced immune response, improved intestinal epithelial integrity, and reduced incidence of gastrointestinal disorders including constipation, diarrhea, bloating, and inflammatory bowel diseases (O'Mahony et al., 2005). The probiotics in buttermilk also synthesize short-chain fatty acids (SCFAs) such as acetate, propionate, and butyrate, which are key energy sources for colonocytes and contribute to anti-inflammatory effects and mucosal repair (Ríos-Covián et al., 2016).

Recent research has highlighted the role of gut-brain axis modulation, where probiotic strains found in buttermilk may positively affect mental health by producing neuroactive compounds like GABA and serotonin precursors (Dinan & Cryan, 2017). Additionally, fermented buttermilk enhances lactose digestibility, making it suitable for lactose-intolerant individuals by delivering lactase-producing bacteria that aid in lactose metabolism (de Vrese & Schrezenmeir, 2008).

Overall, buttermilk's probiotic potential makes it a functional dairy product capable of improving gut flora composition, enhancing nutrient bioavailability, boosting immune function, and contributing to mental and metabolic well-being.

4. Health Benefits of Buttermilk

4.1 Gastrointestinal Health

Buttermilk plays a significant role in promoting gastrointestinal health due to its rich content of probiotics, enzymes, and fermentation-derived bioactives. The presence of lactic acid bacteria (LAB) in cultured buttermilk, such as *Lactobacillus plantarum* and *Streptococcus thermophilus*, helps restore and maintain a healthy gut microbiota, which is essential for digestion, immunity, and nutrient absorption (Marco et al., 2017). These beneficial microbes inhibit the colonization of harmful pathogens by producing antimicrobial compounds and maintaining an acidic gut environment. Buttermilk also enhances intestinal health by promoting the synthesis of mucin, which protects the epithelial lining and prevents gut permeability or "leaky gut" syndrome (Tomasik & Tomasik, 2003).

Furthermore, the fermentation of milk proteins during buttermilk production releases bioactive peptides that have demonstrated anti-inflammatory effects in the gut, which may benefit individuals suffering from inflammatory bowel disease (IBD) and other gastrointestinal disorders (Chatterton et al., 2006). The presence of lactase-producing bacteria also supports the digestion of lactose, making buttermilk more suitable for individuals with lactose intolerance (Vesa et al., 2000). Regular consumption of buttermilk contributes to gut microbial balance, improved bowel function, and protection against gastrointestinal infections, supporting its classification as a functional food in digestive health management.

4.1.1 Gut Microbiota Balance

The consumption of fermented dairy products like buttermilk plays a pivotal role in maintaining and restoring gut microbiota balance, which is critical for overall health. Buttermilk contains live microbial cultures, especially strains of Lactobacillus, Leuconostoc, and Streptococcus, which help populate the gastrointestinal tract with beneficial bacteria (Hill et al., 2014). These probiotics not only compete with harmful microbes for adhesion sites on the intestinal wall but also produce antimicrobial compounds such as bacteriocins, hydrogen peroxide, and lactic acid, which suppress pathogenic growth (O'Toole et al., 2017). This microbial modulation strengthens the mucosal barrier, reduces intestinal inflammation, and improves gut immunity.

Importantly, buttermilk consumption has been shown to enhance microbial diversity, a key marker of gut health, and support the metabolism of complex carbohydrates into beneficial short-chain fatty acids (SCFAs) like butyrate and propionate, which play anti-inflammatory and colonic health roles (Milani et al., 2017). In addition, the symbiotic effect of naturally present prebiotics (milk oligosaccharides) in buttermilk with probiotics helps foster a favorable environment for the growth of commensal bacteria (Zivkovic et al., 2011). By continuously promoting a balance between beneficial and harmful bacteria, buttermilk contributes to maintaining intestinal homeostasis, supporting digestion, immune modulation, and even influencing mental health through the gut–brain axis.

4.1.2 Relief from Acidity and Bloating

Buttermilk has been traditionally consumed as a natural remedy for relief from acidity and bloating, owing to its cooling, digestive, and probiotic properties. It is a low-fat, mildly acidic dairy beverage that helps neutralize excessive stomach acid, providing a soothing effect on the gastric lining (Kaur & Arora, 2012). The presence of lactic acid bacteria (LAB), including *Lactobacillus* and *Streptococcus* species, contributes to improved digestion by enhancing enzymatic activity and maintaining a balanced gut environment (Patel et al., 2011). These probiotics aid in breaking down undigested food in the intestine, reducing fermentation and subsequent gas formation, which directly alleviates bloating and abdominal discomfort.

Buttermilk also contains electrolytes and digestive enzymes, such as amylase and protease, that support gastric emptying and help restore pH balance in the stomach, countering hyperacidity (Rani & Pradeep, 2020). The cooling nature of buttermilk, combined with spices like cumin or ginger (often added in traditional preparations), further enhances its carminative properties and reduces gastrointestinal spasms and flatulence. Studies also suggest that regular consumption of fermented dairy products like buttermilk can improve gut motility and reduce symptoms of dyspepsia and mild gastrointestinal distress (Nagpal et al., 2012). The alkaline buffering capacity of buttermilk assists in regulating gastric pH, preventing the excessive buildup of hydrochloric acid, which is a primary cause of acid reflux and heartburn. Its hydrating effect also helps dilute stomach acids, especially when consumed between meals or after spicy or fatty food intake (Sharma & Bajwa, 2014). The presence of riboflavin and vitamin B12 in buttermilk supports the repair of epithelial cells in the digestive tract, enhancing overall gut health and resilience. Therefore, buttermilk serves not only as a nutritional beverage but also as a functional food for managing acidity and bloating in daily diets.

Table 4: Therapeutic Applications of Buttermilk

Therapeutic Area	Application of Buttermilk	Mechanism/Benefit
Digestive Health	Used to relieve indigestion, bloating, and constipation	Probiotics improve gut flora and promote digestion
Liver Disorders	Traditionally used in Ayurveda for liver detoxification	Enhances liver function and flushes toxins
Hypercholesterolemia	Supports cholesterol management	Contains bioactive peptides and phospholipids
Hypertension	May aid in blood pressure regulation	ACE-inhibitory peptides reduce vascular tension
Dehydration & Electrolyte Loss	Used as a rehydration drink in hot climates	Restores fluids, contains electrolytes like potassium and sodium
Inflammatory Conditions	Helps reduce systemic inflammation	Presence of SCFAs and probiotics with anti-inflammatory action
Lactose Intolerance	Easier to digest than milk	Lower lactose content and presence of lactase-producing bacteria
Obesity and Weight Management	Used as a low-fat, nutritious alternative to milk	Low calorie and fat content helps reduce overall intake
Skin Disorders (Topical/Ayurvedic)	Applied in some traditional remedies for skin cooling	Soothing effect; mild acidity helps in skin cleansing

4.2 Cardiovascular Health

4.2.1 Cholesterol Management

Buttermilk is increasingly recognized for its role in cholesterol management, particularly due to its content of milk fat globule membrane (MFGM) components, bioactive peptides, and naturally occurring phospholipids. MFGM-enriched buttermilk has been shown to significantly reduce low-density lipoprotein (LDL) cholesterol levels without negatively affecting high-density lipoprotein (HDL) cholesterol, making it beneficial for cardiovascular health (Conway et al., 2013). The phospholipids and sphingolipids found in buttermilk actively participate in inhibiting cholesterol absorption in the intestines, thereby lowering overall serum cholesterol levels (Dewettinck et al., 2008).

Additionally, fermentation-derived peptides in cultured buttermilk have angiotensin-converting enzyme (ACE) inhibitory properties, which not only help regulate blood pressure but also indirectly influence lipid metabolism and vascular health (Nakamura et al., 1995). The probiotic strains present in buttermilk may also contribute to cholesterol catabolism by deconjugating bile acids, enhancing their excretion, and prompting the liver to utilize circulating cholesterol for bile synthesis (Jones et al., 2012). These mechanisms collectively make buttermilk a functional dairy beverage that supports effective cholesterol regulation and offers a natural alternative to lipid-lowering agents.

4.2.2 Blood Pressure Regulation

Buttermilk contributes to blood pressure regulation through its unique combination of bioactive peptides, minerals, and probiotic bacteria that support vascular health. During fermentation, casein proteins in buttermilk are broken down into ACE-inhibitory peptides, which suppress the angiotensin-converting enzyme responsible for vasoconstriction, thereby promoting vasodilation and lowering blood pressure (Seppo et al., 2003). Clinical studies have shown that regular consumption of fermented dairy products, including buttermilk, is associated with modest but consistent reductions in systolic and diastolic blood pressure, particularly in individuals with mild hypertension (Jauhiainen & Korpela, 2007).

In addition, potassium and calcium found in buttermilk help maintain electrolyte balance, reduce arterial stiffness, and counteract the effects of dietary sodium, all of which are vital for maintaining normal blood pressure (Appel et al., 2006). The probiotic strains in buttermilk also contribute to reducing systemic inflammation, improving endothelial function, and influencing renin-angiotensin signaling pathways, which further supports blood pressure control (Khalesi et al., 2014). These combined effects position buttermilk as a natural dietary adjunct in the prevention and management of hypertension.

4.3 Anti-inflammatory and Antimicrobial Effects

Buttermilk exhibits both anti-inflammatory and antimicrobial properties, making it a functional food with therapeutic potential. The fermentation process involved in buttermilk production generates bioactive peptides and probiotic cultures that help modulate the immune response and suppress inflammation. Specific peptides derived from milk proteins have been shown to inhibit pro-inflammatory cytokines such as TNF-α and IL-6, reducing systemic inflammation (Korhonen & Pihlanto, 2006). Probiotics such as *Lactobacillus acidophilus* and *Streptococcus thermophilus*, commonly present in buttermilk, can improve gut barrier function and reduce endotoxin levels, further supporting anti-inflammatory responses (Zhou et al., 2010).

In terms of antimicrobial activity, buttermilk contains lactic acid, bacteriocins, and other microbial metabolites that inhibit the growth of harmful pathogens including *Escherichia coli*, *Salmonella typhi*, and *Staphylococcus aureus* (Ouwehand et al., 2002). These effects are enhanced by the acidic pH and competitive exclusion of pathogenic bacteria by beneficial microbes. Moreover, buttermilk-derived phospholipids and immunoglobulins have been found to exert antimicrobial actions, especially in the gut and oral cavity, contributing to overall microbiological balance and reduced infection risk (Marnila & Korhonen, 2011). Thus, the regular intake of buttermilk may serve as a natural and accessible strategy for managing low-grade inflammation and protecting against microbial threats.

4.4 Role in Metabolic Disorders

4.4.1 Diabetes Management

Buttermilk holds promise as a supportive dietary component in the management of diabetes mellitus, especially type 2 diabetes, due to its low carbohydrate content, fermentation-derived bioactive compounds, and probiotic profile. The probiotics in buttermilk, such as *Lactobacillus* and *Bifidobacterium* strains, improve gut microbiota composition, which has been linked to enhanced insulin sensitivity and reduced systemic inflammation—both critical in diabetes control (Yadav et al., 2007). Moreover, fermented milk products like buttermilk are rich in short-chain fatty acids (SCFAs) and lactic acid, which can modulate glucose metabolism and inhibit hepatic glucose production (Delzenne & Cani, 2011).

Several studies suggest that regular consumption of fermented dairy, including buttermilk, is associated with lower fasting blood glucose levels and improved HbA1c outcomes, likely due to the anti-inflammatory effects of bioactive peptides and improved intestinal barrier function (Ejtahed et al., 2012). Additionally, buttermilk's low glycemic load and high calcium and riboflavin content support better glycemic control and pancreatic function. Its ability to promote satiety and reduce postprandial glucose spikes makes it a functional food in diabetic dietary management. Thus, buttermilk, as part of a balanced diet, may serve as a cost-effective, culturally acceptable adjunct in diabetes prevention and care.

However, for optimal benefit, it is advisable to consume unsweetened, low-fat buttermilk prepared under hygienic conditions, preferably from cultured or probiotic-rich sources

4.4.2 Obesity and Weight Control

Buttermilk contributes to obesity and weight control through multiple nutritional and metabolic mechanisms. Being naturally low in fat and calories while rich in high-quality proteins, buttermilk promotes satiety and helps reduce overall calorie intake, making it a beneficial choice in weight management diets (Dougkas et al., 2012). The bioactive peptides and calcium present in buttermilk are known to enhance lipid metabolism and increase fat oxidation, potentially reducing body fat accumulation (Zemel et al., 2000). Furthermore, calcium intake from dairy sources like buttermilk may suppress lipogenesis and stimulate lipolysis in adipose tissue.

Probiotic strains commonly found in fermented buttermilk—such as *Lactobacillus gasseri* and *Bifidobacterium breve*—have been linked to modulation of gut microbiota, which can influence energy harvest, appetite regulation, and fat storage (Kadooka et al., 2010). These strains can also reduce low-grade inflammation associated with obesity, further supporting metabolic balance. Buttermilk's hydration potential and digestive ease make it a culturally acceptable, cost-effective, and sustainable option for healthy weight maintenance. When included in a balanced diet and active lifestyle, it offers a functional, nutrient-rich alternative to high-calorie beverages and snacks.

4.5 Immune Modulatory Effects

Buttermilk demonstrates notable immune modulatory effects, primarily attributed to its rich content of probiotics, bioactive peptides, and milk-derived immunoglobulins. Fermentation enhances the functional properties of buttermilk by generating lactic acid bacteria (LAB) such as *Lactobacillus casei*, *Lactobacillus rhamnosus*, and *Bifidobacterium bifidum*, which stimulate both innate and adaptive immunity (Prajapati & Nair, 2003). These beneficial microbes interact with gut-associated lymphoid tissue (GALT), leading to enhanced production of IgA, interleukins (IL-10, IL-12), and interferon-gamma, thereby improving host resistance to infections (Ng et al., 2009).

Furthermore, milk-derived peptides generated during fermentation have been shown to act as immunostimulants, influencing cytokine expression and modulating inflammatory responses (Matar et al., 2001). The presence of milk fat globule membrane (MFGM) components in buttermilk also contributes to immune function by affecting macrophage activation and antigen presentation (Spitsberg, 2005). Regular intake of buttermilk may thus reduce susceptibility to respiratory infections, support post-illness recovery, and modulate allergic responses. These immune-boosting properties make buttermilk a valuable dietary inclusion, especially in vulnerable populations such as children, the elderly, and immunocompromised individuals.

4.6 Benefits for Skin and Hydration

Buttermilk offers significant benefits for skin health and hydration, both as a dietary component and a traditional topical remedy. Rich in lactic acid, a natural alpha-hydroxy acid (AHA), buttermilk gently exfoliates the skin, removing dead cells and promoting cell renewal, which improves skin texture and tone (Kornhauser et al., 2010). Additionally, its content of vitamins (B2, B12), calcium, and proteins helps nourish the skin from within, enhancing elasticity and moisture retention. The high water content in buttermilk also contributes to internal hydration, which is crucial for maintaining skin softness and preventing dryness (Elia & Stratton, 2009).

Topical application of buttermilk has been historically used in Ayurvedic and folk medicine for treating acne, pigmentation, sunburn, and inflammation, owing to its soothing, cooling, and antimicrobial properties (Patil et al., 2014). The presence of probiotics like *Lactobacillus* in buttermilk can also help restore the skin's natural microbiome and improve barrier function, potentially protecting against eczema and other inflammatory skin conditions (Knackstedt et al., 2020). With its combination of hydration, nourishment, and gentle exfoliation, buttermilk serves as a cost-effective and natural skincare solution, promoting both internal and external dermal health.

5. Buttermilk in Traditional and Modern Systems of Medicine

Buttermilk holds a significant place in both traditional medicine systems and modern nutrition science due to its health-promoting properties. In Ayurveda, buttermilk, known as *Takra*, is considered a sattvic food that aids digestion, balances the doshas, particularly

Kapha and *Vata*, and is used in the treatment of conditions such as irritable bowel syndrome, piles, indigestion, and inflammation (Sharma et al., 2013). It is often prescribed as a digestive tonic and is used in Panchakarma therapies for detoxification. Traditional texts describe its benefits in enhancing gut function and nutrient assimilation, reinforcing its role in gastrointestinal health.

In modern medical nutrition therapy, buttermilk is valued for its probiotic content, low fat, and high bioavailability of calcium, potassium, and vitamins, which support cardiovascular, metabolic, and bone health. Clinical studies have shown that fermented milk products like buttermilk contribute to cholesterol reduction, immune regulation, and glycemic control, making it relevant in managing lifestyle diseases such as diabetes, hypertension, and dyslipidemia (Parvez et al., 2006; Savaiano & Hutkins, 2021). Furthermore, its role in hydration, anti-inflammatory action, and gut microbiota modulation bridges traditional wisdom with contemporary evidence-based practice. Thus, buttermilk remains a functional and therapeutic food with relevance across diverse systems of medicine.

6. Safety, Tolerability, and Consumption Considerations

6.1 Lactose Intolerance and Casein Allergy

Buttermilk offers certain advantages for individuals with lactose intolerance, although caution is necessary in cases of casein allergy. Lactose intolerance results from reduced activity of the enzyme lactase, leading to gastrointestinal discomfort upon consumption of lactose-containing dairy. However, the fermentation process in buttermilk reduces its lactose content significantly, as lactic acid bacteria partially hydrolyze lactose into glucose and galactose, making it more tolerable for lactose-intolerant individuals (Savaiano, 2014). Studies have shown that fermented dairy products like buttermilk are often better tolerated and may even support lactase persistence by altering gut flora (He et al., 2008).

Conversely, casein allergy—an immune response to the milk protein casein—presents a different concern. Casein remains present in buttermilk, and individuals with a true allergy may experience skin rashes, respiratory symptoms, or anaphylaxis (Fiocchi et al., 2010). While some peptides generated during fermentation may reduce allergenicity, buttermilk is still not considered safe for those with confirmed casein allergies. Thus, while buttermilk may be a viable dairy alternative for many with lactose intolerance, it is contraindicated in milk protein allergies, underscoring the importance of individual dietary assessments.

6.2 Microbiological Safety and Storage Requirements

Ensuring microbiological safety of buttermilk is critical, as it is a perishable dairy product highly susceptible to contamination and spoilage due to its high moisture content and nutrient richness. Freshly prepared traditional or cultured buttermilk can harbor pathogenic bacteria such as *Listeria monocytogenes*, *Salmonella spp.*, and *Escherichia coli* if not processed or stored under hygienic conditions (Oliver et al., 2005). To mitigate risks, proper pasteurization of milk prior to fermentation is essential, and adherence to good manufacturing practices (GMP) is strongly recommended. In commercial settings, starter cultures with well-characterized microbial strains are used to maintain consistency and safety.

Storage conditions significantly influence the shelf-life and microbial stability of buttermilk. It should be stored at refrigerated temperatures (4 °C or below) to slow microbial growth and maintain quality. Studies indicate that the total viable count and lactic acid bacteria populations in buttermilk remain within safe limits for up to 7–10 days under refrigeration (Kumar et al., 2011). Packaging in airtight, food-grade containers helps prevent post-fermentation contamination and spoilage. Advances such as high-pressure processing (HPP) and modified atmosphere packaging (MAP) are also being explored to extend shelf life without compromising probiotic viability (Huang et al., 2014). Therefore, strict hygienic protocols, temperature control, and appropriate storage technologies are vital for maintaining the safety and quality of buttermilk.

6.3 Recommended Intake and Precaution

Buttermilk, as a nutritious and functional dairy beverage, can be safely consumed daily in moderate amounts, generally ranging from 200–300 mL per day for healthy adults. This level provides beneficial probiotics, electrolytes, and nutrients without contributing excessive calories or fats (USDA, 2021). Its low-fat, high-water content makes it particularly suitable for hydration and digestion support, especially in warm climates. However, individual tolerance varies based on digestive health, dietary restrictions, and existing conditions such as lactose intolerance or dairy allergies.

Although the fermentation process reduces lactose, individuals with severe lactose intolerance or milk protein allergies (e.g., casein allergy) should avoid buttermilk unless certified lactose-free or hypoallergenic alternatives are used (Misselwitz et al., 2013).

Additionally, people with chronic kidney disease (CKD) or low-sodium diets should monitor intake due to the naturally occurring sodium and potassium content in dairy. Pregnant women and immunocompromised individuals should consume only pasteurized buttermilk to avoid microbial risks (EFSA, 2015). It is also advisable to avoid commercially flavored buttermilk with added salt or sugar, which may counteract health benefits. Thus, while buttermilk can be a valuable addition to a balanced diet, consumption should be personalized based on health status and dietary needs.

7. Limitations in Current Research

7.1 Lack of Human Clinical Trials

Despite numerous studies suggesting the health-promoting properties of buttermilk—such as its probiotic potential, lipid-lowering effects, and immunomodulatory benefits—the lack of robust human clinical trials remains a significant limitation in fully validating these claims. Most existing evidence comes from in vitro experiments, animal models, or studies on fermented dairy products in general, making it difficult to isolate the specific effects of buttermilk (Parvez et al., 2006; Korhonen, 2009). For instance, while some clinical studies have examined the effects of lactic acid bacteria or fermented milk on lipid metabolism and gut health, very few have focused exclusively on traditional or cultured buttermilk in human populations.

This gap creates uncertainty in determining effective dosages, long-term safety, and population-specific outcomes, particularly among individuals with metabolic disorders, allergies, or compromised immunity. Moreover, variables such as regional variations in preparation, starter cultures, and dietary patterns complicate reproducibility and generalizability (Marco et al., 2017). As a result, healthcare professionals often hesitate to recommend buttermilk as a therapeutic food without further validation. Future research should prioritize randomized controlled trials (RCTs) to better assess buttermilk's role in disease prevention, gut health, cardiovascular function, and metabolic balance under controlled human conditions.

7.2 Variability in Buttermilk Composition Across Regions

The nutritional and functional properties of buttermilk can vary significantly depending on geographical region, preparation methods, and cultural practices, which poses a challenge for standardization and clinical evaluation. In India, for example, traditional buttermilk (*chaas*) is prepared by churning curd and often diluted with water and spiced with herbs or salt, whereas in Western countries, cultured buttermilk is typically produced by fermenting skim milk with specific lactic acid bacteria strains such as *Lactococcus lactis* or *Leuconostoc* (Aneja et al., 2002; Walstra et al., 2006). These differences lead to variability in probiotic content, acidity, fat concentration, and bioactive peptide levels.

Additionally, the type of milk used (cow, buffalo, or goat), regional microbial flora, and fermentation time can alter the macronutrient and micronutrient profiles of buttermilk (Hati et al., 2019). This heterogeneity makes it difficult to generalize health benefits across populations or to develop unified dietary guidelines. Such variability also limits the reproducibility of experimental outcomes in scientific studies and complicates efforts to commercialize buttermilk-based functional foods with consistent health claims. Therefore, harmonized production standards and region-specific compositional analysis are essential for validating and optimizing buttermilk's therapeutic potential.

7.3 Standardization and Quality Control Issues

One of the key challenges in the widespread acceptance and therapeutic use of buttermilk is the lack of standardization and consistent quality control across regions and manufacturers. Traditional buttermilk varies in texture, acidity, microbial content, and nutritional composition depending on local preparation methods, water dilution ratios, and fermentation time. Even in industrially produced cultured buttermilk, differences in starter cultures, milk source, and processing conditions result in variability in flavor, viscosity, and probiotic viability (Prazeres et al., 2012). This inconsistency complicates efforts to validate buttermilk's health benefits scientifically and hampers the formulation of uniform dietary recommendations.

Quality control is further hindered by the absence of specific regulatory guidelines in many countries that address the minimum viable count of probiotics, permissible additives, or functional labeling criteria for buttermilk products. Additionally, inadequate monitoring of microbial safety, shelf-life stability, and sensory attributes can lead to reduced consumer trust and marketability (Tripathi & Giri, 2014). Establishing codified standards and implementing Good Manufacturing Practices (GMP) along with Hazard Analysis and Critical Control Points (HACCP) can help improve safety, efficacy, and consistency of buttermilk as a functional food. Thus, addressing standardization and quality assurance is crucial for advancing its use in health promotion and clinical nutrition.

8. Future Perspectives

8.1 Need for Clinical and Mechanistic Studies

While buttermilk is widely consumed and traditionally acclaimed for its digestive, metabolic, and cardiovascular benefits, there remains a significant gap in clinical and mechanistic studies to substantiate these health claims. Most available data stem from in vitro experiments or extrapolated findings from general fermented dairy products, leaving the specific physiological effects of buttermilk underexplored (Marco et al., 2017). Moreover, although buttermilk is rich in bioactive peptides, lactic acid bacteria, and short-chain fatty acids, the exact mechanisms through which these components interact with human systems—such as modulation of gut microbiota, inflammatory pathways, or lipid metabolism—are not yet fully elucidated (Korhonen & Pihlanto, 2006).

Randomized controlled trials (RCTs) assessing dose-response relationships, long-term outcomes, and population-specific responses to buttermilk are sparse. Furthermore, mechanistic studies using omics approaches—like metabolomics and proteomics—could provide deeper insights into how buttermilk constituents impact metabolic pathways and gene expression (van der Kamp et al., 2014). Strengthening clinical evidence with robust human studies and mechanistic models is therefore essential to validate traditional knowledge, establish buttermilk's role as a functional food, and inform regulatory and dietary guidelines.

8.2 Potential for Development as Nutraceutical or Therapeutic Product

Buttermilk possesses significant potential for development as a nutraceutical or therapeutic product due to its rich composition of bioactive peptides, probiotics, conjugated linoleic acid (CLA), vitamins, and minerals. These constituents have been linked to various health benefits, including cholesterol-lowering effects, immunomodulation, and gastrointestinal support (Korhonen, 2009). As consumer interest in functional foods and natural therapies grows, buttermilk stands out as a low-cost, widely accepted vehicle for delivering health-promoting compounds. Moreover, its naturally low fat content, refreshing taste, and ease of digestion make it ideal for inclusion in therapeutic diets, particularly for patients with metabolic disorders, inflammatory conditions, and dehydration-related issues (Giri et al., 2020).

Innovations in fermentation technology and encapsulation techniques can further enhance the stability and targeted delivery of buttermilk-derived bioactives, paving the way for its inclusion in personalized nutrition and clinical nutrition regimes. Regulatory recognition of specific functional claims, combined with standardized production protocols, would support its transformation from a traditional beverage into a scientifically validated nutraceutical product (Sharma et al., 2020). However, to achieve this transition, comprehensive studies—including clinical trials, dose standardization, and safety evaluations—are essential to justify health claims and ensure consumer trust. Such innovations can facilitate the incorporation of buttermilk extracts or concentrates into capsules, powders, fortified beverages, or medical nutrition formulas tailored for specific populations such as elderly individuals, athletes, or immunocompromised patients. Moreover, its compatibility with other functional ingredients such as prebiotics, herbal extracts, and omega-3 fatty acids enhances its scope in synergistic formulations. Regulatory frameworks and clinical substantiation are essential for this transition. Standardized production protocols, quality control for microbial viability, and validation of bioactive potency will be critical in ensuring safety and reproducibility.

Table 4: Therapeutic Applications of Buttermilk

Therapeutic Area	**Application of Buttermilk**	**Mechanism/Benefit**
Digestive Health	Used to relieve indigestion, bloating, and constipation	Probiotics improve gut flora and promote digestion
Liver Disorders	Traditionally used in Ayurveda for liver detoxification	Enhances liver function and flushes toxins
Hypercholesterolemia	Supports cholesterol management	Contains bioactive peptides and phospholipids
Hypertension	May aid in blood pressure regulation	ACE-inhibitory peptides reduce vascular tension
Dehydration & Electrolyte Loss	Used as a rehydration drink in hot climates	Restores fluids, contains electrolytes like potassium and sodium
Inflammatory Conditions	Helps reduce systemic inflammation	Presence of SCFAs and probiotics with anti-inflammatory

		action
Lactose Intolerance	Easier to digest than milk	Lower lactose content and presence of lactase-producing bacteria
Obesity and Weight Management	Used as a low-fat, nutritious alternative to milk	Low calorie and fat content helps reduce overall intake
Skin Disorders (Topical/Ayurvedic)	Applied in some traditional remedies for skin cooling	Soothing effect; mild acidity helps in skin cleansing

8.3 Innovations in Formulation and Delivery

Recent advancements in food science have paved the way for innovative formulation and delivery systems that enhance the nutritional, therapeutic, and commercial value of buttermilk. Novel techniques such as microencapsulation, nanoemulsion, and probiotic fortification have been employed to improve the stability, shelf-life, and targeted delivery of bioactive components like probiotics, peptides, and vitamins (Anal & Singh, 2007). These technologies protect sensitive compounds during processing and gastrointestinal transit, ensuring higher bioavailability and sustained health benefits. Additionally, the development of flavored and functional buttermilk beverages—infused with herbs, prebiotics, and plant extracts—has broadened consumer appeal and allowed product customization for specific health needs, such as diabetes, cardiovascular health, or digestive issues (Kumar & Mishra, 2020).

Furthermore, ready-to-drink formulations, freeze-dried powders, and fortified dairy blends are being explored for use in clinical nutrition and nutraceutical markets, offering convenience and dosage control. Fermentation with targeted lactic acid bacteria strains also allows for tailored functionalities, including immunomodulation, antimicrobial activity, and cholesterol regulation (Tripathi & Giri, 2014). These innovations support the repositioning of buttermilk from a traditional beverage to a modern functional food platform, aligning with the growing global demand for health-oriented dairy alternatives.

9. Conclusion

Buttermilk, whether in its traditional or cultured form, is emerging as a functional dairy product with substantial potential to improve human health. Rich in proteins, essential fatty acids, calcium, B-complex vitamins, and probiotics, it not only provides basic nutrition but also contributes to preventive and therapeutic health care. Numerous studies have highlighted its role in gut microbiota modulation, cholesterol reduction, anti-inflammatory effects, and metabolic regulation, making it particularly beneficial for individuals with cardiovascular diseases, obesity, diabetes, and digestive disorders. Furthermore, its high water content and electrolyte profile make it effective for hydration and detoxification, especially in tropical climates.

In recent years, innovations in dairy biotechnology have allowed for the development of fortified buttermilk, incorporating targeted probiotic strains, prebiotics, plant-based bioactives, and microencapsulated nutrients, thereby extending its utility to the nutraceutical and therapeutic markets. Countries like India, where traditional buttermilk is a dietary staple, are now witnessing its resurgence in clinical and functional formulations. However, challenges such as lack of standardized processing methods, variable microbial profiles, and insufficient human trials hinder its integration into modern medical nutrition.

To fully harness its benefits, future efforts must focus on conducting well-designed randomized clinical trials, establishing universal quality standards, and promoting consumer awareness through scientific communication. With its low cost, sustainability, and cultural acceptance, buttermilk has the potential to serve not just as a nutritional beverage but as a holistic dietary therapy in both traditional and evidence-based medical systems.

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11. Conflict of Interest

The authors declare no conflict of interest related to this research.

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