Vol. 18 (2026): Proceedings of 2026 International Conference on Smart Healthcare and Biomedical Engineering (ICSHBE 2026)
E-ISSN: 3105-0522 P-ISSN: 3105-0514
DOI: https://doi.org/10.70267/shbe.2026273279

Research Progress on Intestinal Health Effects, Targeted Protection Technologies and Applications in Special Populations of Probiotics in Yogurt

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Abstract

With the growing demand for yogurt beverages, people have recognized that probiotics in yogurt can exert positive effects on the human intestinal tract. This paper reviews the benefits of yogurt for intestinal health, discusses strategies to improve the survival rate of probiotics from yogurt in the gut, analyzes their effects on special populations, and prospects the application opportunities and challenges of yogurt-derived probiotics. To comprehensively evaluate probiotic efficacy, the reviewed studies include in vitro digestion models, animal experiments, human cross-sectional analysis, product development, and technological innovations. Key findings show that probiotics promote digestion and modulate immunity via bioactive peptide release and IgA regulation. Protection technologies such as bio-coating, prebiotic supplementation, and spray drying significantly enhance probiotic survival and colonization. For special populations, yogurt probiotics correlate with reduced diabetic kidney disease risk; plant-based analogues serve lactose-intolerant individuals; and postbiotics show anti-obesity effects. Challenges include strain specificity, limited human trials, and the translational gap from animal studies. Future research should focus on personalized products and advanced delivery technologies.

Keywords

probiotics, yogurt, intestinal health, encapsulation technology, special populations, immunomodulation, microcapsules, postbiotics

1. Introduction

As a popular contemporary health beverage, yogurt contains probiotics that exert a wide range of physiological functions. A review of existing literature reveals that the core research question is whether probiotics in yogurt can effectively function in the human intestinal tract and improve the intestinal ecological environment. As a delivery vehicle for probiotics, yogurt faces challenges such as colonization and survival capacity in the gut, necessitating maximum protection and enhancement of probiotic viability. Various novel technologies, including encapsulation technology, prebiotic strategies, and drying technology, have been gradually applied to protect probiotics. Furthermore, the positive effects of yogurt consumption in various diseased populations remain to be explored, including how diabetic patients, lactose-intolerant individuals, and obese patients should consume yogurt. Whether yogurt, as a health beverage, can improve conditions in people with intestinal inflammation, and how to develop yogurt products tailored to the needs of special populations, represent worthy directions for in-depth investigation. Relevant literature from the past two years was retrieved using ScienceDirect, and studies related to yogurt probiotics were screened and summarized.

To ensure a comprehensive and methodologically diverse analysis, the selected studies were organized according to their research approaches. At the mechanistic level, in vitro digestion models were employed, such as those using spirulina probiotic powder and prebiotic-supplemented yogurt, to assess probiotic survival under simulated gastrointestinal conditions [1, 4]. Moving to the physiological level, animal experiments were conducted on newborn alpacas and diet-induced obese mice to evaluate the effects of probiotics on growth, immune response, and metabolic regulation [2, 8]. At the population level, a human cross-sectional study provided epidemiological evidence linking yogurt consumption to reduced risk of diabetic kidney disease [6]. In terms of product development, research focused on plant-based yogurt analogues to meet the needs of lactose-intolerant consumers [7]. Finally, from a technological perspective, studies explored probiotic coating as well as spray- and freeze-drying techniques to enhance probiotic stability and delivery [3, 5]. Leveraging novel technologies to protect probiotic activity, maximize their efficacy, and achieve multi-level health benefits for the human body is a key objective in this field.

2. The Effect of Probiotics

2.1 Promote Intestinal Digestion and Nutrient Absorption

Probiotics facilitate intestinal digestion and nutrient absorption. Enhancing their digestive-promoting effects has become an important research direction in the development of functional foods. Jennyfer Fortuin et al. adopted a compound formula combining probiotics and isolated protein to investigate the degree of protein hydrolysis, peptide profiles and amino acid release during digestion [1]. Proteomic analysis of proteins after gastric digestion revealed that the secondary structure of certain peptide subunits exhibited stronger resistance to pepsin hydrolysis than others. The study concluded that incorporating isolated protein into probiotic powder can effectively protect probiotics from enzymatic hydrolysis and supply sufficient protein nutrition. Meanwhile, bioactive peptides and available amino acids released during digestion can further boost probiotic activity, creating a synergistic effect of “1+1>2”. In terms of probiotic survival rate, Rahmat Attaie et al. studied the application of prebiotics in yogurt [4]. Under simulated in vitro gastrointestinal conditions, they added hemp seed protein concentrate (HP) and carrot powder (CP) to yogurt for probiotic protection. This approach mainly facilitates the intestinal colonization of *Bifidobacteria*, rather than directly mitigating the damage caused by digestive fluids. By contrast, Jennyfer Fortuin et al. used protein as a physical barrier during digestion to reduce direct contact between bacterial cells and digestive enzymes [1]. Additionally, peptides generated from protein hydrolysis serve as nutrients for probiotics, helping sustain their viability and biological activity.

2.2 Immunomodulatory Function of Probiotics

Probiotics exert a certain protective effect on the intestines and also offer benefits in enhancing immunity. Walter Palomino-Guerrera et al. evaluated the effects of multi-strain probiotics on the growth and development, immune response, intestinal function and survival rate of neonatal alpacas [2]. The results showed that supplementation with Polimeve probiotics promoted the growth of neonatal alpacas and increased basophil levels, while Probiolyte probiotics helped raise immunoglobulin levels. The findings indicated that probiotics act on innate immune cells and systemic IgG, mainly contributing to early defense and anti-stress capacity. A study conducted by Kexin Hong et al. in mice elucidated the mechanism by which probiotics strengthen the intestinal mucosal immune barrier via upregulating IgA-related genes, which primarily maintains local intestinal homeostasis [8].

Overall, probiotics regulate intestinal microbiota and intestinal barrier to activate innate immune cells, thereby inducing B cells to secrete IgA and stabilize mucosal immune homeostasis. It is demonstrated that probiotics have promising potential in boosting immune responses, and there exists an interaction mechanism between probiotic strains and the digestive physiology of hosts.

3. Novel Technologies for the Protection of Probiotics in the Intestinal Tract

3.1 Encapsulation Technology Enhances the Colonization Ability of Probiotics

The prerequisite for probiotics to exert health benefits is their ability to tolerate the gastrointestinal environment and successfully colonize the intestinal mucosa. Studies have shown that *Bifidobacterium longum* (BL), a core probiotic in the human gut, plays a vital role in maintaining intestinal health by regulating gut microbiota composition and exerting anti-inflammatory effects. Shang Shi et al. investigated coating encapsulation for this strain under gastric acidic conditions [3]. The MAP coating is formed via a chemically driven self-assembly process. During oxidative cross-linking, the dopamine groups (DOPA) in MAP are oxidized by dissolved oxygen or buffer solutions under weakly alkaline conditions to form quinone structures. These quinone structures react with amino groups ($-NH_2$) or sulfhydryl groups (-SH) on other MAP molecules to generate stable covalent bonds and induce cross-linking among MAP molecules. In addition, abundant non-covalent interactions including hydrogen bonds, π-π stacking and hydrophobic interactions exist between MAP molecular chains, jointly constructing a continuous, dense and adhesive three-dimensional network structure. Unlike MAP, the alginate (Alg) coating does not undergo independent cross-linking; instead, it anchors onto the underlying MAP layer through electrostatic interactions. As a negatively charged polysaccharide, alginate contains carboxylate groups ($-COO^-$) on its molecular chains, which form stable ionic bonds with positively charged lysine residues on the MAP coating surface. This results in a uniform Alg outer shell on BL@MAP. Under identical experimental conditions except for coating treatment, coated BL strains (BL@MAP and BL@MAP@Alg) exhibited higher survival rates and better structural integrity than uncoated BL. *In vivo* imaging of mice after oral administration revealed that BL@MAP@Alg produced remarkably stronger fluorescence signals and remained in the intestinal tract for a longer duration compared with unencapsulated BL. This directly verifies its superior intestinal distribution and accumulation capacity.

3.2 Prebiotics Improve the Survival Rate of Probiotics

Probiotics have limited survivability in the complex intestinal environment. To improve their survival against gastric juice, intestinal fluid and other harsh conditions, Rahmat Attaie et al. studied the addition of prebiotics to yogurt. In an in vitro simulated gastrointestinal model, hemp seed protein concentrate (HP) and carrot powder (CP) were incorporated into yogurt to protect probiotics [4]. The results demonstrated that HP markedly enhanced the tolerance of probiotics to gastric acid and bile salts, while also serving as a nutrient source. Its protein components additionally provided physical protection. By contrast, CP functioned merely as a nutritional prebiotic with no evident physical protective effect. HP exerted a particularly prominent protective effect on *Bifidobacterium*. Not all prebiotics offer equivalent support or protection for the same probiotic strain. In the CP group of the above study, massive loss of probiotic viability was observed in the intestinal tract. This finding is consistent with the research by Wencong Guo et al. on patients with diabetic kidney disease (DKD), which indicated that mismatched combinations of probiotics and prebiotics could greatly compromise clinical efficacy [6]. Selecting prebiotics tailored to specific strains is critical for translating in vitro advantages into clinical benefits.

3.3 Protective Effects of Freeze-drying and Spray-drying on Probiotics

As supplementary ingredients in yogurt formulations, probiotics require excellent long-term storage stability and high viability. Sourav Misra et al. compared the merits of spray drying and freeze-drying [5]. Exopolysaccharides feature outstanding film-forming ability, prebiotic activity and biocompatibility, which can protect probiotics during drying and facilitate their intestinal colonization. The researchers adopted exopolysaccharides as carriers for the co-encapsulation of probiotics and γ-Aminobutyric acid (GABA). The results showed that microcapsules fabricated via both drying methods improved probiotic survival. The high temperature during spray drying caused slight damage to the cell membrane of a small number of probiotics, leading to a moderate loss of viable bacteria. In contrast, notable volatilization and loss of GABA occurred during freeze-drying. Microcapsules produced by spray drying possess a dense spherical structure that acts as a high-temperature resistant barrier. Meanwhile, their low water activity and glassy state further enhance thermal stability. Spray drying also enjoys better industrial applicability, making it more suitable for the development of functional foods subjected to high-temperature processing.

4. Effects of Yogurt Products on Special Populations

4.1 Benefits for Diabetic Patients

The global prevalence of diabetes continues to rise. According to the latest data from the International Diabetes Federation (IDF), there were 589 million adults aged 20 to 79 living with diabetes worldwide in 2024, and the figure is projected to reach 853 million by 2050. As a popular dairy beverage, yogurt is widely consumed among diabetic patients. Wencong Guo et al. conducted a cross-sectional study based on data from the National Health and Nutrition Examination Survey (NHANES) of the United States [6]. Using multistage stratified sampling and multivariate Logistic regression analysis, the researchers adjusted for major confounding factors, including demographic characteristics (age, gender, race, education level and poverty income ratio, PIR), metabolic and clinical indicators (BMI, hypertension, dyslipidemia, glycated hemoglobin, triglycerides, ALT, BUN, uric acid, eGFR and ACR), as well as lifestyle factors such as antibiotic use, which may alter gut microbiota. After full multivariate adjustment, the inverse association between the intake of probiotics, prebiotics, synbiotics and yogurt and reduced risk of diabetic kidney disease (DKD) remained statistically significant (OR=0.71, 95%CI: 0.52–0.96, P=0.03). None of the above confounders substantially altered this correlation, confirming its good stability. Restricted cubic spline analysis revealed no nonlinear relationship or obvious dose-response effect between yogurt consumption and DKD risk. The results demonstrated that intake of yogurt products containing probiotics and prebiotics was significantly negatively correlated with DKD risk in patients with type 2 diabetes. The underlying mechanisms may involve the regulation of gut microbiota and metabolism, the anti-inflammatory and antioxidant properties of probiotics, as well as the improvement of renal function and intestinal barrier integrity. It can be concluded that consumption of probiotic-fortified yogurt exerts no adverse effects and may even lower the risk of developing DKD.

4.2 Development of Products for Lactose-intolerant Populations

Patients with lactose intolerance lack sufficient lactase. To address the inability of such patients to digest lactose, Damodar Dhakal et al. developed plant-based yogurt alternatives [7]. They formulated novel plant-based beverages using lupin protein and oats as raw materials. Using aqueous oat extract as the substrate, lupin protein isolates (ALB/ANG) were incorporated, followed by mixed fermentation with *Lactobacillus plantarum* and *Bifidobacterium animalis* subsp. *lactis* BB12.Initial stage (0–4 h): Lactic acid bacteria proliferated rapidly by utilizing hydrolyzed sugars and oligosaccharides from oat starch. The pH of the system dropped from 6.2–6.5 to approximately 5.5, with a small amount of lactic acid produced. Middle stage (4–8 h): Lupin protein underwent denaturation and gradual hydrolysis, releasing small peptides and free amino acids to facilitate probiotic metabolism. The pH continued to decline to 4.8–5.0 alongside massive lactic acid accumulation, and proteins began to aggregate to form a weak gel. Late stage (8–12 h): The pH fell to 4.4–4.6, close to the isoelectric point of the proteins, and the gel network was fully formed. ALB, which is mainly composed of vicilin, formed a dense gel with high water-holding capacity, while ANG dominated by legumin produced a relatively loose gel with lower hardness. During post-ripening under refrigeration (4 °C, 12–24 h), the product achieved balanced flavor, enhanced gel structure and stable viable count of probiotics. The composition of organic acids changed remarkably throughout fermentation. Lactic acid served as the major component, accompanied by trace amounts of acetic acid, citric acid and other organic acids. These substances endowed the product with proper acidity and promoted protein gelation. The content of fermentable oligosaccharides, disaccharides, monosaccharides and polyols (FODMAPs), including fructans and galacto-oligosaccharides, was greatly reduced. The core mechanism lies in that probiotics secreted α-galactosidase and fructosidase, which decomposed indigestible oligosaccharides into monosaccharides for microbial consumption. Meanwhile, the acidic environment accelerated the hydrolysis of glycosidic bonds, effectively relieving intestinal flatulence. In addition, complex proteases generated during fermentation, together with acid-induced protein unfolding, specifically degraded large allergenic proteins in lupin. The immunodominant epitopes of allergens were destroyed and broken down into small molecular peptides, which markedly reduced the allergenicity of the plant-based yogurt and improved its food safety and nutrient digestibility. Partial degradation of allergens also helps prevent gastrointestinal discomfort in people with sensitive intestines.

4.3 Alleviating Continuous Weight Gain in Obese Patients

Obesity is a metabolic disorder. Exploring the interaction between intestinal inflammation and the immune system is of great significance for obesity research, and dietary intervention targeting gut microbiota offers a promising approach to mitigate obesity. Kexin Hong et al. investigated the anti-obesity and lipid-lowering effects of common probiotic strains in yogurt, as well as their impacts on intestinal immune homeostasis, using mice with high-fat diet-induced obesity [8]. The results revealed that *Lactobacillus bulgaricus*, *Lactobacillus rhamnosus* and *Bifidobacterium longum* could still remarkably regulate host metabolism, activate intestinal IgA-mediated mucosal immunity and remodel gut microbiota homeostasis even after losing viability. They also effectively suppressed chronic inflammation in the intestine and adipose tissue, and alleviated metabolic disorders caused by a high-fat diet. These findings challenge the conventional view that only viable probiotics exert functions, and thereby introduce the concept of postbiotics. Postbiotics refer to inactivated probiotic cellular components, intracellular extracts and bioactive metabolites, which retain physiological regulatory effects. They also possess distinct advantages including high stability, good storage tolerance, resistance to high-temperature processing and no risk of microbial colonization.

In the field of obesity management, postbiotics alleviate obesity and associated metabolic disorders through multiple mechanisms: alleviating systemic low-grade inflammation, repairing the intestinal mucosal barrier, optimizing gut microbiota composition and regulating lipid metabolism. Compared with viable probiotics, postbiotics overcome the limitations of live bacteria, such as vulnerability to gastric acid and bile salts, low colonization rate and highly variable individual responses. With superior environmental resistance, they are more suitable for high-temperature food processing and long-term dietary intervention. This provides novel ideas and practical strategies for non-invasive nutritional intervention against obesity and metabolic syndrome. For obese individuals, replacing high-sugar beverages with yogurt helps control body weight while satisfying taste preferences.

5. Research Challenges and Future Prospects

5.1 Challenges in the Research Process

Despite remarkable progress in the research on probiotic yogurt, numerous issues remain to be addressed urgently. First, the functions of probiotics are strain-specific. Distinct strains differ greatly in physiological characteristics and health benefits, and there is a lack of unified criteria for efficacy evaluation. For instance, Polimeve and Probiolyte probiotics exert different effects [2]. Second, the immune response, colonization mechanisms and survival rate of probiotics in the complex intestinal environment require further in-depth exploration. Current studies are mostly based on in vitro experiments and animal models, while evidence from human clinical trials remains insufficient [2,3,4]. There are also inherent limitations throughout the research. A prominent translational gap exists when findings from probiotic studies in animal models are applied to human clinical practice. This is mainly attributed to fundamental differences between humans and animals in gut microbiota composition, disease pathological features and metabolic environments. In addition, variations in individual responses to strains, errors in dose conversion, uncontrolled dietary factors and inconsistent intervention cycles collectively lead to a marked reduction in the prominent anti-inflammatory, hypoglycemic and renal-protective effects observed in animal trials. Consequently, it is a common phenomenon that probiotics show favorable efficacy in animals but weak effects in human clinical applications.

5.2 Future Prospects

Future research on probiotic yogurt can be carried out in several directions. First, systematically elucidate the interaction mechanisms between probiotics, gut microbiota and host cells, and clarify the efficacy of different strains. Second, in terms of technological innovation, develop low-cost and high-efficiency novel encapsulation materials and processing technologies for the protection and delivery of functional strains [3,5]. Third, adopting advanced probiotic protection technologies, develop personalized products tailored to the health needs of specific populations including infants, the elderly and patients with chronic diseases. For example, novel plant-based beverages made from lupin protein and oats can be developed to improve metabolic regulation, immune regulation and other health benefits [7,8]. Fourth, promote the application of probiotic yogurt in daily dietary healthcare, so as to accumulate sufficient evidence-based medical data supporting the efficacy of probiotics [6,8].

6. Conclusion

Probiotics serve as the core ingredients of functional foods in yogurt. Extensive advances have been made in research on their physiological properties, health benefits and application technologies. By facilitating nutrient absorption and regulating immune responses, probiotics offer comprehensive protection to human health and play a vital role in the adjuvant prevention and treatment of gastrointestinal and metabolic diseases. Innovative applications of encapsulation technology, prebiotic supplementation and spray drying have effectively addressed the industrial challenges concerning probiotic colonization and viability, providing solid technical support for the industrialization of probiotic yogurt. These developments also offer new approaches for managing diabetes, lactose intolerance and obesity. Nevertheless, issues such as strain specificity, complex action mechanisms and technical bottlenecks in industrial production still require further research. In the future, with in-depth interdisciplinary studies and technological breakthroughs, as well as the extensive integration of emerging technologies including artificial intelligence, probiotic yogurt will embrace broader application prospects. It is expected to play a greater role in the field of functional foods and deliver higher-quality products and solutions for human health.

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Funding

This research received no external funding.

Conflicts of Interest

The authors declare no conflict of interest.

Acknowledgment

This paper is an output of the science project.