Review

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*Review*

# Probiotication of Beverages: The Future of Functional Nutrition and Gut Health

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**Abstract:** In recent years, the role of probiotics in human health has gained significant attention, particularly in the functional food industry due to their modulatory potential both at gut and immunological level. Probiotics can be used in various forms, including dietary supplements, fermented foods, and topical applications. Among these probiotication of beverages is gaining significant interest in community due to its multifactorial response. Probiotic beverages, both dairy-based and non-dairy formulations are a better way of introducing beneficial microorganisms into the diet leading to balanced gut microbiota, enhanced immune function, and may also contribute in prevention and management of various health conditions. Moreover, the rising consumer demand for health-centric beverages has propelled the development of novel probiotic formulations, paving the way for future advancements in functional nutrition. Therefore, the current review provides a comprehensive analysis of probiotic beverages vis-á-vis their classification, health benefits, and market growth. Additionally, it highlights challenges in maintaining probiotic viability in different beverage matrices and explores innovative strategies to enhance their effectiveness.

**Keywords:** probiotic beverages; functional foods; fermented drinks; dairy-based probiotics; non-dairy probiotic beverages

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## Introduction

The process of probiotication involves the inoculation of beneficial microorganisms into a liquid substrate to create functional beverages that subsequently add market value due to the numerous health benefits of probiotics (Moreira *et al*., 2025). Consumers have now accepted the notion of "Let food be thy medicine and medicine be thy food" due to more consciousness nowadays for maintaining and taking care of their health, leading to increased life expectancy in developing and developed nations (Kechagia *et al*., 2013). The concept of functional foods initially focused on finding foods that are employed to treat diseases and provide health benefits. Functional foods are also referred as medicinal foods, nutraceuticals, prescriptive foods, therapeutic foods, superfoods, designer foods, foodiceuticals, and medifoods that can be consumed in different forms i.e. either as fermented products/beverages or non-fermented products/beverages, e.g fruit juices, beetroot, fortified juices, fermented milk etc. (Prado *et al*., 2007). Probiotic beverages have been an integral part of human diets for thousands of years as fermentation or supplementation of foods/beverages with probiotics enhances their nutritional value, taste, and shelf life along with numerous health benefits (Panda *et al*., 2021). Moreover, fermentation has long been recognized globally for its role in food processing and preservation, traditionally relying on microorganisms from natural microbiota. However, with the expansion of the functional food market, the use of starter cultures has become prevalent, ensuring greater consistency and efficiency in fermentation processes (Sangwan *et al*., 2014).

The term probiotic is derived from greek word and means "for life" as opposed to the term antibiotic (Hill *et al*., 2014). According to Food and Agriculture Organization/World Health Organization guidelines defined probiotics as 'live microorganisms, which, when administered in

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adequate amounts confer health benefits to the host' (Mazziotta *et al*., 2023). More specifically, probiotics are commonly found both in fermented foods or dietary supplements and have been researched for their potential to modulate gut microbiome vis-à-vis immune system thereby alleviating various gastrointestinal disorders, due to which probiotics are also referred as "Gastrointestinal Interference Therapy".

Fermented beverages are age-old products that serve as carriers of probiotics in the human diet. Probiotic beverages offer a convenient and effective alternative to probiotic-rich foods, providing an easy way to incorporate beneficial bacteria in one's diet due to their gut-modulating potentiality mostly required for efficient digestion and nutrition absorption (Kandylis *et al*., 2016). The fermentation of milk, cereals, and various substrates with probiotics to create health-enhancing beverages is a traditional practice across Asia, Africa, Europe, the Middle East, and South America. Probiotic beverages are mainly categorized as dairy-based probiotic beverages and non-dairy based probiotic beverages based on their source. These drinks, such as kefir, kombucha, and probiotic-infused juices, are typically fermented with live cultures that promote a healthy gut microbiome (Panda *et al*., 2021). Unlike solid probiotic foods, which may require more preparation or have specific dietary restrictions, probiotic beverages are often ready to consume. Additionally, non-dairy probiotic beverages like water kefir, kombucha, or other plant-derived beverages can be a great option for lactose intolerant or preferably vegan individuals. Fermented beverage like kombucha is normally produced by fermenting sweetened tea with a symbiotic culture of bacteria and yeast (SCOBY) has gained popularity as natural sources of probiotics due to presence of beneficial microbes and organic acids leading to improved gut health and antioxidant properties (Jayabalan *et al*., 2014; Villarreal-Soto *et al*., 2018). The beverage industry has responded to the growing demand for probiotic products by developing various non-dairy options e.g. fruit juices, have been supplemented with probiotics to cater to consumers seeking dairy-free alternatives (Ranadheera *et al*., 2017; Reque & Brandelli, 2021; Natt and Katyal, 2022). Moreover, these probiotic beverages have been shown to alleviate symptoms of irritable bowel syndrome (IBS) and reduce the incidence of antibiotic-associated diarrhea vis-á-vis strengthening the immune system (Fenster *et al.,* 2019). Fenster *et al* (2019) have also indicated that regular consumption of probiotic-rich drinks can reduce the duration and severity of respiratory infections. In addition to gut and immune health, emerging research suggests that probiotic beverages may have positive effects on mental health and can alleviate symptoms of anxiety and depression, although more research is needed as efficacy of probiotic beverages are very much dependent on specific species and strains used, dosage, and individual health conditions (Laali *et al*., 2018; Fenster *et al*., 2019; Merkouris *et al.,* 2024). Keeping the beneficial potential of probiotic beverages, this review summarizes different types of both dairy and non-dairy based probiotic beverages and their impact on human health along with their future prospects.

## Traditional Fermented Beverages

Traditional fermented/preserved foods and beverages have long been intertwined with ethnic traditions and cultural heritage, serving as essential components of ancient diets (Flach *et al*., 2018). Moreover, historical records have indicated that between 2000 and 3000 BC, fermented milk products, including milk, butter, and cheese, were consumed widely across the various civilizations, i.e. Indians, Egyptians, Greeks, and Romans (Caramia *et al*., 2008). Further, archaeological evidence from pottery vessels suggests that fermented beverages were made either from rice, honey or fruits, in China as early as 7000 B.C. (Dufresne & Farnworth; 2000). Traditionally, beverages were prepared without an understanding of the scientific principles behind microbial involvement; but nowadays, modern food scientists have started harnessing lactic acid bacteria (LAB) with probiotic properties to transform indigenous foods and beverages into innovative formulations that align with evolving consumer demands (Behera *et al*., 2020).

## Probiotic Beverages

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Functional drinks are among the most advanced products in the market and are widely valued by consumers for their health benefits particularly gut, liver, immune response and nutritional content. The global Probiotic Drinks Market size is estimated at USD 45.17 billion in 2025, and is expected to reach USD 72.15 billion by 2030, at a Compound annual growth rate (CAGR) of 9.82% during the forecast period between 2025 and 2030. Conventionally probiotic beverages were prepared from dairy products that have traditionally served as the vehicles for probiotic bacteria in humans such as yogurt, kefir, acidophilus milk and butter milk, but due to high cholesterol level and lactose intolerance in some people its use was limited (Prado *et al*., 2008). To overcome such issues, non-dairy based probiotic beverages are taking over the market and diverse non-dairy based probiotic beverages from seeds, grains, legumes, fruits, vegetables etc have been developed, for example : oat milk, sesame milk probiotic, apple juice based probiotic beverage etc. (Tiwari *et al*., 2011). More specifically, increased awareness regarding health and fitness trends has prompted young consumers more due to low-calorie, high biotic compound potential and are safe for lactose intolerant population (Panghal *et al*., 2018).

To maximize the modulatory potential of probiotic beverages, fortification is being carried out with a group of nutrients that favors the growth of gut microbiota and is referred as prebiotics that may be present in both dairy and non-dairy products. These prebiotics may interact with probiotics to change their functional properties and majority of them are oligosaccharide such as inulin, fructo-oligosaccharides, galacto-oligosaccharides, isomalto-oligosaccharides, human milk oligosaccharides, xylo-oligosaccharides, xylan, lactulose, oat fiber (β-glucan), pectin, guar gum, resistant starch, stachyose, certain polyphenols, bacteriophages, omega-3 fatty acids, and yeast hydrolysate (Das *et al*.,2019; Ansari *et al*.,2020; Olson *et al*.,2022). Prebiotics are naturally present in different dietary food products, including asparagus, sugar beet, garlic, chicory, onion, Jerusalem artichoke, wheat, honey, banana, barley, tomato, rye, soybean, human's and cow's milk, peas, beans, seaweeds and microalgae. Some of the prebiotics are produced by using lactose, sucrose, and starch as raw material (Varzakas *et al*., 2018). Non-dairy probiotic beverages may contain prebiotics such as inulin that may interact with probiotics to change their functional properties (Ranadheera *et al*., 2017). So, the choice of having a dairy or non-dairy based probiotic beverage totally depends on the purpose of consumption (i.e the health concern) and the consumer's preference. The various types of probiotic beverages with specific examples are summarized in **Figure 1**.

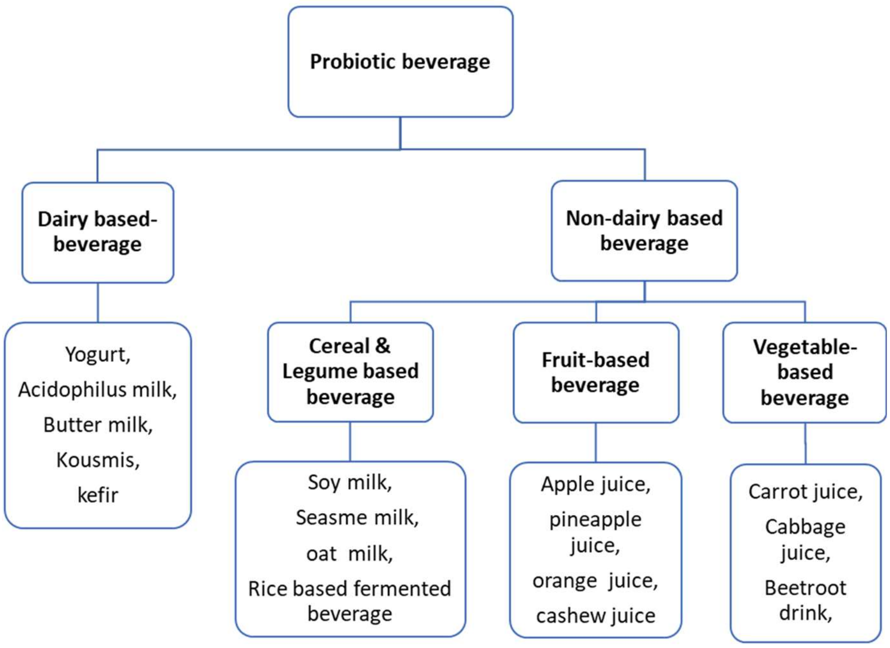


**Figure 1.** Categorization of probiotic beverages into dairy based beverage and non- dairy based beverage with examples.

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## Dairy Based Beverages

Probiotic dairy based beverages, serving as functional foods has long been in the market, accounting for over 40% of this market. As per Future Market insights the segment of dairy based probiotic beverage accounted for 55.4% of the global market in 2022. Since the probiotic growth is considered more favorable in fermented dairy or yogurt based beverages, the consumption or popularity of these probiotic drinks have increased exclusively, all over the world.

Fermented dairy product drinks commonly containing lactic acid bacteria (LAB) as probiotics are becoming increasingly common in the dairy sector. The various types of commercial dairy based probiotic products and the microorganisms used are listed in **Table 1**.

**Table 1.** Different dairy based probiotic beverages along with probiotic strains used.

| Dairy Based Probiotic Product | Probiotic Strains | References |
|---|---|---|
| Acidophilus milk | *L. acidophilus* | Hati *et al.*, 2013 |
| Acido-bifidus milk | *Lactobacillus acidophilus, Bifidobacterium* spp. | Hati *et al.*, 2013 |
| Kefir | *Lactobacillus kefir* | Kandylis *et al.*, 2016 |
| Yogurt | *Lactobacillus bulgaricus, Streptococcus thermophilus* | Sarkar, 2018 |
| Buttermilk | *Lactobacillus bulgaricus, Lactococcus lactis* | Ranadheera *et al.*, 2017 |
| Bifidus milk | *Bifidobacterium bifidum, Bifidobacterium longum* | Khorshidian *et al.*, 2020 |
| Gheu | *Lactococcus lactis, Lactobacillus helveticus, Acetobacter* spp.,*Gluconobacter* spp. | Shangpliang *et al.*, 2018 |
| Whey beverage | *Bifidobacterium lactis, Lactobacillus acidophilus* | Shori *et al.*, 2015 |
| Kumis | *L. delbreuckii, K. marxianus* | Arslan, 2015; García-Burgos, 2020 |

Yogurt, kefir, and acidophilus milk are typical examples of fermented dairy based probiotic drinks and the most frequently utilized probiotics are *Bifidobacterium* sp., *Lactobacillus* sp., *Lacticaseibacillus* sp., *Limosilactobacillus* sp., *Lactiplantibacillus* sp., *Ligilactobacillus* sp., and *Lactobacillus* sp.. The probiotics, *L. plantarum* and *Bifidobacterium* sp. are frequently used due to their strong antioxidant potential and angiotensin-converting enzyme inhibitory effects caused by presence of proteins, minerals, and fermentation-produced bioactive compounds i.e short chain fatty acids (Meybodi *et al.*, 2020).

*Yogurt Beverages*

Yogurt is made by fermenting milk with specific bacteria, mainly *Lactobacillus delbrueckii* subsp. *bulgaricus* and *Streptococcus thermophilus*. Other ingredients like sweeteners, flavors, colors, thickeners, and vitamins A and D can also be added and is available in various forms, such as spoonable, drinkable, Greek (concentrated), dried, low-lactose, shelf-stable, and frozen (Olson *et al.*, 2022; Gürakan *et al.*,2009). It can also be used as an ingredient in other foods e.g. coating or a snack. In addition to traditional varieties, the development of probiotic yogurt beverages is gaining momentum, driven by increasing consumer demand for functional and value-added products (Sarkar *et al.*, 2018).

*Koumiss (Kumiss)*

Koumiss, also known as airag, a traditional fermented beverage widely consumed by nomadic cattle breeders in Asia and certain regions of Russia. It is prepared using mare's milk, which undergoes fermentation either through back-slopping or natural fermentation processes mainly with *L. delbreuckii* and *K. marxianus* (Kim *et al.*, 2017). It has been traditionally recommended for the management of various health conditions, e.g. tuberculosis, asthma, pneumonitis, cardiovascular disorders, and gynecological diseases. Additionally, koumiss is recognized for its potential to promote weight gain, enhance energy levels, and improve overall robustness (Marsh *et al*., 2014).

*Kefir*

Kefir is a fermented milk product produced with kefir grains or mother cultures Kefir grains comprising of lactic acid bacteria (LAB), yeasts, casein, and complex sugars embedded within a polysaccharide matrix. They also include non-lactose-fermenting yeasts and acetic acid bacteria (AAB), forming a unique symbiotic microbial community. The composition of kefir microbiota varies depending on the substrate and production methods employed and probiotic potential of kefir include protection against toxins and inhibition of *Helicobacter pylori* (Arslan *et al*., 2015).

*Acidophilus Milk*

Traditionally, acidophilus milk is prepared using buffalo milk inoculated with *Lactobacillus acidophilus* (3%–5%) and incubated for 12–16 hours at 38°C–40°C. The process includes breaking the coagulum, cooling, packaging, and storing the product at 5°C. While primarily developed with *L. acidophilus*, it can also be produced using *Bacillus acidophilus*. Acidophilus milk has a very distinctive tangy flavor with short shelf-life as most strains of *L. acidophilus* produce more organic acids at low temperature. Acidophilus milk is recognized for its significant gastrointestinal health benefits (Hati *et al*., 2013). While *L. acidophilus* is the predominant strain used for prepration of acidophilus milk, there is potential for incorporating other beneficial strains, such as *Bifidobacterium* and *Propionibacterium*, having enhanced health benefits (Morya *et al*., 2022). As with sweet acidophilus milk, *L .acidophilus* and *B. bifidum* can be added to cold milk around 5 °C to produce unfermented Acidophilus–Bifidus milk (Özer & Kirmaci, 2010).

*Bifidus Milk*

Bifidus milk, first developed in 1948 in Germany, was the first infant formula to incorporate *bifidobacteria*. Heat-treated milk cooled to 37°C is inoculated with a 10% culture of either *Bifidobacterium bifidum* or *Bifidobacterium longum* and is used in the management of gastrointestinal, liver disorders and constipation (Shilby *et al*., 2013).

*Acidophilus–Bifidus Milk*

Acidophilus–Bifidus milk, also referred to as AB culture, is a fermented dairy product containing *Lactobacillus acidophilus* and *Bifidobacterium* species in 1:1 ratio. Inoculation is achieved at 37 °C using *L. acidophilus* and *B. bifidum* and the incubation is ended at pH 4.5–4.6 which usually takes 14–16 h and the end product is slightly acidic and viscous.

## Drawbacks of Dairy Based Beverages

Dairy based probiotic drinks are consumed by people since long but due to major drawbacks of dairy based probiotic beverages such as lactose intolerance, presence of milk protein allergens and high cholesterol content, their use is limited.

*Lactose Intolerance*

Dairy products contain lactose which is digested by the enzyme lactase produced in our small intestine, but individual devoid of lactase are lactose intolerant, therefore, the lactose in the food

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rather than being processed or adsorbed, moves into the colon and interacts with colon's normal flora leading to lactose intolerance characterized by diarrhea, bloating, vomiting etc (Deng *et al*., 2015).

*Milk protein allergens*

Cow's milk allergy is among the most common food allergies in children, and about 15% of allergic children stay allergic due to two major allergens: casein (αs1-CN) and β-lactoglobulin besides, many other milk proteins. Therefore, presence of the milk protein allergens within the probiotics can trigger several allergies. Teitelbaum et al. 2024 have reported that a 13 year old female developed anaphylaxis after consuming cow's milk protein, supporting the notion that children can be allergic to milk protein.

*High cholesterol content*

The fat level of milk varies based on it's source, as it has been observed that cow milk contains about 4-5 % fat, whereas buffalo milk has roughly 7-8 % fat. However, an excessive intake of saturated fats and cholesterol causes an increase in low-density lipoprotein (LDL) in the blood plasma, and the accumulation of these bad cholesterol leads to atherosclerosis, a condition where the artery experiences a blockage due to plaque formation, and the supply of oxygen to the heart is reduced leading to occurrence of heart attacks and, even death (Rafieian *et al*., 2017).

## Non-Dairy Based Beverages

To overcome the adverse effects of dairy based probiotic beverages, nowadays non-dairy probiotic are preferred due to their health promoting properties and high nutritional value (Kumar *et al*., 2015). The continuing trend in vegetarianism and the exorbitant pervasiveness of lactose sensitivity in broad societies across the world are the other reasons why non-dairy probiotic foods have acquired global prominence. Adding probiotics to fruit juices is inherently more challenging than incorporating them into dairy products due to specific intrinsic properties of fruit juices, such as low pH and high organic acid concentration, compounded by critical factors such as storage time and the probiotic viability. Furthermore, the high perishability and significant water content of fruit juices contribute to increased transportation and production costs (Gomes *et al*., 2021). Fermented as well as fortified- probiotic beverage can also be prepared with non-dairy products. Traditional non-dairy fermented beverages come in a vast array of varieties and a large portion of them are non-alcoholic drinks made primarily from cereal grains (Prado *et al*., 2008). Non-dairy probiotic beverages can be cereal based, vegetable based or fruit based as presented in **Figure 1**. Various types of non-dairy based probiotic beverages and the microorganisms used are listed in Table 2.

**Table 2.** Different non-dairy based probiotic beverages with probiotic strains used.

| Non-Dairy based probiotic product | Probiotic strains | References |
|---|---|---|
| **Fruit & vegetable based beverage** | | |
| Apple juice | *Lactobacillus paracasei, Lactobacillus plantarum, Lactobacillus rhamnosus* | Lilio-Perez *et al*., 2021 |
| Mango juice | *Lactobacillus casei* | Lilio-Perez *et al*., 2021 |
| Mosambi juice | *Saccharomyces cerevisiae, Wickerhamomyces anomalus, Pichia barkeri, Yarrowia lipolytica* | Suvarna *et al*., 2018 |
| Mix of orange, carrot, apple | *Lactiplantibacillus plantarum Bifidobacterium breve and Streptococcus thermop hilus* | de *et al*.,2020 |

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| | | |
|---|---|---|
| Lychee | *Lacticaseibacillus casei* | Zheng *et al*., 2020 |
| Pomegranate | *L. paracasei* K5 | Mantzourani *et al*., 2018 |
| Carrot and orange juice | *Lactobacillus spp., Leuconostoc mesenteroides, Bifidobacterium longum* | Xu *et al*., 2019 |
| Apple, orange and tomato | *L. sanfranciscensis* | Zhu *et al*., 2020 |
| Cabbage juice | *Lactiplantibacillus plantarum, Lactobacillus delbrueckii* | Li *et al*., 2019 |
| **Cereal and legume based beverage** | | |
| Sesame milk | *Lactobacillus delbrueckiisubsp. Bulgaricus Streptococcus thermophilus* | Abd-Elsttar *et al*., 2024 |
| Soymilk | *Bifidobacterium animalis, Lactobacillus acidophilus, Kluyveromyces marxianus, Kluyveromyces lactis, Lactobacillus brevis, Lactobacillus kefir* | Sridharan and Das, 2019 |
| Oat milk | *Lactobacillus plantarum, Bifidobacterium lactis* | Asadzadeh *et al*. 2021 |
| Rice and millet grains beverage | *S. thermophilus, L. acidophilus and Bifidobacterium* BB-12 | Hassan *et al*., 2012 |
| Peanut-soy milk | *Pediococcus acidilactici, Lactobacillus lactis, Lactobacillus rhamnosus, Lactobacillus acidophilus.* | do *et al*., 2014 |
| Chickpeas milk | *Lactobacillus plantarum* | Paredes-Toledo, 2021 |

*Fruit and Vegetable Based Beverage*

Fruits and vegetables are naturally rich in carbohydrates, dietary fibers, vitamins, minerals, polyphenols, and phytochemicals, making them valuable components of a healthy diet (Sutton, 2007). Researchers have explored various fruit and vegetable juices, including tomato, mango, orange, apple, grape, peach, pomegranate, watermelon, carrot, beetroot, and cabbage, as potential raw materials for probiotic juice or beverage production. Fruit or vegetable sugar such as glucose, sucrose and fructose are converted into pyruvate and lactic acid. The d- or l-lactate dehydrogenase enzyme (aldolases enzymes) is a component of the metabolic pathway that converts 1 mol of glucose into 2 mol of lactic acid and 2 mol of ATP (Raj *et al*., 2022). This lactic acid is the main byproduct of fermentation carried out by **lactic acid bacteria (LAB), which are key probiotic organisms**. Fruits not only provide fermentable sugars for LAB but also contain prebiotic fibers that enhance their growth and activity. Commonly used probiotics include various ***Lactobacillus*** species such as *L. acidophilus, L. helveticus, L. casei, L. paracasei, L. johnsonii, L. plantarum, L. gasseri, L. reuteri, L. delbrueckii* subsp. *bulgaricus, , L. fermentum,* and *L. rhamnosus*, along with ***Bifidobacterium*** species like *B. bifidum, B. longum, B. adolescentis, B. infantis, B. breve,* and *B. lactis*. Other probiotics studied include *Escherichia coli* Nissle, *Streptococcus thermophilus, Weissella* spp., *Propionibacterium* spp., *Pediococcus* spp., *Enterococcus faecium, Leuconostoc* spp., and *Saccharomyces cerevisiae* var. *boulardii* (Nagpal *et al*., 2012). A probiotic beverage prepared from cashew apple juice has been shown to be a suitable substrate for probiotic growth without the preservatives or even heat treatment and was stable for up to 42 days under refrigeration with minimal viability and with intensified yellowness during fermentation and storage (Pereira *et al*., 2011). However, a key challenge in probiotic beverage production is that of maintaining bacterial viability throughout storage and consumption due to increased acid production resulting in a gradual decline in pH over time vis-à-vis loss in viability (Hossain *et al*., 2022).

*Cereal and Legume Based Beverage*

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Cereals are a significant source of fiber, proteins, carbohydrates, vitamins, and minerals and have high content of oligosaccharides, carbohydrates, phenolic compounds, antioxidants, phytic acid and phytoestrogens, that can serve as prebiotic substances and encourage the growth of probiotic microbes in addition to being a significant source of nutrients (Riveria *et al*., 2010; Mridula *et al*., 2015; Salmeron., 2017).

Oat (*Avena sativa* L.) is rich in proteins, soluble fiber, and antioxidants, with β-glucan as a key prebiotic (Angelov *et al*., 2018). Oat β-glucans make up the majority of soluble fiber in oats and are widely recognized for their health benefits. Fermentation of oat enhances SCFA production, beneficial gut bacteria, antioxidant capacity, and polyphenols while improving sensory properties (Ninios *et al*., 2011). *L. plantarum* LP09 fermentation reduced the starch hydrolysis index and enhanced β-glucan (Kedia *et al*., 2009). As per the European Food Safety Authority (EFSA), products containing β-glucans can be recommended for the regular consumption as β-glucan helps to maintain normal blood cholesterol levels (Luana *et al*., 2014). Funck *et al* (2019) have observed that oat beverages fermented with *L. curvatus* P99 had high probiotic viability (above 7 log CFU/mL) for 35 days when stored at 4 °C. Ghosh et al (2015) have found that rice (*Oryza sativa* L.) based fermented beverages, common in Asia, show strong antioxidant activity, increased enzyme (glucoamylase, α-amylase, phytase), mineral levels, and enhanced vitamin content. A probiotic rice beverage being fermentated by *L. fermentum* KKL1 and *L. plantarum* L7 had high probiotic survivility, antimicrobial potential, high amount of organic acids and minerals (Giri *et al*., 2015).

Maize (*Zea mays* L.) is rich in starch, protein and fibres, scientists have also found that maize-fermented beverage too supports probiotic growth. *L. paracasei* LBC-81 and *S. cerevisiae*-fermented maize beverages maintained microbial viability (>7 log CFU/mL) at 4 °C for 28 days, producing lactic acid and other organic acids which maintained the low pH (around 4.0) that is important for the food safety, taste, and aroma of the beverages(Menezes *et al*., 2012; Wacoo *et al*., 2019). Freire et al (2017) have observed that rice–maize beverages fermented with *L. acidophilus* LACA 4 and *L. plantarum* CCMA 0743, supplemented with fructooligosaccharides (FOS), maintained probiotic levels (>$10^7$ CFU/mL) at 4°C for 28 days (after 24hrs fermentation) and showed high sensory acceptance. Ganguly *et al* (2021) prepared probiotic composite beverage from whey-skim milk (60:40, v/v), germinated pearl millet flour (4.5%, w/v), liquid barley malt extract (3.0%, w/v) and fermented with *Lactobacillus acidophilus* NCDC 13, had enhanced weight gain efficiency, improved protein quality, digestibility, and increased hemoglobin levels in murine model. Different probiotic starter cultures exert distinct influences on the flavor profile, sensory characteristics, and overall acceptability of the products in which they are incorporated. For instance, the presence of mild acidity, relatively high concentrations of acetaldehyde, and the inclusion of the human-derived strain *Lactobacillus plantarum* NCIMB 8826 have been positively correlated with increased acceptability ratings of probiotic beverages formulated from barley and oats (Salmerón *et al*., 2015). The advantages and disadvantages of cereal based probiotic beverages and fruit, vegetable based probiotic beverages are summarized in **Table 3** and **Figure 2** illustrates the common procedure for preparation of non-dairy based probiotic beverages.

**Table 3.** Non-dairy probiotic beverages: Advantages and Disadvantages.

| Beverage Type | Advantages | Disadvantages |
|---|---|---|
| **Cereal-based** | Rich in carbohydrates, proteins, fiber, minerals, and vitamins with low fat and cholesterol. | May increase viscosity due to starch gelatinization. |
| **Fruit-based** | High in carbohydrates, proteins, fiber, minerals, and vitamins, with bioactive compounds offering health benefits. | Various fruit types provide distinct tastes and aromas which are sometimes unacceptable. |

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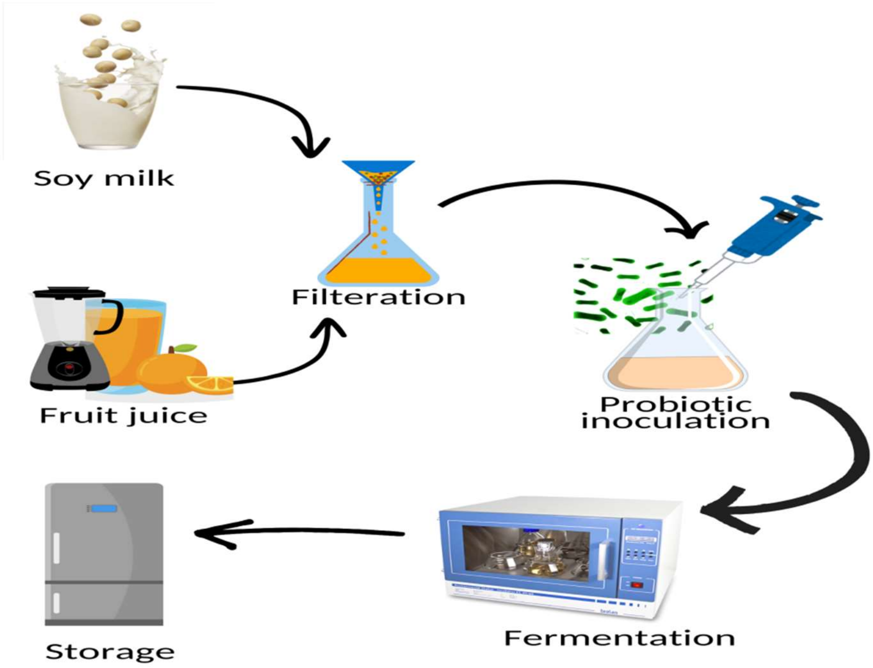


**Figure 2.** Process of production of non-dairy beverages.

## Drawbacks of Non-Dairy Beverages

The viability of probiotics in food products is influenced by several factors, including water activity, pH, and probiotic strain type. Among these, pH plays a critical role, particularly in fruit and vegetable juices, where high concentrations of organic acids and dissolved oxygen create a highly acidic environment that may hinder probiotic survival despite the presence of essential nutrients. Storage conditions further impact probiotic stability as these products are generally stored at room temperature, which can significantly compromise probiotic survival due to increased metabolic activity and potential thermal stress (Abu-Ghanna and Rajauria, 2015). To overcome these challenges and develop a stable non-dairy probiotic product, selection of strain and protective techniques are essential. Methods such as microencapsulation, the incorporation of prebiotic compounds, and optimizing formulation conditions can enhance probiotic survival, ensuring their retained health benefits throughout the product's shelf life. The main characteristic features of dairy and non-dairy based probiotic beverages are described in **Figure 3**.

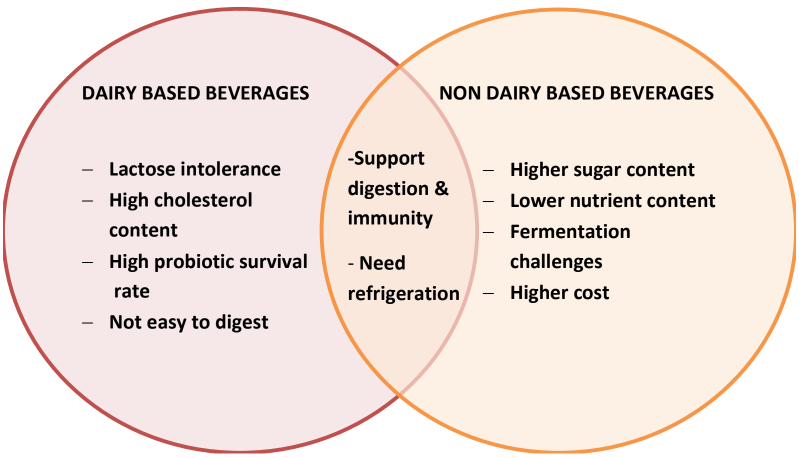


**Figure 3.** Comparison between dairy and non-dairy based probiotic beverages.

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## Strategies to Improve Probiotic Survival in Fruit/Vegetable Juices

Fruit and vegetable juices contain essential nutrients, including minerals, vitamins, dietary fibers, and antioxidants. However, several critical factors can limit the survival of probiotics in juice matrices: (i) **Food-related parameters**: pH, titratable acidity, molecular oxygen levels, water activity, and the presence of salt, sugars, and various chemical compounds such as hydrogen peroxide, bacteriocins, artificial flavoring, and coloring agents; (ii) **Processing parameters**: heat treatment, incubation temperature, cooling rate, packaging materials, storage conditions, oxygen availability, and product volume (iii) **Microbiological factors**: the specific probiotic strains used, as well as the rate and proportion of inoculation (Tripathi and Giri.,2014). These factors collectively influence the viability and functionality of probiotics in juice formulations, making their consideration essential for the successful development of probiotic-enriched beverages. In order to enhance the viability of probiotics in fruit juices methods such as fortification, adaptation & induction to resistance, maintainance of storage conditions, use of antioxidants & microencapsulation techniques can be employed (Naseem *et al*., 2023).

### *Fortification with Prebiotics*

Incorporating prebiotics such as dietary fibers and specific ingredients into fruit juices can bolster probiotic stability (Naseem *et al*., 2023). As it has been observed, enriching beetroot and carrot juices with brewer's yeast autolysate before lactic acid fermentation with *Lactobacillus acidophilus* not only enhanced bacterial growth but also reduced fermentation time. Additionally, it enriched the juices with amino acids, vitamins, minerals, and antioxidants, thereby positively influencing probiotic survival (Rakin *et al*., 2007; Aspri *et al*., 2020).

### *Adaptation and Induction of Resistance*

Exposing probiotics to sub-lethal stress such as mild heat, acidic pH, osmotic pressure, or oxidative stress, can induce adaptive responses that enhance their resilience (Gobetti *et al*., 2020). For instance, cultivating *Lactobacillus reuteri* in media containing red fruit juices or specific stressors prolonged its viability by several days (Bevilacqua *et al*., 2018). Similarly, generating acid-tolerant variants of *Bifidobacterium breve* through UV mutagenesis improved probiotic survival in blended juices (Saarela *et al*., 2021).

### *Storage Conditions and Use of Antioxidants*

Maintaining appropriate storage temperatures is vital, as refrigeration can prolong probiotic viability, while higher temperatures may be detrimental (Sohail *et al*., 2012). Additionally, minimizing oxygen exposure during storage is essential, as oxygen can induce oxidative damage through reactive oxygen species (Varela-Pérez *et al*., 2022). Incorporating antioxidants, such as catechins from green tea extracts, has been shown to enhance the growth and survival of certain probiotic strains (Gaudreau *et al*., 2019). Fortifying juices with vitamin E has also been found to improve probiotic stability during storage (Gaudreau *et al*., 2019).

### *Microencapsulation Techniques*

Microencapsulation involves encasing probiotic cells within protective matrices to shield them from adverse environmental conditions (Ding & Shah, 2009). Although probiotics naturally exhibit acid and bile tolerance, microencapsulation further enhances their survival by providing protection against environmental stressors, ensuring higher viability while incorporating them into food to their final destination in the human intestine (Khalil *et al*., 2020). Additionally, it creates an anaerobic environment for oxygen-sensitive probiotics while acting as a barrier against the high acidity of fruit juices.

Studies have demonstrated that encapsulated probiotics maintain higher viability in fruit juices compared to free cells. For instance, encapsulated *Lactobacillus gasseri* showed improved viability in

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apple juice, highlighting the protective effects of microencapsulation under simulated gastric and intestinal conditions (Varela-Pérez *et al.*, 2022). Layer-by-layer (LbL) encapsulation is a promising method for delivering specific probiotic strains to the gastrointestinal (GI) tract. This approach improves probiotic survival by protecting against stomach acid and bile salts, enhancing adhesion and growth in intestinal tissues, and increasing overall survival *in vivo* (Anselmo *et al.*, 2016). Therefore, implementing these strategies can significantly enhance the stability and efficacy of probiotic-fortified fruit juices, catering to the growing consumer demand for functional non-dairy beverages (Lillo-Pérez *et al.*, 2021).

## Probiotic Beverages & Human Health

Probiotics beverages play a critical role in alleviating various health conditions, including hypertension, inflammatory bowel disease (IBD), mental health disorders, oral health, and non-alcoholic fatty liver disease (Valero-Cases *et al.*, 2020). These beneficial microorganisms offer a wide range of therapeutic effects, positively influencing gut health and systemic inflammation.

Andriani et al. (2020) have shown that administration of probiotic fermented milk to male wistar rats reduced the cholesterol levels to 33.31%, compared with control rats. Angelov et al. (2006) used a probiotic starter culture with whole-grain oat substrate to create a symbiotic functional drink from the oats. The primary functional component of cereal fibers, β-glucan, is found in the highest concentration in barley and oats. According to studies, this chemical has a hypocholesterolemic action that lowers LDL cholesterol by 20–30% and reduces the risk of cardiovascular disease overall, so introducing this probiotic oat beverage in our daily diet is a great option to lower cholesterol levels (Vasudha *et al.*, 2013).

Modi et al. (2024) have demonstrated that a fermented turmeric beverage effectively reversed liver damage and lowered blood glucose levels in both alcohol induced liver damage and diabetic rat model, showing hepatoprotective effects comparable to Liv52 and hypoglycemic efficacy similar to glibenclamide. Interestingly, these scientists have also shown that fermented Amla beverage have hepatoprotective effects against chronic alcohol-induced toxicity by suppressing lipid peroxidation and elevating both enzymatic and non-enzymatic antioxidant levels in the liver.

Fermented milk exhibits antihypertensive properties, enhances immune function, lowers cholesterol levels, contributes to overall blood pressure reduction, manages irritable bowel syndrome (IBS) and alleviates constipation (Tabbers *et al.*, 2011). Hariri et al. (2015) have indicated that consuming probiotic soy milk containing *Lactobacillus planetarium* A7 for 8 weeks lowered blood pressure.

The impact of fermented *Portulaca oleracea* juice on a Caco-2 cell line have shown significantly reduced pro-inflammatory mediator levels and reactive oxygen species while preserving the integrity of Caco-2 cell monolayers exposed to inflammatory stimuli (Di Cagno *et al.*, 2019).

In addition to benefiting gut health, fermented foods and beverages have been suggested to positively impact mental health by reducing inflammation, modulating oxidative stress associated with cognitive impairment and neurodegenerative disorders such as Alzheimer's disease, and potentially lowering the risk of anxiety and depression (Mota *et al.*, 2018). Cannavale et al. (2023) have indicated that consumption of a fermented dairy beverage over four weeks augmented hippocampal function and microbiota composition compared to an isocaloric control beverage in healthy young adults.

Furthermore, a commercially available probiotic beverage containing *Lactobacillus casei* Shirota has been shown to improve gastrointestinal parameters such as bowel movement frequency and stool consistency (Koebnik *et al.*, 2023). Probiotic fruit-based beverages help reduce cholesterol by binding to it in the digestive system, preventing absorption and aiding its removal from the body which may support cardiovascular health and reduce disease risk (Khan *et al.*, 2021). Mostafa et al (2020), have shown that probiotic - *L. sakei* fermented date juice exhibited 150–166% higher antioxidant activity than its unfermented counterpart and demonstrated greater overall acceptability during cold storage, additionaly probotic fermentation of date juice with combination of *L. acidophilus* and *L. sakei* showed

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even better antitumor effect against larynx cell line (Hep-2) compared with non-treated cells and control juice.

## Conclusion

Probiotic beverages, a rapidly expanding segment of the functional food market, offer numerous health benefits, particularly in digestive health, immune support, and chronic disease management. Traditionally, dairy-based probiotic drinks have been consumed while non-dairy based probiotic beverages are increasingly preferred due to lactose intolerance, cholesterol concerns, and vegan dietary trends. Fermented drinks like kefir, yogurt-based beverages, kombucha, and probiotic-infused fruit juices provide diverse options to the consumers. Interestingly, emerging strategies such as microencapsulation, prebiotic fortification, and stress adaptation techniques have been able to enhance the probiotic survival in fermented beverages. With increasing awareness of gut health's role in overall well-being, the probiotic beverage industry is set for exponential growth, promising innovative, health-focused products in the near future.

## Future Perspective

The future of probiotic beverages lies in the development of more stable, effective, and diverse formulations catering to varying consumer needs. No doubt, advancements in biotechnology and food processing techniques will lead to improved probiotic viability, extended shelf life, and enhanced health benefits. Further, personalized probiotic beverages, tailored to individual gut microbiome compositions, may emerge as a breakthrough in preventive healthcare. Additionally, the integration of artificial intelligence and microbiome research could further refine probiotic recommendations for specific health conditions. As research continues to uncover the intricate connections between gut health and systemic diseases, probiotic beverages are poised to become a fundamental component of holistic nutrition and wellness. Moreover, the shift towards sustainable, plant-based alternatives will further drive innovation in non-dairy probiotic beverages, expanding accessibility and inclusivity in global markets.

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