



Scientific Landscape of Plant-Based Fermentation and Probiotics: Insights from a Bibliometric Study

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Abstract

This study aims to analyze the development, research trends, and thematic interrelationships of plant-based fermented probiotics through a bibliometric approach. Despite the growing interest in plant-based probiotic products due to their health benefits and sustainability potential, a comprehensive mapping of research trends and thematic structures in this field remains limited. Therefore, this study provides a systematic overview of the scientific landscape of plant-based fermented probiotic research. Data were collected from the Scopus database, covering 256 publications published between 2020 and 2025. Bibliometric analysis was conducted using VOSviewer software to examine keyword co-occurrence patterns and identify major research themes. The results revealed [number] keywords that met the inclusion criteria and formed four interconnected research clusters. The blue cluster focuses on food microbiology and fermented beverages, emphasizing the safety, quality, and potential of plant-based fermented products. The green cluster is associated with lactic acid bacteria and functional foods, highlighting nutritional value and sensory characteristics. The red cluster reflects studies on probiotic mechanisms, antimicrobial activity, and fermentation processes, while the yellow cluster explores the relationships among the microbiome, digestion, and human health. Keywords such as “probiotics,” “lactic acid bacteria,” and “probiotic agents” exhibited the highest occurrence frequencies, indicating their central role within the research network. These findings demonstrate that research on plant-based fermented probiotics is increasingly evolving toward a multidisciplinary field that integrates food microbiology, biotechnology, nutrition, and health sciences. This study contributes by identifying key research themes, revealing their interconnections, and highlighting emerging directions for future investigation. The results provide valuable insights for researchers and industry stakeholders in developing innovative probiotic-based functional food products and establishing future research priorities in this rapidly expanding field.

Keywords: bibliometric analysis; functional foods; fermented beverages; plant-based fermentation; probiotics; lactic acid bacteria; microbiome, VOSviewer;

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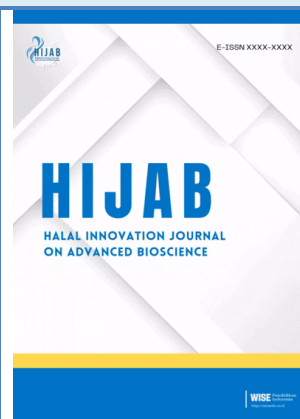
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INTRODUCTION

In recent years, the global demand for plant-based foods has increased substantially due to growing consumer awareness of health, environmental sustainability, and ethical concerns associated with animal-derived products. The shift toward plant-based diets has stimulated the development of innovative functional foods, including fermented plant-based products that offer both nutritional and health-promoting benefits (Sethi et al., 2016). As a result, plant-based fermentation has emerged as an important area of research within food science, biotechnology, and nutrition.

Fermented plant products, such as soy-based beverages, oat drinks, kombucha, water kefir, and fermented vegetables, have attracted considerable attention because they can serve as carriers of beneficial microorganisms and bioactive compounds. Fermentation processes improve nutritional quality, enhance sensory characteristics, increase shelf life, and promote the production of metabolites that support human health (Marco et al., 2021). Among these microorganisms, lactic acid bacteria (LAB) play a central role in fermentation and probiotic functionality, contributing to gut health, immune regulation, and disease prevention.

The growing interest in non-dairy probiotic products has further accelerated research in this field. Traditional probiotic products are primarily dairy-based; however, increasing rates of lactose intolerance, milk allergies, vegan dietary preferences, and demand for sustainable food systems have encouraged the development of plant-based probiotic alternatives (Min et al., 2019). Consequently, plant-based fermented probiotics have become a rapidly expanding research area that integrates food microbiology, functional foods, biotechnology, and human health.

Another important factor driving this research is the rapid advancement of microbiome studies. Recent evidence highlights the crucial role of gut microbiota in digestion, metabolism, immune function, and overall well-being (Valdes et al., 2018). Plant-based fermented probiotic products are increasingly investigated as potential strategies for modulating gut microbial communities and improving health outcomes. This growing intersection between probiotic research and microbiome science has contributed to the diversification of research themes within the field.

Given the rapid growth of scientific publications, bibliometric analysis has become an effective approach for evaluating research performance, identifying emerging topics, and mapping scientific knowledge structures. Previous bibliometric studies have examined probiotics, functional foods, fermented foods, gut microbiota, and lactic acid bacteria separately. These studies have successfully identified publication trends, influential authors, research hotspots, and collaboration networks within their respective domains. However, a comprehensive bibliometric assessment specifically focused on plant-based fermented probiotics remains limited.

Existing studies generally concentrate on individual aspects of probiotics, fermented foods, or microbiome research, without addressing the thematic relationships among plant-based fermentation, probiotic functionality, lactic acid bacteria, functional foods, and human health. As a result, the intellectual structure, research clusters, and emerging trends within the field of plant-based fermented probiotics remain insufficiently explored. This gap limits the ability of researchers and industry stakeholders to identify promising research directions and innovation opportunities.

Therefore, this study aims to conduct a bibliometric analysis of plant-based fermented probiotic research using VOSviewer software. Specifically, the study investigates keyword co-

occurrence patterns to identify major research themes, visualize thematic interrelationships, and examine the evolution of research trends in this field. By providing a systematic scientific mapping of the literature, this study contributes to a better understanding of the knowledge structure of plant-based fermented probiotics and offers valuable insights for future research, product development, and innovation in functional foods.

METHODS

Bibliographic records were systematically collected from the Scopus, Web of Science database on 2025 using a predefined search query targeting publications on plant-based fermentation and probiotics. The search strategy included keywords in the title, abstract, and author keywords fields to ensure comprehensive coverage of relevant literature. A systematic literature search was performed across major scientific databases, including Scopus and Web of Science, to collect relevant publications on plant-based fermentation and probiotics. The datasets from both databases were merged into a single database, and duplicate records were identified and removed during the deduplication process. All analyses were subsequently conducted using the consolidated dataset derived from both databases. The search strategy focused on identifying peer-reviewed journal articles, review papers, and conference proceedings that addressed various aspects of plant-based fermented probiotics, ensuring a comprehensive dataset for analysis. The search included publications from 2020 to 2025, with the inclusion of studies published up to the year 2025 to capture the latest developments in this rapidly evolving field. By selecting diverse types of scholarly documents, the study ensured a broad representation of research trends and multidisciplinary insights, which formed the foundation for the subsequent bibliometric analysis.

Bibliometric analysis was conducted by extracting keyword co-occurrence data from the selected publications. VOSviewer software (version 1.6.20) was employed to create visualization maps that cluster keywords based on their co-occurrence frequencies. Default parameters were used for map normalization and threshold setting to identify significant terms and relationships. Keyword co-occurrence data were systematically extracted from the selected body of literature to capture the frequency and patterns of key terms used in plant-based fermentation and probiotic research. These keywords represent the core topics and concepts within the field, providing insight into how various research themes are related and interconnected. Collecting this data laid the groundwork for constructing a detailed scientific network map.

VOSviewer software was utilized to process the keyword data and generate visualization maps that cluster related terms based on their co-occurrence frequencies in the analyzed publications. This clustering approach groups keywords appearing together frequently, enabling the identification of major research themes and their proximity to one another. The visual representations facilitate an intuitive understanding of the structure and development of the research field.

To ensure robustness and clarity, default parameters for map normalization and threshold settings were applied within VOSviewer. These parameters filter out less significant terms and emphasize stronger relationships, helping to highlight the most relevant and impactful keywords within the dataset. Clustering and Visualization, the software identified clusters representing thematic research areas, with each cluster visually distinguished by color. Central nodes were analyzed to determine the major topics and interdisciplinary connections.

The VOSviewer software identified distinct clusters that represent key thematic research areas within the field of plant-based fermentation and probiotics. Each cluster was visually distinguished by different colors, allowing for clear identification and separation of major topics.

These clusters reflect how certain keywords frequently co-occur, highlighting areas of concentrated research focus and thematic relationships among various subfields. Central nodes within each cluster were further analyzed to pinpoint the major topics that dominate the research landscape. This analysis revealed important interdisciplinary connections, illustrating how different research areas—such as food microbiology, biotechnology, nutrition, and human health—interact and overlap.

Research Design

This study employs a quantitative bibliometric research design to systematically analyze scientific publications related to plant-based fermentation and probiotics. By utilizing bibliometric techniques, the study quantitatively examines patterns in scholarly communication, including keyword co-occurrence, thematic clustering, and research trends within the field. This approach enables the identification of dominant research themes, emerging topics, and interdisciplinary connections based on large-scale publication data, providing an objective and data-driven overview of the knowledge structure and development of plant-based fermented probiotic research.

Data Source

The study population consists of all scientific publications related to plant-based fermentation and probiotics indexed in major academic databases, specifically Scopus and Web of Science. The sample comprises peer-reviewed journal articles, review papers, and conference proceedings published up to 2025 that met the predefined search criteria. These selected documents represent the final dataset analyzed in this study and provide a comprehensive overview of research trends and thematic developments within the field.

Data Collection Procedure

Data were collected over a three-month period, from January to March 2025, through systematic searches of the Scopus and Web of Science databases. A predefined search strategy using relevant keywords related to plant-based fermentation and probiotics was applied to retrieve bibliographic records. The retrieved data were then screened to remove duplicates and irrelevant records before being exported in compatible formats for bibliometric analysis using VOSviewer software.

Data Analytics

Data analytics are quantitative data analysis techniques applied to examine bibliometric indicators derived from the selected publications. These analyses include the evaluation of keyword co-occurrence frequencies, clustering patterns, and network relationships to identify dominant research themes, emerging topics, and structural connections within the field of plant-based fermentation and probiotics. The quantitative analytics provide an objective basis for interpreting research trends and knowledge development using visualization outputs generated by VOSviewer software.

RESULT AND DISCUSSIONS

In this section, the results of the research are presented along with a comprehensive discussion. Results can be displayed in figures, graphs, tables, and other formats that facilitate reader understanding [14], [15]. The discussion may be organized into several sub-sections. Lactic acid bacteria emerged as a central keyword due to their fundamental role in fermentation

processes, probiotic functionality, and their widespread application in plant-based fermented foods, which makes them a core focus in microbial food research. The appearance of the microbiome as an important cluster reflects the growing shift from single-strain studies toward a holistic understanding of microbial communities and their interactions within fermented ecosystems and the human gut. Compared to earlier studies that primarily focused on isolated microorganisms and product-specific fermentation, recent research demonstrates a broader interdisciplinary development integrating food microbiology, health sciences, and systems biology. These advancements have significant implications for the food industry, particularly in the development of functional foods, precision probiotics, improved fermentation technologies, and innovation in plant-based food products with enhanced health benefits and safety profiles.

3.1. Publication Trends and Keywords

An increasing number of publications were observed over the last decade, reflecting growing interest. The bibliometric map revealed four main clusters: Blue cluster: Food microbiology and fermented beverages, emphasizing safety and technological potential of plant-based fermented foods.

Table 1. Number of publications per year (2020–2025)

Year	Number of Publications
2020	120
2021	150
2022	185
2023	230
2024	280
2025	320

Green cluster: Lactic acid bacteria and functional foods, focusing on nutritional and sensory characteristics. Red cluster: Probiotic mechanisms, antimicrobial activities, and fermentation processes. Yellow cluster: Microbiome, digestion, and health-related outcomes.

The results of the bibliometric analysis show that the Blue cluster focuses on food microbiology and fermented beverages, emphasizing the safety aspects and technological potential of plant-based fermented foods. The Green cluster relates to lactic acid bacteria and functional foods, with a primary focus on nutritional and sensory characteristics. The Red cluster covers probiotic mechanisms, antimicrobial activity, and fermentation processes that explain the functions and roles of microorganisms in fermented food systems. Meanwhile, the Yellow cluster is related to the microbiome, the digestive process, and various health outcomes that illustrate the impact of fermented food consumption on human health.

3.2. Network Analysis

Key terms such as "probiotics," "lactic acid bacteria," and "probiotic agents" acted as central hubs linking different clusters, showcasing the multidisciplinary nature of current research.

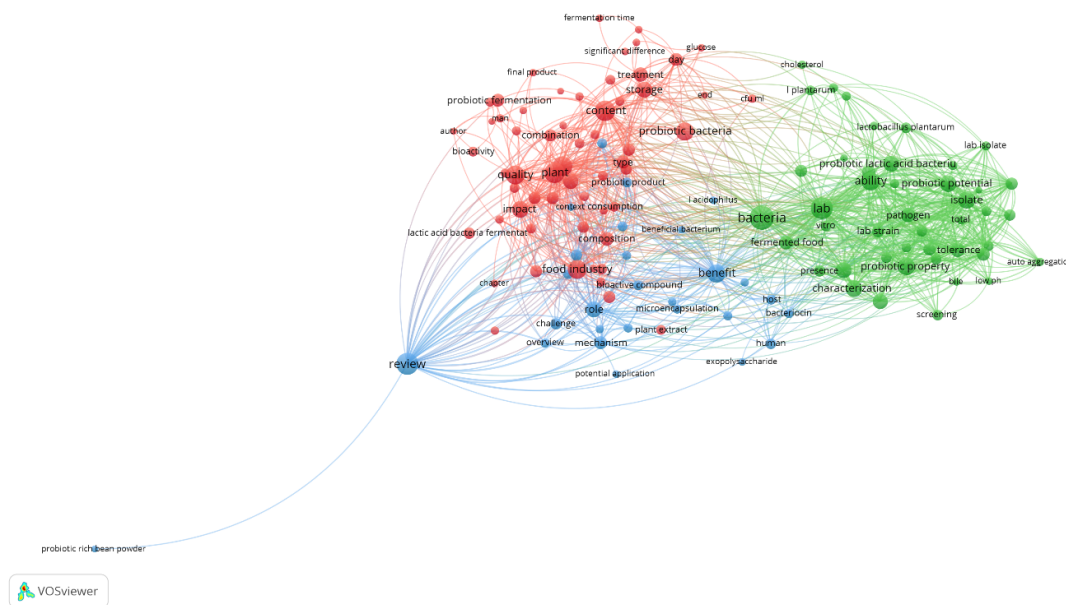


Figure 1. Network visualization of keyword co-occurrence in plant-based fermentation and probiotic research generated using VOSviewer.

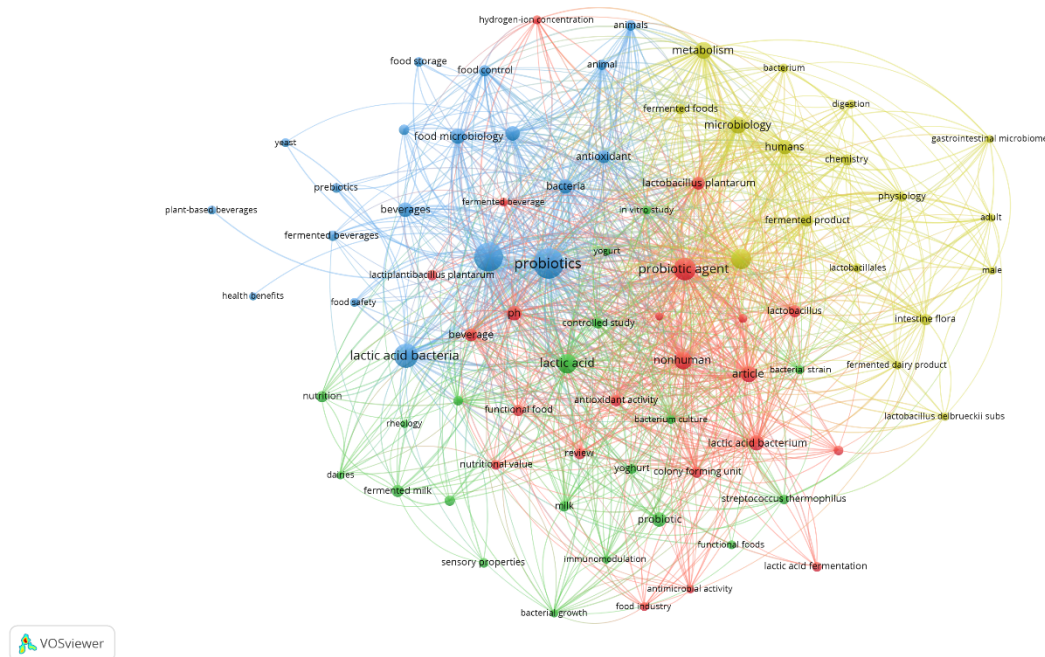


Figure 2. Density visualization of keyword relationships in plant-based fermented probiotic studies.

The four clusters demonstrate the complexity and breadth of research in plant-based probiotic fermentation. The linkage between food microbiology and health sciences highlights a multidisciplinary trend involving biotechnology and nutrition. Key findings indicate a research shift towards integrating microbial safety, functional food development, and human health outcomes. This integrated approach can accelerate the design of novel functional food products with probiotic benefits. Limitations include dependency on indexed literature and keyword

standardization, suggesting future studies could incorporate citation network analysis and expanded databases.

The four clusters demonstrate the complexity and breadth of research in plant-based probiotic fermentation. The linkage between food microbiology and health sciences highlights a multidisciplinary trend involving biotechnology and nutrition. Key findings indicate a research shift towards integrating microbial safety, functional food development, and human health outcomes. This integrated approach can accelerate the design of novel functional food products with probiotic benefits.

This integrated approach also emphasizes the potential for collaborations across fields such as microbiology, nutrition, and consumer science, which can drive innovation in product development and public health outcomes. By prioritizing safety, efficacy, and consumer acceptability, researchers can translate laboratory findings into real-world functional foods that support gut health and overall well-being.

CONCLUSION

This bibliometric study revealed the thematic structure and interconnectivity of research on plant-based fermented probiotics through keyword co-occurrence analysis. Four major research clusters were identified, encompassing food microbiology and fermented beverages, lactic acid bacteria and functional foods, probiotic mechanisms and antimicrobial activities, as well as microbiome-related health outcomes. The strong connections among these clusters demonstrate the multidisciplinary nature of the field, linking microbiology, biotechnology, nutrition, and human health. The findings provide a comprehensive overview of the intellectual structure of the research domain and offer valuable directions for future investigations into plant-based probiotic innovations and functional food development.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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