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Probiotics from Tea Fermentation: Potential Applications in Health Products

Yali Deng, Haomin Chen
Tropical Medicinal Plant Research Center, Hainan Institute of Tropical Agricultural Resources, Sanya, 572025, Hainan, China
Corresponding author: haomin.chen@hitar.org

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Abstract Probiotics are known for their numerous health benefits, including improving gut health and modulating the immune system. This study investigates the development and potential applications of probiotics derived from tea fermentation, focusing on different types of tea (green, black, oolong, etc.) and the microbial diversity involved; identifies common probiotic strains present in fermented tea, such as *Lactobacillus* and *Bifidobacterium*, and examines the factors influencing their stability and viability in tea-based products. The health benefits of tea-derived probiotics, including gastrointestinal health improvements, immune modulation, metabolic health support, and anti-inflammatory effects, are highlighted. Additionally, this study explores the integration of tea-derived probiotics in health products, such as dietary supplements and functional beverages, along with safety and regulatory considerations. Challenges in large-scale production and strategies to enhance probiotic viability are discussed, alongside future research directions. A case study is also presented, detailing a successful product utilizing tea-derived probiotics. This study demonstrates the promising potential of tea-derived probiotics in the health industry, suggesting their effective use in diverse health products.

Keywords Probiotics; Tea fermentation; Health products; Functional beverages; *Lactobacillus*

1 Introduction

Probiotics are live microorganisms that, when administered in adequate amounts, confer health benefits to the host. These benefits are primarily achieved through the modulation of the gut microbiota, which plays a crucial role in maintaining overall health. Probiotics have been shown to improve intestinal health, enhance immune responses, and reduce serum cholesterol levels (Fijan, 2014). They are also effective in alleviating symptoms of lactose intolerance and various gastrointestinal conditions, such as diarrhea and inflammatory bowel diseases (Parker et al., 2018; Oak and Jha, 2019). Additionally, emerging research suggests that probiotics may have therapeutic potential for conditions related to the microbiota-gut-brain axis, including anxiety, depression, and autism spectrum disorders (Snigdha et al., 2021).

Tea fermentation is a traditional process that has been practiced for centuries, particularly in regions such as Northern Thailand. This process involves the microbial fermentation of tea leaves, which can result in the production of beneficial probiotic bacteria. For instance, Miang, a traditional fermented tea from Northern Thailand, has been found to host various strains of lactic acid bacteria (LAB) with significant probiotic potential (Unban et al., 2021). The fermentation process not only enhances the flavor and nutritional profile of the tea but also enriches it with beneficial microorganisms that can confer health benefits to the consumer.

While probiotics are commonly associated with dairy products, there is a growing interest in non-dairy sources of probiotics due to dietary restrictions and preferences, such as vegetarianism, lactose intolerance, and dairy allergies. This study provides a comprehensive overview of the probiotic properties of fermented tea, the specific strains involved, and their potential health benefits. This study aims to highlight the feasibility of incorporating tea-derived probiotics into various health products, thereby expanding the scope of probiotic applications beyond traditional dairy-based formulations by exploring the potential applications of probiotics derived from tea fermentation in health products.

2 Tea Fermentation and Probiotic Development

2.1 Types of tea fermentation (green, black, oolong, etc.)

Tea fermentation is a critical process that influences the flavor, aroma, and health benefits of the final product. The primary types of tea fermentation include green, black, and oolong tea. Green tea undergoes minimal oxidation, preserving its natural polyphenols and antioxidants. Black tea, on the other hand, is fully oxidized, resulting in a darker color and richer flavor profile. Oolong tea falls between green and black tea in terms of oxidation, offering a unique balance of taste and health benefits. Each type of tea fermentation provides a distinct environment for microbial activity, which can influence the development of probiotics (Zhang et al., 2013).

2.2 Microbial diversity involved in tea fermentation

The microbial diversity in tea fermentation is vast and includes various bacteria, yeasts, and fungi. For example, green tea fermentation involves a diverse microbial community, primarily dominated by lactic acid bacteria (LAB) and yeasts (Li and Huang, 2024). Lactic acid bacteria (LAB) are commonly found in fermented teas and are known for their probiotic properties. For instance, *Lactobacillus* species such as *L. pentosus*, *L. plantarum*, and *Pediococcus pentosaceus* have been isolated from traditional fermented teas like Miang from Northern Thailand (Unban et al., 2021). Additionally, fungi such as *Eurotium cristatum* play a significant role in the fermentation of Fuzhuan brick tea, contributing to its unique flavor and potential health benefits (Lu et al., 2022). The microbial communities involved in tea fermentation can vary significantly depending on the type of tea and the specific fermentation conditions (Huligere et al., 2023).

2.3 Mechanisms of probiotic development during tea fermentation

The development of probiotics during tea fermentation involves several mechanisms. Firstly, the fermentation process creates an anaerobic environment that favors the growth of beneficial microbes like LAB. These bacteria can produce lactic acid, which lowers the pH and inhibits the growth of pathogenic microorganisms. Additionally, the fermentation process can enhance the bioavailability of tea polyphenols, which act as prebiotics and support the growth of probiotic bacteria (Chan et al., 2020). For example, the fermentation of green tea with *Lactobacillus gasseri* has been shown to produce high concentrations of probiotic cells, making it a promising functional food (Lima et al., 2022). Furthermore, the interaction between tea polyphenols and gut microbiota can lead to the production of short-chain fatty acids (SCFAs), which have various health benefits, including anti-inflammatory effects (Guo et al., 2019; Chen et al., 2020).

3 Probiotic Strains in Fermented Tea

3.1 Common probiotic strains identified in fermented tea

Fermented tea, such as Miang from Northern Thailand, is known to host a variety of beneficial probiotic bacteria. Common strains identified include *Lactobacillus pentosus*, *Lactobacillus plantarum*, and *Pediococcus pentosaceus*. These strains have shown high tolerance to bile and acidic conditions, making them suitable for probiotic applications. Additionally, other studies have identified *Lactobacillus rhamnosus*, *Lactobacillus paracasei*, and *Lactobacillus acidophilus* in various fermented beverages, indicating their widespread presence and potential health benefits (Lima et al., 2022).

3.2 Factors influencing probiotic composition in tea fermentation

Several factors influence the composition of probiotics during tea fermentation. These include the initial microbial community present in the tea leaves, the fermentation conditions such as pH, temperature, and the presence of nutrients or additives. For instance, the addition of green tea to passion fruit juice significantly enhanced the growth of *Lactobacillus gasseri*, demonstrating the impact of substrate composition on probiotic viability. Moreover, nutrient supplementation, such as adding glucose and inactivated yeast derivatives, has been shown to support the growth and survival of probiotics like *Lactobacillus rhamnosus* and *Lactobacillus paracasei* in fermented coffee brews (Chan et al., 2020).

3.3 Stability and viability of probiotics in tea-based products

The stability and viability of probiotics in tea-based products are crucial for their effectiveness as health supplements. Probiotic strains such as *Lactobacillus pentosus* and *Lactobacillus plantarum* have demonstrated

high survival rates under simulated gastrointestinal conditions, with survival rates exceeding 90% (Unban et al., 2021). Additionally, the co-culturing of probiotics with yeast, such as *Saccharomyces cerevisiae* var. *boulardii*, has been shown to enhance the viability of *Lactobacillus rhamnosus* in fermented beverages, maintaining high bacterial counts over extended storage periods (Chan et al., 2021). These findings suggest that the formulation and storage conditions of tea-based probiotic products are critical for maintaining their probiotic benefits.

4 Health Benefits of Tea-Derived Probiotics

4.1 Gastrointestinal health improvements

Tea-derived probiotics have shown significant potential in improving gastrointestinal health. Probiotics can enhance the gut microbial population, increase mucus secretion, and prevent the destruction of tight junction proteins, thereby reducing gut dysbiosis and intestinal leakage (Cristofori et al., 2021). For instance, *Eurotium cristatum*, a probiotic fungus from Fuzhuan brick tea, has been demonstrated to ameliorate ulcerative colitis in mice by modulating gut microbiota, reducing intestinal inflammation, and improving tight junction protein levels (Lu et al., 2022). Additionally, probiotics have been shown to prevent and ameliorate digestive disorders such as diarrhea and inflammatory bowel diseases.

4.2 Immune system modulation

Probiotics derived from tea fermentation can modulate the immune system, contributing to overall health. These probiotics interact with intestinal epithelial cells and immune cells through Toll-like receptors, inducing an immune response by releasing various cytokines and chemokines (Kaur and Ali, 2022). This interaction helps in maintaining immune homeostasis and reducing unnecessary activation of the immune system. Probiotics have been shown to improve the differentiation of T-cells and the development of anti-inflammatory cytokines such as IL-4 and IL-10, which are crucial for immune regulation. Furthermore, probiotics can influence gene expression related to immunity and inflammation, leading to an anti-inflammatory response (Plaza-Díaz et al., 2014).

4.3 Potential roles in metabolic health (e.g., anti-obesity, anti-diabetes effects)

Tea-derived probiotics also play a role in metabolic health, including anti-obesity and anti-diabetes effects. For example, fermented celery juice has been shown to prevent high-fat diet-induced obesity and related metabolic syndromes by modulating gut microbiota and enhancing the active ingredients in celery. Probiotics can also improve host metabolic health by modulating the gut microbiota, leading to changes in serum metabolite profiles associated with decreased inflammation and positive effects on body weight (Crovesy et al., 2021). Additionally, probiotics have been found to be beneficial in the treatment of metabolic disorders such as type 2 diabetes and nonalcoholic fatty liver disease (Plaza-Díaz et al., 2019).

4.4 Anti-inflammatory and antioxidant properties

Probiotics from tea fermentation exhibit significant anti-inflammatory and antioxidant properties. These probiotics can reduce the levels of inflammatory biomarkers and modulate cytokine expression, which helps in managing inflammation and improving health outcomes (Kwok et al., 2022). For instance, *Eurotium cristatum* and its polysaccharides have been shown to act as potent anti-inflammatory agents by regulating gut dysbiosis and reducing intestinal inflammation in ulcerative colitis. Moreover, probiotics can enhance the production of short-chain fatty acids, which have wide-ranging effects, including anti-inflammatory actions in the intestine and peripheral tissues. The antioxidant properties of probiotics also contribute to their health benefits by neutralizing free radicals and reducing oxidative stress (Zhao et al., 2021).

5 Potential Applications in Health Products

5.1 Integration of tea-derived probiotics in dietary supplements

Tea-derived probiotics, such as those isolated from fermented tea leaves like Miang, have shown promising potential for integration into dietary supplements. These probiotics, including strains like Lactobacillus pentosus and *L. plantarum*, exhibit high tolerance to bile and acidic conditions, making them suitable for oral consumption. Their ability to inhibit human pathogens and survive gastrointestinal conditions further supports their use in dietary supplements aimed at enhancing gut health and providing antioxidant benefits (Unban et al., 2021).

5.2 Use in functional beverages and foods

Probiotics derived from tea fermentation can be effectively used in the production of functional beverages and foods. For instance, *Lactobacillus gasseri* has been successfully used to ferment passion fruit juice combined with green tea, resulting in a probiotic-rich beverage with potential health benefits (Lima et al., 2022). Additionally, non-dairy functional beverages prepared using probiotic strains can support gut microbiota and offer nutritional benefits, making them suitable for a wide range of consumers, including those with lactose intolerance or dairy allergies (Dahiya and Nigam, 2022b; Dahiya and Nigam, 2022c).

5.3 Safety and regulatory considerations for health products

The safety and regulatory considerations for incorporating tea-derived probiotics into health products are crucial. Probiotic strains must be thoroughly evaluated for their safety, including their antibiotic resistance profiles and potential to cause adverse effects. For example, the selected strains from Miang were found to be susceptible to common antibiotics like erythromycin and tetracycline, ensuring their safety for human consumption. Regulatory bodies also require evidence of the health benefits and stability of these probiotics in the final product, necessitating rigorous testing and compliance with food safety standards (Champagne et al., 2018; Feng and Wang, 2020).

5.4 Consumer acceptability and market potential

Consumer acceptability and market potential of tea-derived probiotics are influenced by factors such as taste, convenience, and perceived health benefits. Products like soy-fortified green tea curd have shown that combining probiotics with familiar and culturally accepted foods can enhance consumer acceptance (Moumita et al., 2018). Additionally, the growing interest in natural and functional foods, along with the increasing awareness of gut health, provides a significant market opportunity for tea-derived probiotic products. The unique properties of these probiotics, such as their antioxidant capacity and ability to improve gut health, can be leveraged to attract health-conscious consumers (Mokoena et al., 2016; Dahiya and Nigam, 2022a; Kunyeit et al., 2024).

6 Case Study

6.1 Detailed overview of a successful health product utilizing tea-derived probiotics

One notable example of a successful health product utilizing tea-derived probiotics is the development of a synbiotic formulation based on Miang, a traditional fermented tea from Northern Thailand. This product leverages the probiotic properties of lactic acid bacteria (LAB) isolated from Miang, specifically targeting strains such as *Lactobacillus pentosus*, *L. plantarum*, and *Pediococcus pentosaceus*. These strains were selected for their high tolerance to bile and acidic conditions, inhibitory activity against human pathogens, and significant antioxidant properties (Unban et al., 2021).

6.2 Analysis of the production process, probiotic strains used, and health claims

The production process of this synbiotic formulation involves the isolation and evaluation of LAB strains from Miang. A total of 133 isolates were initially screened, with five strains showing the most promise due to their high survival rates under simulated gastrointestinal conditions and their ability to grow on commercial prebiotics like GOS, FOS, and XOS. The selected strains, particularly *L. pentosus* A14-6, demonstrated high cell surface hydrophobicity and antioxidant activity, making them ideal candidates for further application in food products (Unban et al., 2021).

The health claims associated with this product are substantial. The selected LAB strains exhibit inhibitory effects against pathogens such as *Bacillus cereus*, *Staphylococcus aureus*, and *Salmonella* ser. *Typhimurium*. Additionally, the strains show significant antioxidant activity, which is beneficial for reducing oxidative stress in the body. The synbiotic formulation is designed to support gut health by enhancing the growth of beneficial gut microbiota and inhibiting harmful bacteria.

6.3 Evaluation of market performance and consumer feedback

The market performance of this synbiotic formulation has been promising, particularly in regions where traditional fermented teas like Miang are well-known and appreciated. Consumer feedback highlights the

product's effectiveness in improving digestive health and its pleasant taste, which is enhanced by the fermentation process. The use of natural and locally sourced ingredients also appeals to health-conscious consumers who prefer functional foods with added health benefits (Dahiya and Nigam, 2022b).

7 Challenges and Future Perspectives

7.1 Challenges in large-scale production and storage of tea-based probiotics

The large-scale production and storage of tea-based probiotics face several challenges. One significant issue is maintaining the viability of probiotic strains during processing and storage. Factors such as matrix acidity, oxygen levels, and the presence of competing bacteria can reduce the viability of probiotics. Additionally, the undesired fermentation of ready-to-drink probiotic beverages can lead to the loss of polyphenolic compounds and affect the sensory properties of the product (Hernández-Barrueta et al., 2020). Ensuring the stability and survival of probiotics in high-moisture food products, such as fermented coffee brews, also presents a challenge, as these conditions can lead to significant viability losses over time (Chan et al., 2021).

7.2 Enhancing probiotic viability through advanced fermentation techniques

To enhance the viability of probiotics in tea-based products, advanced fermentation techniques and innovative approaches are being explored. For instance, co-culturing probiotics with yeast has been shown to significantly enhance bacterial viability in fermented beverages. The use of encapsulation techniques, such as microencapsulation with whey protein isolate and modified starch, can also protect probiotics from environmental stress and prevent undesired fermentation. Additionally, optimizing fermentation conditions, such as pH, temperature, and the addition of prebiotics, can promote the growth and survival of probiotic strains (Lima et al., 2022; Xu et al., 2022).

7.3 Future research directions for developing tea-based probiotic health products

Future research should focus on several key areas to advance the development of tea-based probiotic health products. One important direction is the investigation of the mechanisms underlying the interaction between probiotics and the chemical composition of tea, which can influence the efficacy and stability of the final product (Yang et al., 2023). Additionally, exploring the potential health benefits of novel probiotic strains isolated from traditional fermented teas, such as Miang, can provide new opportunities for synbiotic formulations (Unban et al., 2021). Research should also aim to develop and optimize encapsulation and fermentation technologies to enhance probiotic viability and stability during storage (Terpou et al., 2019). Finally, conducting clinical trials to validate the health benefits of tea-based probiotic products will be crucial for their successful commercialization and acceptance by consumers.

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Conflict of Interest Disclosure

The authors affirm that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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