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Research Progress on the Application of Probiotics in Fermented Foods

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Abstract: With the increasing demand for nutritional quality in food, making food more nutritious and healthy has become a popular research topic. This paper introduces the basic concepts of probiotics and fermented foods and their benefits to human health. It focuses on the application of probiotics in fermented foods such as dairy products and fruit and vegetable juices. Research shows that probiotics significantly improve food flavor, extend shelf life, and enhance nutritional value. Additionally, the challenges of probiotic applications, such as strain stability, activity retention, and industrialization bottlenecks, are analyzed. Future research directions, including the development of novel probiotics, combined strain applications, and optimized fermentation processes, are proposed to provide theoretical support for the development of probiotic-fermented foods.

Keywords: Probiotics, Fermentation, Fermented foods, Food nutrition

1. Introduction

The term probiotic originates from Latin and Greek, meaning “for life” [1]. With advances in biotechnology, the definition of probiotics has evolved. It is widely accepted that probiotics are live microorganisms that, when administered in adequate amounts, confer health benefits by colonizing the host’s gut and maintaining microecological balance.

Fermented foods are products of significant biochemical and physical transformations driven by microorganisms such as bacteria, yeast, or mold [2]. China has a long tradition of utilizing fermentation in food preparation, resulting in diverse and nutritionally rich products. Based on raw materials, fermented foods in China can be categorized into meat (sausages, hams, etc.), legumes (soy sauce, fermented beans), cereals (wine, vinegar), aquatic products, dairy, vegetables, fruits, and teas.

Probiotics, as beneficial microorganisms, have garnered significant attention in food science. Fermented foods, known for their unique flavors and nutritional benefits, play an integral role in human diets. The integration of probiotics into fermented foods enhances their health functionality, sensory quality, and preservation capabilities.

This paper reviews recent progress in the application of probiotics in fermented foods, exploring their impacts on food quality and human health. Future research directions are also proposed to support the industry.

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2. Basic concepts and functions of probiotics

2.1. Definition of probiotics

A mutually beneficial symbiotic and co-evolutionary relationship exists between microorganisms and the human body. Disturbance of this balance results in a threat to human health. Probiotics have been widely used in many fields of modern medicine due to their probiotic functions and demonstrated efficacy in the prevention and treatment of numerous diseases[3].

In recent years, some researches has shown that changes in the microbial population in the human gut are closely linked to health and disease. Probiotics play a important role in promoting health. They help keep the balance of gut microbiota, stimulate the immune system, and enhance immune responses. Thus helping the body defend against various diseases.

2.2. Physiological functions of probiotics

2.2.1. Maintaining gut microbial balance

Probiotics balance the microbiomes inside the gut. Dysbiosis of gut microbiota is commonly related to diseases. For example, irritable bowel syndrome, and inflammatory bowel disease. Probiotics restore and maintain the gastrointestinal microbiota through mechanisms involving competitive exclusion of pathogens, production of antimicrobial substances, and stimulation of the gut immune system.

Meanwhile probiotics may also help break down certain hard-to-digest plant components: for instance, it allows people with lactose intolerance to digest lactose more easily, leaving them free of symptoms. Butyrate, a kind of short-chain fatty acids, is a significant energy source of intestinal epithelial cells and can preserve the integrity of intestinal mucosa. SCFAs can be stimulated with probiotics [4].

2.2.2. Supporting immune regulation

Improve immune function of host (promoting the production of antibodies, stimulating morning macrophages and regulating T cells). This mechanism enhances the host's resistance to pathogens and can prevent infections to some degree [5].

Improvement of immune responses through probiotics and prevention of some immune-related diseases through improvement of Th1/Th2 balance and inhibition of excessive inflammatory reactions have been investigated. Through the synthesis of anti-inflammatory cytokines, probiotics could relieve chronic inflammation and the diseases that go with chronic inflammation.

2.2.3. Preventing pathogen infections

Probiotics have the ability to compete with pathogens for adhesion sites and nutrients, thus preventing the colonization and growth of pathogens in the gut. Certain probiotics can also synthesize antimicrobial compounds like lactic acid, hydrogen peroxide, and bacteriocins.

In our study, probiotics not only help with the formation of tight junctions between intestinal epithelial cells, which reduces the chance of pathogens penetrating through the gut epithelium and decreases the risk of infection, but also improve local defense mechanisms by regulating the immune response of the intestinal mucosa.

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2.2.4. Promoting metabolic health

Probiotics also play a very effective role in controlling body weight against obesity. Studies have also shown that certain strains of probiotics can aid in the proper control of body weight via regulation of energy metabolism and fat storage. Certain specific probiotic strains can also help reduce obesity-induced inflammation by regulating the gut microbiota composition[6].

Probiotics can help improve various metabolic markers, including blood sugar levels, insulin sensitivity, and lipid levels. It can help reduce the risk of type 2 diabetes and cardiovascular diseases by affecting the gut microbiome and metabolic pathways [7].

Probiotics, as beneficial microorganisms, have multiple physiological effects on the host's health. It is of great importance to promote health by maintaining the balance of intestinal microflora, regulating the immune system, preventing infection by pathogenic bacteria, and improving metabolic health.

3. Definitions and functions of fermented foods

3.1. Concept of fermented foods

Fermented foods are defined as foods which made through the metabolic activity of microorganisms through a fermentation process [8]. These microorganisms include bacteria, yeasts, and molds, which convert macromolecules such as sugars, proteins, and lipids in raw materials into small molecules such as organic acids, alcohols, and gases and other products through biochemical reactions under suitable conditions, thereby changing the nutrient composition, flavor, and texture of the food. Fermentation not only extends the shelf life of food, but also increases its nutritional value and functionality.

3.2. Key functions of fermented foods

3.2.1. Improvement of nutrient bioavailability

The fermentation process breaks down anti-nutritional factors such as phytic acid in foods, thereby improving the absorption of minerals (e.g., iron, zinc, calcium, etc.). Studies have shown that fermented soy products such as natto and miso can significantly increase their calcium and iron bioavailability [9].

3.2.2. Provide probiotics to improve intestinal flora

Fermented foods are an important source of probiotics, which have a significant role in promoting intestinal health, regulating the balance of intestinal flora, enhancing immune function, and reducing the incidence of intestinal diseases. Common fermented foods containing probiotics include yogurt, kimchi and kefir.

3.2.3. Enhancement of antioxidant capacity

Phenolic compounds and other antioxidant components in fermented foods can significantly improve the body's antioxidant capacity and reduce cellular damage caused by oxidative stress, thereby preventing chronic diseases.

Fermented food has significant advantages in terms of nutritional function, which not only provides the human body with a wealth of nutrients, but also has a variety of health-promoting effects, which is of great significance to the contemporary people's dietary health.

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4. Applications of probiotics in fermented foods

4.1. Urrent applications of probiotics in dairy fermentation

Lactic acid bacteria or probiotics are used to ferment dairy ingredients to prepare probiotic fermented dairy products. These fermented dairy products are known to have higher nutritional value, and are therefore popular for their health benefits, including regulation of gut microbiota and immune stimulation. However, deep search with in-depth research, scientists have explored further about the functions of probiotic fermented dairy products and their usefulness.

4.1.1. Screening and application of probiotic strains

Probiotic strains have been found to possess distinct functional properties during fermentation in recent studies. Some specific lactic acid bacteria strains like Lactobacillus plantarum and Lactobacillus acidophilus have good fermentation properties and health effect by Shokryazdan et al [10]. Utilizing high-throughput screening techniques, Nguyen et al[11] identified new probiotic strains with significant antimicrobial activity and excellent acid resistance.

The use of probiotic strains in fermented dairy products is also becoming more widespread. For example, Jiang et al [12] added Lactobacillus rhamnosus GG to fermented dairy products. The results showed that the product not only had a good taste but also significantly improved the shelf life and antioxidant properties of the dairy products. Significant progress has been made in the composite fermentation technology of multiple probiotics, such as Park et al. [13] studying the enhancement of dairy product quality and functionality by multi-strain mixed fermentation.

4.1.2. Fermentation process optimization

Temperature and the duration of fermentation significantly affect probiotic-fermented dairy product quality. Recent studies show that optimizing fermentation conditions can significantly enhance probiotic activity and the sensory quality of dairy products. Zhao et al[14] significantly improved the survival rate of probiotics and the nutritional content in fermented dairy products by optimizing fermentation temperature and time.

Some physical assistive technologies have also been applied to potentiate the quality and sensory profile of probiotic fermented dairy products. These advanced techniques include ultrasonic assistance, microwave assistance, high-pressure homogenization, etc. According to Wang et al [15], the use of ultrasonic-assisted technology can significantly accelerate the growth rate of lactic acid bacteria and increase fermentation efficiency. Li et al [16] used high-pressure homogenization technology to improve the texture and viability of probiotics in fermented milk.

4.1.3. Health effects

Probiotic fermented dairy products have been widely established for promoting gut health. Long-term intake of fermented milk containing Lactobacillus casei can significantly improve the structure of intestinal microflora and strengthen the intestinal barrier function, as demonstrated by Sun et al [17]. Besides, Zhang et al[18] established that probiotic fermented dairy products significantly ameliorated symptoms of irritable bowel syndrome.

Probiotic fermented dairy products also exhibit good immune modulating effects. Chen et al [19] showed that probiotic fermented dairy products can enhance the host's immune response by regulating the intestinal microbiome and reducing inflammatory responses. Liu et al [20] founded that fermented dairy products containing Bifidobacterium have a significant effect on improving the immunity of children.

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4.2. Applications in fruit and vegetable juices

4.2.1. Screening and application of probiotic strains

Recent studies have primarily focused on traditional probiotic strains such as lactobacillus lactis, plantarum, and bifidobacterium longum. Nazzaro et al [21] studied the application of Lactococcus lactis in fermenting orange juice, finding that it not only significantly improved the product's antioxidant capacity but also improved the taste. Furthermore, Zhang Minghui et al[22] studied the performance of Lactobacillus plantarum in fermenting carrot juice, and the results showed that the strain could effectively increase the vitamin C content of carrot juice..

In addition to traditional probiotic strains, new probiotic strains are also gaining attention from researchers. Peng et al [23] reported the application of Lactobacillus casei in fermenting apple juice, finding that it not only increased the content of prebiotics in the juice but also had potential anti-inflammatory effects. Similarly, Chen et al [24] studied the effect of Lactococcus paracasei on the fermentation of mixed fruit and vegetable juice, and the results showed that it could significantly increase the polyphenol content of the fruit and vegetable juice.

4.2.2. Improvement of fermentation process

Optimizing fermentation conditions is crucial for improving the quality of probiotic fermented fruit and vegetable juices. Yu et al [25] optimized the process parameters of lactococcus lactis fermented orange juice by response surface methodology. The results showed that the optimal fermentation conditions were 37°C, pH 4.5, and 24 hours of fermentation time. Under these conditions, the antioxidant capacity and viability of probiotics reached the optimal level.

Adding different nutrients during the fermentation process can also significantly affect the quality of the final product. Liu et al [26] founded that adding honey during the fermentation process can significantly enhance the antioxidant capacity and taste of fermented apple juice. What’s more, Wu Jun et al [27] looked intod the effects of prebiotics (such as low-fructose oligosaccharides) on fermented carrot juice, and the results showed that they could significantly improve the survival rate and fermentation efficiency of probiotics.

5. Challenges and future prospects

The application of probiotics in fermented foods still faces many challenges. First, Probiotic strains are susceptible to environmental factors during food processing and storage, which may lead to a decrease in their activity and stability, and may affect the ability of probiotics to exert their functional activity in food. Secondly, Different food ingredients have different effects on the survival and functioning of probiotics, and the key issue is to optimize the fermentation process to ensure that probiotics maximize their nutritional value.

In response to these challenges, future research directions include: first, Further research and screening of probiotic strains with higher tolerance, and screening of good strains that can maintain stability and activity in complex environments through genetic engineering techniques; second, Explore the efficacy of multiple probiotics working together to improve the functionality and stability of the product through multi-strain fermentation.; and third, research on fermentation conditions and process control techniques suitable for different food raw materials to maximize the effect of probiotics. In addition, the research on the functionality of probiotics in fermented foods should be strengthened to reveal their specific mechanism of action on human health and provide scientific basis for the development of probiotic fermented foods.

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