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Unlocking the potential of synbiotic fermented beverages for gut health and well-being

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Abstract
Fermented beverages have been popular in cultures worldwide for centuries, contributing distinctive flavors and health benefits. The fermentation process enhances these drinks with probiotics, prebiotics, and bioactive compounds that help in promoting overall well-being. Synbiotics, a combination of prebiotics and probiotics, have considerable scientific interest in supporting a healthy digestive system and strengthening immunity. This review emphasizes the branch of study behind fermentation, probiotics, and prebiotics, emphasizing their specific and combined impact on gastrointestinal microbiota, immunity, and overall health. Synbiotics are known to improve antioxidant activity, anti-inflammatory activity, and anti-aging benefits, as well as highlight antimicrobial qualities and enhance nutrient synthesis and accessibility. Still, challenges endure, considering the need for effective communication, regulation, and innovation in encapsulation techniques and sustainable ingredients. Future studies should focus on unleashing the potential offered by next-generation beneficial microbes and sustainable ingredients, as well as directing the complexity of finding the right synergy between prebiotics and probiotics. By unraveling the science behind fermentation, probiotics, and prebiotics, we can optimize the full potential of synbiotic beverages for improving human health and well-being.

Keywords: Probiotic, prebiotic, synbiotic, gut health, fermentation

Introduction
Since ancient times, people have consumed fermented drinks, which are made by the enzymatic transformation of main and minor dietary ingredients and regulated microbial activity. It is becoming more acknowledged that by modifying substrates and creating bioactive compounds, fermented beverages are increasingly recognized for nutritional and functional advantages (Li *et al*., 2024) [1]. In addition to contributing significantly to dietary intake, beverages have recently drawn a lot of attention for their potential health benefits. The size, form, storage, and potential for desired nutrients and bioactive chemicals are all aspects of beverages that satisfy customer preferences. Nutraceuticals have been discussed about beverages, including their classification, significance, health-promoting effects, interactions with food, prevention throughout storage, and distribution within the human body. Nutritionally important essential fatty acids, various vitamins, minerals, amino acids, and botanicals are among the components of functional drinks. Functional drinks may aid with weight management, enhance gut or cardiovascular health, boost the immune system, or function as an adjuvant to delay the aging process (Nazhand *et al*., 2020) [2]. The synbiotic fermented beverage combines probiotics and prebiotics that improve gut microbiota balance and overall health. Probiotics are live microorganism that promotes health improvement, and prebiotics are the substrate consumed by host microorganisms. Including synbiotic fermented beverages in our diet signifies a functional approach to improving gut health, also enhancing immune function. As research into this is developing, synbiotic fermented beverages hold assurance as a holistic approach for enhancing health (Jäger *et al*., 2022; Dahiya & Nigam, 2022) [3, 4].

Understanding synbiotics and their role in gut health
The synergistic formulation of probiotics (living microorganisms) and prebiotics (indigestible food ingredients) are referred to as synbiotics. Around 25 years ago, the International Scientific Association for Probiotics and Prebiotics (ISAPP) panel revised the

meaning of symbiosis to include "a mixture comprising live microorganism and substrate(s) selectively utilized by host microorganisms that contribute to health benefit on the host" (Mounir *et al*., 2022) [5]. Enhancement of both systemic immune programming and local immune regulation is regulated by the gut microbiota, which is an inherent part of the gastrointestinal tract. To each organism's evolutionary benefit, complex symbiotic interactions have developed between the human host and gut microbiota (Johannsen & Prescott, 2009) [6]. In this regard, a healthy gut microbiota supports proper nutrition to the host by harvesting energy from the meal and facilitating the biosynthesis of vitamins. Additionally, the proliferation of intestinal cells and differentiation, the body's energy balance and pH regulation, the progression of the immune system development, and protection against pathogenic invasions are all supported by gut microbiota. An increasing number of investigations have explored the applications of metagenomics and culturomics for identifying and analyzing components of the human microbiota (Cremon *et al*., 2018) [7]. The human gastrointestinal tract's microbial ecosystem is highly complex, as evidenced by research on intestinal bacteria. The prolonged and sophisticated process of developing a normal intestinal flora is caused by a complicated interaction between environmental, immunological, and dietary factors. Intestinal microflora development is modulated by multiple factors, including the style of delivery, the birth environment, hygiene practices, environmental pollutants, the mother's fecal, vaginal, and skin flora, the gastrointestinal tract's developmental stage, and the type of feed consumed (Sarkar et. Al., 2011) [8].

Fermented beverage: Types and health benefits

Fermented beverages hold a vital role in cultures around the globe for their distinctive taste and health benefits. The fermentation process enriches these drinks with probiotics and bioactive compounds and facilitates overall well-being (Melini *et al*., 2019) [9]. Fermented beverages are classified into alcohol content of above 1.2%, alcohol content not more than 1.2%, and alcohol content of less than 0.5% (Morales-de la Peña *et al*., 2023) [10]. Some examples of fermented beverages are kefir, Tempeh, Natto, kombucha, etc. Kefir is a traditional fermented beverage produced by inoculating milk with kefir starter grains, which are comprised of both yeast and lactic acid bacteria. It helps in enhancing antioxidant activity, inhibiting certain pathogens in the gut serves as an anti-inflammatory and anti-cancer. Tempeh is a fermented soybean product that contains a soft texture and nutty flavor, it is a traditional drink of Indonesia. Natto is a Japanese fermented soybean with a strong flavor and sticky texture (Lee & Turrill, 2024) [11]. Fermented beverages are available in multiple forms, including those made from milk and cereal. One example is Kombucha, a fermented sweetened tea that was first popular in China but is now popular all over the world. Similar to vinegar's mother cultures, it is fermented by a symbiotic combination of bacteria (mostly acetic acid bacteria, with trace amounts of LAB) and yeast integrated into a cellulose network that floats on the fermenting mixture. Its physicochemical characteristics are an essential component governing the functionality of kombucha because of its strong acid concentration (as low as pH 2). It is also rich in diverse vitamins and phenols due to the presence of tea content (Marsh *et al*., 2014) [12].

The science behind fermentation and probiotics

Fundamentally, fermentation refers to a biochemical biotransformation process that converts carbohydrates into organic acids or alcohols (Tang *et al*., 2023) [13]. One of the earliest and widely used techniques of food preservation is fermentation. It is predicated on how microorganisms' biological activity alters food's flavor and appearance while preventing spoilage and degradation over time. Understanding this method has progressively expanded, and scientific and innovations in technologies have made it possible to significantly improve the process, turning small-scale fermented food production into regulated industrial fermentation processes. These items are either offered as main courses or as a side dish to main courses, pickles, sauces, and drinks. Since the time of the Neolithic era (around 10,000 B.C.) microorganisms were inoculated for use in food fermentation and maturation by producing antimicrobial metabolites for example ethanol, bacteriocins, and organic acid together with reduced water activity, fermentation was largely used to preserve food (Anal, 2019) [14]. Lactic acid bacteria, commonly from genera including *Leuconostoc, Lactobacillus, and Streptococcus*, are the main biochemical compounds and microbes involved in food fermentation processes. The food substrates, grapes and other fruits, dairy products, vegetables, various legumes (including soybeans), starchy roots, grains, fish, and meat can also be used to characterize fermentations. Lactic acid bacteria digest raw materials with high concentrations of monosaccharides and disaccharides (Admassie, 2018) [15]. To create products with desired quality characteristics in terms of storage stability, consistency, taste profile, palatability, flavor characteristics, and color profile. Bioprocess technology today aims to use microorganisms and their enzymatic activity involves acidification, ethanol production, proteolysis, and/or amino acid conversions. Furthermore, it contributes significantly to the generation of meals with health-boosting qualities as well as wholesome foods in a sustainable, affordable, and natural manner across the globe (Ashaolu, 2019) [16].

Probiotic bacteria, as per FAO/WHO recommendations, are "live microorganisms that, when administered in adequate amounts, confer a health benefit on the host (Liang *et al*., 2023) [17]. Their health-promoting activities involve several impacts by encouraging the release of soluble factors or the synthesis of SCFAs, probiotics may limit the proliferation of harmful bacteria, enhance gut mechanism action against pathogen intrusion, increase epithelial barrier functionality, or improve disease processes (Cremon *et al*., 2018) [7].

Table 1. Name of the microorganism used as a probiotic (Gupta & Garg, 2009) [18]

Lactobacillus	*Bifidobacterium*	*Streptococcus*	Others
L. bulgaricus *L. acidophilus* *L. gasseri* *L. fermentum* *L. casei (rhamnosus)* *L. johnsonii* *L. paracasei*	*B. bifidum* *B. lactis* *B. breve* *B. longum* *B. adolescentis*	*S. thermophilus* *S. salivarius*	*Bacillus cereus* *Propionibacterium* *Escherichia coli freudenreichii*

Studies have shown that probiotics play a crucial role in the prevention of cancer, as well as in easing the side effects of cancer therapies. They are also effective in managing gastrointestinal conditions like Helicobacter pylori infections, diarrhea, inflammatory bowel disease, and irritable bowel syndrome. Additionally, they help manage allergic reactions and combat metabolic disorders like insulin resistance, obesity, type 2 diabetes, and non-alcoholic fatty liver disease (Markowiak & Śliżewska, 2017) [19].

Prebiotics: The unsung heroes of gut health

According to ISAPP (International Scientific Association for Probiotics and Prebiotics), Prebiotics are described as "substrates that confer a health benefit by being selectively utilized by host microorganisms." Marcel Rober and Glenn Gibson were the first to propose the idea of prebiotics. Examples of common Prebiotics like inulin, fructooligosaccharides, galactooligosaccharides, chitooligosaccharides, xylooligosaccharides, resistant starch, lactulose, and polyphenols. Majorly found in natural sources such as chicory root, onions, bananas, garlic, and whole grains, are indigestible in the GI tract and serve as energy sources for gut bacteria in the colon (Yoo *et al*., 2024) [20]. Through the modulation of the gut microbial environment, prebiotics enhance the abundance of health-promoting bacteria such as *bifidobacterium and lactobacillus*, while suppressing the colonization of pathogenic bacteria (Arapović *et al*., 2024) [21]. Inulin is a polysaccharide that occurs naturally in plant sources and is classified under the fructans class of dietary fibers. Fructooligosaccharides and inulin combine to form a molecule that serves as a dietary fiber resistant to digestion. Inulin is used in food formulation as it fosters the development of *bifidobacteria* in the gastrointestinal system. It is significantly used for its prebiotic effects. However, it is also used to prevent obesity, regulate blood sugar levels, improve lipid metabolism, facilitate mineral absorption, and exhibit protection effects against colon cancer (Maftei *et al*., 2023) [22]. Low DP inulin (shorter chains) is more soluble in water and produces less viscous solutions, making it a better option for replacing sugar in beverages (Chang *et al*., 2025) [23]. Regular consumption of prebiotics has been associated with several health benefits in controlling glycemic index, weight management, immune function enhancement, mental health wealth well-being (Yoo *et al*., 2024; Raimondi *et al*., 2022) [20, 24].

Synergistic effects of synbiotics in intestinal microbiota

Research indicates that the combined action of prebiotics and probiotics in synbiotics can exhibit antioxidant properties, particularly with bifidobacterium and lactobacillus stains identified as key contributors in both human and animal studies (García-Cayuela *et al*., 2022) [25]. Synbiotics are known to reduce the level of harmful metabolites and lessen the activity of nitrosamines and carcinogens. The use of synbiotics stimulates the production of methyl acetates, SCFAs, Ketones, and carbon disulfides, which contribute to improving various health benefits in the host. During fermentation, Short-Chain Fatty Acids (SCFAs), which are essential by-products of carbohydrate metabolism, help strengthen the intestinal defense system (Markowitz & Śliżewska, 2017) [19]. The synergistic effects of probiotics and prebiotics have led to the rise of synbiotic foods focused on gut health enhancement (Kareb & Aïder, 2019) [26]. Gut microbiota plays a crucial role in host metabolism and immunity. An Imbalance state can trigger inflammation and chronic risk. The presence of prebiotics in foods helps good bacteria to grow, positively encouraging gut ecology and host physiology, as shown in the given figure. 1 (Lin *et al*. 2014) [27].

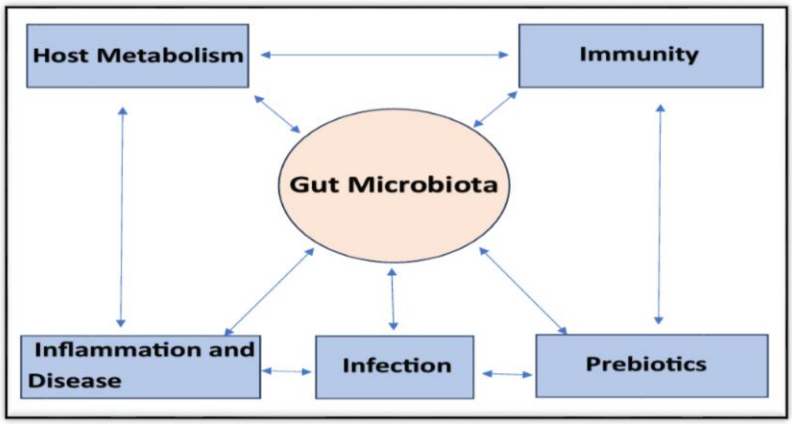

Fig 1: Interaction of gut microbiota and host functions

Synbiotic foods contribute to host wellness through improved survival and successful colonization of live probiotics in the gastrointestinal tract, by selectively stimulating the growth and/or by activating the metabolism of one or a limited number of health-promoting bacteria, and thus improving host welfare (Kareb & Aïder, 2019) [26]. In the human gut, however, the colonic microbiota uses these prebiotic components to survive. Together, prebiotics and probiotics produce molecules that decrease the pH of the gut, stop harmful bacteria from growing, and prevent the buildup of unwanted metabolites, the synergism lowers the risk of health problems. Inulin, resistant starches, galactooligosaccharides, fructooligosaccharide, trans-galactooligosaccharides, β-glucans, and fructans are some of the prebiotic ingredients frequently utilized in the creation of synbiotic drinks. The milk-derived synbiotic fermented beverage's flavor profile was also enhanced by the synbiotic formulation's increased polyunsaturated fatty acid content, higher probiotic bacterial viability (more than 6 log CFU/g), and the production of ketones, carboxylic acid, and esters. As a result, there is a greater need for solutions that include probiotics and prebiotics because they not only support human health but also make the food they are added to more palatable (Jadhav *et al*., 2024) [28].

Health implication of synbiotic fermented beverages

Over recent years, consumers' belief in the positive impact of functional foods on health has significantly increased, and interested in knowing the bioactive compounds present in them. There is a demand for innovation, added health value, and economically accessible functional substances. (Kumar *et al*., 2023; Wang & De Steur, 2022) [29, 30]. It helps in prevention by providing various health benefits such as antioxidant activities, anti-inflammatory, anti-ageing effects, antimicrobial qualities, oxidative stress management, and gut health, this is depicted in Figure 2 (García-Cayuela *et al*., 2022) [25]. Consequently, the food industry actively developing innovative functional products to satisfy consumer preferences (Kumar *et al*., 2023; Wang & De Steur, 2022) [29, 30].

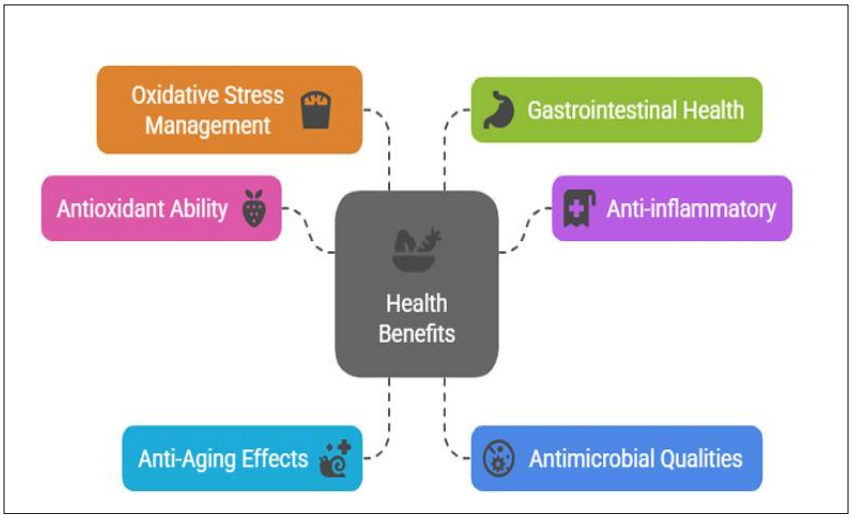

Fig 2: Health benefits of symbiotic fermented beverages

Antioxidant ability

The cellular oxidative imbalance caused by free radicals and reactive oxygen derivatives to cellular components is thought to be one of the causes of many human diseases. These included inflammatory conditions, aging, diabetes, neurological illnesses, arteriosclerosis, and aging (Halliwell, 2001) [31].

Anti-inflammatory

In type 2 diabetes mellitus, certain substances increase, including IL-6, TNF-α, high-sensitivity, and C-reactive protein, which are signs of inflammation. Short-Chain Fatty Acids (SCFA) can inhibit the activity of these inflammatory markers. Nitric Oxide (NO) is involved in immune responses by cytokine-activated macrophages, which produce NO in high concentrations, and SCFA (acetate, propionate, and butyrate) helps to reduce NO concentration (Kim, Keogh, & Clifton, 2018) [32].

Anti-aging effect

The aging of organisms results from free radicals damaging cells over time proposed by the free radical theory of aging. Evidence supports that probiotics and synbiotics can combat stress and DNA damage. In mice models, experimental studies suggested that *L. plantarum* GKM3 helps to slow down the aging process, reduces oxidative stress, and alleviates age-related cognitive impairment (García-Cayuela *et al*., 2022) [25].

Antimicrobial quality

Probiotics are considered to have a major influence on antimicrobial effects. Probiotic microbes prevent intestinal walls from pathogenic attachment. They also activate both immune responses antigen-specific and nonspecific immune responses. They interfere with pathogens for nutrients for survival and lead to providing antimicrobial effects (Verma *et al*., 2012) [33].

Oxidative Imbalance

Oxidative imbalance takes place when there is an excess of oxidants over antioxidants. If oxidants exceed antioxidants, then it results in apoptosis, lipid peroxidation, protein denaturation, and DNA hydroxylation. In biological systems, key Reactive Superoxides (ROS) such as superoxide radicals, hydrogen peroxide, lipid peroxide, and hydroxyl formed during metabolic activity are responsible for oxidative damage (García-Cayuela *et al*., 2022; García-Cayuela *et al*., 2023) [25, 34].

Gastrointestinal health

Among the many and varied bacteria that make up the intestinal microbiota, Firmicutes and Bacteroides are the most prevalent flora. Their gene pool is far more diverse than that of their host. Clinical research has indicated the association between obesity and gastrointestinal microbes. Obese people have a higher Firmicutes/Bacteroidetes ratio than lean patients on the same diet, and this is inversely connected with weight loss (Tang *et al*., 2023) [13].

Consumer trends and market potential for synbiotic beverages

Synbiotic beverages are a combination of probiotics and prebiotics that support maintaining a healthy gastrointestinal microbiome and are gaining huge popularity in the market. In 2024, the global synbiotic market was valued at approximately USD 1.02 billion and is estimated to increase at a Compound Annual Growth Rate (CAGR) of 8.3% from 2025 to 2030, reaching a projected value of USD 1.68 billion by 2030. Today's market is rising due to consumers taking more interest in gut health and a surge in demand for functional foods and beverages (Grand View Research, 2024; MarkWide Research, n.d.) [35]. The Asian Pacific region is growing at a faster rate with a CAGR of 9.5%. Due to faster urbanization, and focus on dietary habits in China and India. At present times people are seeking beverages that not only hydrate but also exhibit health advantages, including boosting digestion, enhanced immunity, and a good source of energy. A functional beverage provides beyond basic nutrition, particularly low sugar content, and several health benefits, which leads to the innovation of synbiotic drinks and creates preferences among people. This trend offers a rise in functional beverages in the market. The shift away from alcohol has also created opportunities for health-focused beverage rises, and synbiotic beverages are a better choice to promote overall well-being for consumers. As growing awareness of gut health, more education on synbiotic products is needed to drive acceptance, and effective communication can enhance trust and encourage the adoption of synbiotic products. Focusing on the navigation of regulatory requirements for synbiotic health claims strengthens product credibility and consumer acceptance (Arthur, 2025; Reed's Inc., 2025) [36, 37].

Challenges and future direction in research

The effectiveness of probiotics relies upon the strain used, as many cannot live in acidic conditions or during storage can influence their performance (Fasoyiro *et al*., 2022) [38]. Finding the right synergy between prebiotics and probiotics is complex, as not all prebiotics support the growth of every probiotic strain (Rai *et al*., 2021) [40]. Maintaining Probiotic viability in Beverages over time is difficult, due to some parameters including temperature, pH, and oxygen exposure (Martínez *et al*., 2020) [41]. Emerging encapsulation techniques offer better probiotic stability and survival period during fermentation and storage (Liu *et al*., 2023) [42]. Next-generation probiotics (NGPs) comprise a novel class of beneficial bacteria including species like *Christensenella minuta, F. prausnitzii, Parabacteroides goldsteinii, Prevotella copri, B. thetaiotaomicron, Akkermansia muciniphila, and B. fragilis* that may provide enhanced health benefits and also sustainable ingredients such as peels of several fruits and vegetable can be a good option as a prebiotic and as an additional source of nutrition, this will not only deal with waste management but also provide various health benefits with their correct usage (Khare *et al*., 2022) [43].

Conclusion

In conclusion, fermented beverages have been a staple in cultures worldwide for their distinctive flavor and health benefits. The integration of probiotics and prebiotics, referred to as synbiotics, has shown promising results in strengthening digestive health and contributing to general health. Probiotics are beneficial microorganisms that support health-promoting effects, and prebiotics are dietary fiber that serves as a substrate for probiotic microorganisms and work synergistically to create a healthy gut microbiome. The fermentation process enhances this beverage with bioactive compounds, promoting overall well-being. The market potential for synbiotic beverages is huge, with the global market estimated to reach USD 1.68 billion by 2030. Consumer trends suggest a growing interest in gut health and functional foods and beverages. However, challenges remain, including finding the right synergy between prebiotics and probiotics, maintaining probiotic viability, and navigating regulatory requirements for health claims. Future research directions include exploring emerging encapsulation techniques for better probiotic stability, next-generation probiotics for enhanced health benefits, and sustainable ingredients as prebiotics. Furthermore, effective communication and education on synbiotic products can drive acceptance and encourage adoption. Overall, synbiotic fermented beverages hold great promise as a natural approach to promoting human health and wholesomeness.

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