



RESEARCH ARTICLE

Exploring the Diversity of Fermented Plant-Based Beverage with an Emphasis on the Therapeutic Role of Probiotics: A Review

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ARTICLE INFO	ABSTRACT
<p>Received: Apr 24, 2024 Accepted: Jul 21, 2024</p>	<p>The incidence of gastrointestinal disorders is on the rise each day, with an increase in incidence rates over time. The worldwide research target is to expose the major food constituents in drinks and beverages to provide health benefits to people. The awareness and market demand for probiotic-enriched plant-based beverages are increasing due to the increase in the number of people with dairy product allergies, lactose intolerance, and gut discomfort. The various plant-based probiotic beverages soymilk, rice milk, and coconut milk are the most crucial carrier matrices used in probiotic beverage formulations and have many health benefits. Probiotic products are safe and beneficial as a preventive approach for the treatment of several diseases, particularly atopic illnesses such as irritable bowel syndrome (IBS), acute infectious diarrhea, and antibiotic-induced disorders, and are suitable carriers for delivering good bacteria in storage due to their ability to carry sufficient probiotic yield. Therefore, this review focuses on the recent development of probiotic beverages and the role of probiotics as an efficient functional component of plant-based fermented beverages.</p>
<p>Keywords Fermented beverage Nondairy Dairy Phytochemicals Probiotic microbiome</p>	
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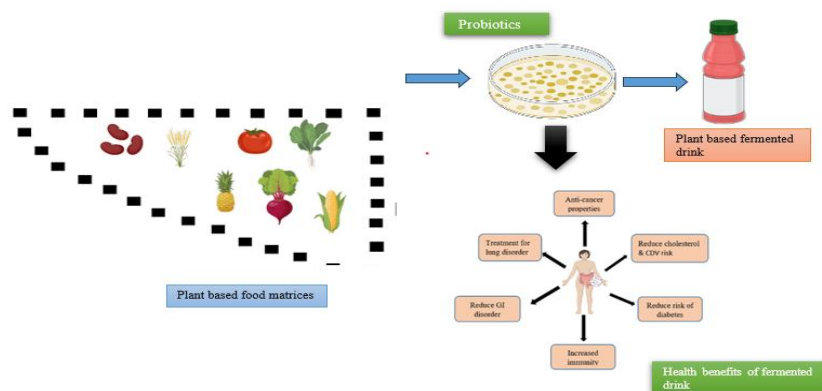


Figure: Graphical Abstract

INTRODUCTION

Probiotics are defined as microorganisms that have a beneficial effect on the host intestinal microbial balance. Lactic acid bacteria and bifid bacteria are the most common types of bacteria used as probiotics. The Latin word “pro” means “for”, and the Greek word “bios” means “life”. In ancient times, people consumed probiotics as fermented milk. Probiotics have been used for many decades because of their good taste and ability to control various diseases, such as intestinal disorders, obesity, diabetes, hypertension, and diarrhea [1]. The use of probiotic-fortified foods and drinks has gained attention globally because of their numerous health benefits. The most commonly used genera, the probiotics *Bifidobacterium* and *Lactobacillus*, which are considered generally recognized as safe (GRAS), are less hazardous to human health[2]. It has been observed that probiotic supplementation helps to promote the maintenance and improvement of a healthy gut microbiota[3]. Probiotics enhance the treatment and prevention of health conditions such as lactose intolerance, high blood pressure and serum cholesterol, irritable bowel syndrome, Crohn's disease, antibiotic-associated diarrhea, and numerous gastrointestinal disorders. In addition, probiotics have anticarcinogenic properties and boost the immune system[4]. Probiotics are added to fruit juices or various drinks for good nutrition and additional health benefits. There are many ways to measure probiotic safety. Probiotics have an ergogenic effect on sportspersons and persons who engage in heavy exercise or gym. The risk of gastrointestinal distress (such as vomiting, nausea, and diarrhea) in sportspersons may decrease with the ingestion of probiotics. The US National Library of Medicine reported that 65% of the world's population now has to reduce the amount of lactose present in cow's milk[5]. With the subsequent use of certain probiotic strains, sportspersons may increase the amount of energy they consume, which leads to increased performance and energization. The administration of a high dose of the probiotic strain *Lactobacillus plantarum* increased the blood glucose concentration during high-speed treadmill running. The present review focused on encouraging researchers and the food industry to explore the potential of nondairy fermented beverages as a source of microorganisms with probiotic potential. In addition, the positive impact of consuming probiotic beverages on human health is briefly shown. To improve culture viability during drying, storage, and/or gastric transit, thermoprotective agents such as trehalose, nonfat milk solids, and/or adonitol, growth-promoting agents such as various probiotic/prebiotic combinations, and granular starch have been used [6]. This review primarily investigated the clinical evaluation of various probiotic strains and their health benefits, as well as the use of plant-based matrices as the best carriers of probiotics in the human body. In India, plant-based gluten-free beverages have not yet gained much popularity and awareness. Plant-based health drinks or beverages are the most beneficial substitutes for those who have different dietary restrictions or allergies[7].

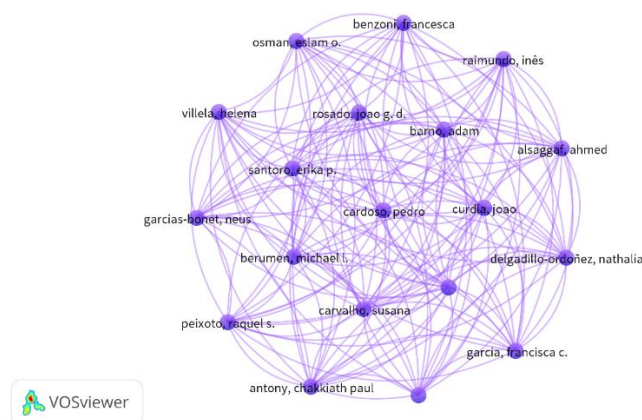


Figure 1: Authors working in the area

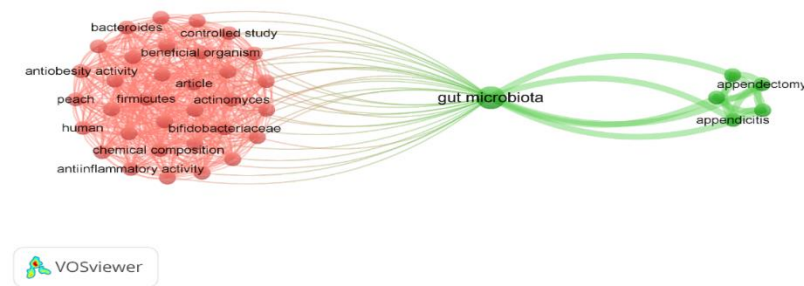


Figure 2: Keywords associated with the manuscript.

Effects of probiotic beverages on human health

Probiotics regulate bacteria within the host environment, thus contributing to the environment's health. Additionally, they aid in the fight against overweight and obesity [8]. Despite the tremendous potential of probiotics in nutritional and therapeutic applications, their integration into human health, nutrition, and the management of many disorders still requires further investigation. The purpose of this review is to showcase the potential positive effects of probiotics on human health, dietary optimization, and the regulation of prevalent metabolic illnesses or anomalies [9].

Probiotics for controlling food allergies

Probiotics have anti-allergic effects on various food allergens, such as milk allergens, peanuts, and soy-allergen. Probiotic bacteria, such as *L. plantarum* L67, fight allergy-related disorders (**Table 1/Figure 3**) via the synthesis of interleukin 12 and interferon-gamma in their host [10]. The health benefits of probiotics are mainly attributed to the instigation of the immune system or the modulation of the immune system since oral doses of probiotics affect the gastrointestinal mucosal area associated with lymphoid tissues, where 70% of immune cells are constrained. Probiotics help to control food allergies by reducing inflammation and strengthening the gut lining [11].

Probiotic for obesity control

Obesity is the root cause of several degenerative diseases. Nonalcoholic fatty liver disease and steatohepatitis, liver abnormalities, etc., may occur due to obesity. Fatty acids, cholesterol, and lipid metabolites are significantly elevated in the liver as a result of lipotoxicity-induced fat storage. The expression of lipogenic genes, such as fatty acid synthase (FAS), peroxisome proliferator-activated receptor gamma (PPAR), and the transcription factor CCAAT/enhancer-binding protein (C/EBP α), regulates these processes [12]. These lipogenic genes significantly influence metabolic disorders induced in the liver. Numerous investigations have demonstrated that liver weight, triglycerides, and lipogenic gene expression are associated with obesity, although the synthesis and storage of fat are reduced by the administration of probiotics, especially LABs. Few researchers have observed that the administration of *Lactobacillus* can decrease the levels of LPS-binding proteins that can reduce insulin levels, which may control diabetes mellitus, by decreasing metabolic profiles such as total cholesterol and triglyceride levels, C-reactive protein (CRP), HbA1c, blood glucose, and insulin levels, as well as systolic and diastolic blood pressure. Therefore, *Lactobacillus*, as mentioned in **Table 1 and Figure 3**, is an alternative therapeutic option for diabetes mellitus and obesity. Reduced tight junction protein expression leads to increased intestinal permeability, which eventually favours the translocation of bacterial lipopolysaccharide, which can cause metabolic endotoxaemia and insulin resistance [13].

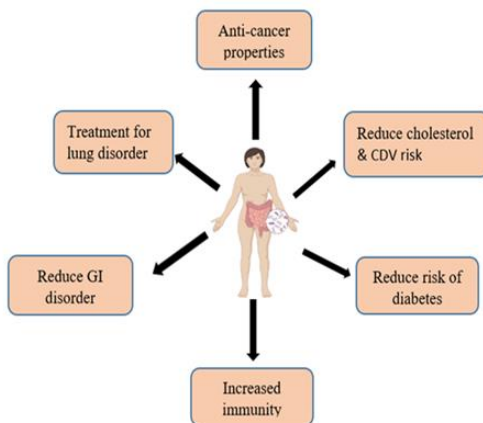


Figure 3:- Health benefits of probiotics adopted and modified from [14] [15].

Probiotics for irritable bowel disease

Irritable bowel syndrome/disease is distinguished by persistent inflammation in the GI tract, and probiotic strains are responsible for reducing IBS, as shown in **Figure 3**. Enteric bacteria may modify proinflammatory and anti-inflammatory cytokine levels in the colon and increase the prevalence of intestinal disorders. Th1 cells generate proinflammatory cytokines, and Th2 cells release anti-inflammatory cytokines that maintain the immune system in the intestinal barrier[16].

Lactobacillus, *Bifidobacterium*, and *Streptococcus* are the predominant probiotic genera in food matrices and dairy products. It has also been shown that plant-based beverages have great potential as carriers for probiotics. Fruits, nuts, cereals, and legumes can be used as novel functional probiotic beverages as alternatives to dairy-based fermented beverages, while plant-based fermented beverages meet the demand of consumers for lactose intolerance and allergies to fat from dairy products, as detailed in **Table 1** [17].

Table 1: Common probiotic strains used in fermented beverages and their therapeutic role

Category of beverages	Name of probiotic beverages	Role of probiotics	Strain	References
Cereal based probiotic beverage	Kombuga	Helps to increase amount of vitamin B, folic acid	<i>Gluconoacetobactor</i> <i>Lactobacillus</i>	[14]
	Borde	Helps to reduce cancer	<i>Lactobacillus</i> <i>Yeast</i>	[18]
	Ogi	Reduce abdominal discomfort & diarrhoea	<i>Lactobacillus plantarum</i> <i>Streptococcus lactis</i>	[19]
	Kunun zaki	Helps to prevent high blood pressure, blood clotting & lower blood glucose level.	<i>Lactobacillus fermentum</i> <i>Lactobacillus coccusla</i>	[20]
	Mandarin juice	Rich in vitC & vitA , helps to improve immunity	<i>Lactobacillussalivarius</i>	[14]
	Hardaliye	Reduce risk of heart disease, improve nervous system	<i>Lactobacillus sp.</i>	[21]

	Mehevu	Strengthen bone health. Rich in antioxidant	<i>Lactobacillus bulgaricus</i> <i>Lactobacillus brevis</i>	[22]
	Togwa	Provide energy for physical activity	<i>Lactobacillus</i> <i>Streptococcus</i>	[23]
	Boza	Fight against varicella zoster infection	<i>Lactobacillus sp</i>	[24]
	Atole	Increase immunity and helps to retain moisture	<i>Lactobacillus ssp</i>	[25]
Whey based probiotic beverage	Whey cheese	Act as an emulsifier	<i>Bifidobacterium sp</i>	[26] [27]
	Kefir	Reduce cholesterol level	<i>Leuconostoc.</i> <i>Lactobacillus</i>	[28]
	Whey sorghum probiotic beverage	Rich in nutritional properties	<i>Lactobacillus casei</i> , <i>L.rahmnosus</i> , <i>acidophilus</i>	[29]
	Grape flavoured whey drink	helps to reduce blood sugar & rich in antioxidant	<i>Lactobacillus casei</i>	[30]
	Bifidus milk	Basically, help for treatment of liver problems	<i>Lactobacillus bifid bacterium</i>	[31]
	Acidophilus milk	Reduce chances of lactose intolerance, reduce gastric inflammation	<i>Acidophilus; L. ssp</i>	[32]
	Shubat	Provides supplementation for basic nutrition	<i>Streptococcus thermophiles</i> <i>Lactobacillus casei</i>	[29]
	Grapefruit whey drink	Reduce blood glucose level	<i>Lactobacillus casei</i>	[30]
	Koumiss kumiss	Helps to treatment for tuberculosis, lung disorder	<i>Lactobacillus bulgericus</i> <i>lactobacillus acidophilus</i>	[33]

Antimicrobial properties of Probiotics

Probiotic microorganisms generate such compounds with low molecular weights, and they compete with illnesses and release antimicrobial agents (such as lactic acid, bacteriocin, and hydrogen peroxide) that boost the host's antimicrobial response, **as shown in Table 1**. The Bacteroidetes phylum, which is primarily composed of gram-negative bacteria, and the Firmicutes phylum, which is primarily composed of gram-positive bacteria, account for approximately 90% of all bacterial species. Transepithelial resistance to invading microorganisms is enhanced, and cytokine production is increased with TLR2 activation. The TLR2 receptors recognize the peptidoglycan present in gram-

positive bacteria such as *Lactobacillus* sp. *Lactobacillus* strains, demonstrating that *L. casei* CRL431 communicated with and interacted with epithelial cells via TLR2 receptors; *L. casei* was found to have a modest effect on IL-12 production. Additionally, they postulated that the intact peptidoglycan of lactobacilli impeded the synthesis of IL-12 via TLR2 signalling. Pepto glycan reduces IL-12 production by 12-48% in TLR2-imperfect macrophages, indicating that the TLR2 self-supporting mechanism is in operation, despite the requirement for TLR2 recognition shown in **Figure 4** [34].

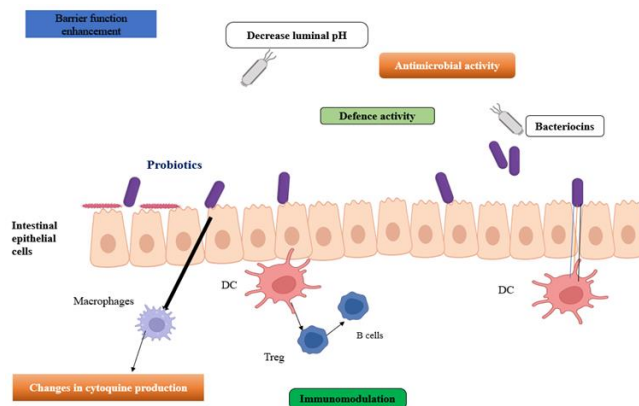


Figure 4: Antimicrobial activity of probiotics in the intestine, adopted and modified from [35].

Although probiotics have substantial potential for nutritional and therapeutic applications, further investigations are needed.

Probiotics and plant-based beverages

Dairy-based probiotic beverages have higher sugar and cholesterol contents. Plant-based beverages differ from dairy-based drinks in that they contain more phytochemicals, dietary fibre, and antioxidants (such as isoflavonoids and tocopherol). It also contains antinutrients that are removed by the mechanical and thermal processing of raw materials, such as roasting, drying, soaking, and germinating[36]. People are concerned about nondairy protein-based drinks, which include cereals, different seeds, pulses, legumes, fruits, vegetables, nuts, etc., to avoid animal-based drinks. It has recently received much attention because of its viable health benefits, including reduced blood sugar levels, improved gut mobility and enrichment of micronutrients. The increased global interest in plant-based beverages containing components that can provide favourable health impacts is driving up consumer demand. Currently, in the vegan food industry, plant-based milk is used as an alternative to animal milk because it is a necessary component of many vegan foods, such as plant-based ice cream, yogurt, butter, and cheese.[37] [38]. Beverage can deliver probiotics, prebiotics, amino acids, essential fatty acids, vitamins, minerals, etc.[39]. There are different ranges of beverages that can be useful to support heart disease and type 2 diabetes, improve gut health, and help in weight management[40]. Over the past decade, obesity has become a major concern in many countries. However, the prevalence of obesity may vary in different ways, such as through the interplay of genetic factors, lifestyle factors, environmental factors, and social factors. [41]. This type of enrichment can be used in a variety of products, not just milk substitutes[42][43]. Another kind of beverage is a functional beverage that is useful for improving gut health, weight management, and delaying the aging process. Both young and old consumers benefit from plant-based milk substitutes. Functional beverages are further classified as animal-based (including probiotics and minerals), plant-based beverages (depending upon the source of the raw materials), sports drinks, etc. In recent decades, plant-based foods have become encouraged worldwide because of their affordability; due to the large consumption of animal-based foods, biodiversity will gradually decrease[44]. Plant-based beverages are accessible on the market and are derived from seeds, cereals, legumes or a

mixture of various food items. The protein sources of beverages are divided into 4 groups: cereals (rice, oats, millets, barley), [45]legumes (chickpea, peas, soy), seeds (sesame seeds, pumpkin seed, sunflower seed, hemp, basil seeds, watermelon seed), and nuts (almond, peanuts, walnut).

Phytochemicals present in plant-based fermented beverages

Phytochemicals present in fruits, vegetables and grains are secondary metabolites of plants, although they are not considered essential nutrients. However, these compounds can decrease the damage caused by oxidative stress, which results in the production of free radicals via metabolism. Phytochemicals can be categorized as polyphenols, beta-glucan, alpha tocopherol isoflavones, carotenoids, betalains, glucosinolates, etc. (**Table 2**). There is a constraint on the bioavailability of these phytochemicals due to interactions with other foods. Some research has shown that phytochemicals act as bioactive compounds only after extraction from their natural source. Researchers have focused on developing dietary plant-based supplements from extracts [46].

Table 2: Phytochemicals present in plant-based fermented beverages

Types of plant beverage	Functional compounds present	Health benefits	References
Plant based	Beta-Glucan alpha tocopherol isoflavones, Phyto sterols, Oryzanol, phytosterol, Phenolic compounds	They have protective characteristics of heart disease, lowering blood glucose level, cholesterol level, osteoporosis.	[47]
Caffeinated beverages	Catechins, flavonoids, caffeine, polysaccharide, trigonelline, chlorogenic acid	Helps to control metabolism, obesity, helps to prevent neurological disorder, urinary stone.	[48]
Fruits and vegetables-based beverage	Lycopene, beta-carotene, allcin, sulforaphane, cynarine	These are high in antioxidants, prevent some cancers, helps to improve digestive system, anti-inflammatory properties.	[49]
Cereal based	Dietary fibre, phenolic contents, phytic acid, oryzanol,	These are anticarcinogenic, antiapoptotic, antiaging. helps to maintain good bacteria level in human gut.	[50]
Dairy based beverage	Prebiotic, mono unsaturated fatty acids, poly unsaturated fatty acid (MUFA, PUFA), proteins, minerals, vitamins.	Dairy based beverage helps to provide good amount of micro minerals like calcium, Potassium, Phosphorus, etc., improve immunity, bone strength, prevent bone related diseases and maintain good amount of gut microflora. Milk also has bioactive compounds.	[51]

Characteristics (pros and cons) of the fermented beverages

The use of plant-based probiotic-fermented beverages with various clinical importance is an interesting area of research. An overview of several contributions of fermented beverages, such as their anti-inflammatory, antidiabetic, anticancer, antiallergic, central nervous system-beneficial, and angiogenic properties, is provided in **Table 3**.

Table 3: Characteristics of plant-based fermented beverages

Type of beverage	Target nutrient	major characteristics	References
Whey based probiotic beverage	Probiotic	Good for gut microbiota Not suitable for lactose intolerance patient	[52]
Fermented food beverage	γ -Aminobutyric acid	Act like antidepressant, sedative, antihypertensive, antidiabetic Not suitable for lactose intolerance patient	[53]
water kefir beverages	Antioxidant	Good in phenolic compound. plant based beverage Low in protein	[54]
Carbohydrate drink	Carbohydrate	to reduce the stress of the work and analgesic affects. High in sugar	[55]
Multigrain beverage	Dietary fibre and low glycaemic index	Rich in antioxidant & low in glycaemic index, develop obesity & lifestyle disorder.	[56]
Fermented soy-based beverage	Probiotics and soy protein, isoflavonoids,	Stimulate gastrointestinal health. May arise food allergy from soy protein	[57]
Conventional milk beverage	oats milk, multi grain milk, soy milk	Reduce chances of lactose intolerance & food allergy	[36]
Probiotic Legumes based beverages.	rich in soluble proteins, peptides, and amino acids	improves antioxidant activity and calcium solubility, plant-based proteins may have poor digestibility.	[58]
Sugar sweetened beverage.	Milk protein, fat.	energy & calorie dense to do daily physical activity.	[59]

Fruit based beverage	Polyphenols (bioactive components)	Rich in vitamins & minerals; fight against noncommunicable disease Chances of contamination from pathogens	[60]
Fermented millet beverage	Iron, calcium, vitamin B.	rich in minerals & antioxidant. Phenolic compound & alkaloids.	[61]
Beverage from peas, cottonseed, lentils, sunflower seeds, beans, peanuts etc.	Protein from plant source	Anticancer, anti-inflammation, anti-anaemic antithrombotic, anti-obesity. Present anti-nutritional factors & limiting amino acid	[45]
Plant based milk.	Vitamins & minerals	Good for teeth health Less amount of iodine & calcium	[62]
Plant based beverage fortified with vit D, vit B12 & calcium	Vitamin D, Vitamin B12	Reduce bone demineralization & reduce the chances of prostate cancer. Lactose free,	[8]
Kefir fermented beverage	exopolysaccharide	Lactose free,	[63]
Oat bran probiotic beverages	Rich in soluble β Glucan, protein, dietary fibre	Anticancer & hypo cholestromaemia. Acidity of beverage may increase.	[64]
Fermented probiotic beverage from jujube extract.	Rich in soluble β Glucan, protein, dietary fibre	Inhibit tumour growth, decrease ageing process, and resist fatigue.	[65]
Beverage from chickpeas & lupine	Rich in essential amino acid	Reduce lactose sensitivity. Due to presence of anti-nutritional factors have adverse effect on metabolism.	[66] [67]
Almond milk beverage with goodness of inulin	Rich in mono and poly unsaturated fatty acids	Constipation relief, good for heart health	[68]

Pathophysiology of plant-based fermented probiotic beverages

Probiotics are considered food supplements, and probiotics make any specific health claims, which means that the importance of safety will be overlooked. However, worldwide, the use of probiotics has increased due to increased intake [69]. Probiotics may be involved in the formation of hazardous metabolites. The synthesis of d-lactate, a chemical responsible for the growth of d-lactic acidosis, is one of the possible safety concerns. Moreover, associations between probiotics, d-lactic acidosis

(metabolic acidosis), small intestine bacterial overgrowth, and symptoms, including abdominal bloating, distention, and gas, have not been proven in reported cases of cognitive impairment[70]. However, one study revealed that when probiotics were stopped and patients were given antibiotics, symptoms of brain fog improved[71]. Lactobacillus-containing probiotics have been related to bacteraemia and endocarditis in immunocompromised patients and those with heart abnormalities[72]. The mortality from Lactobacillus spp. and linked endocarditis is 23%, and because infections correlated with Lactobacillus spp. are highly rare, a popular past record of probiotic intake is necessary to rule out probiotics as a cause of endocarditis. The proposed probiotic mechanisms of action, including whether or not gut colonization is needed, interactions of probiotic strains with the gut microbiota, well-being, and potential in the future. [73][74].

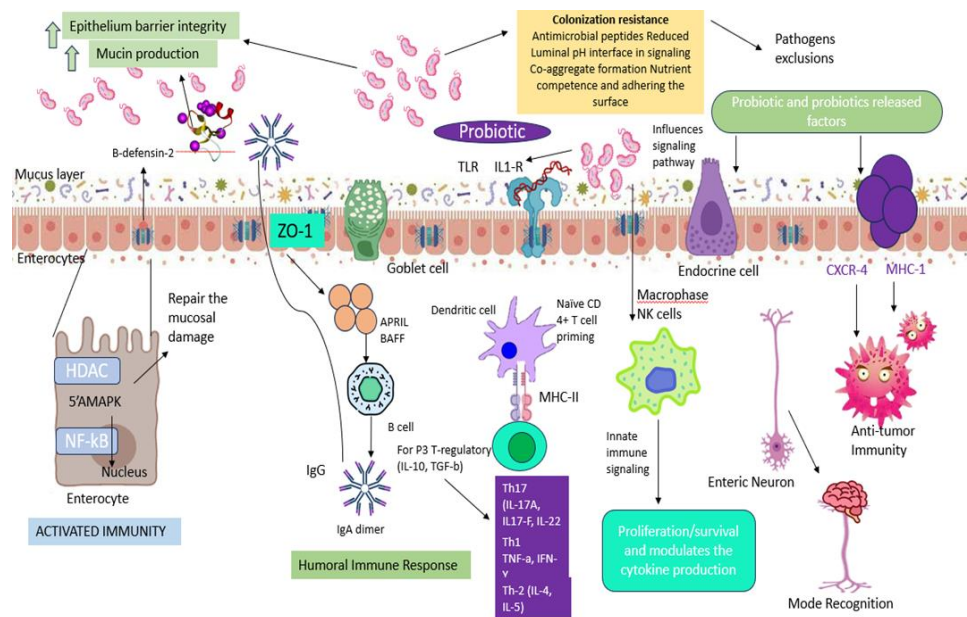


Figure 5: Pathophysiology of probiotic beverages in the human intestine adopted and modified from [9].

Bioavailability of plant-based fermented beverage

Probiotics are added to fruit juices or various drinks for good nutrition and additional health benefits. There are many ways to measure probiotic safety. However, there is controversy regarding probiotic safety; there is controversy regarding the use of probiotics in clinical trials, methodologies, and data for probiotic safety. Some researchers have stated that probiotics have multiple health benefits, but how much probiotics are safe and how much probiotics are safe for patients and consumers[75]. The Food and Agriculture Organization (FAO) & World Health Organization (WHO) provide guidelines for probiotic safety. Probiotic strains should be characterized by a series of inspections, which will determine any potential health hazards.

The efficacy of the administration of probiotic doses for patients who have severe illness is a concern for the population; the bioavailability and bioaccessibility of probiotic beverages is a question for researchers. Because the risk of toxicity from probiotic drinks may increase because of the sometimes-excessive administration of probiotics, which is unaccompanied by healthcare professionals, excess intake of water or table salt (NaOH) can also sometimes cause health hazards. There are several methods for assessing safety [76] [77].

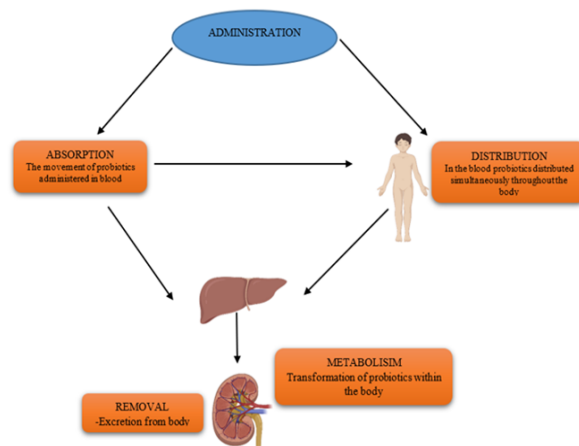


Figure 6: Diagrammatic View of the Bioavailability of Plant-Based Fermented Beverage
CONCLUSION

In conclusion, this review focused on the analytical literature on the numerous health benefits of probiotic beverages, the stability and bioavailability of phytochemicals present in plant-based formulations, the mechanism of action in the intestinal epithelial mucosa, and antimicrobial substance production. There are limited studies on the effectiveness of probiotic-fermented beverages. Non-dairy beverages with good qualities of probiotics have become more demanding globally because of their countless health benefits. It is important to acknowledge the challenges associated with conducting and replicating research on fermented foods, primarily due to the considerable diversity of ingredients and cultures that exist even within food categories. This minor variation may contribute to inconsistent results.

Future scope and global trend for plant-based probiotic beverages

Probiotic products make up the majority of the total functional food market, accounting for 60–70% of sales[78]. Many researchers have successfully investigated the possibility of accessing non-dairy probiotic beverages. However, for the creation of non-dairy beverage-based ready-to-reconstitute powders, the concept of drying such beverages is evolving. Such products can provide consumers with longer shelf lives, preserved nutrients, health benefits, and convenience, allowing commercial application. Nonetheless, commercial production of non-dairy probiotic alternatives in the form of beverages and instant powders faces numerous challenges in the future, including techniques to overcome low pH, the presence of antimicrobial substances and organic acids, and other factors that affect probiotic survival during transportation and storage[79][80]. The most pertinent ready product on the market is any kind of beverage. In the future, human studies in the field of probiotics are needed to determine which probiotic strain has the most efficacy and for which ailment. [81].

In the future, human studies in the field of probiotics are needed to determine which probiotic strain has the most efficacy and for which ailment. Among the probiotics, 50 to 60% are sold as food items, 30 to 40% are sold as beverages or supplements, and 10% are sold as pharmaceutical products. Nevertheless, despite being a recent entry, the market for no approximately 26 billion United States dollars is expected to increase by 2025 [82].

Early in the development of civilizations, plant-based probiotic beverages were less available. Compared with traditional milk, vegan diets are more appealing to consumers because of medical complications such as lactose intolerance, allergens, and a negative association between bovine milk fat and cardiovascular disease, as well as lifestyle factors such as high protein requirements, balanced amino acid profiles, and probiotic beverages[79]. By 2024, the global non-dairy plant milk-based

market will generate more than 38 billion dollars in earnings, with a compound annual growth rate of more than 14% between 2018 and 2024.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest in this work.

ETHICS STATEMENT: The author declares no ethical requirements for this work.

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