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Review Article

Fermented and dairy beverages of Bangladesh: a rich source of probiotic lactic acid bacteria

Tanim Jabid Hossain[1,2]✉, Md Sajib Khan[1,2], Jannatul Ferdouse[3]

[1]*Department of Biochemistry and Molecular Biology, University of Chittagong, Chattogram, Bangladesh*
[2]*Biochemistry and Pathogenesis of Microbes (BPM) Unit, Laboratory for Health, Omics and Pathway Exploration (HOPE Lab), Chattogram, Bangladesh*
[3]*Department of Microbiology, University of Chittagong, Chattogram, Bangladesh*

Abstract

Fermented and dairy beverages, enriched with probiotics, are integral components of Bangladesh's culinary heritage. This article explores the diverse landscape of these beverages, emphasizing their role as reservoirs of probiotic lactic acid bacteria. From iconic fermented beverage date-palm sap to dairy staples like milk, borhani, and laban, each beverage presents unique microbial profile. Studies isolating strains within these drinks underscore their probiotic potential, exhibiting multifaceted benefits including antimicrobial and antioxidant capabilities, cholesterol-lowering effect, exopolysaccharide-production etc. In-vitro probiotic assessments further unveil their potential to withstand gastric conditions and colonize gastrointestinal tract. The exploration extends to genomic dimensions, unraveling the genetic basis for probiotic effects and insights into the mechanisms of action including identification of genes encoding bioactive metabolites, antimicrobial peptides, nutraceuticals, and flavor compounds. Despite advancements, further research is needed to bridge gaps in understanding exact mechanisms of probiotic functionalities, specific health-effects, and unexplored probiotic properties. The interplay between the beverages and probiotics opens avenues for innovative applications beyond tradition, leveraging the full potential of these probiotic-rich beverages for functional food development and health-focused interventions. Importantly, while this research is rooted in Bangladesh's culinary tradition, the implications of probiotics extend globally, enriching our understanding of their health-benefits, offering potential impact worldwide.

Keywords

Traditional fermented drink, yogurt-based beverage, probiotic lactic acid bacteria, date tree sap, laban probiotics, honey probiotics, probiotic drink

✉*Corresponding author: Assoc. Prof. Tanim Jabid Hossain, PhD, Department of Biochemistry and Molecular Biology, University of Chittagong, Chattogram-4331, Bangladesh, tel.: +880 1812092020; E-mail:* tanim.bmb@gmail.com

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Introduction

In recent decades, there has been a notable paradigm shift in scientific emphasis, propelling the exploration of the human microbiome to the forefront of health research. The human microbiome, encompassing trillions of microorganisms residing in the gastrointestinal tract, has emerged as a dynamic ecosystem intricately connected to various facets of human health (Aggarwal et al. 2023). A pivotal revelation stemming from this exploration is the profound correlation between gut health and overall well-being (Kho and Lal 2018). It is increasingly evident that the composition and activity of the microbial inhabitants in our digestive system play a pivotal role in influencing not only gastrointestinal health but also exert systemic effects on the entire body (Sommer et al. 2017).

At the core of comprehending the microbiome's impact on health lies the recognition of probiotics as influential agents in shaping the microbiome's delicate balance within our gut (Ballan et al. 2020). Probiotics, characterized as live microorganisms conferring health benefits when consumed in sufficient quantities, have attracted considerable attention for their potential to positively influence a spectrum of physiological processes. In the era Fourth Industrial Revolution (4IR), the convergence of technological advancements has facilitated a deeper understanding of probiotics through genome and metabolome analysis. This analytical approach involves unraveling and utilizing the genes and bioactive metabolites of probiotic microbes, contributing not only to health but also to industrial advances. By harnessing this knowledge, there is the potential for enhancing sensory properties and nutraceuticals in industries through the strategic application of probiotics to improve food quality and nutrition. These microorganisms, often introduced through fermented foods and dietary supplements, engage in a complex interplay with the existing microbial communities in the gut, contributing to a harmonious and beneficial microbial balance (Wang et al. 2021). Their ability to inhibit harmful pathogens, enhance nutrient absorption, and modulate the immune system positions probiotics as powerful tools for optimizing gut health and its cascading effects on our physical and mental well-being (Tang and Lu 2019). Therefore, understanding the diverse landscape of probiotics and identifying readily available sources holds immense significance. Herein lies the intrigue of Bangladeshi fermented beverages, a dynamic cultural tapestry woven with microbial diversity. These traditional beverages, passed down through generations, offer a fascinating avenue for understanding probiotic potential. Rooted in centuries-old fermentation processes, they nurture distinctive communities of lactic acid bacteria, with each strain contributing to a multitude of beneficial effects. Exploring these microbial populations and their impact on human health promises to expand our knowledge of the probiotic universe. By unraveling the secrets held within these local treasures, we not only celebrate cultural heritage but also contribute to the global understanding of microbiome management and its vital role in shaping human well-being.

In this review, we delve into the intriguing realm of Bangladeshi dairy and fermented beverages, recognizing them as a rich source of probiotic lactic acid bacteria. Through an exploration of these traditional fermented beverages, we aim to elucidate the unique microbial communities they harbor, their potential health benefits, and their contribution to the broader landscape of probiotic research. We specifically focused on studies conducted in Bangladesh using locally collected beverages, ensuring a comprehensive overview of the probiotic landscape in the country. By shedding light on this specific niche within the realm of probiotics, we strive to contribute valuable insights to the evolving discourse on microbial influences on human health.

What are Probiotics?

Probiotics, derived from the Greek "pro bios", meaning "for life," constitute a captivating category of microorganisms renowned for their ability to positively impact host health (Aponte et al. 2020). Comprising primarily bacteria and yeast, probiotics, when consumed in adequate quantities, play a beneficial role in restoring and maintaining a balanced microbial environment within the gastrointestinal tract (Szajewska et al. 2016). Beyond their influence on gut health, probiotics participate in a wide array of physiological processes, including immune modulation and metabolic regulation (Ojeda et al. 2016). The growing interest in unlocking the therapeutic potential of probiotics underscores their significance in establishing a symbiotic relationship with the human body, with lactic acid bacteria emerging as pivotal contributors in this intricate interplay. The exploration of probiotics, rooted in their etymological significance, is a dynamic journey into understanding their role in promoting overall well-being.

Lactic Acid Bacteria - The Major Group of Probiotic Microbes

Lactic acid bacteria constitute a diverse group of microorganisms distinguished by their metabolic ability to convert sugars into lactic acid through fermentation (Bintsis 2018). The name "lactic acid bacteria" reflects this characteristic metabolic process, which not only imparts acidity to the surrounding environment but also contributes to the preservation of fermented foods (Cheng et al. 2019). These bacteria play pivotal roles in fermenting a wide range of foods, including dairy products, pickles, and sauerkraut, influencing taste, texture, and shelf life. The versatility and adaptability of lactic acid bacteria make them indispensable in various industrial applications, ranging from food and beverage production to pharmaceuticals and environmental management (Mora-Villalobos et al. 2020).

The lactic acid bacteria constitute a significant portion of the probiotic microorganisms, highlighting their significance in promoting human health. Among the major groups of probiotic lactic acid bacteria, the “Lactobacillus group” stands out prominently. The *Lactobacillus* genus has been reclassified into 25 distinct genera. Among them, species, such as *Lactobacillus acidophilus* and *Lacticaseibacillus rhamnosus*, are recognized for their resilience in the gastrointestinal tract and their contribution to the fermentation of dairy products (Von Wright and Axelsson 2019). Additionally, other noteworthy species within this group include *Lactiplantibacillus plantarum*, *Lcb. casei*, and *Limosilactobacillus fermentum*, each exhibiting unique attributes that contribute to their probiotic potential (Naghmouchi et al. 2020). Beyond Lactobacillus group, another significant genus in the probiotic landscape is *Bifidobacterium*. *Bifidobacterium* species, like *Bif. bifidum* and *Bif. longum*, are renowned for their ability to thrive in the intestinal environment and their positive impact on gut health (Sharma et al. 2021). These major species of probiotic lactic acid bacteria have become subjects of extensive research to understand their specific characteristics and potential contributions to the intricate balance of the gut microbiota.

Benefits of Probiotic Lactic Acid Bacteria

Probiotic lactic acid bacteria offer a multitude of benefits, including their positive impact on human health, contribution to nutrition, improvement of food sensorial properties, technological advantages etc. The following section provides a concise exploration of the manifold beneficial effects attributed to probiotic lactic acid bacteria.

Health benefits of probiotic lactic acid bacteria. Extensively studied for their influence on human health, probiotic lactic acid bacteria, when consumed in adequate amounts, confer several benefits particularly within the gastrointestinal tract. These bacteria play a pivotal role in maintaining a healthy gut microbiota by promoting the growth of beneficial microorganisms and inhibiting the colonization of harmful pathogens (Saha and Saroj 2022). By doing so, they support digestive health and alleviate symptoms associated with gastrointestinal disorders, such as irritable bowel syndrome (IBS) and inflammatory bowel disease (IBD) (Barbara et al. 2018). Probiotics also aid in the digestion and absorption of nutrients, improve bowel regularity, and alleviate lactose intolerance symptoms. Furthermore, certain strains of probiotics, such as *Lcb. rhamnosus* and *Bif. lactis*, have demonstrated immune-modulating properties, reducing the risk of respiratory tract infections, allergic reactions, and certain autoimmune disorders (Mojgani et al. 2020).

Nutritional benefits offered by lactic acid bacteria. Probiotic lactic acid bacteria provide nutritional benefits as they contribute to the breakdown of complex carbohydrates, proteins, and fats within the digestive system, thereby enhancing nutrient absorption (Wang et al. 2021). For example, these bacteria synthesize and release enzymes, such as lactase, which facilitate the digestion of lactose commonly found in dairy products (Ibrahim et al. 2021). This enzymatic activity is particularly beneficial for individuals with lactose intolerance, as it enables them to consume dairy without experiencing discomfort.

Additionally, probiotics contribute to the production of essential vitamins, including B vitamins like folate, riboflavin, and vitamin B12, which are important for energy metabolism, nerve function, and the production of red blood cells (Hossain et al. 2022).

Role of probiotics in enhancing food quality. The role of probiotics in enhancing food quality is multifaceted, encompassing various aspects of preservation, flavor development, and nutritional enhancement during the fermentation process. Acting as natural preservatives, lactic acid bacteria produce organic acids that inhibit the growth of spoilage microorganisms, effectively extending the shelf life of fermented products without the need for artificial additives (Zapaśnik et al. 2022). Moreover, the metabolic activities of probiotics contribute to the development of unique flavors, aromas, and textures in fermented foods, thereby diversifying the sensory profile and elevating the overall quality of the products. Additionally, probiotics enhance nutrient accessibility and bioavailability, particularly by aiding in the breakdown of lactose in dairy products (Ibrahim et al. 2021). Furthermore, probiotics have the capacity to synthesize various nutraceutical products, further enriching the nutritional value of fermented foods (Hossain 2022). The versatility of probiotics enables the creation of a wide range of fermented products, catering to diverse consumer preferences and contributing to a broader and more enjoyable culinary experience.

Lactic acid bacteria in functional foods and industry. Probiotic lactic acid bacteria, primarily employed as starter cultures in food fermentation, offer benefits that extend beyond enhancing food quality and make significant contributions to industrial and technological domains. These bacteria play a crucial role in the production of various fermented foods, including yogurt, cheese, sauerkraut, and sourdough bread, by initiating and driving the fermentation process, thereby improving the overall quality and safety of these food products (Zapaśnik et al. 2022). Furthermore, probiotics have spurred technological innovation through their application in the production of probiotic-enriched beverages and functional foods. Their antimicrobial properties, coupled with their ability to enhance nutritional content and create a diverse range of food options, demonstrate their substantial impact on both the food industry and technological advancements (Abedin et al. 2023). This dual capability not only promotes improved food quality but also underscores the role of probiotics in fostering a synergistic relationship between health, product excellence, and innovation in various industrial applications.

Fermented Foods and Beverages as Sources of Probiotic Lactic Acid Bacteria

Fermented and dairy beverages comprise a potent source of probiotic lactic acid bacteria, providing a palatable and culturally diverse means of incorporating these beneficial microorganisms into the diet. Kefir, originating from the Caucasus region, is a fermented milk drink that undergoes fermentation through the action of a symbiotic culture of bacteria and yeast (SCOBY) (Lynch et al. 2021). This process imparts kefir with a rich profile of probiotic microbes, predominantly including species from the *Lactobacillus* and *Bifidobacterium* genera (Bourrie et al. 2016). Beyond its probiotic content, kefir is celebrated for its effervescent texture and tangy flavor, making it a popular choice for those seeking a refreshing and probiotic-rich beverage. In addition to dairy-based beverages, there are also fermented plant-based beverages that provide probiotic lactic acid bacteria. Examples include fermented soy milk, coconut milk kefir, and water kefir (Guzel-Seydim et al. 2021). These beverages are produced by fermenting plant-based substrates with specific strains of lactic acid bacteria and yeasts, resulting in a range of flavors and textures. Other fermented beverages, such as kombucha and kvass, also contain lactic acid bacteria (Baschali et al. 2017). Kombucha is a fermented tea beverage made by fermenting sweetened tea with a culture of bacteria and yeast. It typically contains species like *Lactobacillus*, *Acetobacter*, and *Saccharomyces*, which contribute to its beneficial properties. Kvass, a traditional fermented beverage popular in Eastern Europe, is made from fermented grains or bread and often contains lactic acid bacteria, such as *Levilactobacillus brevis* and *Lim. fermentum* (Baschali et al. 2017).

Similarly, traditional dairy foods such as yogurt play a pivotal role in delivering probiotic lactic acid bacteria to the consumer. Yogurt is produced through the fermentation of milk by lactic acid bacteria, primarily strains of *Lb. bulgaricus* and *Streptococcus thermophilus* (Chen et al. 2017). These bacteria convert lactose into lactic acid, contributing to the characteristic texture and taste of yogurt. Importantly, the probiotic lactic acid bacteria present in yogurt survive the acidic environment of the stomach and reach the intestines alive, where they exert their beneficial effects on gut health. Other sources of probiotic lactic acid bacteria include certain types of cheese, such as Gouda and cheddar, which undergo a fermentation process that promotes the growth of beneficial bacteria (Gobbetti et al. 2018). The widespread consumption of fermented foods and beverages thus presents a harmonious fusion of culinary delight and nutritional benefit, illustrating the diverse ways in which probiotic lactic acid bacteria can be integrated into daily dietary practices.

Probiotic Lactic Acid Bacteria in Bangladeshi Dairy and Fermented Beverages

Fascinatingly, Bangladesh holds a rich heritage of dairy and fermented beverages, featuring age-old recipes that have been cherished and transmitted through generations. Among these beverages, including honey, borhani, laban, lassi, matha, date palm sap, and more, which are esteemed for their delightful flavors and culinary significance, lies an intriguing reservoir of probiotic lactic acid bacteria (Fig. 1).

Delving into the distinctive microbial communities thriving within these traditional elixirs presents an opportunity to unravel their latent health benefits (Table 1) alongside probiotic and safety profile (Table 2), and broaden our comprehension of the probiotic realm. This exploration into the realm of Bangladeshi fermented beverages not only unveils a distinctive niche within the vast probiotic landscape but also holds the promise of enhancing gut health and contributing valuable insights to the overarching understanding of the microbiome's impact on human well-being. The following section provides a detailed list and description of various Bangladeshi fermented beverages, along with the probiotic lactic acid bacteria present in each.

Probiotic Lactic Acid Bacteria from Milk

Milk, globally recognized as one of the most widely consumed and versatile beverages, boasts significant nutritional value with various health benefits (Hossain et al. 2011). Derived from mammary glands, this complex fluid serves as a primary source of nourishment for mammalian infants, including humans. Beyond its role as a staple food, milk has garnered attention for its probiotic potential and the presence of beneficial lactic acid bacteria, solidifying its reputation as a functional beverage (Tabit 2016). Rich in essential nutrients such as proteins, carbohydrates, fats, vitamins, and minerals, milk also contains a diverse array of lactic acid bacteria, known for their probiotic properties. The identification of probiotic lactic acid bacteria in milk underscores its potential as a functional beverage promoting gut health and overall well-being. Ongoing research aims to uncover specific strains and their associated health benefits, seeking to optimize the use of milk as a carrier for probiotics while enhancing its functional properties.

Figure 1. Diversity of traditional beverages of Bangladesh. From the dairy staple milk to the delightful dairy based beverages like borhani, laban, lassi, ghol, and mattha, each beverage carries unique cultural significance, forming an integral part of the culinary heritage. The array extends to plant-based drinks, including sugarcane juice and date palm sap, offering a glimpse into the rich tapestry of flavors and choices that contribute to the vibrant beverage culture of Bangladesh. Beyond their sensory appeal, these beverages also hold the potential to serve as sources of probiotic lactic acid bacteria, offering dual contributions to both cultural practices and potential health benefits

This versatile liquid forms the basis for various dairy products integral to many diets, including yogurt, kefir, and cheese (Kok and Hutkins 2018).

Table 1. Beneficial properties of lactic acid bacteria isolated from traditional Bangladeshi beverages. The listed strains, isolated from a variety of beverages, demonstrate diverse beneficial properties, including antimicrobial activity against bacterial and fungal pathogens, antioxidant capabilities, and exopolysaccharide (EPS) production, underscoring their potential contributions to the overall health-promoting characteristics of these culturally significant drinks

Health Benefits	Species	Source	References
Antimicrobial activity	*Lcb. gasseri* *Lcb. rhamnosus* *Lim. fermentum* *Weissella viridescens* *Companilactobacillus farciminis* *Lentilactobacillus buchneri*	Cow milk	(Kamruzzaman et al. 2013)
	Lb. acidophilus *Lim. fermentum* *Bif. longum* *Lcb. casei*	Buffalo milk	(Forhad et al. 2015)
	Lb. delbrueckii subsp. *bulgaricus* *Lcb. casei* subsp. *casei* *Lim. fermentum* *Leuconostoc mesenteroides* subsp. *mesenteroides* *Leu. mesenteroides* subsp. *dextranicum* *Pediococcus pentosaceus* *S. thermophilus* *Lactococcus lactis* *Enterococcus faecalis* *Lb. acidophilus*	Goat milk	(Islam et al. 2021)
	Apilactobacillus kunkeei *P. pentosaceus*	Honey	(Ferdouse et al. 2023)
	Lim. fermentum *Lev. brevis* *W. confusa*	Borhani	(Hossain 2022)
	S. thermophilus	Laban	(Paul et al. 2024)
Antioxidant properties	*P. pentosaceus* *Ap. kunkeei*	Honey	(Ferdouse et al. 2023)
	Lim. fermentum	Borhani	(Hossain 2022)
	P. pentosaceus *S. thermophilus*	Laban	(Paul et al. 2024)
EPS production	*Lb. acidophilus* *Lb. delbrueckii* subsp. *bulgaricus* *Lcb. casei* subsp. *casei* *Lim. fermentum* *Lpb. plantarum* *Leu. mesenteroides* subsp. *mesenteroides* *Leu. mesenteroides* subsp. *dextranicum* *P. pentosaceus*	Goat milk	(Islam et al. 2021)

	S. thermophilus *Lc. lactis* *E. faecalis*		
	Lactiplantibacillus sp. *Lactococcus* sp. *Lacticaseibacillus* sp. *Lactobacillus* sp.	Cow milk	(Tarannum et al. 2023)
	Lim. fermentum *P. pentosaceus*	Borhani Laban, goat milk and honey	(Hossain 2022) (Ferdouse et al. 2023; Islam et al. 2021; Paul et al. 2024)
	S. thermophilus	Laban and goat milk	(Islam et al. 2021; Paul et al. 2024)

Through fermentation, these dairy products foster the growth of beneficial microorganisms, particularly lactic acid bacteria. The microbial landscape within milk-derived products contributes not only to their distinct flavors and textures but also potentially imparts health benefits. Exploring the microbial composition of milk opens avenues to understand the role of probiotic lactic acid bacteria in the broader context of fermented dairy products, providing insights into their impact on digestive health and overall well-being.

Numerous studies have delved into the realm of probiotic lactic acid bacteria in milk; however, this paper narrows its focus to investigations conducted in Bangladesh with the milk samples collected locally. Expectedly, milk, as a widely studied dairy beverage in the country, has been subjected to rigorous analysis to uncover the potential health benefits associated with its lactic acid bacteria content.

Lactic acid bacteria from cow milk. In a study by Reuben et al., raw cow milk was scrutinized for lactic acid bacterial strains with probiotic potential (Reuben et al. 2020). The researchers undertook a comprehensive evaluation encompassing antagonistic activity against pathogens, survivability in simulated gastric conditions, and adherence to ileum epithelial cells. The identified lactic acid bacteria, including *Lcb. casei*, *Lpb. plantarum*, *Lim. fermentum*, and *Lcb. paracasei*, demonstrated probiotic attributes, inhibiting various pathogens, survivability in simulated gastric juice, and exhibiting resistance to certain antibiotics. The study suggested these lactic acid bacteria strains as promising candidates for probiotic applications in the food industry.

Similarly, Kamruzzaman et al. (2013) explored *Lactobacillus* isolates in indigenous Bangladeshi raw milk, reporting strains with probiotic potential. The six isolates, identified as *Lcb. gasseri*, *Lcb. rhamnosus*, *Lim. fermentum*, *W.viridescens*, *Co. farciminis*, and *Len. buchneri*, demonstrated antimicrobial activity against pathogens, and had tolerance to stomach pH, bile salt, and stress conditions. In their investigation, Tarannum et al. rather focused on isolating lactic acid bacteria from cow milk capable of exopolysaccharides (EPS) biosynthesis (Tarannum et al. 2023). From 63 isolates, four strains - *Lactiplantibacillus* sp. ME2b, *Lactococcus* sp. ME7, *Lacticaseibacillus* sp. ME17, and *Lactobacillus* sp. ME27a - demonstrated notable EPS production. The EPS extracts exhibited strong antioxidant activity, antimicrobial potential against both Gram-negative and Gram-positive pathogens, and significant emulsification, anti-inflammatory, and anti-biofilm activities.

Table 2. Probiotic characteristics of lactic acid bacteria isolated from various beverages. Essential probiotic features, encompassing tolerance to low pH, phenol, and bile, along with auto aggregation, coaggregation, and adhesion capabilities, are exhibited by lactic acid bacteria isolated from diverse traditional Bangladeshi drinks. The broad spectrum of observed probiotic traits emphasizes the inherent probiotic potential within these traditional beverages

Probiotic Competence	Strains	Sources	References
Low pH tolerance	*Lcb. gasseri* *Lcb. rhamnosus* *Lim. fermentum* *W. viridescens* *Co. farciminis* *Len. buchneri*	Cow milk	(Kamruzzaman et al. 2013)
	Lb. acidophilus *Lb. delbrueckii* subsp. *bulgaricus* *Lcb. casei* *Lim. fermentum* *Lpb. plantarum* *Leu. mesenteroides* *P. pentosaceus* *S. thermophilus* *Lc. lactis* *E. faecalis*	Goat milk	(Islam et al. 2021)
	P. pentosaceus *Ap. kunkeei*	Honey	(Ferdouse et al. 2023)
Bile tolerance	*Lb. acidophilus* *Lim. fermentum* *Bif. longum* *Lcb. casei*	Buffalo milk	(Forhad et al. 2015)
	Lb. acidophilus *Lb. delbrueckii* subsp. *bulgaricus* *Lcb. casei* subsp. *casei* *Lim. fermentum* *Lpb. plantarum* *Leu. mesenteroides* subsp. *mesenteroides* *Leu. mesenteroides* *S. thermophilus* *Lc. lactis*	Goat milk	(Islam et al. 2021)
	P. pentosaceus *Ap. kunkeei*	Honey	(Ferdouse et al. 2023)
NACL tolerance	*Lcb. gasseri* *Lcb. rhamnosus* *Lim. fermentum* *W.viridescens* *Co. farciminis* *Len. buchneri*	Cow milk	(Kamruzzaman et al. 2013)

	Lb. acidophilus *Lim. fermentum* *Bif. longum* *Lcb. casei*	Buffalo milk	(Forhad et al. 2015)
	P. acidilactici *Enterococcus faecium*	Goat milk	(Islam et al. 2021)
	P. pentosaceus *S. thermophilus*	Laban	(Paul et al. 2024)
Phenol tolerance	*Lb. acidophilus* *Lim. fermentum* *Bif. longum* *Lcb. casei*	Buffalo milk	(Forhad et al. 2015)
	P. acidilactici *E. faecium*	Goat milk	(Islam et al. 2021)
	P. pentosaceus	Honey, laban	(Ferdouse et al. 2023; Paul et al. 2024)
	Ap. kunkeei	Honey	(Ferdouse et al. 2023)
	S. thermophilus	Laban	(Paul et al. 2024)
Adhesion ability	*P. acidilactici* *E. faecium*	Goat milk	(Islam et al. 2021)
	P. pentosaceus	Honey, laban	(Ferdouse et al. 2023; Paul et al. 2024)
	Ap. kunkeei	Honey	(Ferdouse et al. 2023)
	S. thermophilus	Laban	(Paul et al. 2024)
Autoaggregation and coaggregation	*P. pentosaceus*	Honey, laban	(Ferdouse et al. 2023; Paul et al. 2024)
	Ap. kunkeei	Honey	(Ferdouse et al. 2023)
	S. thermophilus	Laban	(Paul et al. 2024)
Tolerance to intestinal/ pancreatic juice	*Lb. acidophilus* *Lb. delbrueckii* subsp. *bulgaricus* *Lcb. casei* subsp. *casei* *Lim. fermentum* *Lpb. plantarum* *Leu. mesenteroides* subsp. *mesenteroides* *Leu. mesenteroides* *S. thermophilus* *Lc. lactis*	Goat milk	(Islam et al. 2021)

Additionally, genomic analysis of the prominent strain, ME2b, revealed EPS biosynthesis genes. These results enhance our understanding of EPS properties, opening avenues for innovative applications, particularly in food industry and biotechnology. The findings hold implications for industries seeking sustainable alternatives, as EPSs with bioactive properties can be utilized in novel product and process development. Additionally, the identification of EPS biosynthesis genes sets the stage for future genetic and metabolic engineering to optimize EPS production and tailor their properties for specific applications.

Lactic acid bacteria from goat milk. Moving beyond cow's milk, Islam et al. (2021) conducted an in-depth investigation into the probiotic potential of lactic acid bacteria isolated from raw goat milk. Their comprehensive study identified fifty strains, primarily belonging to the Lactobacillus genus, demonstrating inhibitory effects against pathogenic microorganisms. Noteworthy findings included the strains' survivability under gastrointestinal conditions and the exhibition of safety aspects alongside valuable technological characteristics. These identified strains emerge as promising candidates for the development of fermented foods. Additionally, Islam et al. (2022) extended their study to further explore *Lpb. plantarum* strains Lpb01 and Lpb02. Both strains exhibited commendable effects, encompassing bile salt deconjugation and cholesterol-lowering capabilities.

In a separate study by Sarkar et al. (2020), *P. acidilactici* and *E. faecium*, also isolated from raw goat milk, exhibited notable probiotic potential. Their attributes included antagonistic properties, gastrointestinal transit tolerance, and adherence to mucosal epithelial cells. These collective findings underscore the diverse probiotic capabilities present in raw goat milk-derived LAB.

Lactic acid bacteria from buffalo milk. While yogurt made from buffalo milk is prevalent in certain regions, buffalo milk itself has received limited attention regarding probiotic lactic acid bacteria. In a study conducted by Forhad et al., focused on buffalo milk, several strains of lactic acid bacteria (LAB) were isolated and identified (Forhad et al. 2015). Among these strains were *Lim. fermentum*, *Lcb. casei*, *Lb. acidophilus*, and *Bif. longum*. The isolated strains demonstrated some probiotic properties, such as the ability to tolerate bile salt and NaCl concentrations, as well as exhibiting antimicrobial activity.

The above studies collectively underscore the richness of lactic acid bacteria in various types of milk, presenting a diverse array of strains with probiotic potential. From cow's milk to goat milk and even buffalo milk, these investigations contribute valuable insights into harnessing lactic acid bacteria for probiotic applications in the realm of fermented foods and beyond.

Probiotic Lactic Acid Bacteria from Yogurt-Based Beverages

Lactic acid bacteria from borhani. Borhani, a yogurt-based beverage hailing from Bangladesh, is distinguished by its spicy flavor derived from an array of carefully selected spices (Hossain et al. 2022). While the exact composition can vary based on regional and individual preferences, the key ingredients include yogurt, coriander, mint, and chili, complemented by smaller quantities of pepper, mustard, cumin seeds, rock salt, table salt, and sugar. Borhani's preparation involves fermenting milk with live bacterial cultures from natural yogurt, resulting in a refreshing and potentially probiotic drink with a delightful tang. A longstanding tradition in Bangladeshi households, Borhani is often served post-meals to aid digestion. In recent years, the popularity of borhani has led to commercial production, making it more widely available to consumers. Despite this growth, traditional preparations are still preferred by many, with borhani often being made at home using age-old recipes passed down through generations. Enjoyed by individuals of all ages, borhani has become an integral part of South Asian culinary culture.

The diverse array of ingredients in borhani hints at its potential as a reservoir of various microbial species. In an analysis conducted by Islam et al. (2021), which focused on the microbial taxa present in borhani, the composition revealed a significant presence of *Lactobacillus*, constituting nearly half of the microbiota, underscoring the potential of borhani as a probiotic source (Table 1). *Streptococcus* was the next predominant genera, accounting for around 20%. Among the fungal genera, *Xylaria*, *Aspergillus*, *Alternaria*, and *Candida* were prominently identified. In a contrasting approach, Hossain et al. (2022) focused on harnessing the probiotic potential of borhani's microbes. They isolated and characterized four promising lactic acid bacteria strains including *Lim. fermentum* LAB-1, *Lev. brevis* LAB-5, *W. confusa* LAB-11, and *Lpb. plantarum* (unpublished). Notably, *Lim. fermentum* LAB-1 has been extensively studied for its genomic features (cf. below) and EPS production (Tarannum et al. 2024), while all three strains demonstrated a broad spectrum of antimicrobial activity against both gram-positive and negative pathogens (refer to Table 1). Despite being a potential opportunistic pathogen, *W. confusa* LAB-11 is also known for its probiotic potential and displayed antibacterial and antifungal properties. Additionally, the EPS from LAB-1 exhibited antimicrobial, antioxidant, anti-biofilm, and anti-inflammatory activities, highlighting borhani's multifaceted health benefits. These findings suggest that borhani, with its rich microbial diversity, holds potential beyond its cultural significance, offering a blend of tradition and health-promoting attributes.

Lactic acid bacteria from laban. Laban, a cherished fermented dairy beverage, is an integral part of South Asian culinary traditions, enjoyed in countries like Bangladesh, India, Nepal, Pakistan, and Afghanistan. This cultured dairy product undergoes fermentation with lactic acid bacteria, often using a natural starter culture for its distinctive tangy flavor. Fermentation not only shapes Laban's unique taste but also extends its shelf life, potentially cultivating probiotics known for digestive health benefits. Laban varies from a buttermilk-like liquid to a thicker yogurt-like consistency, adapting to regional preferences. Spices or herbs like mint, cumin, or black salt enhance both flavor and health benefits, making Laban a delightful and nutritious choice.

In a recent study, Paul et al. delved into the evaluation of lactic acid bacteria isolated from this laban. Among the 15 lactic acid bacterial isolates initially screened, seven were selected for their antimicrobial activity against bacterial and fungal pathogens. Strikingly, *P. pentosaceus* strain L1 and *S. thermophilus* strain L3 demonstrated potent antimicrobial effects, paving the way for further probiotic scrutiny. These isolates exhibited robust resistance to gastric conditions, along with aggregation and adhesion capabilities alongside antioxidant activity. Moreover, their technological prowess, including milk coagulation and exopolysaccharide production, suggests their potential for enhancing the quality of dairy products (Paul et al. 2024a).

Lactic acid bacteria from mattha. Mattha, another traditional dairy beverage, occupies a prominent place in South Asian culinary culture, particularly in Bangladesh. The preparation involves blending yogurt with water and incorporating spices such as roasted cumin seeds, black salt, and coriander leaves, sometimes complemented with lemon to enhance its flavor. The mixture is then vigorously churned to achieve a smooth consistency. Mattha is regarded as a cooling beverage, particularly favored during hot and humid weather to combat dehydration and provide relief. It is deeply ingrained in the indigenous culture and consumed during festive occasions, religious celebrations, and social gatherings.

In the exploration of mattha, Paul et al. focused on the isolation of potential probiotic lactic acid bacteria (Paul et al. 2024b). Their selection criteria were centered on the strains' ability to inhibit pathogenic microbes. Among the isolated strains, one notable candidate identified as *S. thermophilus* exhibited promising attributes beyond pathogen inhibition. This particular strain exhibited multifaceted benefits, including antioxidant activity, aggregation, and adhesion properties, as well as resistance to low pH, bile salts, and phenol. Importantly, the strain proved non-hemolytic, indicating safety considerations, and displayed some resistance to specific antibiotics.

Lactic Acid Bacteria in Date Palm Sap

Date palm sap, also recognized as date palm juice, stands as a revered beverage in Bangladesh, renowned for its taste, nutritional richness and potential health benefits (Hossain et al. 2023). The sap, extracted from date palm tree (*Phoenix dactylifera*), reveals a complex composition shaped by the tree's physiology, sapwood and environmental factors. One key contributor to the unique qualities of date palm sap is its diverse sugar content, encompassing diverse types such as glucose, fructose, and sucrose. The presence of these fermentable sugars, particularly glucose and fructose, positions date palm sap as an attractive substrate for microbial activity, especially for lactic acid bacteria and fructophilic lactic acid bacteria. These bacteria, known for their role in fermentation processes, may find a favorable niche in the sap due to the availability of these sugars. Lactic acid bacteria, known for their role in fermentation processes, may find a favorable niche in the sap due to the availability of these sugars. Moreover, the potential involvement of fructophilic lactic acid bacteria, which thrive on fructose-rich substrates, may add an additional layer to the dynamics of sap fermentation. Although specific studies on lactic acid bacteria and fructophilic lactic acid bacteria in date palm sap are limited, the sugar composition remains a pivotal factor influencing microbial interactions during the fermentation of this traditional beverage.

Recently, Hossain et al. (2023) reported the first metagenomic analysis to explore the bacterial diversity and community in data palm sap. Employing high-throughput sequencing of the V3-V4 region of the 16S rRNA gene, their study unveiled a complex microbial composition. The major phyla identified were Proteobacteria and Firmicutes, jointly accounting for over 85% of the microbiome. Particularly noteworthy was the higher relative abundance of lactic acid bacteria groups including *Leuconostoc* and *Lactobacillus*, suggesting their potential contribution in sap fermentation. Additional bacterial groups such as *Zymomonas*, Acinetobacter, *Fructobacillus*, *Lactococcus*, *Pseudomonas*, *Sphingomonas*, *Ralstonia*, and others were also identified in the samples. Functional predictions indicated a primary association of the sap microbiome with metabolic functions, genetic information processing, environmental information processing, and cellular processes. Proteins predicted to be predominantly associated with membrane transport, amino acid metabolism, and carbohydrate metabolism. Despite the need for further investigation into specific correlations, these findings offer valuable insights into the intricate microbial ecology of date palm sap. Subsequent studies are encouraged to prioritize the isolation of key bacterial species, elucidating their precise contributions to distinct juice characteristics. Simultaneously, investigating their potential probiotic attributes will not only unravel the specific roles of individual bacterial species in the fermentation process but also shed light on their potential health-promoting attributes. These investigations will contribute to a significant understanding of the importance of microbial communities within this traditional beverage.

Lactic Acid Bacteria from Honey

Honey, a natural sweetener produced by bees from the nectar of flowers, has been consumed for centuries and is renowned for its unique taste and medicinal properties. It is a viscous liquid with varying colors, flavors, and aromas, depending on the floral source from which the bees gather nectar. Honey is composed primarily of sugars, such as glucose and fructose, but it also contains trace amounts of vitamins, minerals, enzymes, and antioxidants. Due to its antimicrobial properties, honey has been used as a traditional remedy for wound healing and cough suppression. Additionally, recent studies have shed light on the presence of probiotic lactic acid bacteria in certain types of honey, further expanding its health benefits.

Honey, while traditionally not classified as a fermented beverage, has been incorporated into this review due to its potential association with probiotic lactic acid bacteria. Recent research has indicated the presence of these beneficial bacteria in certain types of honey. Despite the promise of honey as a source of lactic acid bacteria, information regarding lactic acid bacteria in Bangladeshi honey and their probiotic potential has been limited, with studies predominantly conducted outside Bangladesh, utilizing honey from other geographical regions. A recent study by Ferdouse et al. (2023) addressed this gap by comprehensively isolating and characterizing bacterial strains from Bangladeshi natural honey. Their findings highlighted substantial probiotic potential within Bangladeshi honey. Through detailed biochemical characterization and evaluation of antimicrobial effects, the authors selected and identified three strains – two strains of *P. pentosaceus* and one of *Ap. kunkeei* – from a total of 25 isolates. These strains exhibited promising health benefits such as antioxidant effects demonstrated by hydroxyl free-radical scavenging activity, alongside initially observed antimicrobial effects. The strains displayed resilience to simulated gastric conditions, exhibiting survival in low pH, bile salts, and phenol. Their adhesion ability and aggregation characteristics, coupled with safety assessments revealing the absence of hemolytic activities and resistance to various antibiotics, collectively suggest that Bangladeshi honey may indeed serve as a valuable source of lactic acid bacteria, particularly *P. pentosaceus* and *A. kunkeei*, offering promising probiotic advantages.

Potential Beverages Yet Unexplored

Lassi. Lassi is also a popular dairy beverage and shares similarities with borhani and mattha, as they are all based on yogurt. However, there are slight differences in their preparation. Lassi is made using sweet yogurt, whereas laban and mattha utilize sour yogurt. Moreover, lassi has a sweet taste and is relatively simpler to prepare, typically requiring yogurt, sugar, and occasionally ingredients like pistachio nuts and cinnamon.

Although there is a lack of specific studies on probiotic lactic acid bacteria in lassi, it can be assumed that lassi may contain similar strains found in yogurt. Since lassi is primarily made from yogurt, it is reasonable to expect the presence of beneficial lactic acid bacteria in the beverage. However, further research is necessary to explore and confirm the presence of specific species in lassi and their probiotic properties.

Ghol. Ghol, also known as "chana water", is a byproduct usually derived from the cheese manufacturing process. This beverage, particularly renowned in Old Dhaka and the Sirajganj district of Bangladesh, is made by introducing edible acidic substances, such as lemon juice, to milk, leading to the coagulation of milk proteins. The coagulated portion is utilized for cheese-making, while the residual liquid whey forms the foundation for Ghol, to which soda and salt are added. The distinctive taste of Sirajganj's traditional solop's Ghol, with a century-old tradition, can be attributed to its unique recipe that harmonizes the flavors of yogurt and lemon. While considered to possess significant nutritional value, encompassing all the components found in milk except for casein, the potential presence of lactic acid bacteria with beneficial properties in Bangladeshi Ghol remains a topic that merits future exploration due to the limited studies in this context.

Sugarcane juice. Sugarcane juice, a popular and refreshing beverage, is derived from the pressing of sugarcane stalks to extract its sweet and nutrient-rich liquid. Commonly consumed in tropical regions, the juice is celebrated for its natural sweetness and is often served fresh, sometimes with a hint of lime or ginger to enhance its flavor. Rich in vitamins, minerals, and antioxidants, sugarcane juice is cherished for its potential health benefits, including its role in hydration and providing a quick energy boost. Its sweet and invigorating taste makes it a favorite street-side beverage in many cultures, enjoyed both for its flavor and perceived nutritional value.

There appears to be a lack of research on the probiotic lactic acid bacteria specifically present in sugarcane juice. However, the beverage's high sugar content and plant-based nature can provide a favorable environment for the growth of such beneficial bacteria. Probiotic lactic acid bacteria are known to thrive in environments rich in carbohydrates, and sugarcane juice's natural sugars may serve as a suitable substrate for their growth. Therefore, exploring microbial composition of sugarcane juice could unveil unique strains of lactic acid bacteria with potential probiotic properties. As a non-dairy beverage, the lactic acid bacteria found in sugarcane juice may differ from those in traditional dairy-based drinks, and their potential health benefits could also vary, offering an intriguing avenue for further investigation. The distinctive properties of lactic acid bacteria in sugarcane juice could contribute to the expanding understanding of probiotics in plant-based beverages, paving the way for innovative developments in functional foods.

Omics in Probiotic Exploration: Power of Genomics, Metagenomics, and Metabolomics

The utilization of informatics, particularly in the genomic and metagenomics analysis of probiotic lactic acid bacteria in foods and beverages, plays a pivotal role in advancing probiotic research. Metagenomics analysis offers valuable insights into the presence and diversity of lactic acid bacteria within these beverages, illuminating their microbial composition and potential probiotic properties (Hossain et al. 2023; O'Donnell et al. 2020). Through culture-independent metagenomics analysis, researchers can identify and classify different lactic acid bacteria species, revealing the richness and abundance of these beneficial microorganisms in traditional drinks. The application of informatics in the functional prediction of the microbiome allows for insights into the potential health benefits associated with these probiotic-rich beverages.

In the age of 4IR, innovative technologies and data-driven approaches empower researchers to harness the full potential of genomics, metagenomics, and metabolomics. Genomic analysis of specific probiotic strains further enhances our understanding of their genetic basis for probiotic functionality (Wu et al. 2017). Utilizing whole-genome sequencing and functional genome analysis, researchers can explore the genetic content of these strains, identifying genes and pathways associated with probiotic roles (Hossain 2022). This analysis unveils the mechanisms underlying their ability to survive the harsh conditions of the gastrointestinal tract, adhere to intestinal surfaces, and exert beneficial effects on the host. By elucidating the genomic basis of these probiotic strains, researchers gain valuable insights into their potential applications in functional food development and health promotion (Wu et al. 2017).

In addition to genomics and metagenomics, the characterization of metabolites in probiotic lactic acid bacteria has become increasingly significant. Techniques such as high performance liquid chromatography (HPLC), gas chromatography (GC), mass spectrometry (MS), LC-MS, GC-MS etc. are employed in the metabolomics study of these bacteria, providing a comprehensive analysis of their metabolic profiles (Sharma et al. 2023). These methods enable the identification and quantification of specific metabolites, shedding light on the intricate metabolic pathways within probiotic LAB. By unraveling the metabolomic landscape, researchers can uncover bioactive compounds, understand metabolic interactions, and assess the potential impact of probiotic metabolites on human health. This integrative omics approach, combining genomics, metagenomics, and metabolomics, contributes to a holistic understanding of probiotic lactic acid bacteria and fortifies the foundation for future advancements in functional food development and health-focused applications.

The integration of these advanced technologies into probiotics research allows for a more nuanced exploration of their enormous potential. For instance, in a comprehensive genome-based analysis, Hossain et al. unraveled the myriad beneficial properties encoded in the genome of *Lim. fermentum* LAB-1 isolated from borhani (Hossain 2022). This probiotic strain, exhibiting potent antimicrobial effects against clinical pathogens, was scrutinized for its metabolic, probiotic, fitness, and safety attributes. The genomic investigation unveiled a rich repertoire of genes related to carbohydrate metabolism, including a heterofermentative system for carbon dissimilation. Furthermore, the analysis identified genes associated with key metabolic pathways such as pyruvate oxidation, pentose phosphate, and PRPP biosynthesis. The genome encodes a diverse array of carbohydrate-active enzymes, transporters, peptidases, and uptake systems for peptides and amino acids. Noteworthy traits encompass stress tolerance proteins, restriction-modification, and CRISPR-Cas systems for phage defense, and genes facilitating the biosynthesis of B-group and K vitamins. Additionally, the bacterium demonstrated industrial relevance through the production of flavor compounds, exopolysaccharides, acetoin, and butanediol. Importantly, antimicrobial peptides with high sequence identity to experimentally validated bacteriocins were predicted. Remarkably, the genome analysis indicated the absence of negative traits such as transmissible antibiotic resistance, pathogenicity, or virulence, positioning LAB-1 as a safe and promising probiotic candidate. This in-depth genomic exploration sets the stage for targeted laboratory research, unlocking the full probiotic potential of LAB-1 in diverse applications, including functional foods, biotechnology, and health-related interventions. Building upon the genome analysis, the identification of EPS genes has guided further exploration of LAB-1's exopolysaccharides, revealing promising bioactive properties, including antioxidant, anti-inflammatory, antagonistic, and biofilm inhibition activities. This integrated approach enhances our understanding of LAB-1's functional capabilities, paving the way for innovative applications in various fields.

Addressing Gaps and Unexplored Avenues

Certain limitations and gaps in existing studies on probiotic lactic acid bacteria present opportunities for future research avenues. While some investigations isolated specific bacteria based on defined criteria, others conducted metagenomic analyses without isolating individual strains. Combining both approaches could foster a more comprehensive understanding of the microbial composition, enabling a nuanced exploration of the probiotic potential within these beverages. Moreover, there persists a critical need for further research to unravel the exact mechanisms and specific health effects attributed to these bacteria. Current studies have laid the foundation; yet, comprehensive insights into how these lactic acid bacteria exert their potential impacts on human health are still evolving, warranting continued exploration and investigation. Additionally, certain probiotic properties, such as tumor suppression and immune modulation, remain relatively unexplored in the context of probiotic lactic acid bacteria in Bangladeshi beverages. Future studies should delve into these uncharted territories to uncover additional health benefits associated with the consumption of these traditional drinks.

Another aspect that merits consideration is the role of lactic acid bacteria during different fermentation stages and how they contribute to the overall fermentation process. A comprehensive analysis of the changes in lactic acid bacterial species throughout fermentation could provide valuable insights into the dynamics of these microorganisms and their impact on the final composition of the beverages.

Furthermore, a notable gap exists in in vivo studies, especially those utilizing animal models like mice, in the current body of research. Such studies could offer a more holistic understanding of the physiological effects of probiotic lactic acid bacteria in the context of these beverages, providing a bridge between laboratory findings and potential human health outcomes.

Conclusions

The exploration of fermented and dairy beverages in Bangladesh as sources of probiotic lactic acid bacteria reflects the intersection of cultural richness, microbial diversity, and health. These traditional drinks, from milk to borhani, mattha and laban showcase a myriad of LAB strains, including notable ones like *Lpb. plantarum*, *Lim. fermentum*, and *S. thermophilus* and others. Hence, beyond their cultural significance, these beverages emerge as potential reservoirs of health-promoting probiotics, offering a dynamic interplay between traditional practices and modern health perspectives. The discovery of robust probiotic properties, such as antimicrobial effects, stress tolerance, and technological capabilities within these LAB strains, propels these beverages into the spotlight of potential therapeutic and nutritional applications. The synergy between natural ingredients and probiotic microorganisms hints at a broader spectrum of health benefits, extending beyond their conventional roles. This dual significance, rooted in cultural heritage and scientific potential, encourages a reevaluation of these beverages as not only carriers of flavor but also as contributors to public health.

However, journey into the probiotic landscape of Bangladeshi beverages also reveals gaps and beckons for future exploration. The precise mechanisms and specific health impacts of these potential probiotic strains remain in the shadows, urging for in-depth investigations. Unexplored beverages, untapped probiotic properties, and the role of lactic acid bacteria during different fermentation stages create exciting avenues for further research. The absence of comprehensive in vivo studies, especially those employing animal models, underscores the need for bridging the gap between laboratory findings and potential human health outcomes.

In essence, while celebrating the current understanding of fermented and dairy beverages in Bangladesh, the journey is an ongoing expedition. The identified probiotic strains not only pay homage to cultural traditions but also beckon scientists to venture deeper into the microbial intricacies of these beverages. The fusion of cultural heritage with scientific curiosity not only enriches Bangladesh's culinary landscape but also hints at untapped potential for advancing public health through these traditional elixirs.

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