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MORALITY BEFORE KNOWLEDGE

The strategic role of fermented foods in enhancing sustainable food security: Integrating policy, nutritional value, and local food system empowerment

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ABSTRACT
Background: Food security is a fundamental aspect of sustainable development, particularly in Indonesia, which faces challenges such as climate change, land conversion, import dependency, and uneven food distribution. Fermented foods have considerable potential to enhance the sustainability of food security by diversifying food sources, improving nutritional value, and reducing food waste. Previous studies have shown that fermentation processes can extend the shelf life of food products, increase year-round food availability, and support supply stability for communities. In addition, fermented foods contain probiotics and enzymes that benefit digestive health and nutrient absorption, thereby improving the overall nutritional quality of the population. **Methods:** This study utilizes a literature review to analyze a range of governmental policies and strategies aimed at optimizing the role of fermented foods in national food security. The analysis covers regulatory frameworks, incentives for local producers, and educational initiatives regarding the benefits of fermented food consumption. **Findings:** The findings indicate that integrating fermented foods into food security policies can promote a more resilient and sustainable food system, reduce reliance on imported products, and empower local small and medium-sized enterprises. There is a positive correlation between increased consumption of fermented foods and both improved nutritional outcomes and economic independence. **Conclusion:** The integration of fermented foods into national food security strategies may significantly strengthen Indonesia's capacity to achieve a self-reliant, healthy, and sustainable food system. **Novelty/Originality of this article:** This article offers a novel perspective on the strategic role of fermented foods in enhancing sustainable food security in Indonesia by synthesizing policy analysis and current trends, an area that has not been extensively addressed in previous research.

KEYWORDS: fermented foods; food security; sustainability; food diversification.

1. Introduction

Food security is a condition in which food availability is ensured from the national level down to the individual level, characterized by adequacy in both quantity and quality, including aspects of safety, diversity, and nutritional content (Ariani et al., 2023; Mutea et al., 2020). Indonesia, as an agrarian country, faces various challenges in achieving sustainable food security. Factors such as the conversion of agricultural land, climate change, and dependence on food imports pose significant obstacles. Data indicate that Indonesia's food security remains below the global average, with a Global Food Security

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Index (GFSI) score of 60.2 in 2022, lower than in 2018, which was the highest score achieved in the past ten years (Miyasto, 2014).

Griana & Kinasih (2020) state that traditional Indonesian fermented foods have great potential to support national food security. Products such as tempeh, tape, and fermented fish are not only rich in nutrients but also have a longer shelf life, thus helping to reduce food wastage. In addition, the fermentation process enhances nutritional value, supports health by strengthening the immune system, and creates economic opportunities for local communities (Rizky et al., 2024). The fermentation process involves microorganisms such as lactic acid bacteria and yeast, which improve food quality and safety (Nurada. Besides increasing nutrient availability, fermentation also produces beneficial bioactive compounds and reduces antinutrients. Fujiana et al. (2021) state that fermentation can enhance both macro- and micronutrient content, supporting optimal growth. For example, the fermentation of soybeans into tempeh increases the content of vitamin B12 and essential amino acids, which are important for health.

The Indonesian government, through the Ministry of Agriculture (2019), has demonstrated a commitment to strengthening food security through various strategic programs. However, the role of fermented foods within national food security policies has not yet received adequate attention (Peng & Berry, 2019; Simelane & Worth, 2020). In fact, integrating fermented foods into food security strategies could be an effective solution for enhancing food diversification, improving the nutritional quality of the population, and supporting the sustainability of the food system (Azhari et al., 2013). In addition, the livestock sector also plays an important role in supporting Indonesia's food security. Livestock products such as meat, milk, and eggs are essential sources of animal protein for fulfilling the nutritional needs of the population. The sustainable development of the livestock sector can increase food availability and the welfare of farmers (Widianingrum & Septio, 2023). According to Syarikotin et al. (2023), government strategies to promote food security and farmer welfare include developing national food security systems, ensuring food availability through self-sufficiency and price stabilization, improving food accessibility, and integrating food policies with national development programs to reach households and individuals. These efforts are expected to increase food self-sufficiency and reduce dependence on imports.

Food safety is also a crucial aspect of food security. According to PATPI (2020), food safety should serve as a support rather than an impediment to the achievement of global food security. Food that is free from biological, chemical, and other contaminants that can endanger human health must be ensured. Efforts to strengthen quality control and compliance with food safety standards need to be enhanced so that comprehensive food security can be achieved. This study aims to analyze the role of fermented foods in enhancing the sustainability of food security in Indonesia, as well as to explore policies and strategies that can be implemented to optimize their potential. By understanding the roles and benefits of fermented foods, it is hoped that policies supporting their development and utilization can be formulated in order to achieve sustainable national food security.

2. Methods

This study employs a Systematic Literature Review (SLR) approach to identify, evaluate, and synthesize relevant research concerning the strategic role of fermented foods in sustainable food security in Indonesia. This methodology aligns with the ontological and epistemological aspects of the research by providing a comprehensive and evidence-based understanding of the existing scientific landscape on fermented foods and food security. Furthermore, VOSviewer was utilized for bibliometric analysis of scientific publications obtained from the Scopus database. The chosen timeframe for publications (2014-2025) ensures the relevance of the most current research in this rapidly evolving field.

2.1 Literature search and selection process

The literature search and selection process was conducted systematically to ensure that only relevant and credible sources were utilized in this research. The process commenced with the selection of Scopus as the primary database, given its established reputation for providing high-quality scientific literature. Strategic keyword selection was performed to accurately reflect the research focus and ensure comprehensive coverage. The specific keyword combinations employed were: "Fermented" AND "Food" AND "Food" AND "Security" AND "Policy" AND "Framework" to investigate how policies support the development of fermented foods for food security; "Fermented" AND "Food" AND "Sustainability" AND "Economic" AND "Impact" to analyze the contribution of fermented foods to economic sustainability and the food industry; "Fermented" AND "Food" AND "Nutrition" AND "Health" AND "Benefits" to explore the nutritional and health benefits of fermented foods within community consumption patterns; and "Fermented" AND "Food" AND "Indonesia" AND "Local" AND "Food" AND "System" to examine the role of fermented foods in Indonesia's local food system for supporting food security. The conceptual framework illustrating these four main keyword categories for bibliometric analysis is presented in Gambar 1. Following the keyword determination, a rigorous literature filtering process was implemented to ensure the inclusion of only relevant and credible articles. The filters applied included: document type (journal articles), publication year (2014-2025 to ensure the most recent research), and subject areas (agriculture, food science, health, and environmental science). This selection process was executed in two stages: an initial screening of titles and abstracts to assess alignment with the research focus, followed by a full-text review of articles that passed the initial screening for in-depth analysis and synthesis.

2.2 Bibliometric analysis with VOSviewer

Upon the collection of relevant literature, a bibliometric analysis was conducted using VOSviewer to identify patterns and trends in research related to fermented foods and food security. This analysis primarily involved Co-occurrence keyword analysis, which identifies keywords that frequently appear together in the literature, thereby indicating the main topics under investigation. This method allowed for the mapping of research patterns in the field of fermented foods and food security, including emerging major trends and existing research gaps that warrant further exploration.

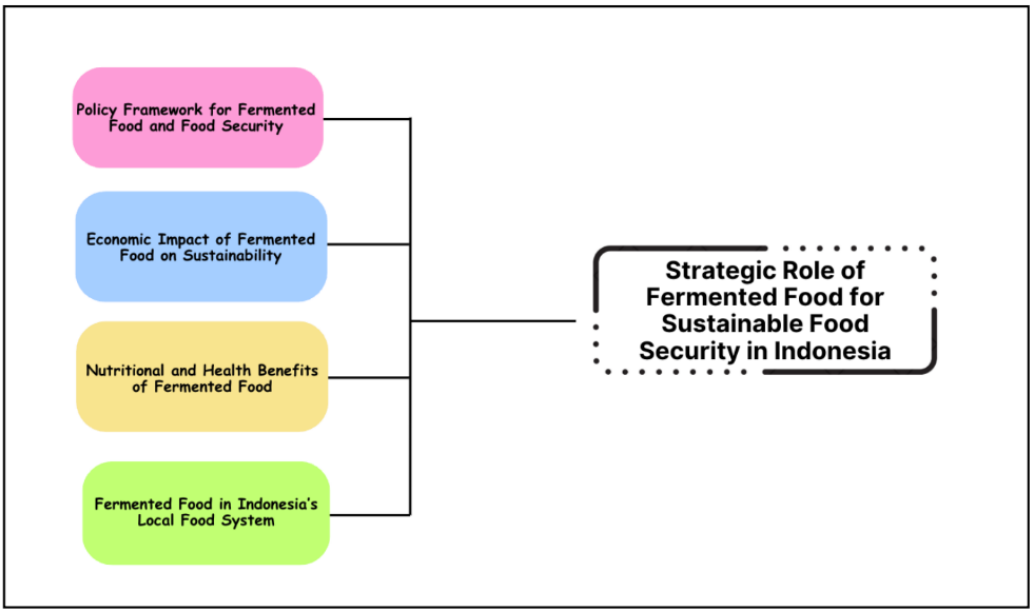

Fig. 1. Scheme of four main keywords for bibliometric analysis

2.3 Data synthesis

Following the bibliometric analysis, a qualitative data synthesis was applied using a narrative approach to summarize the key findings from the collected literature. This approach aimed to deepen the understanding of the relationship between fermented foods and food security, as well as to identify their contributions, challenges, and opportunities within the context of food policy. Several key aspects were analyzed, including: the types of fermented foods most frequently researched in relation to food security, their characteristics, benefits, and consumption patterns across various regions; the impact of fermented food consumption on community health and nutrition, both from the perspective of enhanced nutritional value and their role in supporting gut microbiota health and the immune system; the role of fermented foods in national and global food security strategies, considering factors such as production sustainability, resource efficiency, and the potential for import substitution; and the challenges and opportunities in developing policies related to fermented foods, including regulations, government support, and public acceptance of fermentation-based food innovations. Through this synthesis, the research endeavors to provide comprehensive insights into the contribution of fermented foods to food security and its implications for developing policies that support the sustainability of the food system in the future.

3. Results and Discussion

3.1 Fermented foods in food security

Fermentation is a food processing technique that utilizes microorganisms to extend shelf life (Alhanannasir & Sebayang, 2021; Tamang et al., 2016a, 2016b). Fermentation also has a strategic role in supporting food security, particularly in terms of availability and utilization. Through this process, various traditional products such as tempeh, tape, and oncom not only become affordable and accessible sources of plant-based protein but also experience significant improvements in shelf life, thereby helping to reduce post-harvest losses and supporting more equitable food distribution. To further explore the scientific linkages between fermented foods, food security, and policy, this study also incorporates a bibliometric analysis using the VOSviewer software.

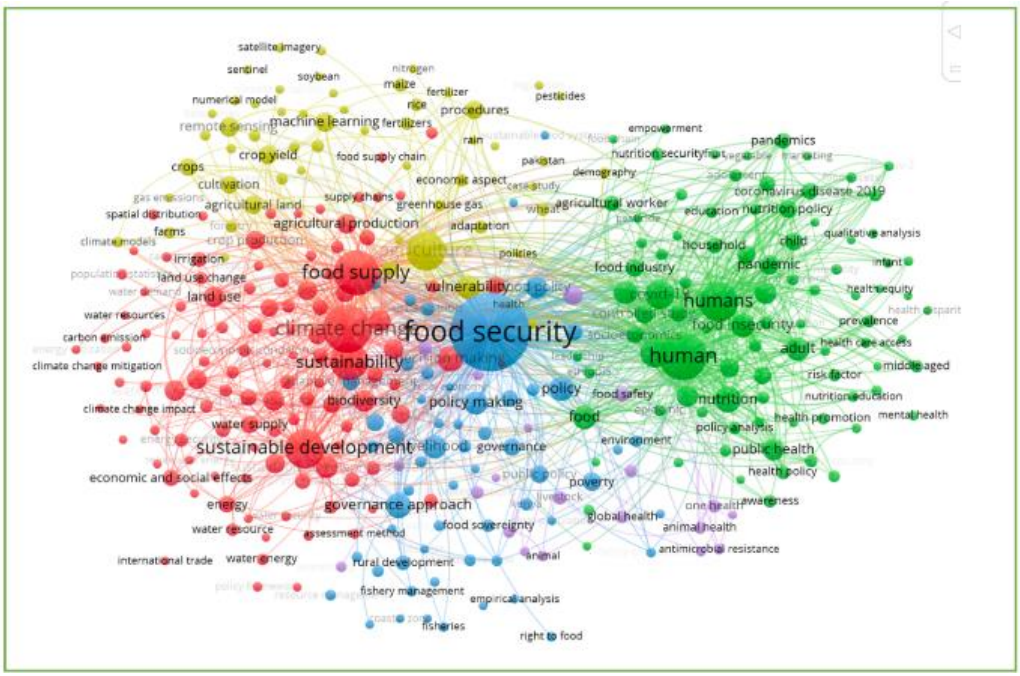

Fig. 2. Bibliometric map of fermented foods in food security

The mapping results indicate that themes related to "food security" are closely connected to five main clusters, which conceptually represent the dimensions of policy, environmental sustainability, public health, food production, and access equity. The blue cluster dominates the keyword map, focusing on food security, policy, and governance, highlighting the significant attention given to strengthening policy frameworks to ensure food security. The red cluster emphasizes dimensions of climate change and sustainable development, such as climate change, sustainable development, and land use change, underscoring that ecological challenges are critical pressure factors on the food system.

In the green cluster, issues such as nutrition, public health, and food insecurity demonstrate the close relationship between food security and public health. This is where the role of fermented foods becomes highly strategic: not only as traditional foods but also as culturally based interventions that can address nutritional and food access challenges. For example, in the Sekhukhune District of South Africa, traditional fermentation and drying practices are used by households to prolong shelf life and increase the economic value of local food materials. These fermented products are also sold, thereby contributing to household incomes (Masekoameng & Molotja, 2023).

Another study in Kenya demonstrates that traditional fermentation produces a variety of microbiome-rich foods with health benefits. This fermentation process contributes to food security and local economic development, and it has significant potential to become an integral part of sustainable food systems (Khayeka-Wandabwa et al., 2024). This indicates that fermentation is not merely a technical process but also a part of community adaptation and empowerment strategies. Meanwhile, the yellow cluster focuses on aspects of agricultural production and technology, such as crop yield, machine learning, and remote sensing, which relate to productivity and supply chain efficiency. In the context of local food diversification, fermentation can also be integrated with local crops such as quinoa, amaranth, and millet, which possess high nutritional potential and contribute to food security. However, obstacles remain, such as lack of awareness and marketing challenges, which have prevented these crops from being fully utilized (Kaur et al., 2025).

Finally, the purple cluster illustrates the importance of food justice perspectives through keywords such as food sovereignty, poverty, and right to food. Locally based and low-cost fermented foods have the potential to bridge access gaps and become part of inclusive food policies that are not only market-driven but also based on rights and culture. To summarize the strategic position of fermented foods within the food security ecosystem based on these clusters, the following table presents the relationship between the role of fermentation and each of the main dimensions identified in the bibliometric analysis.

Table 1. Categories and descriptions of fermented foods in food security

Cluster	Main Topics	Relation to Fermented Foods
Blue	Food policy, governance, food security	Integration of fermented foods is needed in local and national food security policies
Red	Climate change, land use, sustainability	Fermentation extends shelf life, reduces food waste, and supports climate adaptation
Green	Nutrition, public health, food insecurity	Fermented foods support nutrition, gut microbiome, and access to affordable food
Yellow	Agricultural production, supply chains	Can be developed from local crops with high nutritional value, supporting local agricultural sustainability
Purple	Food sovereignty, poverty, right to food	Fermented foods support community self-sufficiency and strengthen community-based food systems

3.2 Economic impact and sustainability of fermented foods

From both sustainability and economic perspectives, fermented foods have proven capable of making tangible contributions to the Sustainable Development Goals (SDGs), particularly Goal 2 (Zero Hunger) and Goal 12 (Responsible Consumption and Production). Small- to medium-scale fermented food industries, such as tempeh production, not only

create business opportunities and employment but also employ simple, environmentally friendly, and energy-efficient technologies. Moreover, fermentation also plays a role in processing organic waste, such as food scraps, into biogas and organic fertilizers. This process involves microorganisms under anaerobic conditions to break down organic materials, thereby reducing the volume of waste while producing alternative energy beneficial for daily needs (Astutik et al., 2024).

The economic role of fermentation is further evident in both traditional practices and technological innovations. For instance, bread fermentation has long been used to improve the quality and shelf life of flour-based foods. This process not only adds nutritional value but also enriches culinary traditions and local markets (Sadowski et al., 2024). In the Amazon region, traditional fermentation techniques such as those used for tucupi and caxiri possess great potential for the development of a sustainable bioeconomy, although challenges remain in terms of industrialization and community empowerment (Sousa et al., 2023). On the other hand, innovations such as osmosis dehydration and edible coating in olive fermentation demonstrate how fermented foods can be further developed to improve nutritional value, extend shelf life, and remain both economically viable and environmentally friendly (Mari et al., 2024).

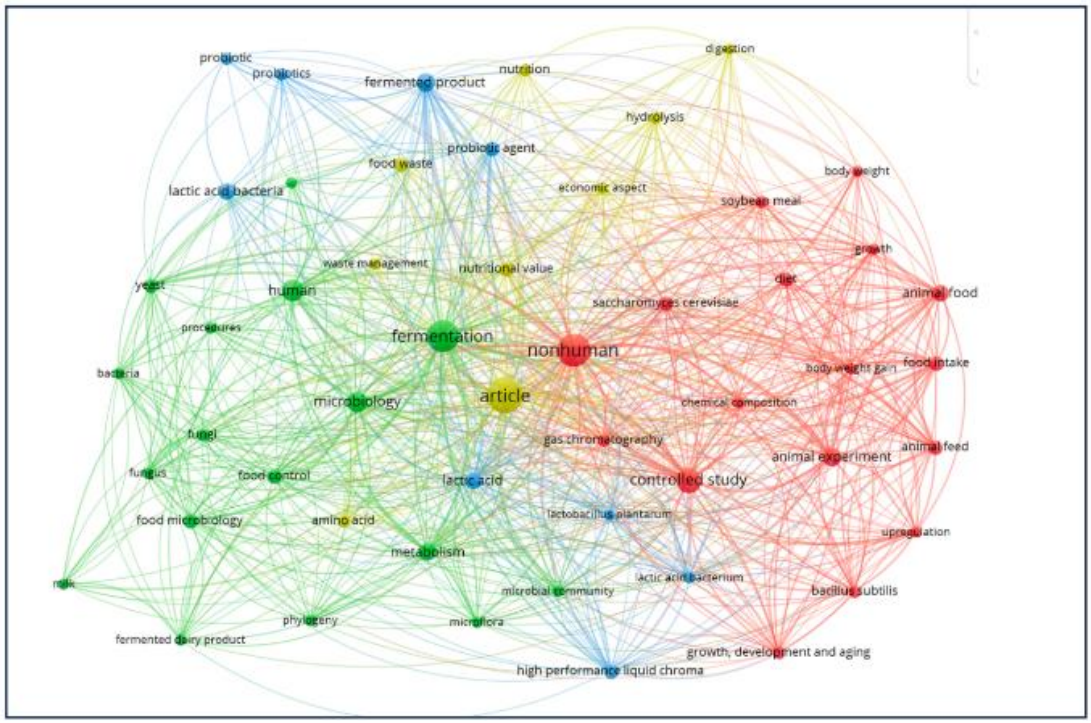

Fig. 3. Bibliometric map of the economic impact and sustainability of fermented foods

Bibliometric findings through VOSviewer analysis also reveal a close relationship between the concepts of fermentation, sustainability, and economic aspects within the context of global food systems. The mapping results show that fermentation is not only explored in food technology and nutrition but is also gaining increasing attention in the discourse on the circular economy and food waste reduction. The main clusters identified in this analysis demonstrate significant links between terms such as economic aspect, nutrition, food waste, fermented product, and probiotic agent. This interconnectedness reflects that fermentation holds multidimensional potential, ranging from improving nutritional value and resource efficiency to creating economic value as an essential part of developing a more resilient and sustainable food system.

Furthermore, this analysis provides strategic direction in identifying emerging research foci and areas that remain underexplored, particularly concerning the role of fermented foods in local food systems and national policy. Therefore, these bibliometric findings serve as an important basis for formulating both conceptual and practical

syntheses regarding the role of fermentation in future food security. Below is a summary of the thematic connections from the bibliometric findings in Table 2.

Table 2. Categories and descriptions of the economic impact and sustainability of fermented foods

Cluster	Main Theme	Related Topics	Example Study/Case
Green	Fermentation and Microbiology	Lactic acid bacteria, yeast, human health	Traditional bread fermentation (Sadowski et al., 2024)
Red	Fermentation for Animal Feed	Animal food, animal experiment, growth	Fermentation of local Amazon products (Sousa et al., 2023)
Blue	Fermented Products and Probiotics	Probiotics, food waste, fermented product	Low-salt olive fermentation (Mari et al., 2024)
Yellow	Nutritional Value and Economic Impact	Economic aspect, nutritional value, chemical composition	Development of value-added food products

3.3 Nutritional value and health benefits of fermented foods

Fermentation plays a vital role in enhancing the nutritional quality of foods through the activity of live probiotic bacteria, as found in traditional fermented milk products like dadih, which helps maintain digestive health by balancing gut microflora (Marco et al., 2021; Nasri et al., 2023). Additionally, fermented foods are associated with other functional benefits, such as increased absorption of micronutrients, strengthened immune systems, and reduced risks of metabolic diseases (Sonik et al., 2023). The following bibliometric analysis, conducted using VOSviewer, shows that research on fermented foods in the context of nutrition and health benefits is rapidly evolving, with strong interconnections among topics. The cluster visualization reveals five main groups in different colors, each representing a dominant research theme.

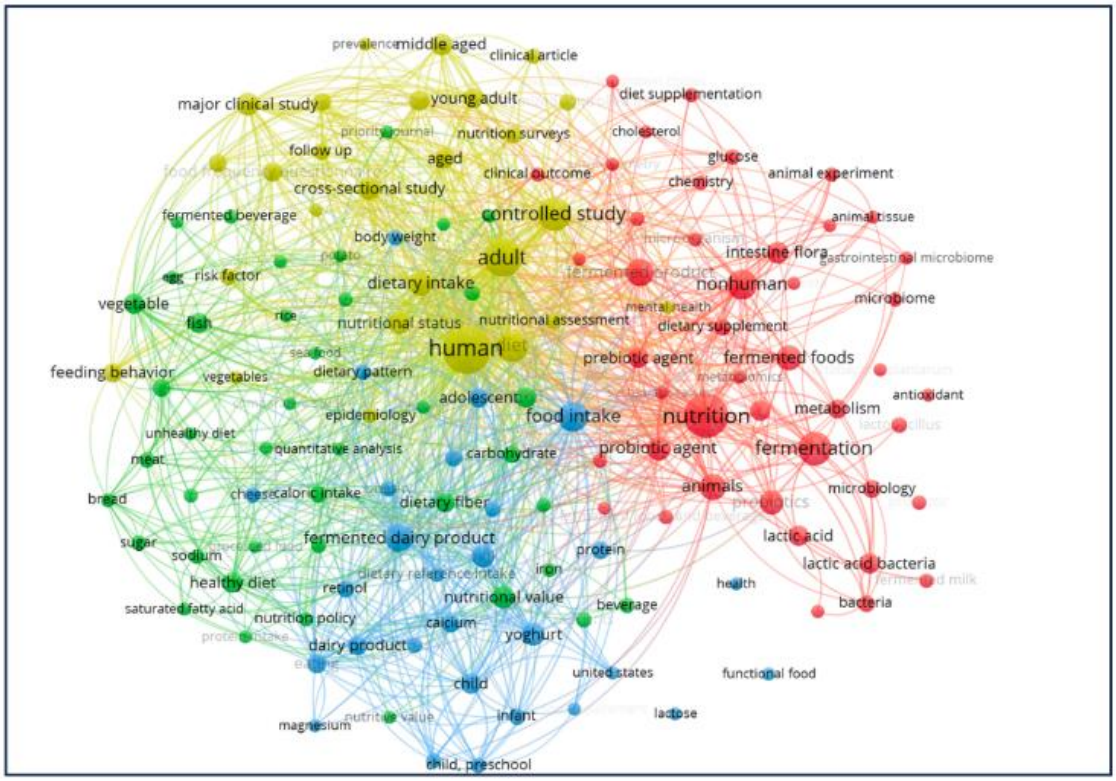

Fig. 4. Bibliometric map of the nutritional value and health benefits of fermented foods

The red cluster focuses on topics such as fermentation, fermented foods, nutrition, and microbiome. This cluster highlights how the fermentation process plays a role in shaping

gut microbiota and body metabolism, including its influence on lactic acid bacteria, probiotic agents, and gut health. A recent study by Shin et al. (2024) demonstrated that consuming fermented gold kiwi (FGK) for eight weeks is safe and can improve digestive health, alleviate stomach and intestinal disorders, and enhance the quality of life in patients with functional dyspepsia. These findings reinforce the role of fermented foods in supporting microbiota health and digestive system function.

The green cluster comprises topics related to dietary intake, healthy diet, and feeding behavior, focusing on community consumption patterns and the relationship between fermented foods and balanced nutrition. Several fermentation process innovations have also been shown to influence the nutritional content of food materials. A study by Maleke et al. (2024) and Nuraida (2015) demonstrated that fermentation, malting, and ultrasonication can enhance the health benefits and nutritional content of sorghum, mopane worms, and Moringa oleifera leaves, with ultrasonication being the most effective method for preserving nutrients. This opens opportunities for optimizing local foods through modern fermentation techniques.

The yellow cluster centers on methodological aspects of research, such as controlled study, cross-sectional study, and nutritional assessment, indicating heightened attention to the validity of clinical and epidemiological data. The blue cluster contains keywords such as infant, child, calcium, and dairy product, highlighting the importance of fermented foods in supporting child growth and nutritional status. The light blue cluster focuses on specific nutritional values (protein, iron, magnesium) as well as the added value of yogurt and fermented dairy products in meeting micronutrient needs. Additionally, traditional fermented foods such as hentak, produced from small fish and Alocasia macrorhiza stalks, have also demonstrated great health potential. According to Kabui et al. (2025), hentak is high in protein, essential amino acids, and minerals, and possesses anti-inflammatory and antibacterial properties. This research underlines the high nutritional value and functional benefits of local fermented foods, which are often underexplored scientifically. These findings reinforce the understanding that fermented foods are an integral part of a sustainable food system that supports overall nutritional status and community health. A summary of the inter-cluster relationships from the bibliometric analysis is presented in the following Table 3.

Table 3. Categories and descriptions of the nutritional value and health benefits of fermented foods

Cluster	Main Topic	Explanation
Red	Fermentation, Nutrition, Fermented Foods, Microbiome	Focus on biological processes and their impact on the microbiota and metabolism
Green	Dietary Intake, Healthy Diet, Feeding Behavior	Related to eating habits and healthy food consumption, including innovations in fermentation techniques
Yellow	Controlled Study, Nutritional Assessment, Clinical Study	Methodological focus on clinical and epidemiological studies
Blue	Infant, Child, Dairy Product, Calcium	Highlights the importance of fermented foods in child nutrition
Light Blue	Protein, Iron, Yoghurt, Nutritional Value	Emphasis on the specific nutritional value and health benefits of fermented products

3.4 Policies and fermented food systems in Indonesia

The production of traditional fermented foods in Indonesia is generally carried out by Small and Medium Enterprises (SMEs), which are a vital part of the local food industry (Mulyani et al., 2022). Despite their significant role, the national policy framework that specifically regulates or supports fermented foods remains limited. In fact, these fermented products reflect local wisdom with the potential to be strengthened within community-based food security strategies. Providing incentives for SME actors and integrating fermented foods into national nutrition programs could be strategic steps to reinforce a resilient and sustainable local food system.

The bibliometric visualization using VOSviewer reveals the complexity of the topic of "fermented foods" in the context of Indonesia and local food systems. There are strong interconnections between fermentation themes and nutrition, microbiology, public health, and the diversity of local foods. Five major clusters emerged from this analysis, each representing different but overlapping research focuses.

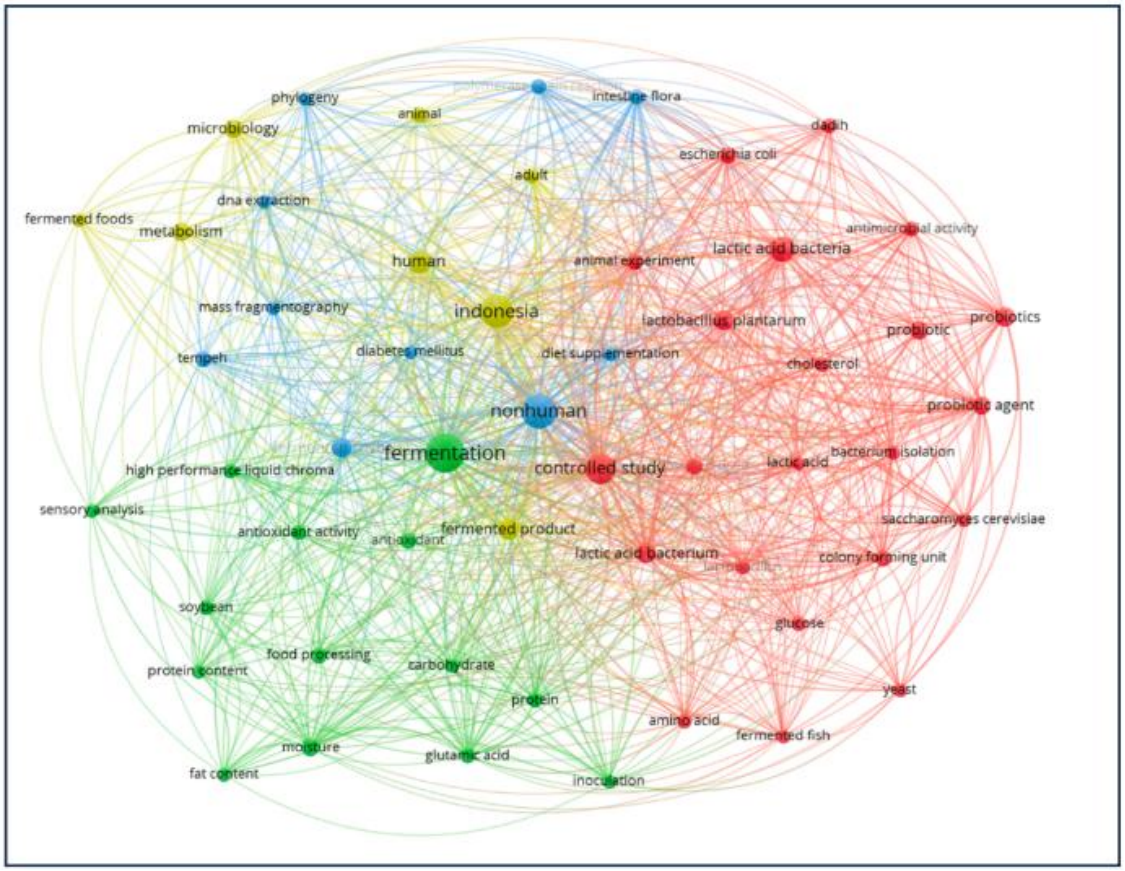

Fig. 5. Bibliometric map of policies and fermented food systems in Indonesia

The red cluster dominates research related to probiotic microorganisms, particularly lactic acid bacteria, Lactobacillus plantarum, Saccharomyces cerevisiae, and their health benefits such as antimicrobial activity, cholesterol reduction, and enhanced immunity. Local products such as dadih attract attention due to their probiotic potential. Recent research by Chihombori et al. (2025) confirmed that probiotic yeast from dadih, a traditional fermented food from West Sumatra, is able to survive acidic and bile salt conditions and shows proteolytic and lipolytic enzyme activity, making it a strong candidate for health applications. The green cluster highlights aspects of nutritional composition and food processing technology, with a focus on protein, carbohydrate, fat content, and techniques such as inoculation and the impact of fermentation on nutritional value. A concrete example is the innovation of tempeh produced from a blend of 30% cowpea and 70% soybean, which still meets National Standards/*Standar Nasional Indonesia* (SNI) and is favored by consumers, demonstrating potential for reducing dependence on imported soybeans (Sundari et al., 2024). This indicates the role of fermented foods in improving the nutritional quality of local food ingredients and strengthening national food self-sufficiency.

The yellow cluster is oriented toward geographical and social contexts, such as the prevalence of diseases (diabetes mellitus), target populations (human and animal), and Indonesia's geographic location. Research in this cluster tends to highlight the potential of fermented foods as dietary interventions and for improving local public health. The blue cluster reflects an experimental research base, with keywords such as controlled study, animal experiment, and nonhuman, indicating the strong influence of biomedical and

laboratory microbiology approaches in evaluating the benefits of fermented foods. For example, a study by Murwani et al. (2024) identified three types of lactic acid bacteria from *cincalok* and *tempoyak* in Kalimantan—*Tetragenococcus halophilus*, *Levilactobacillus brevis,* and *Lactiplantibacillus plantarum*—which showed antimicrobial activity against pathogenic bacteria, although further clinical efficacy studies are required.

The green cluster highlights sensory approaches and food analysis technology, which are important for assessing the quality of fermented products in a local context, such as the use of high-performance liquid chromatography methods and antioxidant activity analysis. These findings underscore that local fermented foods are not only viewed from a cultural or traditional perspective, but have also become the focus of multidisciplinary scientific attention, encompassing aspects of health, food technology, and the local economy. This bibliometric analysis is summarized in the following Table 4 to illustrate the distribution of thematic clusters and their interconnections.

Table 4. Categories and descriptions of policies and fermented food systems in Indonesia

Cluster Color	Main Focus	Related Keywords
Red	Probiotic Microorganisms & Health	lactic acid bacteria, dadih, probiotics, antimicrobial activity
Green	Nutrition and Food Technology	protein, carbohydrate, inoculation, fermented product
Yellow	Social and Geographical Context	Indonesia, diabetes mellitus, human, animal
Blue	Experimental Studies and Microbiology	controlled study, animal experiment, nonhuman, Escherichia coli
Teal Green	Sensory & Food Analysis	antioxidant activity, sensory analysis, HPLC

3.5 Synthesis of findings and strategic implications

The discussion of the previous four subsections demonstrates that fermented foods play a strategic role in supporting sustainable food security through four main dimensions; (1) food availability and utilization, (2) economic impact and local industry sustainability, (3) nutritional value and health benefits, and (4) their role in Indonesian food policies and systems. Bibliometric analysis reinforces that these topics are closely interconnected in recent scientific literature. In the context of food security, fermentation enhances the utility value of local food ingredients such as tempeh, tape, and other Indonesian specialties, which are widely accessible and affordable to the public. From an economic perspective, fermented foods have been shown to create microenterprise opportunities and support local economies using energy-efficient and environmentally friendly technologies. Meanwhile, health benefits remain the most frequently discussed dimension in global literature, particularly regarding digestive improvement, probiotic content, and reduced risk of degenerative diseases.

Recent research also highlights innovations in traditional technologies for fermented foods. For example, pre-treatments such as sprouting (soaking until germination) of sorghum grains have been found to improve protein digestibility in Ethiopia's traditional fermented bread, while parching (roasting) reduces it. Additionally, finer grinding of grains tends to make proteins more easily digestible (Belaineh et al., 2024). These findings indicate that modifications to local techniques can enhance the nutritional quality of fermented foods. Meanwhile, local innovations such as Formula Minasarua, a traditional fermented drink from Bima, have been successfully optimized to have high antioxidant content. The final product demonstrates a rich presence of phenolic compounds, flavonoids, and anthocyanins, which are beneficial for health (Maramy et al., 2024). This serves as evidence that Indonesia's local potential remains vast for supporting healthy and functional food systems rooted in tradition. Additionally, traditional fermentation practices in various countries highlight their important role in preserving cultural heritage. For example, Jiuqu, a fermentation starter used by the Chuanqing community in Guizhou, China, is still primarily

known among the older generation. Its production process involves various types of plants and microbes that are not only beneficial for health but also essential for maintaining local cultural heritage (Zhao et al., 2024).

New studies even show that processing techniques such as parboiling and cooking methods significantly affect the mineral content in fermented rice water, especially in the Naveen variety. One notable finding is that pressure cooking can increase the potassium content retained in the fermented water, which is highly beneficial for enhancing the nutritional value of the final product (Sivashankari et al., 2025). This knowledge opens new opportunities for the development of fermented products based on staple foods such as rice.

On the other hand, challenges to the global food system are also becoming increasingly complex. The decline in the number of pollinators, such as bees, for example, can have a significant impact on agricultural production. Around 17% of the value of global agricultural production relies on pollination services, and without mitigation, a reduction in pollinator populations could lead to food prices rising by up to 30% and a global economic welfare loss of USD 729 billion (Feuerbacher, 2025; Indrianawati, 2019). This underscores that sustainability interventions in food systems must not only consider the food aspect itself, but also the supporting ecosystems. Nevertheless, as efforts are made to increase access to safe and high-quality food in developing countries, it should be noted that this could result in increased CO_2 emissions due to more intensive energy use. This reveals a trade-off that requires careful policy to balance food security objectives with environmental sustainability (Hasan & Adnan, 2023).

As a long-term solution, food system transformation can be driven by digitalization, as implemented in the Lower Austria region. Studies have shown that the involvement of multiple stakeholders in developing future scenarios is key to the successful transition toward more sustainable agriculture and food systems (Wepner et al., 2025). Such collaborative and technology-based approaches can serve as inspiration for the development of fermented foods in Indonesia, making them more adaptive to current and future challenges. Taking into account the dimensions of sustainability, nutrition, economy, and locality, an integrative strategy must be developed. One such approach is the formulation of national policies that support the production, consumption, and promotion of fermented foods based on local wisdom.

Table 5. Synthesis of findings and strategic implications from each subsection

Dimension	Key Findings of Subsection	Main Bibliometric Findings	Strategic Implications
Food Security (3.1)	Availability, utilization	"Food Security", "Availability", "Utilization"	Expand promotion of local fermented foods
Economy & Sustainability (3.2)	SMEs, appropriate technology	"Sustainability", "Economic Impact", "Microenterprise"	Support business incubation and training
Nutrition & Health (3.3)	Probiotic, bioactive, nutrition	"Nutrition", "Probiotic", "Gut Health", "Bioactive Compounds"	Further research on functional fermented foods and labeling
Locality & Policy (3.4)	Local food system, policy	"Indonesia", "Local Food System", weak connection to "Policy"	Encourage regulation and incentives for fermented foods

4. Conclusions

The findings of this study affirm that fermented foods play a strategic role in strengthening sustainable food security, not only by enhancing nutritional value and shelf life but also through their contribution to local food systems. The analysis reveals that both global and national research are increasingly emphasizing the importance of fermented

foods across four key dimensions of food security: availability, accessibility, utilization, and stability, with an additional focus on sustainability. Thus, adaptive public policies that support the development of fermented foods are required, addressing production, distribution, and consumption aspects. Furthermore, Indonesia needs to maximize the potential of traditional fermented foods through research, innovation, and regulatory support so that they can become a tangible solution to future food and nutrition challenges. Policy implementation should involve collaboration between the government, local food industry actors, and the scientific community to ensure inclusive and evidence-based practices. By integrating economic, social, health, and environmental aspects, fermented foods can be developed as an integral part of a resilient and sustainable national food system.

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Author Contribution
The author independently conducted the research, including the design, data collection, analysis, and manuscript preparation.

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Informed Consent Statement
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Data Availability Statement
Not available.

Conflicts of Interest
The author declare no conflict of interest.

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