

The Role of Gut Microbiota in the Health Effects of Fermented Dairy Products

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Abstract

*The human gut microbiota plays a crucial role in maintaining physiological health, influencing digestion, metabolism, immune function, and even mental well-being. Among dietary interventions aimed at modulating gut microbiota, fermented dairy products have emerged as particularly promising due to their rich content of live microorganisms, bioactive compounds, and nutrients. This review explores the intricate interactions between fermented dairy products and the gut microbiota, highlighting their potential health benefits and underlying mechanisms. Fermented dairy foods, such as yogurt, kefir, and cultured milk contain probiotic strains – primarily from the genera *Lactobacillus* and *Bifidobacterium* – that may transiently colonize the gastrointestinal tract and modulate the composition and activity of the resident microbiota. These interactions contribute to enhanced gut barrier function, inhibition of pathogenic microbes, and regulation of immune responses. In addition, bioactive metabolites produced during fermentation, including peptides and short-chain fatty acids, further support host health by exerting anti-inflammatory and antioxidant effects. The consumption of fermented dairy products has been associated with improvements in gastrointestinal disorders (e.g., lactose intolerance, irritable bowel syndrome), metabolic health (e.g., insulin sensitivity, lipid regulation), immune modulation, and even mental health through the gut–brain axis. However, the health outcomes are influenced by multiple factors, including individual microbiota composition, the type and dose of dairy consumed, and the presence of other dietary components. Despite promising evidence, challenges remain, including variability in clinical outcomes, short-term survival of probiotics in the gut, and regulatory complexities surrounding health claims. Future research should focus on personalized nutrition approaches, synergistic synbiotic formulations, and the application of advanced metagenomic and metabolomic tools to unravel the complex host–microbe–diet interactions. Overall, fermented dairy products represent a functional food category with significant potential to beneficially influence gut microbiota and human health, warranting further investigation through well-designed human trials.*

Keywords: Gut microbiota, fermentation, human health, metabolic health, immune system

INTRODUCTION

The human gut microbiota, a complex and dynamic community of microorganisms residing in the gastrointestinal tract, plays a vital role in maintaining host health by regulating digestion, immune responses, nutrient absorption, and even neurological functions. Diet is one of the most significant modulators of gut microbiota composition and activity, with fermented dairy products, such as yogurt, kefir, and cheese standing out for their rich content of beneficial microbes and bioactive compounds. These products not only provide essential nutrients but also deliver live microorganisms – primarily probiotics – that may influence the balance and function of the gut microbiota. Given the rising interest in gut health

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and functional foods, understanding the mechanisms by which fermented dairy products interact with the gut microbiota is essential. This review aims to examine these interactions, explore the health benefits mediated through microbial modulation, and identify factors influencing efficacy. The discussion is structured to provide an overview of gut microbiota and fermented dairy composition, followed by mechanistic insights, clinical evidence, limitations, and directions for future research [1].

OVERVIEW OF GUT MICROBIOTA

The gut microbiota comprises trillions of microorganisms, including bacteria, archaea, viruses, and fungi, that colonize the human gastrointestinal tract, primarily the colon. This microbial community is highly diverse, with dominant bacterial phyla including Firmicutes, Bacteroidetes, Actinobacteria, and Proteobacteria, though its composition can vary significantly between individuals. The gut microbiota performs a wide range of essential functions, such as fermenting indigestible dietary fibers into short-chain fatty acids (SCFAs), synthesizing vitamins (e.g., B and K), regulating immune system development and responses, protecting against pathogenic invasion, and influencing host metabolism and energy balance. Several intrinsic and extrinsic factors shape the composition and function of the gut microbiota. These include age, genetics, mode of birth delivery, and environmental exposures, with diet being one of the most powerful modulators. Antibiotic use, infections, stress, and lifestyle also contribute to microbial shifts, which may influence susceptibility to various diseases. Maintaining a balanced and diverse gut microbiota is thus critical for overall health, and targeted dietary interventions – such as consuming fermented foods – are gaining attention as potential strategies to support and restore microbial equilibrium [2].

COMMON TYPES OF FERMENTED DAIRY PRODUCTS

Fermented dairy products are widely consumed across cultures for their taste, nutritional value, and health benefits. Common examples include yogurt, kefir, cultured buttermilk, cheese, and fermented creams. Yogurt is produced by the fermentation of milk using specific bacterial cultures, typically *Lactobacillus delbrueckii* subsp. *bulgaricus* and *Streptococcus thermophilus*. Kefir, a fermented milk drink originating from the Caucasus region, is made using kefir grains that contain a complex community of bacteria and yeasts. Cultured buttermilk results from the fermentation of low-fat milk, usually with mesophilic lactic acid bacteria. Each of these products has a unique microbial composition and texture, contributing to distinct sensory profiles and potential health effects [3].

STARTER CULTURES AND PROBIOTIC STRAINS USED

The fermentation of dairy products relies on the use of specific starter cultures, which are carefully selected strains of bacteria responsible for initiating and controlling the fermentation process. Traditional starters include *Lactobacillus*, *Streptococcus*, and *Leuconostoc* species, which produce lactic acid, aiding in preservation and flavor development. In addition to these, many fermented dairy products are enriched with probiotic strains – live microorganisms that confer health benefits when consumed in adequate amounts. Common probiotic strains used include *Lactobacillus acidophilus*, *Lactobacillus casei*, *Bifidobacterium bifidum*, and *Bifidobacterium animalis* subsp. *lactis*. These strains are known for their ability to survive gastrointestinal transit, adhere to intestinal mucosa, and modulate the host's immune and microbial environment. The combination of traditional starter cultures and added probiotics enhances both the functional and nutritional value of fermented dairy products [4].

BIOACTIVE COMPOUNDS GENERATED DURING FERMENTATION

During the fermentation of dairy products, microbial activity leads to the production of a variety of bioactive compounds that contribute to both the nutritional value and health-promoting properties of these foods. One of the key groups of compounds generated are bioactive peptides, which are released from milk proteins (such as casein and whey) through the enzymatic action of lactic acid bacteria. These peptides have been shown to exhibit diverse biological activities, including antihypertensive, antioxidant, antimicrobial, and immunomodulatory effects. Another important class of fermentation-derived compounds are short-chain fatty acids (SCFAs), such as acetate, propionate, and butyrate, which are produced primarily through microbial fermentation of lactose and other carbohydrates. SCFAs serve

as an energy source for colonocytes, help regulate inflammation and contribute to maintaining gut barrier integrity. Other fermentation by-products include vitamins (such as folate and B12), exopolysaccharides (which can improve gut health and texture of dairy), and organic acids, like lactic and acetic acid, which inhibit pathogen growth and enhance shelf life. Collectively, these bioactive compounds play a crucial role in mediating the beneficial health effects associated with fermented dairy consumption [5].

COLONIZATION VS. TRANSIENT EFFECTS OF PROBIOTIC STRAINS

Probiotic strains present in fermented dairy products typically exert their effects during their passage through the gastrointestinal tract, but most do not permanently colonize the gut. Instead, they exhibit transient colonization, meaning they may temporarily increase in abundance but are eventually cleared once consumption stops. Despite this transient presence, probiotics can still modulate gut function and microbial activity by interacting with resident microbes, epithelial cells, and the host immune system. Their efficacy often depends on factors like strain specificity, dose, and frequency of intake [6].

MODULATION OF RESIDENT MICROBIOTA COMPOSITION

Fermented dairy products can influence the composition and metabolic activity of the resident gut microbiota. By providing live bacteria and fermentation by-products, these products may increase the abundance of beneficial taxa, such as *Bifidobacterium* and *Lactobacillus*, while reducing potentially harmful microbes. Moreover, the metabolic outputs of probiotic bacteria, such as SCFAs, can alter the gut environment (e.g., pH), making it more favorable for beneficial microbes. These shifts can contribute to improved microbial balance, diversity, and resilience against dysbiosis [7].

COMPETITIVE INHIBITION OF PATHOGENS

One of the key protective roles of fermented dairy probiotics is competitive exclusion of pathogenic microorganisms. Probiotic strains can compete with pathogens for nutrients and adhesion sites on the gut mucosa, produce antimicrobial substances (e.g., bacteriocins, organic acids), and modulate local conditions to inhibit pathogen survival. This mechanism reduces the risk of infections and may help prevent conditions, such as antibiotic-associated diarrhea or gastrointestinal disturbances caused by pathogenic bacteria [7].

ENHANCEMENT OF BARRIER FUNCTION AND IMMUNE SIGNALING

Fermented dairy products also support gut health by enhancing intestinal barrier integrity and regulating immune responses. Probiotics can stimulate the production of mucins and tight junction proteins, which strengthen the gut barrier and prevent the translocation of harmful substances. Additionally, they interact with immune cells via pattern recognition receptors (e.g., toll-like receptors), leading to the modulation of cytokine production and promoting a balanced immune response. This immunomodulatory action contributes to both local (gut) and systemic health benefits [8].

HEALTH BENEFITS MEDIATED THROUGH GUT MICROBIOTA

1. *Gastrointestinal Health:* Fermented dairy products have been widely studied for their positive effects on gastrointestinal health, particularly through the modulation of gut microbiota. One of the most well-established benefits is the alleviation of lactose intolerance. Probiotic strains in fermented dairy, such as *Lactobacillus acidophilus* and *Streptococcus thermophilus*, produce the enzyme β -galactosidase, which helps break down lactose in the gut, thereby reducing symptoms like bloating, diarrhea, and gas in lactose-intolerant individuals. In conditions, such as irritable bowel syndrome (IBS) and Inflammatory Bowel Disease (IBD), probiotic-containing dairy products may help by balancing the gut microbiota, reducing inflammation, and enhancing mucosal barrier function. Some clinical studies suggest that probiotics can alleviate abdominal discomfort, reduce bloating, and decrease flare-ups in ulcerative colitis and Crohn's disease. Fermented dairy can also positively influence gut motility and stool consistency. By modulating microbial activity and promoting the production of short-chain fatty acids (SCFAs), these products can help regulate bowel movements and reduce constipation, especially in elderly populations [9].

2. *Metabolic Health*: Regular consumption of fermented dairy may support metabolic health by influencing energy regulation and lipid metabolism via the gut microbiota. Specific probiotic strains can modulate the abundance of bacteria involved in energy harvest and fat storage, potentially aiding in obesity prevention and management. Studies have also indicated improvements in type 2 diabetes risk markers, including better insulin sensitivity and glycemic control. Probiotic-driven modulation of inflammation, gut permeability, and bile acid metabolism further contributes to favorable changes in lipid profiles, including reduced LDL cholesterol and triglyceride levels [10].
3. *Immune System Modulation*: The gut microbiota plays a central role in shaping immune responses, and fermented dairy products can enhance this interaction. Probiotics have been shown to reduce the incidence and severity of allergies and respiratory tract infections, particularly in children and the elderly, by modulating systemic and mucosal immune activity. They may also strengthen mucosal immune responses by increasing the production of secretory IgA and stimulating regulatory T cells. These effects contribute to maintaining immune homeostasis and protecting against inflammatory and autoimmune conditions [11].
4. *Mental Health (Gut–Brain Axis)*: Emerging research highlights the influence of gut microbiota on brain function, forming the basis of the gut–brain axis. Fermented dairy products containing probiotics – often referred to as psychobiotics – may have beneficial effects on mental health, including reductions in anxiety, depressive symptoms, and improved cognitive function. The mechanisms include modulation of neurotransmitter production (such as GABA and serotonin), reduction of systemic inflammation, and improved gut barrier integrity, which collectively contribute to a more balanced stress response and better emotional regulation [12].

FACTORS AFFECTING EFFICACY

The health benefits of fermented dairy products are influenced by several factors, making their effectiveness variable across individuals and populations. One major determinant is individual microbiota variability. Each person's gut microbiome is unique, shaped by genetics, diet, environment, and health status. This diversity affects how an individual responds to probiotic strains or fermented foods, with some people showing more pronounced microbial and clinical changes than others. Personalized responses to the same product highlight the need for tailored dietary interventions based on microbiome profiles.

Another important factor is the type and dose of fermented dairy consumed. Different products (e.g., yogurt, kefir, cheese) contain varying microbial strains, concentrations, and fermentation by-products, all of which influence health outcomes. Higher doses of live probiotics are generally associated with greater efficacy, but the optimal dose often depends on the specific strain and target health condition. Similarly, multi-strain formulations may offer broader effects than single-strain preparations [13].

The duration of consumption also plays a critical role in determining benefit. Many probiotic strains do not permanently colonize the gut; thus, continuous or long-term intake is often necessary to maintain their presence and functional impact. Short-term consumption may provide temporary benefits, but sustained use is typically needed to support lasting changes in the gut microbiota and associated health outcomes.

Finally, matrix effects – the physical and chemical composition of the dairy product – can influence the survival and function of probiotics during digestion. Components, such as fat, protein, and pH levels can protect probiotic strains from stomach acid and bile, enhancing their viability as they pass through the gastrointestinal tract. Additionally, the presence of prebiotic substrates in the matrix may support microbial growth and activity, potentially amplifying the health effects of the fermented product. These factors should be carefully considered when designing or selecting fermented dairy products for functional or therapeutic use [14].

LIMITATIONS AND CONTROVERSIES

Despite growing interest and promising findings, several limitations and controversies surround the use of fermented dairy products for gut health and disease prevention. One major concern is the

inconsistency in clinical evidence. While many studies report beneficial effects of fermented dairy on gastrointestinal, metabolic, and immune health, results often vary depending on study design, population, probiotic strain, and endpoints measured. Small sample sizes, short durations, and lack of standardized methodologies contribute to these inconsistencies, making it challenging to draw firm conclusions or develop universal recommendations.

Another limitation is the short-term colonization of probiotics. Most strains used in fermented dairy products do not permanently integrate into the gut microbiota. Their effects are typically transient and dependent on regular consumption. Once intake stops, the introduced bacteria often diminish rapidly, raising questions about the sustainability of benefits and the need for long-term adherence [15].

Furthermore, there are regulatory challenges and issues related to health claim substantiation. The definition and regulation of probiotics vary across countries, and many products on the market make generalized or unverified health claims. In jurisdictions, like the European Union, strict regulations require robust scientific evidence for any health claim, yet many studies fall short of these standards. This creates confusion for consumers and limits the ability of producers to market the full potential of their products.

Collectively, these limitations highlight the need for more rigorous, long-term, and strain-specific human trials, along with better regulatory alignment and clearer labeling practices. Addressing these issues is essential to validate the efficacy of fermented dairy products and integrate them effectively into dietary guidelines and healthcare strategies [16].

CONCLUSIONS

Fermented dairy products offer a promising dietary avenue for modulating the gut microbiota and promoting human health. This review highlights their multifaceted interactions with the gastrointestinal ecosystem through probiotic action, production of bioactive compounds, and modulation of resident microbial communities. Key health benefits include improved digestion, metabolic regulation, enhanced immune function, and potential support for mental well-being via the gut–brain axis. However, these effects are influenced by individual microbiota variability, the type and dose of dairy consumed, and the nutritional matrix of the product.

Despite the supportive evidence, several limitations – such as inconsistent clinical outcomes, the transient nature of probiotic colonization, and regulatory challenges – underscore the need for caution in generalizing findings. Nevertheless, the potential role of fermented dairy in maintaining gut health remains strong, particularly when incorporated as part of a balanced, diverse diet.

To fully harness and substantiate these benefits, future research must integrate advanced multi-omics approaches (metagenomics, metabolomics, proteomics) with well-designed, longitudinal clinical trials. Such efforts will allow for a deeper understanding of host–microbe–diet interactions and pave the way for personalized nutrition strategies using fermented dairy as a functional food component.

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