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REVIEW PAPER

Non-dairy Probiotic Beverages: A Comprehensive Review of Innovations, Health Benefits, and Future Trends

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ABSTRACT

The enhanced popularity of plant-based probiotic drinks can be linked to increasing lactose intolerance, trend towards veganism, and interest in functional foods that promote health and well-being. The present paper is a critical review of plant-based probiotic drinks sourced from fruits, vegetables, cereals, pulses, soy, and fermented drinks such as wine and beer. It discusses the advancements in fermentation methods, viability of health-promoting microorganisms, and synergistic benefits seen on combining probiotics with prebiotic fibers. Data indicate that the drinks can promote digestive well-being, increase immune response, provide antioxidant activity, and prevent harmful microbes. The discussion also includes consumer attitudes, market pressures, and palatability acceptability, which indicate a trend towards plant-based probiotic drinks. Although promising advancements have been made, challenges are in bacterial viability, industry regulations, and public awareness. Future studies must address optimization of formulating, expanding the scope of clinical trials, and enhancing product shelf-life to cater to global demand. This study emphasizes the role of non-dairy probiotic drinks as healthy and environmentally friendly alternatives to conventional dairy-based probiotics.

Keywords: Non-dairy probiotics, Functional drinks, Fermentation technology, Gut microbiota, Plant-based probiotics, Synbiotics

Probiotics also play an important role in enriching the nutritional content of food, with fruit juice and milk foods commonly employed as delivery systems for these beneficial microbes (Chaturvedi and Chakraborty, 2021). However, diet changes, including the popularity of veganism and increasing lactose intolerance, have prompted more intense investigation of non-dairy foods as probiotic delivery systems (Meena *et al*. 2023). Functional drinks can also include prebiotics, and the synbiotic blend of prebiotics and probiotics has been documented to enhance the viability of microbes. For example, fructo-oligosaccharides, inulin, and cultures such as *Lactobacillus rhamnosus* and *Lactobacillus bulgaricus* have been employed in fermented carrot juice supplemented with these for the purpose (Çopur *et al*. 2019).

Although the worldwide probiotic market is dairy-driven, lactose intolerance and cholesterol linked with fermented dairy foods have led to modest innovation attempts with substrates other than dairy (Angelov *et al*. 2006). Fig. 1 shows a sample classification of non-dairy probiotic drinks. The latest research focuses on substrates like fruits, vegetables, cereals, and legumes

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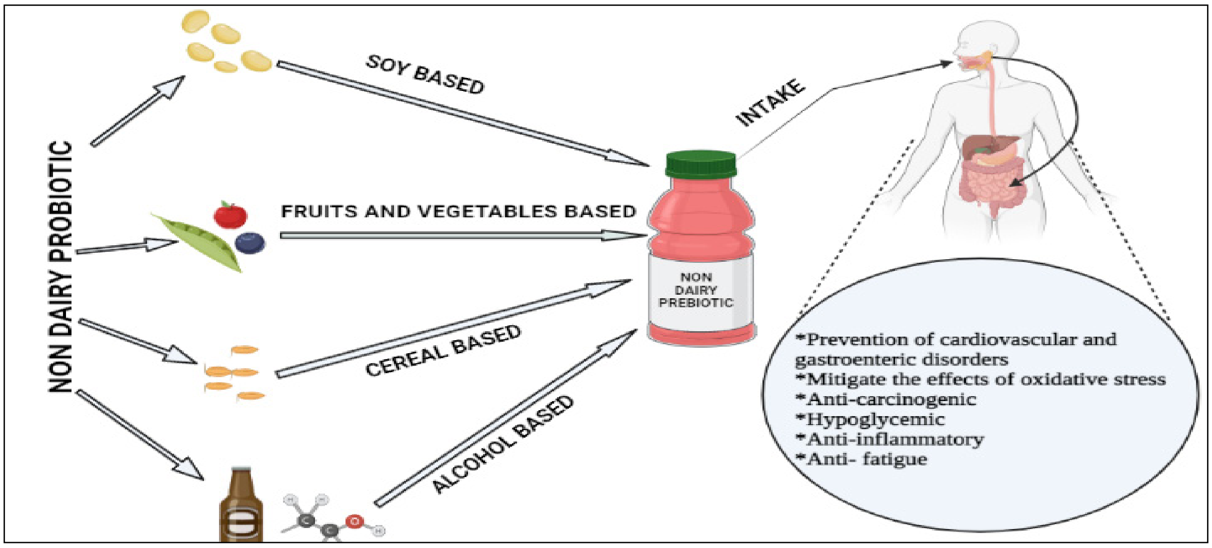

Fig. 1: Most prevalent categories of alternative, non-dairy probiotic drinks

(Vasudha and Mishra, 2013). Some of the significant developments include Proviva®, the first dairy-free probiotic drink that was created by fermenting oatmeal using lactic acid bacteria and mixing it with fruit juice, and Vita Biosa®, a plant-based fermented drink distinguished by its health effects (Prado *et al*. 2008).

The growing number of individuals who experience lactose intolerance together with milk allergy cases and plant-based diet demands have driven the development of probiotic products made from plant materials like vegetables, cereals and fruits. These alternative products address dietary requirements while meeting ethical standards about animal-derived components (da Silva Vale and colleagues, 2023). The development process for such beverages requires the addition of specific microbial cultures which include bifidobacteria and lactic acid bacteria to enhance sensory characteristics and maintain probiotic survival during product storage. Research demonstrates that substrates including sorrel together with pineapple juice and wheat bran along with root vegetables and baobab pulp prove effective for sustaining strains *of Lacticaseibacillus paracasei, Lactiplantibacillus plantarum* and *Limosilactobacillus fermentum* to produce health-enhancing beverages (Zamfir *et al*. 2022).

The nutritional composition together with prebiotic substances such as inulin and fructooligosaccharides in non-dairy substrates supports beneficial bacterial growth through the stimulation of probiotic activity (Dahiya and Nigam, 2022). Various storage conditions maintain the high probiotic viability of non-dairy probiotic drinks which exhibit antimicrobial properties against common pathogens to improve gut health and well-being (Tavares *et al*. 2024). Consumers highly accept the product because of its high sensory evaluation specifically for sorrel-pineapple juice blends at a 50:50 ratio (Marius *et al*. 2023).

Non-dairy probiotic drinks address the growing need for functional food in the developing world, where inexpensive and readily available substrates are needed to support probiotic functionality and stability. Fermentation enhances the nutritional content of the substrates and enables the bioavailability of bioactive molecules, such as phenolics and flavonoids, to impart antioxidant properties to the drinks (Zamfir *et al*. 2022). As functional food gains worldwide interest, non-dairy probiotic alternatives represent a major nutrition breakthrough that offers an inclusive solution to address diverse food needs (Sanlibaba, 2023).

This review offers a detailed overview of the most recent trends in non-dairy probiotic drinks, their biotechnological uses, health impacts, and innovations in production methods and marketing. Key aspects, including health impacts, market trends, and scientific progress, are summarized in Table 1. The article also offers an in-depth exploration of major categories of non-traditional, non-dairy probiotic drinks.

Probiotic beverages from vegetables and fruits

Juices of fruit and vegetables are promising substrates for forming probiotic drinks (Zheng *et al.* 2017). One of the main areas of research on the subject is finding their potential as probiotic carriers, especially in forming ready-to-reconstitute plant-derived probiotic drink powders. Table 2 represents results of research work and the therapeutic applications of different probiotic drinks based on fruit and vegetable juices.

Table 1: Overview of the various aspects of non-dairy probiotic beverages, their health benefits, market trends, and scientific advancements

Aspect	**Details**	**Reference**
Probiotic role in food products	Probiotics enhance the functionality of food products, with dairy-based items and fruit juices being popular media.	Chaturvedi and Chakraborty, 2021
Shift to non-dairy substrates.	Due to the rise of veganism and lactose intolerance, exploring non-dairy substrates for probiotics is increasingly essential.	Meena *et al*. 2023
Synbiotics (probiotics + prebiotics)	Functional beverages can be fortified with prebiotics to enhance probiotic viability. Synbiotics are the combination of prebiotics and probiotics.	Çopur *et al*. 2019
Market for probiotic foods	The global market for probiotics is predominantly milk-based, but lactose intolerance and cholesterol content in dairy are significant downsides.	Angelov *et al*. 2006
Non-dairy probiotic beverages	Research focuses on substrates like fruits, vegetables, cereals, and legumes for non-dairy probiotic beverages. Examples include Proviva® and Vita Biosa®.	Vasudha and Mishra, 2013; Prado *et al*. 2008
Lactose intolerance and vegan diets	Lactose intolerance, milk protein allergies, and vegan diets drive the development of non-dairy probiotic beverages.	da Silva Vale *et al*. 2023
Microbial strains for non-dairy beverages	Non-dairy probiotic beverages are formulated with specific strains like lactic acid bacteria and *Bifidobacterium*.	Zamfir *et al*. 2022
Health benefits of non-dairy beverages	Non-dairy beverages offer benefits such as antimicrobial properties, improved gut health, and high levels of viable probiotic cells.	Dahiya and Nigam, 2022; Tavares *et al*. 2024
Sensory acceptability	Non-dairy beverages, like sorrel and pineapple juice blends, show high consumer preference.	Marie *et al*. 2023
Affordability in low-income countries	Non-dairy probiotic beverages provide affordable, accessible functional foods in low-income countries, addressing the need for probiotic survival.	Zamfir *et al*. 2022
Nutritional enhancement	The fermentation process increases the bioavailability of bioactive compounds like phenolics and flavonoids, contributing to antioxidant properties.	Zamfir *et al*. 2022
Global Demand for Functional Foods	Non-dairy probiotic beverages significantly advance nutrition and health, offering a versatile option for consumers worldwide.	Sanlibaba, 2023

Table 2: Probiotic-enriched fruit and vegetable beverages Strains, health values, and major studies

Fruit/Vegetable	Probiotic strain(s)	Research/Development highlights	Reference
Orange juice	*Lactobacillus casei*	Development of powdered probiotic orange juice.	Lascano *et al*. 2019
Passion fruit juice	*Lactobacillus plantarum*	Successful development of probiotic-infused passion fruit juice powder.	Shah *et al*. 2010
Tomato Juice	*Lactobacillus acidophilus* LA39, *Lactobacillus plantarum* C3, *Lactobacillus casei* A4, *Lactobacillus delbrueckii* D7	Demonstrated probiotic potential with significant viable cell counts and stability after cold storage.	Yoon *et al*. 2004; Şanlıbaba, 2023
Sorrel and pineapple juices	*Lacticaseibacillus paracasei* 62L	Probiotic beverage with enhanced fibre, protein, lipid contents, and DPPH scavenging activity.	Marius *et al*. 2023
Kiwifruit extract	Lactic acid bacteria and Yeast	Probiotic-fermented kiwifruit extract with enhanced polyphenols, SOD, and γ-aminobutyric acid (GABA)levels.	Cai *et al*. 2022
Blueberry juice	*Lactobacillus plantarum*, *Lactobacillus fermentum*	Fermented blueberry juice has elevated phenolic content and antioxidant capacity, promoting digestive health.	Li *et al*. 2021
Beet juice	*Lactobacillus acidophilus*, *Lactobacillus plantarum*	Probiotic beet juice has antimicrobial, antioxidant, and potential anticancer properties.	Yoon *et al*. 2005; Zamanpour*et al*. 2023
Cabbage juice	*Lactobacillus plantarum* C3, *Lactobacillus casei* A4, *Lactobacillus delbrueckii* D7	Probiotic cabbage juice has enhanced nutritional value and digestive health benefits.	Yoon *et al*. 2006; Olamide and Whong, 2024
Grain fields whole grain liquid	Lactic acid bacteria, Yeasts	Fermented grain-based beverage with amino acids, vitamins, and enzymes.	Vasudha and Mishra, 2013
Hardaliye	Lactic acid bacteria	Probiotic beverage made from fermented red grapes.	Arici and Coskun, 2001
Gefilus (fruit juice)	Lactic acid bacteria	Probiotic fruit juice with enhanced B-vitamin synthesis.	Nyanzi and Jooste, 2012
Cranberry juice	Lactic acid bacteria	Probiotic cranberry juice with antimicrobial properties aids in urinary tract infection prevention.	Colletti *et al*. 2021
Pineapple juice	*Lactobacillus casei*, Inulin	Synbiotic pineapple juice with enhanced probiotic viability and favourable sensory characteristics.	Ghafari and Ansari, 2018
Grapefruit juice	*Lactobacillus*, *Bifidobacterium*	Probiotic grapefruit juice with reduced bitterness and augmented nutritional attributes.	Tran *et al*. 2020
Cornelian cherry juice	*Lactobacillus plantarum* ATCC 14917	Fermented cherry juice with increased phenolic content and improved probiotic viability.	Mantzourani *et al*. 2018
Jackfruit juice	*Lactobacillus casei* ATCC334	Probiotic jackfruit juice has enhanced antioxidant and antibacterial activities.	Muhialdin *et al*. 2021
Cashew apple juice	*Lactobacillus plantarum*	Fermented cashew apple juice with improved antioxidant activity and reduced astringency.	Kaprasob*et al*. 2018
Beetroot and carrot juices	*Lactobacillus acidophilus*	Probiotic beverage enriched with amino acids, vitamins, and antioxidants through brewer's yeast autolysate incorporation.	Rakin *et al*. 2007
Citrus puree	*Lactobacillus paracasei*, *Bifidobacterium infantis*	Enzymatically hydrolyzed and fermented citrus puree with enhanced antioxidant capacities.	Tao *et al*. 2022

Advancements in non-dairy probiotics include the development of powdered orange juice incorporating *Lactobacillus casei*, showcasing industry innovation (Lascano *et al.* 2019). Similarly, passion fruit juice powder fortified with *Lactobacillus plantarum* demonstrates progress in stabilizing probiotics within fruit-based matrices (Shah *et al.* 2010). These developments reflect rising demand for plant-based probiotic beverages, expanding access to convenient, health-focused options. Commercial innovations like Biola®, a probiotic fruit juice by Tine BA (Norway), utilize *Lactobacillus rhamnosus* GG (LGG®), a clinically validated strain licensed from Valio Ltd. (Finland). Biola® contains over 95% fruit content, excludes added sugars, and features flavors such as orange-mango and apple-pear. Another notable product, Rela®, developed by Sweden's BioGaia, incorporates *Lactobacillus reuteri* MM53, aligning with global trends in health-oriented, non-dairy beverages (Vasudha and Mishra, 2013).

Yoon *et al*. (2004) demonstrated that tomato juice fermented with *Lactobacillus acidophilus* LA39, *Lactobacillus plantarum* C3, *Lactobacillus casei* A4, and *Lactobacillus delbrueckii* D7 serves as an effective probiotic medium. Fermentation reduced pH to 4.1 within 72 hours, with viable cell counts reaching 1.0–9.0 × 10^9 CFU/mL, confirming robust microbial activity. Four weeks of cold storage (4°C), counts remained clinically relevant (10^6–10^8 CFU/mL), underscoring strain resilience (Şanlıbaba, 2023). This retained viability positions fermented tomato juice as a practical alternative for lactose-intolerant or vegetarian consumers, circumventing traditional dairy-based probiotics like yogurt. Additionally, tomatoes inherent nutrients and antioxidants amplify the juice's health benefits, offering a palatable means to support digestive health.

Probiotic-enriched tomato juice, sourced from the widely consumed tomato, offers a versatile vehicle to support digestive and systemic health for diverse populations (Şanlıbaba, 2023). Its adaptability to various dietary preferences enhances its appeal as a functional addition to balanced diets, fostering broader accessibility to probiotics and encouraging dietary diversity. This innovation exemplifies a strategic approach to expanding probiotic product availability, promoting both public health and nutritional inclusivity.

Marius *et al*. (2023) formulated a probiotic beverage by combining sorrel and pineapple juices with *Lacticaseibacillus paracasei* 62L, demonstrating significant therapeutic promise. The probiotic drink contains fiber, fat and protein which delivers extra nutritional benefits to the body. The drink functions to improve its DPPH radical-fighting capabilities. The regular consumption of this product provides benefits for both gut health and antioxidant protection and general well-being alongside its enjoyable taste and health-promoting properties.

The research by *Cai et al.* (2022) examined probiotic-fermented kiwifruit extract fermented with lactic acid bacteria (LAB) and yeast for controlling bioactive components. The polyphenol and superoxide dismutase (SOD) content increased through the LAB fermentation process whereas the GABA content rose through yeast fermentation. The extract functions as a powerful functional food because its antioxidant properties and immune-boosting effects and stress-reduction effects combine with the lactic acid content. The addition of better taste profiles helps to attract more consumers. The research also pinpointed major strains, *Lactobacillus plantarum* LG1034, *Bacillus rhamnosus* LG0262, *Lactobacillus paracasei* LG0260, and *Saccharomyces cerevisiae* J2861—as best suited to ferment acidic fruit matrices. The opportunity exists to create specialized probiotic-fermented fruit products that address particular health requirements and consumer preferences. The combination of probiotics with fermentation and fruit bioactives creates new therapeutic foods that adhere to contemporary nutritional trends.

Li *et al.* (2021) analyzed the health benefits of fermented blueberry juice containing *Lactobacillus plantarum* and *Lactobacillus fermentum* bacteria. Through fermentation, the juice experienced significant modifications by reducing malic acid content while increasing levels of lactic acid which led to a decrease in juice acidity. The change in pH helps stomach patients who experience food digestion problems while supporting the development of healthy gut microbiomes. The therapy enhanced the level of total phenolics and antioxidant activity, with such phenolics as rutin, myricetin, and gallic acid increasing despite anthocyanins decreasing. These phenolics have been linked to anti-inflammatory, cardiovascular, and cognitive effects, making the beverage an effective drink for the alleviation of oxidative stress and overall health (Li *et al.* 2021).

Yoon *et al*. (2005) investigated the use of red beet juice as a medium for the culture of probiotics by LAB strains, particularly *Lactobacillus acidophilus* and *Lactobacillus plantarum*, which exhibited remarkable reduction of pH through lactic acid production. Despite a gradual decline in cell viability during cold storage (4°C), the cell populations remained significant (10^6–10^8 CFU/mL) after four weeks (Zamanpour*et al*. 2023). The health benefits of the drink are credited to its capacity to deliver probiotics, antimicrobial, and antioxidant activities of vitamins, phenols, amino acids, and exopolysaccharides. Its flavor and many benefits—anticancer, antidiabetic, and anti-inflammatory activities—position it as a potential daily drink to promote gut health, decrease oxidative stress, and suppress disease (Yoon *et al.* 2005).

Yoon *et al.* (2006) first established the probiotic-rich cabbage juice manufacture with *Lactobacillus plantarum* C3, *Lactobacilluscasei* A4, and *Lactobacillusdelbrueckii* D7, with strong fermentation of cell concentrations of ~1×10^9 CFU/mL within 48 hours. Not only did this enhance the nutritional content of the juice, but it also revealed its therapeutic potential, especially to restore gut microbiota, immune systems, and mental health through probiotic effects. Bioactive organic acids produced during the fermentation process added flavor as well as possible health benefits, such as suppressing pathogens and promoting the bioavailability of nutrients. Plant-based and lactose-free, the beverage meets vegetarians' and lactose-intolerant people's dietary requirements, providing gut health benefits at an affordable price (Olamide and Whong, 2024).

Throughout the world, various probiotic drinks have been developed. AGM Foods in the United States has developed Grainfields Wholegrain Liquid, produced by fermenting seeds, beans, and grains, which contains lactic acid bacteria and yeasts, along with amino acids, vitamins, and enzymes (Vasudha & Mishra, 2013). Turkey's Hardaliye (red grape-LAB ferment), and Finland's Valio Ltd.'s Gefilus® fruit juice (Arici and Coskun, 2001). Fermentation also supports B-vitamins through LAB synthesis and develops bacteriocins that inhibit pathogens such as *Listeria monocytogenes* (Nyanzi and Jooste, 2012). Cranberry extracts applied as adjuncts for urinary tract health (Colletti *et al*. 2021), and mass market favorites such as kimchi-based beverages (Luckow and Delahunty, 2004), vegetable juices (Lambo *et al.* 2005), and fruit blends (Sheehan *et al.* 2007; Kumar *et al.* 2013) illustrate the potential of plant probiotics. Other examples include cashew apple (Pereira *et al.* 2011), plum (Sheela and Suganya, 2012), and table olive (De Bellis *et al.* 2010) drinks, which blend sensorial attractiveness with functional properties, responding to consumer demand for health-oriented, non-dairy products (Panghal*et al.* 2018).

Rakin *et al.* (2007) created a new process for beetroot-carrot juice enrichment with brewer's yeast autolysate before fermentation with *Lactobacillus acidophilus*. Such synergy between the yeast waste products and lactic acid fermentation stimulated the development of healthy microbes, enriching the beverage with amino acids, vitamins, minerals, and antioxidants. The process shortened the fermentation time while intensifying nutrients, leading to health effects like immune system stimulation, cellular repair, and oxidative stress avoidance. Sustainability in the circular economy became the primary concern because spent yeast transform into green products. The therapeutic benefits of beetroot and carrot become enhanced by their natural pigments and micronutrients which boost immune function and energy metabolism and support skin health (Astuti *et al.* 2023). The drink stands as an ideal choice for dieting individuals because it contains no lactose while delivering probiotics alongside essential nutrients for complete wellness support.

Tao *et al*. (2022) demonstrated that enzymatic hydrolysis combined with fermentation using *Lactobacillus paracasei* and *Bifidobacterium infantis* produced a whole fruit equivalent citrus puree which contained more antioxidants and better flavor. The processing method generated elevated organic acids and phenolic compounds and flavonoids to develop a versatile nutrient-rich product suitable for various food uses. Enzymatic and microbial techniques prove useful for creating functional foods that meet the needs of health-conscious consumers.

Ghafari and Ansari (2018) achieved the development of a synbiotic pineapple juice through the addition of *Lactobacillus casei* and inulin. The functional drink proved superior to sucrose-based products because it maintained better probiotic survival while demonstrating better physicochemical stability and sensory quality. By adding prebiotics to probiotics, the product successfully caters to the trend towards gut-health-focused, plant-based drinks and provides a sound dietary supplement option.

Tran *et al*. (2020) showed the viability of grapefruit juice as a growth medium for *Lactobacillus* and *Bifidobacterium* species without supplementation with nutritional ingredients. The work significantly lowered naringin, the prevalent bitter constituent, without compromising antioxidant activity and polyphenol content. *Lactobacillus plantarum* 01 achieved effective naringin reduction, showing potential for the manufacture of less bitter, nutrient-dense probiotic citrus beverages with balanced flavor and functionality. This work opens the door to optimizing sensory and nutritional qualities in plant-based probiotic drinks.

Mantzourani *et al.* (2018) created a low-alcohol functional beverage by fermenting Cornelian cherry juice with *Lactobacillus plantarum* ATCC 14917, both in free and immobilized cells. Immobilization on delignified wheat bran enhanced probiotic survival during cold storage due to the prebiotic nature of the carrier. The process of fermentation enhances the concentration of phenolic compounds while preserving the sensory quality of beverages thus creating a healthy substitute to standard drinks. The study discovered that immobilized probiotics present an actionable solution to prolong shelf life of functional beverages while maintaining their taste profile.

Muhialdin *et al.* (2021) used *Lactobacillus casei* ATCC334 to ferment jackfruit juice, yielding an economically sustainable, bioactive beverage. The treatment maximized probiotic growth and ensured high survival rates during storage. Fermentation maximized antioxidant and antibacterial activity, along with increasing levels of lactic acid and γ-aminobutyric acid (GABA), thus linking the beverage to stress relief and metabolic health. The authors suggest additional studies be carried out on strain diversification as well as encapsulation procedures to maximize probiotic delivery and scalability, thus positioning jackfruit as a sustainable source for lacto-fermented functional beverages.

Kaprasob*et al.* (2018) highlighted the health-promoting capacity of *Lactobacillus plantarum*-fermented cashew apple juice (CAJ) and concentrated cashew apple juice (CCAJ). The research assessed physicochemical characteristics, astringency-related compounds, antioxidant activities, and aromatic profiles of the fermented juices. Interesting results were consistent with uniform total phenolic content after fermentation, where condensed tannins increased and hydrolyzable tannins decreased, thus lowering astringency. Antioxidant activity varied but remained constant overall. Fermented CAJ had higher DPPH radical scavenging, while fermented CCAJ had higher ABTS activity, which reflects different mechanisms of antioxidant action. Higher volatile compounds in CAJ led to a more desirable flavor, hence qualifying as a functional beverage with lower astringency and increased health benefits. The research identifies the cashew apple juice value-added potential as probiotic products through lactic acid fermentation, opening gates to further innovation in this direction.

The application of probiotics in plant matrices is an emerging area of food biotechnology, but some challenges persist. Appropriate strain selection, inoculum optimization, and viability on storage at 4°C are major challenges. Substrate-dependent parameters—pH, acidity, and phytonutrient-micronutrient interaction—are also significant in determining probiotic viability (Valero-Cases *et al.* 2020; Bernal-Castro *et al.* 2023). The substrate matrix and dosage also directly impact probiotic functionality in the colon.

Development of probiotic carriers from plants is vital to the progress of dairy alternatives. Effective production depends on a comprehensive understanding of fermentable phytochemicals in various crops and quality control during fermentation. Stringent control of physicochemical parameters, including pH and nutrients, is essential to maintain probiotic viability and functional ability. Overcoming these challenges will facilitate cost-effective production of non-dairy probiotics at sensory, nutritional, and therapeutic levels to meet various consumer requirements.

Cereal-based probiotic beverages

The extensive accessibility and rich nutritional profile of cereals have piqued interest in utilizing them as viable resources for crafting innovative fermented goods. Cereal and cereal component-based products provide options for the human diet, including probiotics, prebiotics, and fibre. Cereals are claimed to fulfil the prebiotic principle because they contain water-soluble fibre like glucan and arabinoxylan, oligosaccharides such as galacto- and fructo-oligosaccharides, and resistant starch. Phytoestrogens, phenolic compounds, antioxidants, phytic acid, and sterols are the phytochemicals present in whole grains (Katina *et al*. 2007). Fermented cereals, popular mainly in Africa, are also health benefits as they possess the plant-based Phyto-constituents that exert anti-carcinogenic, hypoglycemic, anti-inflammatory, and antioxidative properties. Further, the enzymes such as phytase, lipase, protease, and amylase, which are released during fermentation, also improve the nutritional status of the beverage. A probiotic non-dairy beverage was launched in Sweden in 1994. The product was a *Lactobacillus plantarum* fermented cooked oatmeal gruel blended in a fruit drink. It contains approximately 5×10^{10} CFU/gof *Lactobacillus plantarum* 299v/L (Molin, 2001). The probiotic organism in the fermented oat gruel reduced abdominal bloating in individuals with irritable bowel disorder when given to them as a rosé hip fruit beverage supplement. The bacteria significantly boosted carboxylic acid levels in healthy subjects' faeces and decreased fibrinogen levels in their blood. The mucosal cells get their energy from short-chain fatty acids (SCFAs) like carboxylic acid. Increased SCFA could be related to a shift in intestinal microbial composition caused by *Lactobacillus plantarum* use.

Consumers gain benefits from probiotics as well as wholegrain foods, such as nondigestible carbohydrates, soluble fibre, phytochemicals, and other bioactive components, when probiotics are combined with wholegrain products. When *Lactobacillus rhamnosus*, *Lactobacillus plantarum*, and *Lactobacillus lactici* were tested for their capability to ferment oat bran carbohydrates and oligosaccharides, all three bacterial strains ferment oat gluco-oligosaccharides, while only *L.plantarum* fermentxylo-oligosaccharides. Lactic acid, acetic acid, formic acid, and ethanol were the predominant fermentation end products (Lamsal and Faubion, 2009). Functional Cereal-Based Probiotic Beverages offer several health-promoting properties (Table 3).

While probiotics have long been associated with fermented dairy products, cereal-based products were established primarily to provide a combination of probiotics, prebiotics, and dietary fibre. The bran and germ give the majority of the bioactive components present in grains. In contrast, whole grain cereals and cereal components could be used as probiotic carriers, which give both healthy bioactive components and fibre. The cereals with the highest glucan content, recognized as the principal functional component of cereal fibres, are oats and barley. Research indicates that this compound exhibits a hypocholesterolemic effect, leading to a 20–30% decrease in LDL cholesterol levels and reducing cardiovascular risk

Table 3: Functional Cereal-Based Probiotic Beverages: Ingredients, Fermentation, and Health-Promoting Properties

Beverage	Ingredients	Microbial composition	Health benefits	Fermentation process	Key Findings	Reference
Cereal-based probiotic beverage	Cereal grains (oats, barley, buckwheat, red rice)	*Lactobacillus plantarum, Lactobacillus rhamnosus, Lactobacillus lactici*	Probiotics, prebiotics, fibre, antioxidants, anti-inflammatory, anti-carcinogenic, hypoglycemic, and gut health benefits	Fermentation with probiotics like *Lactobacillus* spp.	Improved nutritional profile, including high fibre, antioxidants, and prebiotics. Probiotic count: 9.70 log CFU/ml.	Kokwar *et al*. 2022
Boza	Wheat, rye, millet, maize, sugar, saccharine	*Lactobacillus plantarum, Lactobacillus acidophilus, Saccharomyces cerevisiae, Candida species*	Probiotic effects, gut health, immune support, bioactive compounds, and antioxidative properties	Fermented for 1–3 days with yeasts and LAB	Rich in lactic acid bacteria and yeasts. Potential health benefits include digestive health and immune support.	Blandino *et al*. 2003; Kaur *et al*. 2024
Bushera	Sorghum or millet flour, water, germinated millet/sorghum flour	*Lactobacillus brevis, Lactococcus, Leuconostoc, Enterococcus, Streptococcus*	Gut health, digestion, immune support, enhanced nutrient absorption, and probiotic effects	Fermentation for 1–6 days	Probiotic-rich foods increase the bioavailability of nutrients and support digestive health.	Mahajan *et al*. 2024; Vasudha and Mishra, 2013
Mahewu	Maize porridge, sorghum/millet malt, wheat flour, water	*Lactococcus lactis subsp. lactis*	Probiotic effects, gut health, hydration, energy, and digestive support	Natural fermentation with *Lactococcus lactis*	Probiotic-rich foods enhance nutrient bioavailability and improve digestion.	Blandino *et al*. 2003; Chawafambira and Jombo, 2024; Vasudha and Mishra, 2013
Pozol	Maize, lime solution, banana leaves	Diverse microbial community (LAB and yeasts)	Gut health, digestion, immune function, bioactive compounds, and antioxidant properties	Fermentation for 0.5–4 days in banana leaves	Enhances bioavailability of nutrients, rich in antioxidants, and promotes gut health.	Vasudha and Mishra, 2013; Wacher *et al*. 2000; Kirmizigul and Sengun, 2023
Togwa	Maize flour, finger millet malt, cereal or cassava flour	Lactic acid bacteria, beneficial microorganisms	Probiotic effects, gut health, enhanced nutrient bioavailability, and digestive support	Fermentation until pH drops from 4.0 to 3.2	Probiotic-rich, enhances nutrient absorption, supports immune function.	Ajagekar *et al*. 2023; Molin, 2001; Vasudha and Mishra, 2013
New cereal-based probiotic beverage	Oats, barley, buckwheat, red rice, fructo-oligosaccharide, inulin, guar gum, xanthan gum	*Lactobacillus plantarum* NCIM 2084/NCIB 8531	Probiotics, fibre, antioxidants, prebiotics, low glycemic index, lactose-free	Roasting, cooking, and fermentation with *Lactobacillus plantarum*	Probiotic count: 9.70 log CFU/ml, prebiotic score: 1.75, glycemic index: 46.005, shelf-life of 2 weeks.	Kokwar*et al*. 2022

(Enujiugha and Badejo, 2017). Balanov *et al*. (2023) showcased the possibility of creating probiotic wheat beverages abundant in lactic acid and secondary metabolites through fermentation by lactic acid bacteria such as *Lactobacillus delbrueckii, Lactobacillus brevis, Lactobacillus buchneri, Lactobacillus plantarum,* and *Lactobacillus fermentum*, alongside various strains of *Saccharomyces cerevisiae* yeasts. The sensory profile had good aromatic properties like clove, fruity, and banana notes, which predictflavour profiles. These results highlight the possibility of creating probiotic plant-based beverages that have beneficial health effects and good sensory characteristics, hence offering a substitute for animal-based probiotic products.

Boza, a rural-type drink in Bulgaria, Albania, Turkey, and Romania, offers not just a sweet taste but also possible health benefits. The sweet and acidic colloidal suspension of pale to dark beige colour is made from a mixture of wheat, rye, millet, maize, and other cereals, and is usually sweetened with saccharine or sugar. Microbiological examination of Bulgarian boza demonstrates predominance of yeasts and lactic acid bacteria, and a standard LAB/yeast ratio of 2:4. Some of the lactic acid bacteria found were *Lactobacillus plantarum, Lactobacillus acidophilus, Lactobacillus fermentum, Lactobacillus coprophilus, Leuconosto creffinolactis, Leuconostoc mesenteroides,* and *Lactobacillus brevis.*

Furthermore, the yeast strains isolated from boza are *Saccharomyces cerevisiae, Candida tropicalis, Candida glabrata, Geotrichum penicillatum*, and *Geotrichum candidum* (Blandino*et al*. 2003; Kaur *et al*. 2024). Microbial diversity of the ingredients shows possible health-benefiting characteristics of boza. Lactic acid bacteria are widely recognized as probiotics, which help digestion, enhance gut well-being, and enhance immune system functioning.

Yeast-driven fermentation enriches beverages like *boza* with bioactive compounds and nutrients, while grain fermentation enhances nutrient bioavailability and antioxidant capacity, positioning *boza* as a functional drink with therapeutic value and revitalizing properties (Kaur *et al.* 2024).

Bushera, an esteemed food in Uganda's Western highlands, requires 1–6 days of millet or sorghum flour fermentation. Bushera contains many different kinds of lactic acid bacteria with *Lactobacillus brevis* as the most prevalent strain before *Lactococcus* and *Leuconostoc* and *Enterococcus* and *Streptococcus* (Mahajan *et al.* 2024). The LAB bacteria that ferment Bushera help to enhance nutrient absorption in the gut and provide immune system support and probiotic benefits as fermentation increases vitamin and mineral bioavailability. Bushera demonstrates a dual value as a food that supports digestive health and that maintains connections between traditional and modern therapeutic practices (Vasudha and Mishra, 2013).

Mahewu is a traditional drink from both African and Arabian Gulf regions that consists of fermented maize porridge combined with malted sorghum or millet. The fermented maize porridge with *Lactococcus lactis* subsp. *lactis* shows boosted vitamin and mineral as well as bioactive compound levels which enable it to function as a probiotic food that maintains gut microbiota and immune system balance while enhancing digestive performance. The food exhibits dual cultural and health-based benefits through its stimulating acidity and energy-providing functions (Vasudha and Mishra, 2013; Blandino *et al.* 2003; Chawafambira and Jombo, 2024).

Pozol from Southeastern Mexico undergoes nixtamalization with lime and fermentation with banana leaves to generate a beneficial microbial-rich therapeutic drink. Its probiotic-enriched content from microbial fermentation aligns with traditional medicinal use (Vasudha and Mishra, 2013) despite the presence of leftover plant material. Research demonstrates that Pozol fermentation and similar fermented drinks support gut health through their capacity to boost beneficial microorganisms and enhance digestion and immune system regulation. The fermentation of maize in Pozol leads to increased bioavailability of essential nutrients and bioactive metabolites that produce antioxidants together with vitamins and minerals for general health and disease protection. The fermentation process creates therapeutic by-products through microbial activities that produce short-chain fatty acids and antimicrobial peptides which demonstrate anti-inflammatory and immune system regulating capabilities. Pozol functions as both an essential dietary element in cultural traditions and an innovative functional food which delivers extraordinary biotherapeutic benefits. The investigation of microbial components and bioactive properties within Pozol would strengthen its position for nutraceutical and therapeutic uses. (Wacher *et al.*2000; Kirmizigul and Sengun, 2023).

The African staple food known as Togwa serves as both a drink and medicinal remedy throughout the continent. People use this drink to stimulate workers and provide suitable infant food while being made from fermented maize flour and finger millet malt. The process involves boiling cereal/cassava flour and then cooling it so that it can be inoculated with a starter culture derived from germinated seeds and pre-fermented togwa. The fermentation process reduces the pH level to 3.2 through enzymatic breakdown achieved by lactic acid bacteria (LAB) and probiotics. The regular consumption of togwa supports gut health by balancing the microbiota while promoting nutrient digestion and immunity. Research indicates that using togwa as infant nutrition can lead to better developmental outcomes because of its higher digestibility and increased nutritional benefits (Molin, 2001; Vasudha and Mishra, 2013).

The fermentation process during togwa production enhances the bioavailability of nutrients which leads to better absorption of vitamins and minerals along with bioactive compounds that support overall health. Togwa functions as both an energizing beverage and a therapeutic food with medicinal properties. The nutritional benefits of togwa become apparent through its use as an infant weaning food because its digestibility and nutrient content support the achievement of early growth milestones. Togwa serves as a vital dietary element for African populations because of its probiotic-rich content and high nutrient availability that supports better health (Ajagekar *et al*. 2023).

Kokwar*et al.* (2022) designed a cereal drink consisting of oat, barley, buckwheat, and red rice in a 6:2:1:1 ratio. The grains underwent roasting, cooking, and homogenization before being inoculated with *Lactobacillus plantarum* (NCIM 2084/NCIB 8531). Sensory and functional qualities of the product improved through the use of fructo-oligosaccharides (flavor enhancement, probiotic growth) together with guar gum for textural stability. The drink contained 4.50 grams of dietary fiber per 100 milliliters alongside 55.28 milligrams GAE of phenolics per 100 milliliters and 34.61 percent antioxidant activity and a glycemic index of 46.005. The product contained 9.70 log CFU/mL of probiotic viability and lasted for two weeks when refrigerated. The lactose-free beverage serves as an alternative for dairy-allergic consumers through its prebiotic and probiotic

Soy-based probiotic beverages

Soy-based probiotic beverages offer a promising avenue for harnessing the health benefits of soy while incorporating beneficial probiotic strains. Some symbiotic soy drinks with their traits are indicated in Table 4.

A standard soy-based beverage is soy milk *Lactobacillus casei, Lactobacilluspara casei, Bifidobacterium breve,* and *Lactobacillus mali* have been recognized as efficient starters for fermenting soy milk, resulting in enhanced fermented soy milk products with increased flavour and bioactivity (Shimakawa*et al*. 2003). According to Gomes *et al*. (2021), an eight-week consumption of a vegetable drink based on soy fermented with kefir was capable of lowering blood lactate, increasing physical performance, and buffering the effects of oxidative stress on the skeletal muscle of Wistar rats exposed to high-intensity anaerobic exercise.

The weight loss properties of a probiotic soy drink have been investigated in mice with diet-induced obesity (de Carvalho Marchesin *et al.* 2018). The daily consumption of this drink caused a significant decrease in body mass while stopping the increase of fat cell size and altered cytokine patterns which promote obesity-related inflammation. The study

Table 4: Soy-based probiotic and symbiotic beverages: Innovations, health benefits, and consumer trends

Aspect	Details
Common soy-based beverage	Soy milk fermented with probiotics like *Lactobacillus casei*, *Lactobacillus paracasei*, *Bifidobacterium breve*, and *Lactobacillus mali*.
Enhanced fermentation benefits	Improved flavour and bioactivity of soy milk through fermentation.
Health benefits	Lowering blood lactate levels, increasing physical performance, and buffering oxidative stress in skeletal muscles (Gomes *et al*. 2021). - Anti-obesity effects: Reduced weight gain, adipocyte hypertrophy, and modulation of gut microbiota and cytokine expression in diet-induced obesity models (de Carvalho Marchesin *et al*. 2018).
Consumer trends	There is a growing demand for vegan, low-fat, mineral-rich, and low-calorie products with disease-preventive properties.
Innovative symbiotic beverage	Combination of soy milk with sea buckthorn syrup (20%) or powder (3%), fortified with inulin (1% or 3%), fermented using *Lactobacillus casei* subsp. *paracasei*. - Fermentation at 30°C or 37°C, with storage at 4°C ± 1°C for 14 days. - Measured parameters: survival of probiotics, pH, titratable acidity, and water holding capacity.
Sensory and nutritional benefits	The addition of inulin ensures microbiological safety and enhances sensory attributes. - Sea buckthorn contributes bioactive compounds, enhancing the beverage's health benefits.
Key study outcomes	Novel symbiotic beverages with favourable sensory and health-promoting properties. - Effective probiotic viability and microbiological safety during storage (Maftei *et al*. 2023).

results showed that probiotic intervention through microbial community management led to positive changes in gut microbiota structure which affected metabolite generation and inflammation responses that reduced obesity development.

Maftei *et al*. (2023) created symbiotic soy beverages which contain sea buckthorn and inulin fermented with *Lactobacillus casei* subsp. *paracasei*to serve the increasing vegan-friendly functional food market. The researchers established ideal fermentation conditions by identifying temperature ranges between 30 and 37 degrees Celsius combined with inulin concentrations between 1 and 3 percent and proper probiotic viability levels. Refrigerated storage at 4 degrees Celsius with a deviation of up to 1 degree Celsius for 14 days enabled the preservation of probiotic strength and pH levels and water content. Inulin addition to the product improved both taste quality and safety standards thus creating a vegan-friendly low-calorie product that contains abundant minerals. The research demonstrates the potential of plant-based symbiotics to produce health advantages which align with commercial sensory and functional requirements.

Alcoholic probiotic beverages

Beverages often consumed, such as wine, and beer, can provide a significant quantity of dietary antioxidants. The rapid rise in global interest in non-dairy probiotics has prompted researchers and the industry to devote time and resources to developing various non-dairy probiotics. Another category of probiotic beverages/drinks includes alcoholic or non-alcoholic wines and beers, which have emerged as a new alternative in the present scenario.

Probiotic wines

Probiotic wines combine the benefits of traditional fermentation with health-promoting microorganisms, offering enhanced antioxidant, antibacterial, and digestive properties while maintaining desirable flavour, ethanol content, and microbial viability during storage. Some of the functional probiotic wines and their therapeutic potentials are depicted in Table 5.

Red wine polyphenols and probiotic strains have been found to offer several benefits in the enhancement of colonic metabolism and health. Caffeic and p-coumaric acids, as well as grape seed

Table 5: Functional probiotic wines: Microbial insights, additives, and therapeutic potential

Aspect	Details
Health benefits	Red wine polyphenols and probiotics enhance colonic metabolism and health.- Antiadhesive properties against pathogens like *Saccharomy cesmutans* through phenolic compounds (Esteban-Fernández *et al*. 2018).
Functional additions	*Aloe vera* and mint as substrates yielded wines with desirable ethanol, phenolic content, and antibacterial activity (Chauhan *et al*. 2015).
Probiotic strains	*Lactobacillus brevis*, *Lactobacillus hilgardii*, *Lactobacillus plantarum* isolated from wine showed strong antibacterial activity (Kačániová *et al*. 2020).
Herbal probiotic wine	*Tinospora cordifolia* fermented with *Lactiplantibacillus pentosus GSSK2* exhibited high ethanol, phenol content, and antioxidant capacity, with significant antibacterial activity (Kamboj *et al*. 2023).
Rosé wine	First instance of *Saccharomyces cerevisiae var. boulardii* used in rosé wine, retaining probiotic viability for 6 months, suitable for large-scale production (Mulero-Cerezo *et al*. 2023).
Functional Huangjiu	*Saccharomyces cerevisiae* strain BR14 enhanced ethanol and volatile flavour compounds, showcasing its potential in functional food applications (Mu *et al*. 2023).

and red wine oenological extracts, have antiadhesive properties, according to Esteban-Fernández*et al*. (2018) when mixed with *Saccharomyces dentisani*, both caffeic and p-coumaric acids improved their ability to block *Saccharomyces mutans* adherence. Additionally, UHPLC–MS/MS study revealed that wine phenolics are metabolized in the mouth due to both cellular and bacterial action.

Wine has long been studied to see if it has any potential health advantages. Much recent research has claimed that moderate wine drinking is favorable to our health. LAB strains have antagonistic properties. This includes pathogen adhesion to the intestine, pathogen alteration for adhesion to the intestinal epithelium, aggregation, co-aggregation, and production of antimicrobial substances, such as LAB of animal origin products, and the gut microbiota of both humans and animals has been extensively researched, with their antagonistic and probiotic properties thoroughly documented.

Chauhan *et al*. (2015) used Aloe and mint as substrates for wine production. The wine exhibited favorable ethanol levels and significant phenolic content, suggesting strong potential as a novel functional beverage. Probiotic-supplemented wine had better in vitro antibacterial activity than Aloe-Mint extract and Aloe-Mint wine, suggesting that it is a better beverage in terms of medicinal usefulness. As a result, value-added probiotic wine made from Aloe vera and *Mentha arvensis* could be a contender in the growing category of health-beneficial beverages. Kačániová *et al*. (2020) isolated *Lactobacillus brevis, Lactobacillus hilgardii,* and *Lactobacillus plantarum* from the wine, which exhibited antibacterial activity against the tested bacterial pathogens. Probiotics can include a wide range of microorganisms. The most prevalent are bacteria from the *Lactobacillus, Lactococcus*, and *Bifidobacterium* genera. Many articles have already discussed the benefits of yeasts from the *Saccharomyces* genus, such as *Saccharomyces boulardii*, alongside other non-*Saccharomyces* yeasts, sometimes also known as wine yeasts (Vilela *et al*. 2020).

The scientifically established medicinal advantages of *Tinospora cordifolia*, coupled with the increasing demand for functional foods, have ignited considerable interest in advancing functional beverages. Kamboj *et al*. (2023) conducted a study to create a probiotic-enhanced herbal wine that incorporates the advantages of both phytochemicals and probiotics, with a specific emphasis on *Lactiplantibacillus pentosus* GSSK2. Through a series of experiments, it was determined that the fermentation of *Tinospora cordifolia* stems, when combined with ammonium dihydrogen phosphate, potassium phosphate, magnesium sulfate, isoleucine, and thiamine, yielded the most favourable results. This combination optimized physical parameters and led to the highest levels of ethanol content (ranging from 6.8% to 10%), total phenol concentration (ranging from 419 to 791.5 μg/ml), and antioxidant capacity (ranging from 98.2 to 160.4 μmol/ml). Subsequently, the prepared herbal wine was individually supplemented with seven distinct probiotic strains, with *Lactiplantibacillus pentosus* GSSK2 emerging as the most robust, boasting an 88.6% survival rate compared to other probiotics. Moreover, it demonstrated complete safety by exhibiting 100% survivability in HEK-293 and THP-1 cells. Interestingly, both the probiotic-supplemented herbal wine and the probiotic-enhanced herbal wine exhibited vigorous antimicrobial activity against Gram-positive and Gram-negative bacterial strains. The probiotic-supplemented herbal wine showed a strong inhibition zone of 19 to 21 mm, greater than the 18 to 19 mm inhibition zone of the control herbal wine. It is a novel study demonstrating the in vitro antibacterial and antioxidant activities and the safety profile of probiotic-enhanced herbal wine as a novel and valuable functional beverage.

A pioneering study explored the use of *Saccharomyces cerevisiae* var. *boulardii* to develop alcoholic and non-alcoholic rosé-style wines, marking the first application of this probiotic yeast in wine-making. Researchers analyzed volatile acidity, lactic acid, and malic acid levels pre- and post-fermentation/distillation, comparing results to conventional *Saccharomyces cerevisiae* EC-1118. The study also quantified gluconic acid and free amino nitrogen in initial musts. Notably, the probiotic rosé maintained viability for six months under ambient and refrigerated conditions, highlighting its suitability for large-scale production with prolonged storage needs, benefiting both manufacturers and consumers (Mulero-Cerezo *et al.* 2023).

Parallel research by Mu *et al.* (2023) investigated *Saccharomyces cerevisiae* BR14 in functional Huangjiu production. As a probiotic starter, BR14 augmented ethanol content while elevating acidity, particularly acetic and lactic acid concentrations. It also catalyzed the synthesis of diverse volatile aroma compounds, enhancing the wine's flavor complexity. These findings underscore BR14's multifunctional role, demonstrating the potential of probiotic yeasts to improve nutritional and sensory profiles in fermented foods, aligning with growing interest in health-focused food innovation.

Probiotic beers

Functional beers can be made using probiotic yeast or *lacticaseibacilli* strains during fermentation. Putative probiotics must exhibit therapeutic activity and be resistant to in vivo activity because they are usually added to the diet to promote intestinal balance. Functional and Sensory Enhancements in Probiotic Beer Production are given in Table 6. Beer containing probiotic bacteria must be declared as alcohol-free beers (AFBs) with less than 0.5% (v/v) ethanol or low-alcohol beers (LABs) with less than 1.2% (v/v) ethanol. *Saccharomyces cerevisiae* var. *boulardii* was found to ferment brewery wort. Through regulation of process parameters and conditions, the same yeast could produce higher volatile chemicals (Senkarcinova *et al*. 2019).

In a study, Domínguez-Tornay *et al*. (2024), explored the production of probiotic beer through investigating various brewing techniques, hop varieties, and fermentation methods. They compared the effects of boiling stage hopping and dry hopping methods, the utilization of Bobek or Crystal hop varieties, and the fermentation process involving solely *Sacharomyces cerevisiae* yeast or co-fermentation with *Lactobacillus plantarum* bacteria. Their findings revealed that dry hopping, particularly with Bobek hops, resulted in higher *Lactobacillus plantarum* cell viability levels, meeting the minimum thresholds for health-promoting benefits. Furthermore, beers produced through co-inoculation with *Lactobacillus plantarum* and dry hopping showcased elevated polyphenols and volatile compounds concentrations. This combination contributed to enriched sensory profiles characterized by fruity and floral descriptors. While co-fermentation with *Lactobacillus plantarum* led to higher levels of phenolic acids, it did not significantly affect the beer's overall composition and flavor properties compared with the beers fermented in the absence of *Lactobacillus plantarum.*

Table 6: Enhancing beer with probiotics: Health and functional insights

Aspect	Details
Health benefits	Probiotic beers can enhance intestinal balance with therapeutic effects.
Probiotic strains	*Saccharomyces cerevisiae var. boulardii* used for beer fermentation, enhancing volatile compounds and sensory profiles (Senkarcinova*et al.* 2019).
Functional beer studies	Co-fermentation with *Lactobacillus plantarum* and dry hopping increased polyphenols and volatile compounds, enriching sensory properties with fruity and floral notes (Domínguez-Tornay *et al.* 2024).
Craft beer advantages	Craft beers with *Saccharomyces boulardii* showed increased antioxidant activity and polyphenol content, offering unpasteurized and unfiltered health benefits (Capece *et al.* 2018).
Probiotic delivery	Beer with *Saccharomyces boulardii* demonstrated lower turbidity, reduced alcohol content, and marginally lower pH, presenting a healthier alternative with enhanced nutritional value and sensory satisfaction (Diaz *et al.* 2023).

Craft beers have gained popularity concerning all beers in the past few years. Craft beer, being unpasteurized and unfiltered, can be a novel agent that contributes to health benefits. Due to high phenolic antioxidants and low ethanol content of beer, people have been more attracted to this beverage in recent years. Compared to beers made from single starters, application of *Saccharomyces cerevisiae* var. *boulardii* strain with mixed starters improved antioxidant activity and polyphenol content, which means that *Saccharomyces cerevisiae* var. *boulardii* strains were found to affect these parameters. Some of the mixed starting cultures used in this research proved to be a promising way of enhancing the product's health value, e.g., antioxidant activity and polyphenol content (Capece*et al.* 2018).

The search for new non-dairy probiotic food sources has become significant due to lactose intolerance, milk allergy, and the rising trend towards vegetarianism. Diaz *et al*. (2023) carried out research focused on beer as a carrier to convey probiotics, utilizing the *Saccharomyces boulardii* strain as a new alternative to the traditional brewer's Yeast. There were significant differences in the physicochemical characteristics between beers manufactured by utilizing *Saccharomyces boulardii* and beers manufactured by the conventional brewer's Yeast. The probiotic beers had lower turbidity, a characteristic that could be beneficial to the subsequent filtering processes, along with comparatively lower alcohol content in some instances. This positioning as a healthier alternative, coupled with slightly lower pH values, is an interesting line of reducing the risk of spoilage. Including a sensory analysis aspect, both the probiotic and control beers were analyzed, with the same findings in the overall experience. This overall study contributes to the production of non-dairy probiotic foods by suggesting the possibility of utilizing probiotic *Saccharomyces boulardii* for beer manufacture, with additional nutritional value and sensory experience.

Gaps and potential solutions

Despite their great potential and rapid growth, several gaps and obstacles need to be addressed to unlock their full potential and market value.

Limited evidence of specific health benefits

While there is overall evidence regarding the health benefits of probiotics, there is minimal direct scientific evidence on the health benefits of non-dairy probiotic beverages. More research has to be conducted to determine their effectiveness in maintaining gut health, boosting immunity, and preventing disease.

Variation in probiotic viability

The stability of probiotics in non-dairy drinks is variable concerning pH, fermentation conditions, and storage. It is essential that the number of live probiotics be adequate when consumed for their efficacy.

Consumer education and awareness

There is insufficient consumer knowledge and education on the benefits of non-dairy probiotic beverages compared to traditional dairy beverages, which may restrict market development and consumer adoption.

Regulatory and quality control problems

The regulatory environment for probiotic foods is heterogeneous across the markets, and thus there is variation in label statements and quality. Securing high-quality standards and compliance is a significant challenge for manufacturers.

Sensory and taste acceptability

Non-dairy probiotic beverages are generally faced with flavour, texture, and general sensory acceptability. Ensuring they taste good and are palatable is central to the product's success.

Solutions

Expanding clinical validation

Conducting rigorous, targeted clinical trials is critical to validate the health impacts of non-dairy probiotic beverages conclusively. Robust scientific evidence will strengthen credibility and clarify their role in promoting gut health, immune function, and disease prevention.

New production methods

Scientific developments in fermentation systems and ingredient preparation may enhance probiotic viability and stability in plant-based matrices. Studies on novel delivery systems, including microencapsulation, may enhance probiotic shelf-life stability, providing therapeutic efficacy from manufacturing to consumption.

Consumer awareness programs

Educational efforts and education programs are required to generate awareness of the special benefits of non-dairy probiotics, such as allergen-free products and digestive health. Correct labeling with clearly defined health claims will ensure informed consumer choice and stimulate market demand.

Global regulatory alignment

The implementation of universal probiotic labeling regulations together with standardized quality control measures and health claims requirements will create market standardization. A unified approach between industry organizations and regulatory bodies leads to better transparency which results in products that meet consistent safety and effectiveness standards.

Sensory optimization strategies

Companies should allocate their R&D resources to develop sophisticated flavor profiles and mouthfeel while incorporating natural sweeteners along with flavor modulators and texture enhancers to enhance consumer acceptance of non-dairy probiotic drinks while maintaining their nutritional value.

Market expansion and public health effects

Strategic innovations designed to overcome these challenges will result in better product quality and increased consumer trust leading to faster market development. The combination of overcoming formulation and regulatory barriers along with addressing sensory appeal issues establishes non-dairy probiotics as practical options for both public health advantages and dietary variety expansion.

Future outlook and customer trends

Growing market demand

Lactose intolerance together with plant-based eating and probiotic health trends have resulted in soaring consumer demand for dairy-free products. The quest for animal-free gut health products drives consumers to choose new non-dairy alternatives for their probiotic benefits.

Ingredient diversification

Modern research teams explore nontraditional substrates including algae and tubers and pseudocereals as probiotic delivery systems. The growing trend of product differentiation allows companies to reach more consumers by offering vegan and allergen-free options.

Technological breakthroughs

Probiotic survivability within plant matrices improves through strain-specific fermentation together with nano-encapsulation and stabilization technologies. The new methods ensure that beneficial microbes remain active during manufacturing and storage so they last for extended periods with medical benefits retained.

Varied health benefits

Non-dairy probiotic drinks receive attention from consumers because of their antioxidant capabilities and immune system support and prebiotic fiber symbiosis as well as their ability to maintain good gut health. Consumers perceive these products as comprehensive health boosters because they offer various beneficial functions.

Global market penetration

Businesses create region-specific products to match local taste preferences and nutritional demands in response to the increasing market fragmentation of consumer preferences. Market expansion occurs through the implementation of regionalized strategies which target different consumer segments across different geographic regions.

Regulatory harmonization

Market transparency is growing because of better global standards that address probiotics labeling together with efficacy proof and quality assurance. The combined effort of industry representatives and regulatory bodies establishes consistent product quality and develops trust among consumers.

Integration with wellness movements

The growing public interest in holistic health methods has led to an increase of non-dairy probiotics and related products which are now part of personalized nutrition and functional food strategies. Individual dietary therapy becomes more adaptable through their implementation to achieve better long-term well-being objectives.

Green production

The implementation of sustainability-based practices which use upcycled ingredients alongside carbon-neutral packaging systems and energy-efficient processing methods has created a major shift in production approaches. Companies that implement such approaches gain increased market share through their appeal to environmentally conscious customers. Consumer empowerment through education.

Scientific research and success stories from real life are de-mystifying probiotics. Transparent communication of benefits and usage enables well-informed decision-making and accelerates mainstream penetration.

CONCLUSION

The non-dairy probiotic drinks market is a fast-growing niche of the functional food market, appealing to health-conscious and diet-restricted consumers. Trends such as fermented vegetable juice, cereal-based drinks, soy and alcoholic drinks pro-biotic-fortified produce probiotic ingredients' potential to enhance digestion, stabilize the immune functions, and impart antioxidant benefits. However, with enormous challenges looming on the horizon, such as the shelf life of probiotics on storage, sensory improvement of characteristics, and adapting to complex regulatory regimes, their complete potential in the marketplace must be confronted. For their full realization of marketplace potential, future research must increasingly emphasize strain-specific studies, encapsulation technology to ensure improved stability, and large-scale clinical trials to substantiate claims of health benefits. Simultaneously, consumer awareness of probiotic use and adherence to sustainable manufacturing practices must continue to promote enhanced acceptance. As global demand for plant-based and functionally enriched beverages keeps rising, non-dairy probiotics are bound to be a part of the world's nutrition, harmonizing health, sustainability, and food variety. Fulfillment of this potential must be preceded by collaborative working among the research community, industry stakeholders, and policymakers to overcome technical and regulatory hurdles. This review highlights the diverse sources and innovative strategies pushing these beverages toward fulfilling extensive consumer demands. Robust scientific evidence underpins their functionality in promoting gut health, immune system support, and contributing to chronic disease risk reduction, making non-dairy probiotics a natural part of current nutritional planning.

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