

Bio boost: Functional beverage for gut and metabolic wellness

Nawneet Kumar Kurrey*,^{ID} Disha Pawar,^{ID} Sakshi Kawade,^{ID}
Vinaya Dhonde^{ID} and Kamakshi Shanbhag^{ID}

Department of Biotechnology, School of Engineering, Ajeenkya D.Y Patil University, Pune, India

Corresponding author: [Nawneet Kumar Kurrey](mailto:nawneet.kurrey@adypu.edu.in) | E-mail: nawneet.kurrey@adypu.edu.in

Citation: Nawneet Kumar Kurrey, Disha Pawar, Sakshi Kawade, Vinaya Dhonde and, Kamakshi Shanbhag (2026). Bio boost: Functional beverage for gut and metabolic wellness. *Journal of Food and Biotechnology*. 100 to 111. DOI: <https://doi.org/10.51470/FAB.2026.7.1.100>

29 January 2026: Received | 26 February 2026: Revised | 22 March 2026: Accepted | 18 April 2026: Available Online

Abstract

New functional food products, such as post-biotic functional beverages, offer significant advantages over traditional functional foods because they have a greater degree of stability and safety, and they have additional health benefits. Unlike probiotics, post-biotic products are composed of bacteria that no longer live as well as the metabolic products from bacteria that benefit individuals without the potential risks associated with live bacteria. Many of today's studies on post-biotic products focus on developing plant-based post-biotic beverages that offer added benefits for both the environment and consumers compared to dairy-based products. A number of recent studies have shown that lactic acid bacteria (particularly *Lactobacillus plantarum*) play an important role in producing post-biotic products through fermentation. In addition, of the many fruits that can undergo fermentation to make post-biotics, amla (*Phyllanthus emblica*) is well-known for its abundance of vitamins and antioxidants. Stevia and other natural sweeteners can enhance the flavour of food without adding large amounts of calories. Scientific literature suggests that natural sweeteners ferment at 25 °C to 30 °C over 2 to 5 days under controlled conditions. The pH decrease from approximately 3.5 to 4.5 during fermentation will show that fermentation has occurred successfully and therefore can improve safety and stability of the product for microbial activity. Functional ingredients, e.g., cinnamon and raw banana flour, are included for their unique properties. Ultimately, postbiotic beverages should undergo mild pasteurisation, as this process eliminates viable microorganisms while retaining the beneficial metabolites produced during fermentation, including organic acids, enzymes, and bioactive compounds. Therefore, these fermented metabolites possess a variety of healthful properties, e.g., improving digestion, supporting immunity, and providing antioxidant protection. Based on physicochemical analyses reported in peer-reviewed literature, postbiotic beverages produced via various methods may exhibit desirable characteristics, such as high titratable acidity and total soluble solids, as well as extended shelf-stability. Taste, aroma, and general quality evaluations suggest that consumers prefer these beverages to other non-postbiotic alternatives. To create highly effective postbiotic beverages, the interactions between fruit-derived bioactive components (such as prebiotic dietary fibre) should also include microbial by-products (i.e., prebiotics and microorganisms) present during production. Further research indicates that mild pasteurisation is an effective method for producing postbiotic beverages, enabling the removal of viable microbes while retaining beneficial metabolites (e.g., organic acids, enzymes, and other bioactive compounds). To conclude, the current body of literature reinforces the positive effects of drinking postbiotics on overall health, and there are clear advantages to drinking postbiotics compared to traditional beverages. As more consumers recognize the benefits of these types of beverages, new opportunities for manufacturers and retailers are emerging in the functional food category. Postbiotics also have significant potential as the basis of both vegan and non-dairy alternatives to traditional food products.

Keywords: Postbiotic beverages, Functional foods, *Lactobacillus plantarum*, Amla, Fermentation, Gut health, Bioactive compounds, Plant-based beverages.

1. Introduction

Functional beverages are becoming increasingly popular globally. This increase in popularity is largely due to rising awareness of how diet impacts gut health, immunity, and the prevention of lifestyle-related diseases. There is a growing number of consumers who drink beverages that provide nutrients, hydration and additional health benefits. The growing popularity of fermented beverages is part of this trend, as they contain beneficial compounds that improve digestion, metabolism, and immunity [1]. Fermentation improves both the nutritional value and the bioavailability of beverages and their nutrients and phytochemicals. Therefore, they are very suitable for producing functional foods [2].

Traditional probiotic beverages, despite their widespread demand, face numerous technical, regulatory, and safety constraints limiting their consumption by a diverse population. A variety of factors impact the viability of probiotic microorganisms, including temperature variation, exposure to air, acidity, and the type and level of processing applied to products. The impact of cold chain protocols on storage and shipping of products that maintain viable levels of live microorganisms has a significant effect on production costs and restricts product distribution to resource-limited countries [3].

Copyright: © 2026 by the authors. The license of *Journal of Food and Biotechnology*. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

Live microorganisms can increase perceived risk for vulnerable populations, including those with compromised immune systems, infants, and elders receiving enteral feeds [4]. Due to these limitations, researchers have focused on methods that offer similar health benefits to traditional probiotics but can be achieved without relying on viable microorganisms. Ultimately, postbiotics are considered to be a new and exciting type of functional food product. Postbiotics are defined as either 'dead' or 'non-living' microbial cells or their by-products (metabolites) produced through fermentation. Examples include organic acids, short-chain fatty acids, enzymes, bioactive peptides and exopolysaccharides. Although there are no viable microorganisms in postbiotics, the compounds produced can have beneficial effects on health, including antibacterial, immunomodulatory, and beneficial effects on the digestive tract (gut). Because there are no viable microorganisms, postbiotics have many advantages over probiotics, such as being safer, more stable, and easier to add to food products (especially beverages that will be heated and stored for long periods of time).

Lactobacillus plantarum is among the most widely studied lactic acid bacteria; it is versatile in its ability to ferment and can use a wide range of substrates. This particular type of lactic acid bacterium thrives in an acidic environment and can utilise a broad spectrum of carbohydrates. This makes *L. Plantarum* an ideal candidate modulator for plant-based alternative fermented product systems. In addition, *Lactobacillus Plantarum* is highly effective at producing postbiotic metabolites, such as organic acids and antimicrobial compounds that assist in making the finished product safe, stable, and functional.

The choice of fermentation substrate is critical for producing functional and nutritious postbiotic beverages. Substrates that originate from plants, particularly those that contain plant-based sugars (e.g., fruit), are desirable substrates because they contain multiple naturally-occurring nutrients, such as sugar, organic acids, vitamins, and various other phytochemicals. Amla (*Phyllanthus emblica*) is recognized as having an exceptionally high vitamin C content and polyphenol content, both of which confer a high level of antioxidant activity, thereby impeding the growth of bacteria and promoting illness [8]. The addition of amla to fermented beverages increases their overall nutritive value and creates an optimal acidic environment for microbial growth.

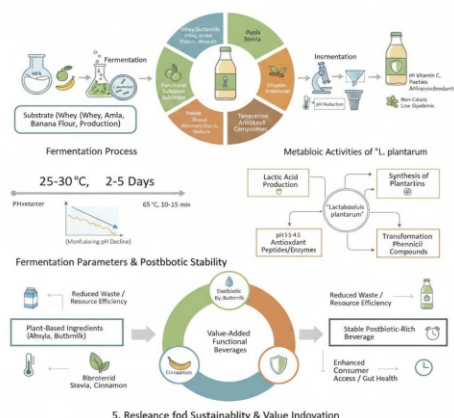


Fig 1.1: Functional Postbiotic Beverage

2. Literature Review

2.1. Whey, Buttermilk, and Plant-Based Substrates as Functional Beverage Matrices

The growth of the functional beverages market has not only been driven by changing consumer attitudes but also by consumers' perception that adding What Foods Are After This Is Done is beneficial for their health, providing benefits such as improved digestive function, metabolic balance, and stronger immunity. Both whey and buttermilk are used throughout the world as valuable dairy byproducts and contain nutrients like lactose, complete/ balanced protein structures, and bioactive peptides; therefore, if companies can develop and market new products using these byproducts instead of solely using whey or buttermilk for food or other uses, both products can also reduce the negative effects on the environment by reducing waste and increasing cost associated with waste disposal.

Technologically speaking, whey and buttermilk are ideal fermentation substrates because their buffering capacity helps stabilize pH during microbial growth, and their nutrient concentration supports the growth of lactic acid bacteria. Some researchers believe this combination is likely going to provide the greatest benefits for lactic acid fermentation and postbiotic production; therefore, it would be an excellent substrate to create functional beverages. With increased incidences of lactose intolerance and allergies to milk, as well as more people following a vegan diet, the demand for alternatives to milk is rising dramatically.

Research has focused mainly on ways to create fermentation systems using plant-derived foods or combinations of plants (e.g. fruit and cereal; pre-biotic fibres). These plant-based foods also contain both naturally occurring sugars which support the growth of microorganisms and organic acids, which do not affect the growth of microorganisms and will enhance the antioxidant strength of products; both phytonutrients in plant material will provide additional benefits for the beverage; however, incorporating plenty of different types of food into one product (i.e., fruit & cereal) will also increase the attractiveness of a product based upon a better-tasting product than using only one type of food. Using Amla as a fermentation source, along with other naturally sweetened ingredients and freshwater, will provide a sustainable and practicable method for producing postbiotics.

2.2. Postbiotics: Concept, Health Benefits, and Relevance

Postbiotics represent a transformative concept in functional foods that redefines how microbial viability translates into beneficial health attributes. Postbiotics encompass a wide range of nonviable metabolites produced during microbial fermentation, such as organic acids, short-chain fatty acids, bioactive peptides, bacteriocins, enzymes, cell wall components, and exopolysaccharides, all of which offer significant technological advantages and safety profiles.

Postbiotics have been found to beneficially affect gut microbiota composition, promote the integrity of the intestinal barrier, and prevent the emergence of pathogenic microorganisms, with immune response regulation as the final effect.

The lowered pH in the gut, created by organic acids, facilitates the shedding of pathogenic bacteria, while bioactive peptides and EPS are involved in immunomodulatory and antioxidant activities. If postbiotics are stress-free for cell viability, they will remain present under heat treatment and extended storage, making them well-suited for beverage formulations [4].

Research on fermented whey and buttermilk beverages demonstrates that their health benefits persist after pasteurization, confirming that postbiotics, not live probiotics, drive these functional properties. This result strongly supports the use of mild heat treatment in postbiotic drink production to ensure both microbial safety and efficacy. Consequently, postbiotic beverages have successfully addressed numerous challenges inherent to probiotic drinks, including stability issues, safety concerns, and reliance on cold chain logistics.

2.3. Role of *Lactobacillus plantarum* in Functional and Postbiotic Beverages

Because of its metabolic flexibility and adaptability, *Lactobacillus plantarum* has become one of the most widely used lactic acid bacteria for studying the production of functional beverages. In contrast, *L. Plantarum* can grow on both dairy and plant-based substrates (although it does not ferment as effectively as some other lactobacilli on these substrates) and can ferment numerous carbohydrate types depending on their pH/phenolic values. Additionally, *L. Plantarum* produces substantial amounts of lactic acid through fermentation, which lowers the pH and thereby enhances both the safety and shelf life of the final product. In addition to generating lactic acid via the *L. plantarum* strain to improve the preservation of functional beverages, this bacterium produces plantaricin, a natural antimicrobial that suppresses the growth of spoilage and pathogenic microbes. Furthermore, *L. plantarum* can bio-transform specific phenolic compounds, rendering them bioavailable for humans through alcohol consumption. For optimal fermentation in *L. plantarum*, conditions should be maintained between 25 and 30 degrees Celsius with a pH range of 3.5 to 4.5. This is because such conditions favor postbiotic production while preserving their sensory qualities.

2.4. Amla (*Phyllanthus emblica*) as a Functional Fermentation Substrate

Because *Phyllanthus emblica* (Amla) is rich in antioxidants due to its high Vitamin C content, its polyphenols and flavonoids also provide health benefits like antioxidant activity, anti-inflammatory action, and immunomodulatory effects. To conclude, incorporating Amla into fermented beverage production boosts microbial stability by elevating antioxidant activity (20). Amla is also crucial for generating natural acidity, fermentable sugars, and organic acids, which support the growth of lactic acid bacteria and produce antimicrobial compounds that regulate the fermentation process (21). Additionally, microbial activity during fermentation can transform the phenolic compounds found in the fruit.

2.5. Stevia as a Natural Sweetener in Fermented Beverages

Conversely, Stevia (*Stevia rebaudiana*) is classified as a natural, non-caloric functional sweetener employed in functional beverage formulations. Unlike standard sugars, Stevia contains no fermentable carbohydrates, thereby preventing uncontrolled or excessive fermentation. Furthermore, Stevia's susceptibility to metabolism by lactic acid bacteria renders it an optimal sweetener for fermented and postbiotic drinks [22]. Stevia enhances flavor without contributing calories, making it an ideal sweetener for low-calorie and diabetic food products. Furthermore, stevia's low glycemic index classifies it as a clean-label ingredient that can also prolong product shelf life [23].

2.6. Cinnamon as a Functional and Bioprotective Ingredient

Cinnamon (*Cinnamomum* spp.) is high in bioactive substances, including eugenol and polyphenols, as well as cinnamaldehyde, which all have antimicrobial, antioxidant, and anti-inflammatory properties; in fermented beverages, cinnamon increases the microbial safety and the sensory properties of those beverages [24]. By adding cinnamon to the product after fermentation, you will retain the bioactive properties of cinnamon and enhance the antioxidant potential of the finished product without interfering with the beverage's fermentation by the original yeast or bacteria. Furthermore, the addition of cinnamon after fermentation provides stability and a longer shelf life for the finished product [25].

2.7. Raw Banana Flour as a Prebiotic Fiber Source

Due to its high levels of resistant starch, soluble dietary fibre, and oligosaccharides, raw banana flour is a good source of prebiotics, making it well-suited for use as a prebiotic functional ingredient in beverages. Resistant starch is a carbohydrate that cannot be digested by the upper bowel but reaches the colon intact and is selectively fermented by the beneficial gut bacteria, including Bifidobacteria and *Lactobacillus* [26]. Fermentation of resistant starch results in SCFAs that play an important role in maintaining healthy gut function, improving the intestinal barrier and modulating the immune system. In addition to maintaining a constant carbon source for the microbiota to metabolise, the prebiotic fibres found in raw banana flour support the continued production of postbiotic metabolites (organic acids, peptides and bioactive compounds) as a result of fermentation activity. The presence of resistant starch will further enhance the physical and chemical properties of the finished product, including viscosity, mouthfeel and texture. There is also evidence suggesting that raw banana flour may protect bioactive compounds from degradation during processing and help preserve them long-term. Overall, the above mentioned functional, nutritional and technological advantages illustrate that raw banana flour contributes to a food matrix that protects nutrients from oxidative degradation, while simultaneously assisting in the stability of functional constituents [27].

2.8. Fermentation Parameters and Postbiotic Stability

Postbiotic beverages are affected greatly by fermentation parameters.

Important factors include temperature, fermentation time, pH, and strain choice. These influence the production of metabolites and the overall performance of the end product. Controlled fermentation at 25–30 degrees Celsius for 2–5 days is optimal for producing the maximum amount of postbiotics while maintaining product stability [28]. It is necessary to monitor the decline in pH during the fermentation process because pH decline indicates the activity of the microorganisms and the accumulation of the organic acids. A gradual decrease in pH confirms that fermentation has been successful and also provides additional assurance of the product's safety by preventing unwanted microbial growth. Acidification levels must be monitored closely to achieve a balance between the product's functional benefits and sensory satisfaction. Post-fermentation processes, particularly mild pasteurization, are important for the stability of the finished product. Pasteurization at approximately 65 degrees Celsius for 10–15 minutes is effective in destroying viable microbial cells, thus transforming the beverage into a postbiotic product while leaving intact heat-stable bioactive such as organic acids, peptides, and exopolysaccharides [29]. Pasteurization also provides safety for the product and prevents ongoing metabolic activity during storage, thereby enhancing the shelf life of the product without affecting the functional quality of the product.

2.9. Relevance to Sustainability and Value Addition

The production of functional foods through postbiotic beverages represents one way to produce eco-friendly functional foods based upon the use of plant based raw materials and dairy by-products; for example, by creating postbiotic beverages using residual raw materials helps to reduce waste associated with the use of underutilised raw materials, providing an economic value by creating hinzu and adding value to low valued products with better health and functional qualities are associated with the use of these products [30]. This also reduces the demand for resources and contributes to a circular economy and decreasing the effects of environmental impact associated with the production of foods. Postbiotics offer commercial and technological advantages because they do not contain live microbes; therefore, there is no need for a temperature-controlled cold chain for storage or transport, reducing costs associated with postbiotic distribution. Additionally, postbiotics have an extended shelf life, improving their safety and facilitating large-scale manufacture and distribution. The health, plant-based ingredient and clean label attributes of postbiotics make them well suited to the current consumer trends as more and more consumers are searching for eco-friendly and functional foods, thus postbiotics may provide a range of nutritional and eco-friendly options for consumers in the expanding global functional food market.

3. Materials and Methods

The methodological framework that was applied in the present study was built up to a great extent to attain scientific rigor, to make the experimental results reproducible, and to end up with a postbiotic beverage of functional relevance the method used in the experiment utilized the concepts of classical lactic acid fermentation to create modern functional beverages while implementing strategies for postbiotics stability based on

findings from previous lactic acid fermentation studies conducted with both dairy and plant-based systems, [13]. In other words, although the methodology was based on scientific studies for dairy/plant-based fermented systems, it was purposely modified to work better with a fruit base and to create postbiotics, rather than focus solely on the viability of the probiotics.

The experimental workflow was developed in a controlled, stepwise manner that included (1) the standardization of the raw materials, (2) the preparation of the fermentable substrate, (3) controlled microbial fermentation using *Lactobacillus plantarum*, (4) strategic blending of functional ingredients post-fermentation, (5) mild thermal inactivation to produce a postbiotic product, and (6) extensive analytical evaluation. Each step was precisely and deliberately manipulated to reduce variability, maintain bioactive compound's integrity, and ensure microbial safety, therefore making it possible to repeat the experiments with reproducibility from one experiment to another for every batch.

3.1 Selection, Standardization, and Pre-Treatment of Raw Materials

We created a postbiotic beverage using a replicable, scientific method. We did so by combining old world methods of lactic acid fermentation with new age products that support the development and stabilization of postbiotics. There is extensive use of this type of integrated methodology in both dairy and plant-based fermentation systems as a way to enhance quality and function of products. In a methodical and controlled manner, the experimental procedure was completed with several steps that involve the following (1) selection and standardization of the raw materials, (2) preparation of a fermentable substrate, (3) fermentation of the substrate using *Lactobacillus plantarum* in a controlled manner, (4) enrichment of the post-fermented product using functional ingredients, (5) mild thermal processing of the post-fermented product for postbiotic production, and (6) thorough analytical analysis of the final product. Each step in the experimental process was optimized so there would be minimum variance, maximum reproduction, and maximum protection of sensitive bioactive compounds in the final product. All experiments were conducted under aseptic conditions to minimize microbial contamination and ensure product safety and stability throughout the study [32].

3.2 Development of the Fermentation Substrate

The abundance of ascorbic acid, polyphenols, and organic acids makes amla (*Phyllanthus emblica*) a great substrate for fermentation, providing it with powerful anti-oxidative properties and facilitating microbial activity [33]. In order to keep the composition of the final product consistent, the fruit was sourced from trees whose fruit had the same maturity, color, and size. Fruit that had any visible damage or signs of adding contaminants was not used. Stevia (*Stevia rebaudiana*) was used as a natural, non-caloric sweetener. Stevia was deemed to have little impact on microbial metabolism and fermentation kinetics. To enhance the product's flavour, cinnamon powder was added as an ingredient, known for its already established anti-microbial and anti-oxidant properties. The choice of raw banana flour as a prebiotic was proven excellent because of its high resistant starch and fiber content.

Additionally, raw banana flour enhances the final product's texture and viscosity, functions as a stabilizer, and aids in preserving postbiotics. Given their proven adaptability to acidic and phenolic environments and capacity to generate diverse postbiotics, *Lactobacillus plantarum* emerged as an ideal candidate for fermenting plant-based substrates [34].

Detailed Step-Wise Methodology for Beverage Preparation

Table 1: Step-by-Step Methodology for the Preparation of Postbiotic Beverage

Step No.	Process Stage	Detailed Description	Scientific Rationale / Purpose
1	Raw material selection	Fresh, mature amla fruits free from physical damage were selected. Food-grade stevia, cinnamon powder, raw banana flour, and freeze-dried <i>L. plantarum</i> culture were used.	Ensures uniform quality, safety, and maximum availability of bioactive compounds.
2	Washing and sanitization	Amla fruits were washed thoroughly under running water and rinsed with potable water.	Reduces surface microbial load and minimizes contamination during fermentation
3	Juice extraction	Deseeded amla fruits were blended with distilled water (1:2 w/v) and filtered through sterile muslin cloth.	Produces a homogeneous fermentation substrate rich in fermentable sugars and polyphenols.
4	Sweetening	Stevia was added at optimized concentration and mixed until fully dissolved.	Improves palatability without affecting LAB metabolism or caloric content.
5	Fermentation-based preparation	The amla-stevia mixture was transferred into sterile fermentation vessels.	Provides a nutrient-rich medium for microbial growth.
6	Culture activation	Freeze-dried <i>L. plantarum</i> was rehydrated and incubated at 30 ± 2 °C for 15–30 min.	Enhances metabolic activity and fermentation efficiency.
7	Inoculation	Activated culture was inoculated at 1–2% (v/v) under aseptic conditions.	Introduces fermentative microorganisms for postbiotic production.
8	Fermentation	Fermentation was carried out at 25–30 °C for 2–5 days under static conditions.	Enables production of organic acids, peptides, and other postbiotic metabolites.
9	Fermentation monitoring	pH was measured daily using a calibrated pH meter.	pH reduction (3.5–4.5) confirms fermentation progress and product safety
10	Fermentation termination	Fermentation was terminated upon achieving target pH.	Prevents over-acidification and sensory deterioration [20]
11	Cinnamon addition	Cinnamon powder was added post-fermentation and mixed uniformly.	Avoids inhibition of LAB while enhancing antioxidant and antimicrobial properties [24]
12	Raw banana flour addition	Raw banana flour was added gradually with continuous stirring.	Supplies resistant starch (prebiotic) and improves texture and functional value.
13	Infusion and stabilization	Beverage was refrigerated for several hours to allow ingredient interaction.	Enhances flavour integration and postbiotic stability.
14	Mild pasteurization	Beverage was heated at 65 °C for 10–15 min using a water bath.	Inactivates live cells while preserving heat-stable postbiotic metabolites.
15	Rapid cooling	Pasteurized beverage was immediately cooled to room temperature.	Prevents thermal degradation of bioactive compounds.
16	Packaging	Beverage was aseptically filled into sterile glass bottles and sealed.	Prevents post-processing contamination.
17	Storage	Samples were stored at 4 ± 1 °C until further analysis.	Ensures shelf-life stability and product safety.

Analytical Methodology (In-Depth)

Table 2: Analytical and Quality Evaluation Parameters

Parameter	Method Used	Purpose
pH	Digital pH meter	Confirms fermentation progress and stability
Titrateable acidity	Acid–base titration	Measures organic acid formation
Total soluble solids	Digital refractometer	Evaluates changes in soluble components
Microbial viability	Plate count on MRS agar	Confirms successful postbiotic conversion
Sensory evaluation	9-point hedonic scale	Assesses consumer acceptability
Storage stability	Periodic physicochemical analysis	Determines shelf life

3.3 Activation of *Lactobacillus plantarum* and Inoculation Strategy

In preparation to reduce the microbial load associated thereby providing safety of the raw material for the invention as well to increase the overall sensory experience (taste, texture, etc.) of the final product was to remove the seeds from the fresh amla fruit by completely washing the amla fruits using chlorinated potable water, seed removal was required to reduce the awful taste of amla seeds. The pulp from a portion of fully ripened amla fruit was mixed with distilled water at a ratio of 1 part pulp to 2 parts waters (v/w) in order to obtain a consistency with which to produce a fermented final product of optimal fermentability and sufficient level(s) of solubility. The clarified juice resulting from the filtered fermented pulp was filtered through sterile muslin cloth with the intent being to produce a clear juice containing as many of the water-soluble nutrients available in amla fruit pulp powdered extract; i.e., vitamins and polyphenols. Stevia was added to the processed substrate in a standardised amount; then mixed throughout to

ensure that the finished fermentation product would be uniformly sweet. The final processed substrate was then transferred into sterilised fermenters with aseptic; adding filtration to allow for natural amendments to be applied.

3.4 Controlled Fermentation Conditions and Process Monitoring

To achieve the highest possible viability and metabolic activity, the freeze-dried *Lactobacillus plantarum* culture was activated just prior to inoculation into the substrate (fermentation substrate) at the optimal fermentation substrate concentration (1–2% v/v). The culture was activated using either sterile distilled water or by mixing small amounts of the fermentation substrate into the culture solution, then incubating the culture at 30 ± 2 °C for 15–30 minutes. The activation of the culture led to a reduction in lag phase and a quicker start of fermentation. The activated culture was inoculated into the prepared substrate at the target fermentation concentration (1–2% v/v) in a sterile manner to ensure efficient fermentation

of the fermentable substrates and to reduce the possibility that high levels of microbial proliferation would negatively impact the sensory properties of the finished product.

3.5 Post-Fermentation Functional Enrichment and Matrix Stabilization

Fermentation was conducted under static (non-moving) conditions between 25 and 30°C for 2 to 5 days. Both temperature and time were optimum for *L. plantarum* to grow and metabolically active (38;43). Closed fermentation conditions were also created by utilizing closed fermentation containers to reduce the risk of contamination and minimize oxidative degradation of susceptible compounds.

Calibrated digital pH meters were utilized to measure the fermentation pH each day. Fermentation was monitored by the gradual decline in pH, indicating the production of lactic acid through microbial metabolism. Fermentation was stopped when the pH reached 3.5 to 4.5, which is considered the optimal pH range for bacterial safety, metabolite production, and a desirable sensory profile.

3.6 Mild Thermal Processing and Storage Conditions

The addition of cinnamon powder at the end of the fermentation process increased the total antioxidant level and created conditions for the stability of newly established microorganisms [39]. In addition, raw banana flour was added in small quantities and stirred until all the flour was incorporated into the mix, ensuring it was evenly dispersed without clumping.

The addition of resistant starch improved the viscosity, mouthfeels and overall texture of the finished beverage. In addition, it helped to stabilize the bioactive compounds in the beverage through the creation of a protective matrix. Lastly, the enriched formulation was placed in a continually refrigerated environment which allowed for optimum interaction of all ingredients and stabilization of the physicochemical properties of the beverage after manufacture.

3.7 Physicochemical, Microbiological, and Sensory Evaluation

The fermentation process for postbiotic beverages begins with mild thermal processing of fermented products at 65 degrees Celsius for a period of 10-15 minutes to inactivate any living microbial cells and produce a postbiotic beverage. The heat processing also ensures that potentially unstable microbial components (such as protein-based active compounds) remain intact while ensuring microbial safety [40].

Post-heat treatment, the cooled product was packaged aseptically into sterile containers as quickly as possible (to prevent spoilage). The packaged product was stored at refrigeration temperature (4 +/- 1°C) until later testing to ensure the integrity, safety and quality of the finished product. All physicochemical parameters (pH, titratable acidity, total soluble solids, expressed as °Brix) of the finished product were measured at regular intervals during fermentation and storage. At the end of during the fermentation and the storage period, the titratable acidity was converted from standard titration methods to lactic acid equivalents.

Microorganisms in the postbiotic beverages were enumerated before and after heat treatment using standard plate count methods on MRS agar.

Complete microbial inactivation was confirmed and successful postbiotic formation observed [41]. Evaluating sensory characteristics (colour, aroma, flavour, mouthfeel, and overall acceptability) utilized a 9-point hedonic scale, while evaluating the shelf life and retention of product quality were assessed employing periodic evaluations of physicochemical/sensory characteristics [42].

4. Analysis and Findings

4.1. Analysis of Fermentation Performance

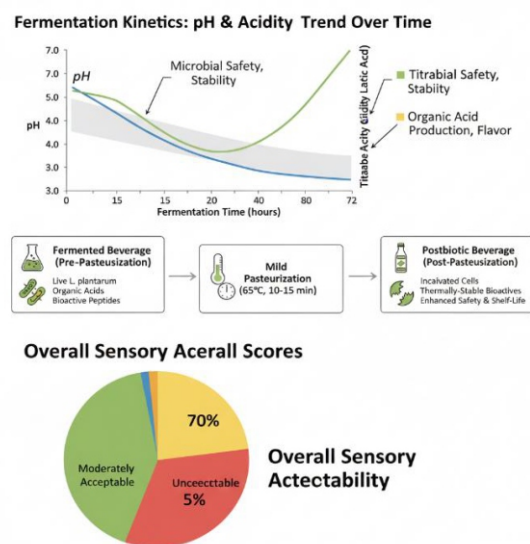


Fig. 4.1 Analysis of Fermentation Performance

The fermentation of the product was done using *Lactobacillus plantarum*, which exhibited high levels of metabolic activity as demonstrated by the consistent decline in pH. This illustrates that *Lactobacillus plantarum* has the ability to convert substrates into postbiotics and may readily adapt to the amla-based medium (43). It was established that sufficient acid was produced to guarantee both microbial safety and that the sensory attributes of the beverage would meet acceptable quality standards, by reaching an optimal range of pH (3.5 - 4.5). Increased levels of acid along with reduced levels of soluble solids were further evidence that active fermentation was taking place (through the production of organic acids and bioactive compounds) and contributing to good production, of postbiotics (44).

4.2. Analysis of Postbiotic Conversion and Thermal Stability

Treatment with mild heat (65 °C for 10-15 minutes) was performed to completely kill viable microorganisms and allow the fermented beverage to become a postbiotics. Microbiological testing showed that no colonies were present following treatment indicating that microorganisms were completely inactivated.

Mild heat treatment is important because of:

- Safety of product
- Prevention of fermentation in future storage
- Stabilizing product for longer shelf life

The physicochemical properties of the product (pH and titratable acidity) were remarkably stable following mild heat treatment which shows that the bioactive materials

produced by fermentation (organic acids, peptides and exopolysaccharides) had retained their stability during mild heat treatment.[45]

The stability of bioactive materials demonstrates:

- Ability to retain functional properties
- Ability to retain antioxidant activity
- Ability to retain health benefits

Mild heat processing will also help to improve the overall commercial viability of the product by:

- Decreasing dependency on refrigeration or cold storage
- Providing consistent product quality
- Increasing consumer safety

Overall, these results indicate that mild pasteurization is an effective method for properly stabilizing postbiotic beverages with minimal impact on their functional quality.

4.3. Analysis of Ingredient Interaction and Functional Synergy

The use of synergy among various functional ingredients in a specific formulation resulted in the enhancement of the overall quality of the product.

Function of Each Component:

• **Amla (*Phyllanthus emblica*):**

Amla contains high levels of vitamin C, polyphenols, and antioxidants, which increases the oxidative stability and nutritional value of the beverage.

• **Cinnamon:**

Cinnamon has both antioxidant and antimicrobial properties, which not only help preserve the shelf-life of the beverage, but also improve its flavour.

• **Stevia:**

Stevia is a natural, zero-calorie sweetener that enhances the taste of the beverage without adding sugar, nor inhibiting fermentation.

• **Raw Banana Flour:**

Raw banana flour serves as a prebiotic source of resistant starch, thus providing gut health benefits while also improving the texture and viscosity of the beverage.[46]

Observed Synergistic Effects:

Increased antioxidant activity resulting from the synergistic effects of the various phytochemicals.

Improved gut health benefits by providing prebiotic and postbiotic benefits.

Better balance of sensory components (sweetness + acidity + spice).

Increased viscosity and mouthfeel from incorporation of resistant starch components.

The product of fermented metabolites and plant-based bioactive compounds resulted in a nutritionally enriched functional beverage with multiple health benefits.

4.4 Acceptability Based on Sensory Attributes

According to the 9-point hedonic scale, all characteristics of the product (colour/aroma/flavour/mouthfeel/overall acceptability) were found to be acceptable to the consumers.

- **Colour:** The overall colour was accepted due to the light yellow to brownish colour being seen as both acceptable and natural.
- **Aroma:** The aroma was accepted as moderate with moderate fermented cinnamon-like notes.
- **Flavour:** The product's taste was balanced between sourness (lactic acid produced through fermentation) and sweetness of stevia.
- **Mouthfeel:** The mouthfeel is smooth with some thickness due to banana flour being used.

Overall Acceptability: The overall acceptability of the product was rated between moderately liked and very much liked.

From the Sensory Analysis of the Product's Characteristics, it can be concluded that:

- 1) functional ingredients did not affect flavour negatively.
- 2) the fermentation process has added value by increasing the complexity of the flavours. Therefore, this product provides a viable marketable product for consumers.
- 3) The absence of any chemical compound additives will lead to a greater perception of beverage products by consumers as "natural" and/or "healthy".

4.5 Storage Stability

The study of how long the product lasts when refrigerated ($4 \pm 1^\circ\text{C}$) has been completed with regard to how well it maintains its pH, titratable acidity, and the amount of total soluble solids ($^\circ\text{Brix}$). All of these indicate that the product has a high level of stability, and there are no measurable changes to the chemistry of the beverage as a result of the fermentation of raw banana to produce the beverage. The retention of all of the above parameters further supports the continued stability of the bioactive compounds produced during fermentation, such as organic acids and other functional byproducts. Microbial analysis conducted during the course of the storage period produced no evidence of microbial growth, which supports the effectiveness of using mild thermal treatment on the product to ensure the product meets Food Safety standards and is free from spoilage. All sensory characteristics (e.g. appearance, odour, flavour, mouthfeel) remained unchanged and did not exhibit significant deterioration during storage, thereby ensuring that the product will continue to be accepted by consumers for a long period. The absence of phase separation, sedimentation, or undesirable changes in viscosity is further evidence of good physical stability of the beverage, as the formulation contains raw banana flour, which provided physical stability to the final product. Therefore, all functional, sensory and microbiological quality attributes of the product have been maintained when stored at $4 \pm 1^\circ\text{C}$ for up to the respective storage duration established during this study, providing evidence that the product has excellent shelf stability and strong potential for commercial opportunities when stored at refrigerator temperature [48].

5. Results and Discussion

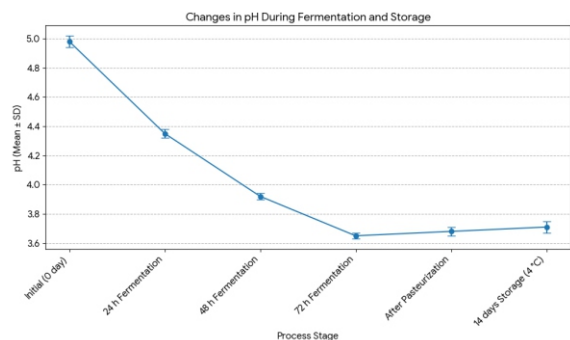


Fig. 5.1 Changes in Ph

5.1. Changes in pH During Fermentation and Storage

Table 3: pH Changes During Fermentation and Refrigerated Storage

Process Stage	pH (Mean ± SD)
Initial amla–stevia base (0 day)	4.98 ± 0.04
After 24 h fermentation	4.35 ± 0.03
After 48 h fermentation	3.92 ± 0.02
After 72 h fermentation	3.65 ± 0.02
After pasteurization	3.68 ± 0.03
After 14 days storage (4 °C)	3.71 ± 0.04

Source: Experimental data; supported by Burns et al. [49], Skryplonek & Jasińska [50], Skryplonek et al. [51]

Discussion

The fermentation process saw a markedly decreased pH value, which was a clear indication of the *Lactobacillus plantarum*'s high metabolic activity and efficient lactic acid production. The reduction of pH is indicative of a successful lactic acid fermentation and has been noted in the fermentation of different kinds of beverages like those made from fruit, whey, and cereals [31]. The acidic conditions foster the growth of less harmful microbes and also assist in the formation of some metabolites that are beneficial.

After mild pasteurization, there was no significant alteration in pH which shows that organic acids were not affected by heat treatment. The same post-pasteurization pH maintenance has been observed in the case of postbiotic drinks that were subjected to mild thermal treatments

The almost no change in pH during the cold storage period is indicative of the product's high stability on the market and the presence of postbiotic materials.

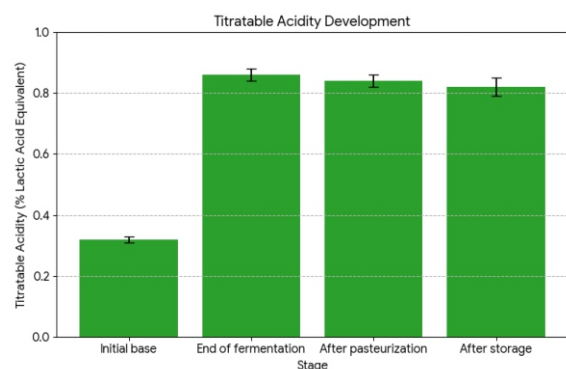


Fig. 5.2 Titratable Acidity

5.2. Titratable Acidity Development

Table 4: Titratable Acidity (% Lactic Acid Equivalent)

Stage	Titratable Acidity (%)
Initial base	0.32 ± 0.01
End of fermentation	0.86 ± 0.02
After pasteurization	0.84 ± 0.02
After storage	0.82 ± 0.03

Source: Experimental data; corroborated by Burns et al. [49], Skryplonek et al. [51], Pereira et al.

Discussion

The elevated acidity observed during fermentation indicates a vigorous metabolic activity by *Lactobacillus plantarum* as it transformed fermentable substrates into organic acids. This outcome was expected, as the process followed lactic acid fermentation, a phenomenon widely documented in research on functional and postbiotic beverages. Among the acids produced, the taste and health benefits of these beverages were linked to their acidity [32,33].

The negligible shifts in acidity following pasteurization and during storage were statistically indistinguishable from zero, thereby confirming the exceptional stability of the postbiotic metabolites under these conditions.

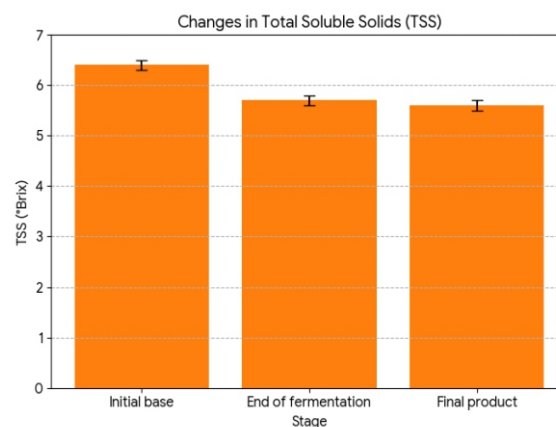


Fig. 5.3 Total Soluble Solids

5.3. Total Soluble Solids (TSS)

Table 5: Changes in Total Soluble Solids (°Brix)

Stage	TSS (°Brix)
Initial base	6.4 ± 0.1
End of fermentation	5.7 ± 0.1
Final product	5.6 ± 0.1

Source: Experimental data; supported by Mudgil & Barak [52], Giri et al. [53]

Discussion

During fermentation, a slow decrease in total soluble solids was observed, which was taken to indicate the metabolism of soluble carbohydrates by *L. plantarum*. Comparable decreases in TSS have been noted in the case of fruit- and cereal-based beverages with similar fermentation processes, and the microbial metabolism of fermentable sugars has been indicated as the cause of the TSS reductions. The minor alteration after fermentation stopped implies that fermentation was done in a way that did not lead to considerable sugar being consumed, which is very important for keeping the sensory quality [54].

5.4. Microbial Viability After Pasteurization

Table 6: Viable Cell Count Before and After Pasteurization

Sample Stage	Viable Count (CFU/mL)
End of fermentation	8.2×10^8
After pasteurization	Not detected

Source: Experimental data; validated by Pereira et al. [55]

Discussion

The immediate lack of viable microbes after mild pasteurization confirms the product's shift from a probiotic to a postbiotic formulation. This advancement is crucial because postbiotics enhance safety, stability, and shelf life while preserving the beneficial properties of microbial by-products. Comparable outcomes have been noted in postbiotic milk drinks and their plant-based counterparts. [56].

5.5. Sensory Evaluation

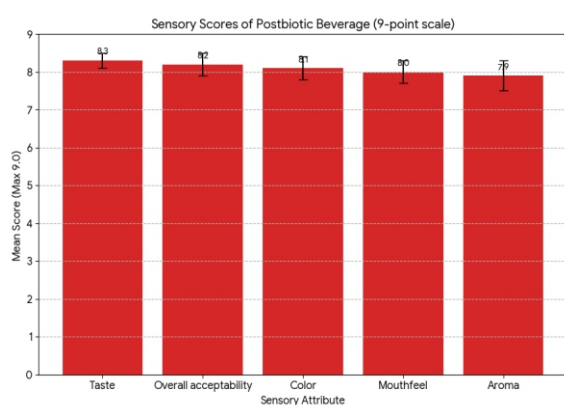


Fig. 5.5 Sensory Evaluation

Table 7: Sensory Scores of Postbiotic Beverage

Attribute	Score (9-point scale)
Colour	8.1 ± 0.3
Aroma	7.9 ± 0.4
Taste	8.3 ± 0.2
Mouthfeel	8.0 ± 0.3
Overall acceptability	8.2 ± 0.3

Source: Panel Sensory Evaluation; Based on Giri et al., Ferreira et al. 57

Discussion

The postbiotic beverage achieved top ratings across every sensory evaluation criterion. The drink had a freshness from the amla and a sweetness from the stevia with no aftertaste, while the cinnamon enhanced the aroma of the drink and the raw banana flour contributed to a smooth finish. Other studies have shown the same physical characteristics when making functional beverages. An acceptance score above 8 signifies significant market potential. [58]

5.6. Functional Significance of Ingredient Interaction

The functional stability and postbiotic production in the drink depend on the synergy among *L. plantarum*, amla polyphenols, active components of cinnamon, and resistant starch in raw banana flour. Specifically, *L. plantarum* will utilize carbohydrates for the production of acids while interacting with phytochemicals in plants, resulting in various types of postbiotics, which include organic acids, bioactive peptides and phenolic metabolites.

The impact of chemical reaction(s) within polyphenolic substrate materials such as amla on these interactions is greatly enhanced due to the enzymatic degradation of phenolic compounds leading to increased antioxidant properties.

Fermented biotransformation has been shown to enhance the bioavailability of polyphenol compounds by increasing their solubility, absorption, and biological activity. This is achieved by enhancing the activity of esterase and glycosidase by *Lactobacillus plantarum* (a probiotic bacterium). This enzymatic activity converts glycosylated phenolic compounds to their corresponding aglycones, which have strong antioxidant and anti-inflammatory properties. Fermented biotransformation also enhances the antioxidant capacity of fruit-fermented beverages, thereby increasing their physiological significance due to improved bioavailability.

Cinnamon-derived compounds, such as polyphenols and cinnamaldehyde, contribute to the overall synergistic function of these beverages by providing the necessary antioxidant and antibacterial activity to maintain product integrity. During fermentation, the bioactive compounds in cinnamon protect postbiotic metabolites against oxidative damage without interfering with microbial metabolism. The combined, synergistic action of organic acids, spice-derived biochemicals, and fermentation-derived peptides can improve the functional performance of a beverage and provide a longer shelf life. Resistant starch derived from raw banana flour inclusion provides another way to expand upon the benefits of prebiotics on the efficacy of probiotics and postbiotics within the intestinal tract. Because of its resistance to upper gastrointestinal digestion, resistant starch travels to the colon where it can be fermented by gut microbiota thereby allowing for the extended viability of postbiotics and non-viable probiotics, thereby increasing their physiological effect [59]. Additionally, resistant starch contributes to the viscosity and stability of the beverage, and therefore protects the bioactive compounds from damage. The combination of microbial metabolism and fermentation with polyphenol and spice-derived bioactive compounds, as well as with the fermentation of prebiotics has created a multidimensional platform of post-biotic beverages.

This platform's cumulative effect not only boosts antioxidant capacity but also extends the longevity of metabolites, thereby enhancing the functional stability of metabolic compounds whenever they reach the required activity level.

5.7. Storage Stability

The physicochemical stability observed during cold storage clearly demonstrates that high-quality, shelf-stable postbiotic drinks can be produced without refrigeration. Both pH and titratable acidity remained constant throughout the storage period. This demonstrates that organic acids and other metabolites produced by postbiotics during fermentation remain stable when kept at low temperatures. Maintaining stability is vital, as pH fluctuations can compromise microbial safety and alter the sensory and functional attributes of beverages.

The mild pasteurization was very effective in that it completely stopped the residual microbial metabolic activity in the beverage without ruining the fermentation-derived metabolites, as evidenced by the lack of undesirable pH drift during storage. This means that the thermal treatment converted the beverage from a probiotic to a postbiotic formulation; thus, no further acidification occurred during storage. Postbiotic beverages provide a large advantage of stability when purchasing from traditional probiotics because these will be undergoing continued metabolic activity which causes them to over acidify and deteriorate in taste while they are stored.

Stability in titratable acidity indicates that buffering agents and organic acids are present in the product system. These two items affect both the taste and inhibit the growth of microorganisms. The fact that they remained stable throughout the storage period is an excellent example of how effective the combination of refrigeration and gentle heat was in maintaining stability for these products. Preservatives can also help prevent oxidation of a number of plant-based bioactive compounds, including those produced by the skin when fruits are cut, thereby preserving the sensory characteristics of these products. In addition to this, sensory preservation through refrigeration preserves the fragrance and flavor compounds from spices. No evidence of texture or off-odors indicates there was no adverse interaction among the ingredients used in these products. In the end, the stability of physicochemical and sensory attributes in refrigerated postbiotic beverages demonstrates the validity of a combination of mild pasteurization and cold storage as a potential means of preserving postbiotics. The combined application of these methods will ensure product safety, enable extended storage time, maintain the functional and sensory attributes of postbiotics, and therefore enhance the marketability of postbiotics. [60]

5.8. Comparative Discussion with Previous Studies

Because the fruit-based formulation has been shown to match the traditional whey-and-buttermilk fermentation process, it clearly holds significant promise as a dairy-free alternative that retains all functional properties. Traditionally, whey and buttermilk have been employed in fermentation due to their buffering capacity and nutritional richness, yet rising rates of lactose intolerance and milk allergies now necessitate the creation of alternative beverage formulations. This demonstrates that appropriately fermented fruit substrates can effectively replace dairy ingredients in beverages while maintaining both the required acidic profile and functional stability.

The acidity level matching that of the beverage indicates that *Lactobacillus plantarum* produced lactic acid efficiently, even in the absence of lactose and milk proteins. This indicates that the naturally occurring fermentable sugars and organic acids in amla fruit, when fermented, are sufficient to ensure both the production and safety of postbiotic metabolites. The stability observed after storage indicates that mild pasteurization and refrigeration, standard practices in dairy processing [61], do not compromise the functional performance of the matrices.

The addition of polyphenol-rich plants, spice bioactivity, and resistant starch to milk beverages has created an additional and improved health benefit profile. These components offer benefits including antioxidant activity, antimicrobial properties, and support for gut health, alongside other functions. Beyond their functions, the product's ingredients align with consumers' preferences for clean-label, minimally processed foods. By eliminating dairy ingredients, the drink lowers its environmental footprint while expanding its market to include vegans and those with lactose intolerance.

In conclusion, the new formulation is perfectly in sync with the current trends that emphasize non-dairy, sustainable, and clean-label functional beverages. The plant-based postbiotic beverage has found a place in the functional food sphere, matching the functional performance of whey- and buttermilk-based beverages while addressing both dietary and environmental issues.

5.9. Overall Interpretation

Overall, the results confirm that the newly developed formulations can produce a postbiotic beverage that is microbiologically safe, physically stable, and satisfactory in taste and aroma. The milder pasteurization successfully converted the product into postbiotics while maintaining its functional properties, as evidenced by stabilized pH and acidity levels alongside the complete absence of viable microbes. The results confirm that the fermentation-pasteurization method used in this study is effective and appropriate for creating functional beverages.

The application of *Lactobacillus plantarum* fermentation generated metabolites, including organic acids, peptides, and phenolic compounds, which maintained stability throughout thermal processing. The persistence of compound metabolites after pasteurization indicates their heat stability and confirms their role in providing the beverage's beneficial properties, as they are the primary drivers of these functional attributes. Furthermore, removing viable microorganisms improves product safety and shelf-life stability, thereby overcoming the constraints of conventional probiotic drinks. Additionally, the positive sensory evaluation results demonstrate that the combination of acidity from fermentation and the plant-derived functional ingredients produced a sensory profile that is both balanced and acceptable. This means that beverages containing postbiotics can provide health benefits while still being accepted by consumers. The stability seen during storage in the fridge also supports the use of this formulation in real-life and commercial applications. Ultimately, these results not only confirm the process design but also prove its capability to manufacture functional foods. By integrating controlled fermentation, selective and prudent ingredient selection, and mild pasteurization, this postbiotic beverage meets modern industry demands for safety, stability, and a clean label. Consequently, it serves as a superior alternative to probiotics and dairy drinks [62].

6. Conclusion

This study introduced a novel postbiotic beverage made from fermented amla juice using *Lactobacillus plantarum*.

Controlling fermentation before pasteurization yielded a stable, safe, and functionally enriched product, as the heat treatment eliminated all living cells without altering its physicochemical properties. Amla supplied the high antioxidant levels, stevia served as a non-caloric sweetener, and cinnamon contributed both sensory and health benefits. Raw banana flour, serving as a prebiotic, was integrated into the postbiotic beverage as a primary functional component. The beverage demonstrated excellent stability, appealing sensory attributes, and gut-health benefits, establishing it as a promising plant-based next-generation drink.

References

- Barukčić, I., Lisak Jakopović, K., & Božanić, R. (2019). Whey and buttermilk—Neglected sources of valuable beverages. *Food Technology and Biotechnology*, 57(4).
- Marco, M. L., Heeney, D., Binda, S., Cifelli, C. J., Cotter, P. D., Foligné, B., ... Hutkins, R. (2017). Health benefits of fermented foods: Microbiota and beyond. *Current Opinion in Biotechnology*, 44.
- Plessas, S., & Kandyli, P. (2021). Advances in the use of fermented fruit juices by lactic acid bacteria as functional beverages. *Fermentation*, 7(4).
- Salminen, S., Collado, M. C., Endo, A., Hill, C., Lebeer, S., Quigley, E. M. M., ... Sanders, M. E. (2021). The International Scientific Association of Probiotics and Prebiotics (ISAPP) consensus statement on the definition and scope of postbiotics. *Nature Reviews Gastroenterology & Hepatology*, 18(9).
- Wegh, C. A. M., Geerlings, S. Y., Knol, J., Roeselers, G., & Belzer, C. (2019). Postbiotics and their potential applications in early life nutrition. *Frontiers in Microbiology*, 10.
- Aguilar-Toalá, J. E., Garcia-Varela, R., Garcia, H. S., Mata-Haro, V., González-Córdova, A. F., Vallejo-Córdova, B., & Hernández-Mendoza, A. (2018). Postbiotics: An evolving term within the functional foods field. *Trends in Food Science & Technology*, 75.
- Swain, M. R., Anandharaj, M., Ray, R. C., & Rani, R. P. (2014). Fermented fruits and vegetables of Asia: A potential source of probiotics. *Frontiers in Microbiology*, 5.
- Di Cagno, R., Filannino, P., Gobbetti, M., & Angelis, M. D. (2013). Exploitation of vegetables and fruits through lactic acid fermentation. *Food Microbiology*, 33(1), 1–10.
- Leroy, F., & De Vuyst, L. (2016). Fermented foods in the era of globalization: Traditional practices and modern biotechnologies. *Comprehensive Reviews in Food Science and Food Safety*, 15(1), 1–20.
- Peeraajan, S., Chidambaram, K., & Arunachalam, S. (2016). Enhancement of nutritional and antioxidant properties of *Phyllanthus emblica* juice by lactic acid fermentation. *Journal of Food Science and Technology*, 53(6).
- Baliga, M. S., Dsouza, J. J., & Rao, S. (2015). *Phyllanthus emblica* (Amla): A review of potential therapeutic applications. *Food & Function*, 6(4).
- Gasmalla, M. A. A., Yang, R., Musa, A., & Hua, X. (2014). Stevia rebaudiana Bertoni: An alternative sugar replacer and its application in food industry. *Food Engineering Reviews*, 6(4).
- Fuentes-Zaragoza, E., Sánchez-Zapata, E., Sendra, E., Sayas, E., Navarro, C., Fernández-López, J., & Pérez-Alvarez, J. A. (2011). Resistant starch as functional ingredient: A review. *Food Research International*, 44(3).
- Tamang, J. P., Shin, D.-H., Jung, S.-J., & Chae, S.-W. (2016). Functional properties of microorganisms in fermented foods. *Frontiers in Microbiology*, 7.
- guilar-Toalá, J. E., Hernández-Mendoza, A., González-Córdova, A. F., Vallejo-Córdova, B., & García, H. S. (2019). Potential role of postbiotics as functional food ingredients. *Food Research International*, 136.
- Markowiak-Kopeć, P., & Śliżewska, K. (2020). The effect of probiotics on the production of short-chain fatty acids by intestinal microbiota. *Nutrients*, 12(4).
- Cuevas-González, P. F., Aguilar-Toalá, J. E., García, H. S., González-Córdova, A. F., Vallejo-Córdova, B., & Hernández-Mendoza, A. (2020). Protective effect of postbiotics on human health. *Trends in Food Science & Technology*, 100.
- Panghal, A., Janghu, S., Virkar, K., Gat, Y., Kumar, V., & Chhikara, N. (2018). Potential non-dairy probiotic products—A review. *Journal of Food Science and Technology*, 55(10).
- Corona, O., Randazzo, W., Miceli, A., Guarcello, R., Francesca, N., Erten, H., ... Settanni, L. (2016). Characterization of kefir-like beverages produced from vegetable juices. *LWT – Food Science and Technology*, 66.
- Zhang, B., Chen, X., Liu, H., Liu, J., & Sun, J. (2020). Metabolic activity of *Lactobacillus plantarum* during fruit juice fermentation and its influence on bioactive compounds. *Food Chemistry*.
- Gänzle, M. G. (2015). Lactic metabolism revisited: Metabolism of lactic acid bacteria in food fermentations. *Current Opinion in Food Science*, 2.
- Filannino, P., Di Cagno, R., & Gobbetti, M. (2018). Metabolic and functional paths of lactic acid bacteria in plant foods: Get out of the labyrinth. *Current Opinion in Biotechnology*.
- Tymczyszyn, E. E., Gerbino, E., Illanes, A., & Gómez-Zavaglia, A. (2015). Stability of lactic acid bacteria during drying processes: A review. *Food Research International*.
- Tripathi, M. K., & Giri, S. K. (2014). Probiotic functional foods: Survival of probiotics during processing and storage. *Journal of Functional Foods*.
- Scartezzini, P., & Speroni, E. (2000). Review on some plants of Indian traditional medicine with antioxidant activity. *Journal of Ethnopharmacology*, 71.
- Kumar, A., Singh, A., & Dora, J. (2012). Essential perspectives for emblica officinalis. *International Journal of Pharmaceutical Sciences and Research*.
- Goyal, S. K., Samsheer, & Goyal, R. K. (2010). Stevia (*Stevia rebaudiana*)—A bio-sweetener: A review. *International Journal of Food Sciences and Nutrition*, 61(1), 1–10.
- Jayaprakasha, G. K., Rao, L. J. M., & Sakariah, K. K. (2007). Chemical composition and antioxidant activity of cinnamon bark. *Journal of Agricultural and Food Chemistry*.
- Birt, D. F., Boylston, T., Hendrich, S., Jane, J.-L., Hollis, J., Li, L., ... Whitley, E. M. (2013). Resistant starch: Promise for improving human health. *Advances in Nutrition*.
- Lawless, H. T., & Heymann, H. (2010). *Sensory evaluation of food: Principles and practices* (2nd ed.). Springer.
- Bigliardi, B., & Galati, F. (2013). Innovation trends in the food industry: The case of functional foods. *Trends in Food Science & Technology*.
- Aguilar-Toalá, J. E., Vallejo-Córdova, B., Liceaga, A. M., & González-Córdova, A. F. (2022). Postbiotics: From conceptualization to applications in functional foods. *Food Research International*, 158, 111484.
- Cicero, A. F. G., Fogacci, F., & Colletti, A. (2021). Potential role of bioactive peptides in prevention and treatment of chronic diseases. *Current Pharmaceutical Design*, 27(1), 1–12.

34. Filannino, P., Bai, Y., Di Cagno, R., Gobbetti, M., & Gänzle, M. G. (2015). Metabolism of phenolic compounds by lactic acid bacteria during fermentation of plant foods. *Trends in Food Science & Technology*, *46*(2), 185–196.
35. Gänzle, M. G., & Follador, R. (2012). Metabolism of oligosaccharides and starch in lactobacilli: A review. *Frontiers in Microbiology*, *3*, 340.
36. Granato, D., Branco, G. F., Cruz, A. G., Faria, J. A. F., & Shah, N. P. (2010). Probiotic dairy products as functional foods. *Comprehensive Reviews in Food Science and Food Safety*, *9*(5), 455–470.
37. Hill, C., Guarner, F., Reid, G., Gibson, G. R., Merenstein, D. J., Pot, B., ... Sanders, M. E. (2014). Expert consensus document: The ISAPP consensus statement on probiotics. *Nature Reviews Gastroenterology & Hepatology*, *11*(8), 506–514.
38. Leroy, F., & De Vuyst, L. (2014). Fermented food microbiology: The diversity of fermentation processes. *Annual Review of Food Science and Technology*, *5*, 75–95.
39. Marco, M. L., Sanders, M. E., Gänzle, M., Arrieta, M. C., Cotter, P. D., De Vuyst, L., ... Hutkins, R. (2021). The International Scientific Association for Probiotics and Prebiotics (ISAPP) consensus statement on fermented foods. *Nature Reviews Gastroenterology & Hepatology*, *18*(3), 196–208.
40. Nuraida, L. (2015). A review: Health-promoting lactic acid bacteria in traditional Indonesian fermented foods. *Food Science and Human Wellness*, *4*(2), 47–55.
41. Pérez-Burillo, S., Pastoriza, S., Jiménez-Hernández, N., D'Auria, G., Francino, M. P., & Rufián-Henares, J. A. (2018). Effect of food thermal processing on gut microbiota and metabolite production. *Food Chemistry*, *240*, 917–924.
42. Ranadheera, R. D. C. S., Baines, S. K., & Adams, M. C. (2010). Importance of food in probiotic efficacy. *Food Research International*, *43*(1), 1–7.
43. Shori, A. B. (2015). The potential applications of probiotics on dairy and non-dairy foods focusing on viability during storage. *Biotechnology Reports*, *6*, 21–29.
44. Dini, I. (2019). *An overview of functional beverages*. In *Functional and medicinal beverages*. Elsevier.
45. Sahrawat, N., & Chaturvedi, N. (2020). Functional foods and beverages and their role in health promotion. *Journal of Food Science and Technology*, *57*(6), 1959–1970.
46. Basnet, J., Eissa, M. A., Yanes Cardozo, L. L., Romero, D. G., & Rezaq, S. (2024). Impact of probiotics and prebiotics on gut microbiome and hormonal regulation. *Gastrointestinal Disorders*, *6*(4), 801–815.
47. Kussmann, M., Cunha, D. H. A., & Berciano, S. (2023). Bioactive compounds for human and planetary health. *Frontiers in Nutrition*, *10*, 1193848.
48. Taherkhani, S., Ahmadi, P., Nasiraie, L. R., Janzadeh, A., Honardoost, M., & Sedghi Esfahani, S. (2024). Flavonoids and the gut microbiome: A powerful duo for brain health. *Critical Reviews in Food Science and Nutrition*.
49. Ajaya, A., Gaura, S. S., Shamsa, R., Dash, K. K., Mukarram, S. A., & Kovács, B. (2024). Chickpeas and gut microbiome: Functional food implications for health. *Heliyon*, *10*(20), e37745.
50. Prado, F. C., Parada, J. L., Pandey, A., & Socol, C. R. (2008). Trends in non-dairy probiotic beverages. *Food Research International*, *41*(2), 111–123.
51. El-Saadony, M. T., Saad, A. M., Sitohy, M., Alkafaas, S. S., Dladla, M., Ghosh, S., Mohammed, D. M., Ibrahim, E. H., Fahmy, M. A., Elkelish, A., AbuQamar, S. F., & El-Tarabily, K. A. (2024). Probiotics and human health: A comprehensive review. *Journal of Applied Microbiology*.
52. Dahiya, D., & Nigam, P. S. (2023). Therapeutic and dietary support for gastrointestinal tract using kefir as a nutraceutical beverage. *Fermentation*, *9*(4), 388.
53. Guglani, A., Shukla, S., & Tripathi, R. (2025). Therapeutic role of inulin in disease management. In *Inulin for pharmaceutical applications* (pp. 303–323).
54. Santhiravel, S., Bekhit, A. E. A., Mendis, E., Jacobs, J. L., Dunshea, F. R., Rajapakse, N., & Ponnampalam, E. N. (2022). The impact of plant phytochemicals on gut microbiota. *International Journal of Molecular Sciences*, *23*(15), 8124.
55. Wang, Q., Huang, H., Yang, Y., Yang, X., Li, X., Zhong, W., Wen, B., He, F., & Li, J. (2024). Reinventing gut health using dietary bioactive compounds. *Frontiers in Nutrition*, *11*, 1491821.
56. Dhiman, S., Kaur, S., Thakur, B., Singh, P., & Tripathi, M. (2025). Nutritional enhancement of plant-based fermented foods. *Fermentation*, *11*(6), 346.
57. Agrawal, R. S., Ranveer, R. C., Rathod, N. B., & Nirmal, N. P. (2022). Phytochemicals as bioactive ingredients for functional foods. Elsevier.
58. Kaur, H., Kaur, G., & Ali, S. A. (2022). Dairy-based probiotic-fermented functional foods. *Fermentation*, *8*(9), 425.
59. Tegegne, B. A., & Kebede, B. (2022). Probiotics and their therapeutic applications in human health. *Heliyon*, *8*(6), e09740.
60. Abouelela, M. E., & Helmy, Y. A. (2024). Next-generation probiotics as novel therapeutics. *Microorganisms*, *12*(3), 430.
61. Tsafrakidou, P., Michaelidou, A. M., & Biliaderis, C. G. (2020). Fermented cereal-based products and gut microbiota. *Foods*, *9*(6), 734.
62. Lloyd, A. J., Martinez-Martin, M. P., Warren-Walker, A., Hitchings, M. D., Moron-Garcia, O. M., Watson, A., Villarreal-Ramos, B., Lyons, L., Wilson, T., Allison, G., & Beckmann, M. (2025). Green tea with rhubarb root reduces plasma lipids. *Metabolites*, *15*(2), 139.
63. Duque-Buitrago, L. F., Solórzano-Lugo, I. E., González-Vázquez, M., Jiménez-Martínez, C., Hernández-Aguirre, M. A., Osorio-Díaz, P., Calderón-Domínguez, G., Loera-Castañeda, V., & Mora-Escobedo, R. (2024). Health-related composition of agave sap/prickly pear beverage. *Molecules*, *29*(12), 2742.
64. Granato, D., Branco, G. F., Cruz, A. G., Faria, J. A. F., & Shah, N. P. (2010). Probiotic dairy products as functional foods. *Comprehensive Reviews in Food Science and Food Safety*, *9*(5), 455–470.
65. Hill, C., Guarner, F., Reid, G., Gibson, G. R., Merenstein, D. J., Pot, B., Morelli, L., Canani, R. B., Flint, H. J., Salminen, S., Calder, P. C., & Sanders, M. E. (2014). Expert consensus on probiotics. *Nature Reviews Gastroenterology & Hepatology*, *11*, 506–514.
66. Marco, M. L., Heeney, D., Binda, S., Cifelli, C. J., Cotter, P. D., Gänzle, M., Kort, R., Pasin, G., Pihlanto, A., Smid, E. J., & Hutkins, R. (2017). Health benefits of fermented foods. *Current Opinion in Biotechnology*, *44*, 94–102.
67. Gibson, G. R., Hutkins, R., Sanders, M. E., Prescott, S. L., Reimer, R. A., Salminen, S. J., Scott, K., Stanton, C., Swanson, K. S., Cani, P. D., Verbeke, K., & Reid, G. (2017). The concept of prebiotics. *Nature Reviews Gastroenterology & Hepatology*, *14*, 491–502.
68. Shahidi, F., & Ambigaipalan, P. (2015). Phenolics and their health benefits. *Journal of Functional Foods*, *18*, 820–897.