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Article

Exploration of the Health Benefits of Probiotics Under High-Sugar and High-Fat Diets

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Abstract: In recent years, high-sugar and high-fat diets (HSHF) have become a major global health issue, closely associated with the onset of various chronic diseases. Probiotics, as microorganisms that regulate gut microbiota balance, have gained significant attention for their potential role in modulating the metabolic disturbances induced by HSHF diets. This paper describes the potential mechanisms through which probiotics counteract the negative effects of HSHF diets and their associated health benefits. By analyzing recent research literature, we explore the role of probiotics in regulating gut barrier function, reducing inflammatory responses, modulating the immune system, and improving lipid metabolism. Additionally, the use of probiotics has been linked to an increase in gut microbiota diversity and a reduction in inflammatory markers under pathological conditions. Although existing studies provide support for the health benefits of probiotics, further clinical trials and in-depth research are required to better understand their specific effects and mechanisms in clinical applications. This paper highlights the need for future research to focus on the specificity of probiotic effects under particular health conditions, dose-response relationships, and the mechanisms of host-probiotic interactions. Through these studies, we aim to gain a deeper understanding of the potential of probiotics in the prevention and treatment of HSHF diet-related diseases, thereby providing more effective strategies for public health.

Keywords: high-sugar and high-fat diet; probiotics; gut health; metabolic pathology; chronic disease prevention

1. Introduction

In modern society, the prevalence of high-sugar and high-fat diets (HSHF) has been steadily increasing, and this dietary pattern is closely associated with the rise of various chronic health issues, including obesity, type 2 diabetes, cardiovascular diseases, and non-alcoholic fatty liver disease. The negative health impacts of HSHF diets are primarily mediated through mechanisms such as the induction of systemic inflammation, metabolic disorders, and gut microbiota imbalance. In recent years, researchers have gradually turned their attention to the application of probiotics as a potential strategy to mitigate these health consequences.

Probiotics are live microorganisms that confer health benefits to the host, and they combat the adverse effects of HSHF diets through multiple mechanisms. First, probiotics help stabilize and restore the balance of gut microbiota, which is crucial for maintaining gut barrier function and inhibiting the excessive growth of pathogenic microbes. Second, probiotics can reduce inflammation induced by HSHF diets by modulating immune responses. Additionally, some probiotics have shown promise in improving host metabolic functions, such as lowering blood glucose and insulin resistance, as well as improving lipid metabolism.

Although these health benefits of probiotics have been preliminarily validated, their mechanisms of action remain incompletely understood, and significant variations in efficacy exist among different probiotic strains. Therefore, this paper aims to systematically review the current literature on the regulatory effects of probiotics on the negative impacts of HSHF diets, explore their potential health benefits, and propose directions for future research, in order to provide scientific evidence for clinical applications and the development of public health strategies.

2. The Impact of High-Sugar and High-Fat Diets on Health

High-sugar and high-fat (HSHF) diets have shown a significant correlation with the rising prevalence of various chronic diseases worldwide. This section explores the extensive effects of HSHF diets on human health, including their mechanisms of action on metabolic functions, the immune system, gut health, and overall disease risk.

2.1. Metabolic Dysregulation

One of the primary adverse effects of HSHF diets on health is the induction of metabolic dysregulation. Prolonged excessive intake of high-sugar and high-fat foods leads to significant weight gain and abnormal expansion of adipose tissue. These changes disrupt energy balance and substantially increase the risk of metabolic diseases, such as type 2 diabetes and cardiovascular disease, through complex physiological mechanisms. Type 2 diabetes, a common outcome of metabolic dysregulation, is characterized by insulin resistance, elevated blood glucose levels, and lipid metabolism disorders. These metabolic traits collectively form the pathological foundation of diabetes and its complications.

Studies indicate that glucotoxicity and lipotoxicity are two key pathophysiological mechanisms driving metabolic abnormalities. Chronic high-sugar intake can cause excessive insulin secretion, β-cell dysfunction, and elevated systemic inflammation. High-fat intake, on the other hand, disrupts metabolic function through increased fatty acid accumulation and lipid metabolism disorders. The dietary proportions of fats and carbohydrates are strongly associated with the onset of metabolic dysregulation, with high-fat or high-carbohydrate diets identified as major risk factors.

While the negative effects of HSHF diets on metabolic health are well-documented, the precise molecular mechanisms remain incompletely understood. Notably, there is ongoing debate regarding the differences between high-fat and high-sugar diets in inducing metabolic disorders. This debate arises partly from variations in dietary definitions and metabolic evaluation methods across studies and highlights the complex effects of these diets on metabolic regulation.

Current research reveals that high-sugar and high-fat diets differ in their mechanisms of inducing insulin resistance but converge on mitochondrial dysfunction, including the overproduction of reactive oxygen species (ROS) and impaired mitochondrial function. These disruptions damage insulin signaling pathways, leading to reduced insulin sensitivity and metabolic dysregulation. The resulting mitochondrial damage exacerbates the imbalance in glucose and lipid metabolism, perpetuating a vicious cycle of metabolic abnormalities.

2.2. Inflammation and Immune Regulation

In addition to their impact on metabolic health, HSHF diets disrupt immune balance by triggering systemic and localized inflammatory responses. Studies have shown that HSHF diets significantly elevate levels of pro-inflammatory cytokines, including tumor necrosis factor-α (TNF-α) and interleukins (IL-1β, IL-12). These cytokines activate inflammatory signaling pathways, amplifying the intensity and scope of inflammation. Furthermore, HSHF diets upregulate the expression of inducible nitric oxide synthase (iNOS), resulting in excessive nitric oxide (NO) production, which exacerbates tissue damage and inflammation.

Simultaneously, HSHF diets suppress the activity of anti-inflammatory macrophages (M2), significantly reducing the secretion of anti-inflammatory cytokines such as IL-4, IL-10, IL-13, and TGF-β, and downregulating the expression of key molecules such as arginase-1 (Arg-1) and CD206. This imbalance between pro-inflammatory and anti-inflammatory mechanisms profoundly affects inflammation regulation, promoting metabolic dysregulation and immune dysfunction.

The impact of HSHF diets on gut health is particularly prominent, as the gut serves as a primary site for inflammation induction. Studies have linked HSHF diets to an increased risk of inflammatory bowel disease (IBD). HSHF diets enhance inflammation and disrupt the gut microbiota, increasing the proportion of pathogenic bacteria while reducing beneficial microbes such as Lactobacillus and Bifidobacterium. This microbial imbalance weakens gut barrier function and impairs immune regulation.

The effects of dysbiosis extend beyond localized gut inflammation to systemic effects through mechanisms such as the gut-liver axis and the gut-brain axis. Via the gut-liver axis, imbalanced gut microbiota and their metabolites exacerbate hepatic inflammation, affecting lipid metabolism and insulin sensitivity. Through the gut-brain axis, gut inflammation and microbial dysbiosis influence central nervous system function via neural signals and inflammatory mediators, altering systemic metabolic and immune responses.

These mechanisms demonstrate the multifaceted impacts of HSHF diets on gut health and their broader implications for overall health, highlighting the need for further research to comprehensively understand these effects.

2.3. Gut Health

The impact of high-sugar and high-fat (HSHF) diets on gut microbiota is a critical aspect of their health effects. The gut microbiota, a complex ecosystem composed of diverse microorganisms, plays a key role in maintaining intestinal stability by breaking down nutrients and providing energy to the host [1–7].

However, a prolonged unbalanced HSHF diet can significantly alter the composition of gut microbiota, leading to reduced microbial diversity and an increased proportion of pathogenic bacteria. High-fat diets, in particular, have been shown to markedly disrupt the ecological characteristics of gut microbiota, transforming it from a relatively uniform state to a more dispersed structure. While the total quantity of gut microorganisms may not change significantly, their species diversity often decreases noticeably. Studies have demonstrated that the gut microbiota of Bama miniature pigs, which share structural similarities with humans, predominantly consists of Firmicutes, Bacteroidetes, and Proteobacteria. After an eight-month HSHF dietary intervention, the relative abundance of Firmicutes in the feces of these pigs significantly increased, while the abundance of Bacteroidetes and Proteobacteria decreased [8].

This dysbiosis not only weakens gut barrier function but also increases intestinal permeability, potentially triggering localized and systemic inflammation. Additionally, the gut microbiota imbalance caused by HSHF diets can indirectly affect central nervous system functions through the “microbiota-gut-brain axis.” Short-chain fatty acids (SCFAs), key metabolites of gut microbiota, are particularly noteworthy for their role in regulating cognitive functions. SCFAs contribute to improved immune regulation and blood-brain barrier integrity. Studies have shown that SCFAs, especially butyrate, play a crucial role in modulating inflammation and immune function, as well as improving insulin resistance, thus offering dual protection for the host’s neurological and metabolic health [9].

HSHF diets affect human health through a range of complex mechanisms, from inducing metabolic dysregulation to increasing the risk of chronic diseases. Understanding these mechanisms is essential not only for elucidating the pathways through which HSHF diets impact health but also for developing targeted intervention strategies. Current and future research should further investigate the specific health effects of HSHF diets and assess the potential efficacy of interventions such as probiotics. These efforts could provide a scientific basis for more effective public health strategies.

3. Physiological Functions of Probiotics

Probiotics’ impact on animal gut health has become a prominent focus of current research. As vital members of the gastrointestinal microbiota, probiotics contribute to digestion, nutrient absorption, and immune function regulation through various mechanisms, playing a critical role in promoting host health and productivity.

3.1. Promoting Digestion and Nutrient Absorption

Probiotics enhance the functionality of the digestive system [10]. The enzymes produced by probiotics facilitate the breakdown of complex carbohydrates, proteins, and fats in food, making these nutrients more digestible and absorbable. Additionally, probiotics improve intestinal barrier function and epithelial cell health, increasing the efficiency of nutrient absorption. These effects significantly promote animal growth and development, enhance feed utilization, and provide biological support for high-efficiency livestock production.

3.2. Maintaining Gut Microecological Balance

Probiotics help maintain gut microecological balance by inhibiting the growth of pathogenic bacteria and exerting competitive exclusion effects. This balance reduces the risk of intestinal infections and mitigates dysbiosis caused by high-sugar and high-fat diets. Recent studies have shown that common probiotic strains such as Lactobacillus acidophilus, Lactobacillus rhamnosus, and Bifidobacterium can regulate gut microbiota composition and alleviate symptoms associated with type 2 diabetes [11]. These findings provide a theoretical basis for using probiotics as a potential intervention to treat obesity-related metabolic disorders.

3.3. Enhancing Immune Function

Probiotics play a crucial role in immune modulation by regulating the host immune system. On one hand, probiotics stimulate the production of intestinal immunoglobulins, enhancing the host's ability to combat pathogens. For example, Lactobacillus plantarum (YRL45) has been found to promote cytokine release, activate phagocytic functions of digestive tract macrophages, and significantly increase the levels of secretory immunoglobulin A (sIgA), immunoglobulin A (IgA), and immunoglobulin G (IgG) in the intestinal tract of mice [12]. Additionally, probiotics promote mucosal immune responses by delivering antigens to intestinal lymphoid follicles, thereby increasing sIgA secretion. This immune-enhancing effect is critical for maintaining intestinal homeostasis and protecting against external adverse factors [13].

On the other hand, probiotics directly regulate host immune system activity by enhancing intestinal epithelial barrier function, altering mucus secretion, and competitively excluding pathogens. Lactobacilli and their metabolites have demonstrated significant effects in strengthening innate and adaptive immunity, alleviating allergic reactions, preventing the progression of gastric mucosal lesions, and combating infections caused by intestinal pathogens [14,15].

3.4. Positive Effects on Glucose and Lipid Metabolism

Probiotics also play a vital role in regulating glucose and lipid metabolism. Studies have shown that patients with lipid metabolism disorders often exhibit significant gut microbiota dysbiosis, characterized by increased pathogenic bacteria and decreased beneficial bacteria [16]. By improving the gut environment, probiotics effectively reduce the expression of inflammatory factors, restore gut microbiota balance, and indirectly contribute to glucose and lipid metabolism regulation. These functions make probiotics a promising therapeutic strategy for alleviating glucose and lipid metabolic disorders and improving related metabolic diseases.

Through these mechanisms, probiotics demonstrate significant potential for enhancing gut health and managing metabolic disorders in animals, providing both theoretical and practical value in the field of health and production performance improvement.

4. Mechanisms by Which Probiotics Counteract High-Sugar and High-Fat Diets

4.1. Mechanisms of Probiotics in Counteracting High-Fat Diets

Pharmacological treatments remain the primary approach to controlling hyperlipidemia, but long-term drug use can lead to side effects, emphasizing the need for safer alternatives. Probiotics have gained attention for their potential efficacy and high safety profile in improving hyperlipidemia. The lipid-regulating effects of different probiotic strains vary, primarily depending on their physiological properties and abilities to modulate bile salt dissociation and lipid metabolism. Screening probiotics with lipid-lowering effects and elucidating their mechanisms can provide novel solutions for clinical applications.

4.1.1. Inhibition of Cholesterol Absorption

Probiotics reduce cholesterol absorption in the gut through mechanisms such as adhesion, adsorption, and co-precipitation [1]. Cholesterol synthesis primarily occurs in the liver and gut via a multi-step process. Key steps include the conversion of acetyl-CoA into HMG-CoA, catalyzed by acetyl-CoA hydroxylase, followed by its transformation into mevalonate by HMG-CoA reductase, and eventually forming sterol compounds such as bile acids. HMG-CoA reductase serves as the rate-limiting enzyme in this pathway. Studies by Kumar et al. demonstrated that administering Lactobacillus rhamnosus to mice on a high-cholesterol diet increased HMG-CoA reductase mRNA expression in liver tissues and lowered serum cholesterol levels [17].

Additionally, Lactobacillus rhamnosus BFE5264 reduces cholesterol absorption by activating liver X receptors (LXR) and upregulating ATP-binding cassette transporters G5 (ABCG5) and G6 (ABCG6) [18]. Probiotics can also incorporate cholesterol into their cell membranes or convert it into sterol compounds, thereby decreasing its absorption [19]. These findings highlight the potential of probiotics in regulating cholesterol metabolism.

4.1.2. Promotion of Short-Chain Fatty Acid Production

Probiotics ferment dietary fiber-rich foods, such as whole grains, vegetables, and fruits, to produce SCFAs, including acetate, propionate, and butyrate. SCFAs play essential roles in regulating gut health and immune function. Acetate and propionate mitigate gut inflammation by reducing inflammatory cytokine production, while butyrate serves as a key energy source for intestinal epithelial cells, promoting cell repair, proliferation, and mucosal integrity. SCFAs also regulate lipid metabolism, glycogen metabolism, and inflammation, and improve β-cell functionality and insulin resistance [20]. Propionate and butyrate effectively lower triglyceride levels, thereby addressing metabolic disorders caused by high-fat diets and supporting the functional applications of probiotics.

4.1.3. Inhibition of Cholesterol Synthesis

Cholesterol synthesis, primarily occurring in the liver and gut, involves multiple steps. The conversion of acetyl-CoA into HMG-CoA, catalyzed by acetyl-CoA hydroxylase, followed by HMG-CoA's transformation into mevalonate, is a key process regulated by HMG-CoA reductase. Studies have shown that high-cholesterol diets suppress HMG-CoA reductase mRNA expression, while consumption of probiotic-fermented dairy products reverses this suppression, enhancing HMG-CoA reductase activity and reducing serum cholesterol levels [17]. This suggests that probiotics play a significant role in inhibiting endogenous cholesterol synthesis.

4.2. Mechanisms of Probiotics in Counteracting High-Sugar Diets

Probiotics, as natural dietary supplements, have been extensively studied for their role in preventing and managing diabetes. Different probiotic strains exhibit varying effects on diabetes through mechanisms such as enhancing gut barrier function, regulating systemic lipopolysaccharide (LPS) levels, increasing incretin secretion, alleviating endoplasmic reticulum (ER) stress, and improving peripheral insulin sensitivity. Probiotics also regulate gut microbiota composition and SCFA production, providing novel approaches to alleviating diabetes symptoms. For example, lipoteichoic acid derived from Lactobacillus shows potential in reducing inflammation, modulating immune responses, and lowering oxidative stress [21]. Studies have demonstrated that probiotics delay early bacterial translocation in prediabetic stages, potentially mitigating diabetes progression [22].

4.2.1. Regulation of Nutrient and Energy Absorption and Utilization

The gut plays a critical role in glucose absorption and utilization, maintaining systemic glucose homeostasis. Gut microbiota secrete glycosidases to break down complex carbohydrates into monosaccharides and SCFAs, supporting host energy metabolism. Microbial regulation of energy metabolism involves modulating fasting-induced adipose factor (Fiaf), an inhibitor of lipoprotein lipase (LPL) that facilitates triglyceride storage. Backhed et al. found that normal gut microbiota suppress Fiaf expression, enhance peroxisome proliferator-activated receptor γ (PGC-1α) activity, and increase LPL activity, promoting fat storage [23]. Furthermore, gut microbiota regulate hepatic lipid deposition by enhancing the expression of carbohydrate response element-binding protein (ChREBP) and sterol regulatory element-binding protein 1 (SREBP-1), transcription factors that promote fatty acid synthesis [24].

4.2.2. Improvement of Gut Barrier Function

Type 2 diabetes is characterized by low-grade systemic inflammation and increased gut permeability, which are closely associated with gut dysbiosis. Probiotics enhance gut barrier function by upregulating protein kinase C isoforms, strengthening epithelial tight junctions, and maintaining intestinal integrity [25,26]. This reduces gut toxin permeability and systemic inflammation, providing new insights into diabetes intervention.

4.2.3. Modulation of Host Immune Response

The gut contains a high density of immune cells, making probiotics critical in immune regulation. Probiotics enhance SCFA production, which indirectly influences immune-mediated glucose regulation by activating G-protein coupled receptors and modulating intracellular signaling pathways [27,28]. Probiotic strains also induce anti-inflammatory gene expression and suppress pro-inflammatory gene expression, effectively modulating host immune responses [29].

4.2.4. Reduction of Inflammatory Levels

Type 2 diabetes is now recognized as a chronic low-grade inflammatory disease, where elevated blood glucose levels significantly increase inflammatory markers and trigger systemic inflammation. Studies have shown that feeding diabetic mice with Bifidobacterium lactis 420 for six weeks reduces metabolic endotoxemia, inflammation, and LPS translocation, improving overall metabolic status [30]. SCFAs participate in G-protein coupled receptor signaling, regulating dendritic cell function and enhancing the secretion of antimicrobial substances such as IL-8, thus reducing inflammation. Probiotic strains such as LG2055 modulate insulin secretion and inflammatory cytokine expression, improving glucose levels and systemic inflammation in diabetic patients. Furthermore, multi-strain probiotic formulations effectively lower blood glucose and inflammatory cytokine levels, mitigating the chronic inflammatory state of diabetes.

Through these diverse mechanisms, probiotics exhibit promising potential as therapeutic agents for mitigating the negative effects of high-sugar and high-fat diets on metabolic health.

5. Minerals, Depression & Anxiety Disorders

Although current studies provide substantial theoretical support for the potential role of probiotics in addressing health issues associated with high-sugar and high-fat (HSHF) diets, many critical scientific questions remain unresolved. Future research should focus on deepening our understanding of the mechanisms of probiotic action and advancing their practical applications.

5.1. Specific Effects of Probiotics under Certain Health Conditions

Probiotics exhibit diverse effects under different disease conditions, but their efficacy and mechanisms in specific health states remain unclear. For example, the effects of probiotics on obesity, type 2 diabetes, or non-alcoholic fatty liver disease (NAFLD) caused by HSHF diets may be influenced by factors such as host genetics, age, sex, and lifestyle. Future studies should focus on the adaptability of specific probiotic strains to various host characteristics and explore their targeted effects. Additionally, rigorously designed clinical trials are needed to validate the effectiveness of probiotics in these diseases, supporting the development of precision nutrition interventions.

5.2. Mechanisms of Probiotics in Modulating Gut Microbiota

The current understanding of how probiotics regulate gut microbiota to improve HSHF diet-related health issues remains limited. Future research should investigate the long-term effects of probiotics on gut microbiota diversity, functional gene expression, and metabolite production. For instance, how do probiotics enhance gut barrier function, inhibit the proliferation of pathogenic bacteria, or strengthen the competitiveness of beneficial microbes? Additionally, studies should explore the synergistic interactions between probiotics and other gut microbes and how these ecological dynamics influence overall host health.

5.3. Molecular Mechanisms of Host-Probiotic Interactions

Probiotic-host interactions are central to their health effects, yet the underlying molecular mechanisms remain incompletely understood. Future research integrating omics technologies—such as genomics, transcriptomics, metabolomics, and proteomics—can elucidate the detailed processes by which probiotics regulate gut epithelial function, immune signaling, and endocrine metabolism. In particular, further exploration of mechanisms related to inflammation regulation, insulin sensitivity improvement, and lipid metabolism enhancement will help develop more precise probiotic intervention strategies.

5.4. Dose-Response Effects and Development of Probiotic Combinations

The dose and strain composition of probiotics largely determine their health effects. Systematic studies on dose-response relationships remain scarce, and future research should employ large-scale randomized controlled trials (RCTs) to determine optimal dosages for different health conditions. Additionally, multi-strain probiotic combinations may exhibit synergistic effects. Such combinations should be designed and optimized based on complementary functions among strains, enhancing their effectiveness in practical applications.

5.5. Research on Probiotic Metabolites

Probiotic metabolites, including short-chain fatty acids (SCFAs), neurotransmitter precursors, and anti-inflammatory molecules, are key mediators of their health effects. Future research should focus on the types of these metabolites, their production mechanisms, and their specific effects on the host. For example, how do SCFAs alleviate metabolic disorders associated with HSHF diets by regulating gut immunity, enhancing epithelial function, and improving insulin sensitivity? Additionally, identifying specific conditions that enhance the metabolic activity of probiotics to boost metabolite production is an important area of future study.

5.6. Potential Extra-Gut Effects of Probiotics

While most probiotic research has focused on their effects on gut health, their potential impact on extra-intestinal organs such as the liver, brain, and cardiovascular system warrants further investigation. Future studies should explore how probiotics regulate systemic health through multi-system pathways such as the gut-liver axis, gut-brain axis, and gut-heart axis. For instance, can probiotics influence neural function via gut microbiota regulation, alleviating cognitive decline and emotional disorders caused by HSHF diets? This is a promising area for future research.

5.7. Long-Term Safety and Stability of Probiotics

Although probiotics have shown good short-term safety profiles, their potential side effects and stability in long-term use have not been fully evaluated. Future studies should focus on the long-term safety of probiotics in immunocompromised populations, the elderly, and other vulnerable groups. Additionally, research is needed to develop technologies that enhance the viability and stability of probiotics during storage, processing, and consumption, ensuring sustained efficacy in practical applications.

5.8. Integration of Personalized Nutrition and Probiotics

With the rapid development of precision medicine and personalized nutrition, probiotic research should align with these trends. Future studies could leverage big data and artificial intelligence to analyze individual gut microbiota profiles, genomic characteristics, and metabolic states, enabling the development of personalized probiotic intervention strategies. This precision approach not only improves intervention outcomes but also promotes the application of probiotics in public health.

5.9. Combined Effects of Probiotics and Dietary Interventions

The interaction between probiotics and dietary components (e.g., prebiotics) is an important direction for future research. For example, dietary fibers as prebiotics can serve as substrates for probiotics, enhancing their activity. Future studies should investigate the combined effects of probiotics with polyphenols, dietary fibers, and unsaturated fatty acids, assessing their synergistic roles in addressing HSHF diet-related health issues.

Through these research efforts, a deeper understanding of probiotics' mechanisms and applications can be achieved, providing scientific support for more effective strategies to improve public health.

6. Conclusion

High-sugar and high-fat (HSHF) diets are significant risk factors for metabolic diseases such as obesity, type 2 diabetes, and cardiovascular diseases. These diets adversely affect health by disrupting gut microbiota balance, increasing inflammatory responses, inducing metabolic dysregulation, and compromising gut barrier function. Probiotics, as a safe and effective biological intervention, have demonstrated substantial potential in addressing health issues associated with HSHF diets. This paper systematically reviews the mechanisms and effects of probiotics in regulating metabolism, improving gut function, and enhancing the immune system.

Probiotics mitigate the negative impacts of HSHF diets through multiple pathways, including reducing cholesterol absorption, promoting short-chain fatty acid (SCFA) production, inhibiting cholesterol synthesis, and modulating glucose and lipid metabolism. These actions effectively lower lipid levels, improve insulin sensitivity, and enhance hepatic fat metabolism. Furthermore, probiotics restore gut microbiota diversity and functionality, maintain gut microbial balance, strengthen gut barrier integrity, and reduce intestinal permeability, thereby alleviating systemic low-grade inflammation. SCFAs, as probiotic metabolites, also activate immune pathways and regulate the release of inflammatory factors, further mitigating chronic inflammation caused by HSHF diets.

In terms of glucose metabolism, probiotics play a proactive role in preventing and managing diabetes. Studies have shown that probiotics improve nutrient absorption and energy utilization, regulate host immune responses, and reduce oxidative stress, delaying the onset and progression of type 2 diabetes. Specific probiotic strains have shown remarkable efficacy in modulating insulin secretion and lowering blood glucose levels, providing novel strategies for the intervention of diabetes and its related complications.

Despite the promising potential of probiotics in alleviating health issues related to HSHF diets, challenges remain regarding strain specificity, dose optimization, and long-term safety. Future research should focus on the development of personalized probiotics, precision modulation of gut microbiota, and the synergistic effects of probiotics with other dietary interventions. These efforts aim to offer more effective strategies for the prevention and treatment of diseases associated with HSHF diets.

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