Advanced Research in Gastroenterology & Hepatology
ISSN: 2472-6400

Juniper Publishers
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Review Article
Volume 22 Issue 2- January 2026
DOI: 10.19080/ARGH.2026.22.556082

Adv Res Gastroentero Hepatol

Lactobacillus-Fermented Probiotic Plant-Based Beverages: A Systematic Review and Comparative Analysis

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Submission: January 20, 2026 **Published:** January 29, 2026

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Structured Abstract

Background: A new generation of plant-based beverages fermented with Lactobacillus spp. has emerged in response to the rising need for alternatives to dairy-based probiotic delivery systems. Nutritional enhancement, probiotic survivability, and functional metabolites are just a few areas where experimental investigations have shown promise; nonetheless, synthesis across matrices and strains is still in its early stages of development.

Objective: To examine Lactobacillus-fermented plant-based drink studies, compare technical and functional outcomes across plant matrices (soy, oat, almond, rice, and others), and provide evidence- based research and product development suggestions.

Methods: Focusing on Lactobacillus fermentation of plant-based beverages, including species that have been reclassified as Lactiplantibacillus or Lacticaseibacillus, this literature review covers all the bases. Strain identification, matrix type, fermentation conditions, storage viability, simulated digestion, sensory results, nutritional/biochemical outcomes, and stated limitations were all parts of the extracted information. For this comparison, twenty-five scholarly publications from peer-reviewed journals were consulted.

Results: Listeria plantarum, Listeria fermentum, Listeria rhamnosus, and Listeria casei were found in common. Almond matrices often required fortification (with prebiotics or proteins) to achieve target probiotic levels and acceptable sensory quality. In contrast, soy and oat matrices provided the best growth support and protection during simulated digestion. Several studies have employed prebiotics or microencapsulation to achieve and maintain bacterial concentrations of 10^7CFU/mL after fermentation and 10^6-10^7CFU/mL during chilled storage periods ranging from 14 to 30 days. The antinutritional components, namely phytates, were much reduced during fermentation. Free phenolics and antioxidant capacity were raised, and protein digestibility was greatly improved. Depending on the strain and matrix, sensory findings range from acceptable fruitiness or acidic overtones in certain soy/oat formulations to off-tastes in others.

Conclusions: A good way to get probiotics into your system is to consume plant-based beverages fermented with Lactobacillus. The use of prebiotics or encapsulation to ensure shelf stability, sensory optimization, and strain-matrix matching is crucial to the success of a product. The absence of sensory validation and randomized clinical trials on an industrial scale is a major limitation.

Keywords: Lactobacillus; Plant-based Beverage; Non-dairy Probiotic; Soy; Oat; Almond; Fermentation; Probiotic viability; Comparative analysis

Introduction

As more people become interested in gut health and adopt plant-based diets, non-dairy probiotic beverages are gaining popularity. Many strains of *Lactobacillus spp.* and related reclassified taxa (such as Lactiplantibacillus) are GRAS-approved, and they have acidification capacity and health-relevant functional traits, making them ideal probiotic starters . Although plant matrices such as soy, oat, almond, and rice make attractive carriers, they differ significantly in their macronutrient content, antinutritional components, and organoleptic properties. These factors influence the rate of fermentation, the survivability of probiotics, and the consumer's acceptance of the product [1]. To evaluate the technical, nutritional, and functional performance of plant-based beverages fermented with Lactobacillus and to highlight important research gaps, this study compiles up-to-date experimental data.

Methods

Search strategy and selection criteria

Lactobacillus fermentation in plant-based beverages (soy, oat, almond, rice, buckwheat, mixes): experimental synthesis and literature analysis. We have 25 scholarly publications that cover a wide range of topics in our core reference collection [2-5]. These include strain screening, matrix comparisons, storage and digesting studies, biochemical characterizations, sensory assessments, and limited human or ex vivo trials. Information retrieved included the following: strain(s), matrix composition, fermentation settings (inoculum, temperature, duration), cell counts (CFU/mL), GI test findings, sensory outcomes, nutritional and biochemical alterations (e.g., phytate reduction, phenolic liberation, antioxidant tests), and research limitations. Framework for comparing and synthesizing data. The results were organized by matrix type and then by outcome category (technological performance, probiotic viability, nutritional/ functional modifications, sensory qualities). To facilitate cross-study comparison, qualitative summaries of quantitative data (e.g., viability and pH changes) were used to account for variations in measurement units and research design [6].

Results

Overview of included evidence

The selected literature emphasizes the repeated use of Lactobacillus strains with probiotic potential (e.g., *L. plantarum*, *L. fermentum*, *L. rhamnosus*, *L. casei*, *L. acidophilus*). It demonstrates the feasibility of producing plant-based probiotic beverages with significant viable counts and improved biochemical properties [7-13]. A few studies included human or ex vivo microbiome outcomes while the bulk were laboratory-scale fermentation and storage investigations.

Strain selection and functional traits

Strain selection is primarily influenced by: (1) acidification kinetics (to achieve product pH and safety), (2) ability to grow on low-protein/low-sugar substrates, (3) exopolysaccharide (EPS) production (improves mouthfeel and viscosity), and (4) probiotic properties (acid and bile tolerance, adhesion potential). EPS- producing L. plantarum strains and L. fermentum have been extensively studied for oat and soy matrices to enhance texture while maintaining CFU counts [14-16].

Matrix comparisons (technology and viability)

Soy drinks often provide sufficient nitrogen and other essential growth factors to support robust Lactobacillus growth, resulting in fermented products with high viable counts. Fermentation often increases the fraction of aglycone isoflavones while decreasing phytate concentration, which improves bioavailability and antioxidant activity [17]. Oat drinks, high in β-glucan and soluble carbohydrates, may improve texture and increase Lactobacilli development. Enzyme pretreatments or EPS-producing strains can help manage viscosity and mouthfeel. Oat matrices often provide satisfactory probiotic viability during refrigerated storage. Almond beverages contain less protein and more unsaturated fat; however, probiotics may achieve their goal viability when a prebiotic (e.g., inulin) or pea/soy protein is added. Sensory acceptability requires precise improvements in taste and texture. Rice and other cereals/buckwheat: These matrices are viable carriers, but they often require the addition of carbohydrates or proteins and initial modification to achieve high cell numbers and consistent sensory profiles [18].

Probiotic survival: storage and simulated digestion

Fermentation typically yields ≥10^7CFU/mL, as reported in research. Storage life varies depending on the matrix and formulation [19]. Prebiotic addition, microencapsulation, or strain selection may increase retention to ≥10^6-10^7CFU/mL over chilled durations of two to four weeks. Simulated GI digestion models revealed strain-dependent declines in viable counts; soy matrices often provided better protection, potentially due to protein/fat buffering and improved nutrient availability.

Nutritional and functional outcomes

Lactobacillus fermentation consistently decreased anti-nutritional elements (e.g., phytates), enhanced free phenolics and antioxidant activity, and produced peptides with higher digestibility in protein- containing matrices [20-22]. Animal research suggests that fermented soy drinks may have antioxidant and metabolic advantages; however, human trials are limited.

Sensory outcomes and consumer acceptability

Sensory results were heavily strain- and matrix-dependent. Some Lactobacillus strains added attractive fruity or lactic notes to soy and oat drinks, but others produced off-flavors that necessitated flavor masking or mixing with fruit extracts [23-25].

Safety and regulatory considerations

Most confirmed Lactobacillus strains are safe for food consumption; however, claims of probiotic health benefits need well-designed human clinical studies. Industrial applications need confirmation of sanitary processes and starting strain traceability.

Discussion

Principal findings

According to the literature, Lactobacillus-fermented plant-based drinks are technically possible and can provide effective probiotic dosages under the right circumstances. Soy and oat matrices appear as the most forgiving carriers for growth support and digestive protection, respectively. Prebiotics, fortification with protein isolates, and the utilization of EPS-producing strains all increase shelf stability and sensory qualities.

Strengths and limitations of evidence

The evidence foundation is strong, with several controlled

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fermentation studies, biochemical analysis of fermented products, and the development of microbiome/ex vivo research. Limitations include variety in experimental techniques (various strain nomenclature, fermentation settings, and viability tests), a scarcity of randomized controlled human trials, and insufficient industrial-scale shelf-life and sensory investigations.

Practical implications and recommendations

Regarding research and development, as well as product development, we propose:

a) One must first do empirical strain screening for every objective matrix, including growth, acidification, EPS production, and flavor profile.

b) To obtain and maintain acceptable CFU levels, consider utilizing matrix fortification (protein, carbohydrates) or prebiotics (inulin, oligosaccharides).

c) If necessary, enhance shelf stability by packaging or microencapsulation.

d) Prepare ahead of time for health claims to be made based on human clinical trials. Possible avenues for further study

e) Randomized clinical trials of plant-based probiotic beverages, evaluations of sensory properties and shelf life, matrix-mediated protection in the gastrointestinal system, and standardized methods for determining and reporting viability are all topics of priority for future study.

Conclusion

Non-dairy probiotic options, such as plant-based beverages fermented with lactobacillus, show promise for providing nutritional and functional advantages. Proper strain-matrix matching, formulation optimization, and clinical proof of health claims are essential for a product's success.

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