



A Bibliometric Review of Tempeh Research: Trends, Collaborations, and Emerging Themes (1928–2025)

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Abstract

Tempeh, a traditional Indonesian fermented soybean product, has garnered increasing global attention due to its rich nutritional profile, health benefits, and suitability as a sustainable alternative protein source. This study presents a bibliometric analysis of tempeh-related scientific publications retrieved from the Scopus database, aiming to map the evolution of research, identify leading contributors, and uncover prevailing and emerging research trends. A total of 897 documents published between 1928 and 2025 were analyzed using VOSviewer to generate visualizations of keyword co-occurrences and bibliographic data. The results show a notable rise in tempeh research after 2010, with significant contributions from Indonesian institutions and increasing global interest. Thematic clusters identified include microbiological fermentation, nutritional and technological applications, animal-based functional food studies, and clinical health research. This study highlights tempeh's expanding role in functional food science and emphasizes opportunities for interdisciplinary collaboration and further research, particularly in underexplored health and sustainability dimensions.

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Introduction

Tempeh is one of the original Indonesian foods made from boiled soybeans and fermented using a starter, namely *Rhizopus sp.* Tempeh is a rich source of protein, dietary fiber, vitamins (notably B12), and bioactive compounds (Shurtleff and Aoyagi, 2011). Health benefits of tempeh are gaining in popularity not only in Indonesia but in several other countries. The popularity of tempeh has increased significantly as a sustainable and nutritious alternative protein, probiotic benefits, and suitability for vegetarian, vegan, and flexitarian diets.

Research on tempeh has gained attention as a result of worldwide concerns related to health-promoting diets, innovative protein alternatives, and sustainability. More recent research highlights tempeh's functional benefits and advances in tempeh processing technology. Zahra *et al.* (2023) found that co-fermentation using *Rhizopus oligosporus* and *Lactobacillus rhamnosus* GG significantly improved lipid profiles and inflammatory markers in obese rats. Nuryanti *et al.* (2024) also developed tempeh from durian seeds (*Durio zibethinus* Murr) with acceptable organoleptic qualities. Technological improvements in tempeh production have

also been reported by Wisnujati *et al.* (2024), who integrated automation in soybean processing to support small-scale enterprises.

While several bibliometric studies have explored fermented foods more broadly (Frediansyah, 2024), none have provided an in-depth bibliometric analysis dedicated exclusively to tempeh. This study addresses that gap by providing an up-to-date bibliometric synthesis of tempeh from 1928 to 2025. The objectives of this study are to: (1) map the evolution of tempeh research over time; (2) identify the most influential institutions, countries, and journals; and (3) uncover the main thematic clusters and emerging research trends. This study contributes to identifying collaboration opportunities and underexplored areas, thereby supporting policymakers and food innovators in understanding the potential of tempeh as an alternative protein.

Methods

Data collection was conducted in May 2025 utilizing scientific publications indexed in the Scopus database. The search was carried out in the “advanced

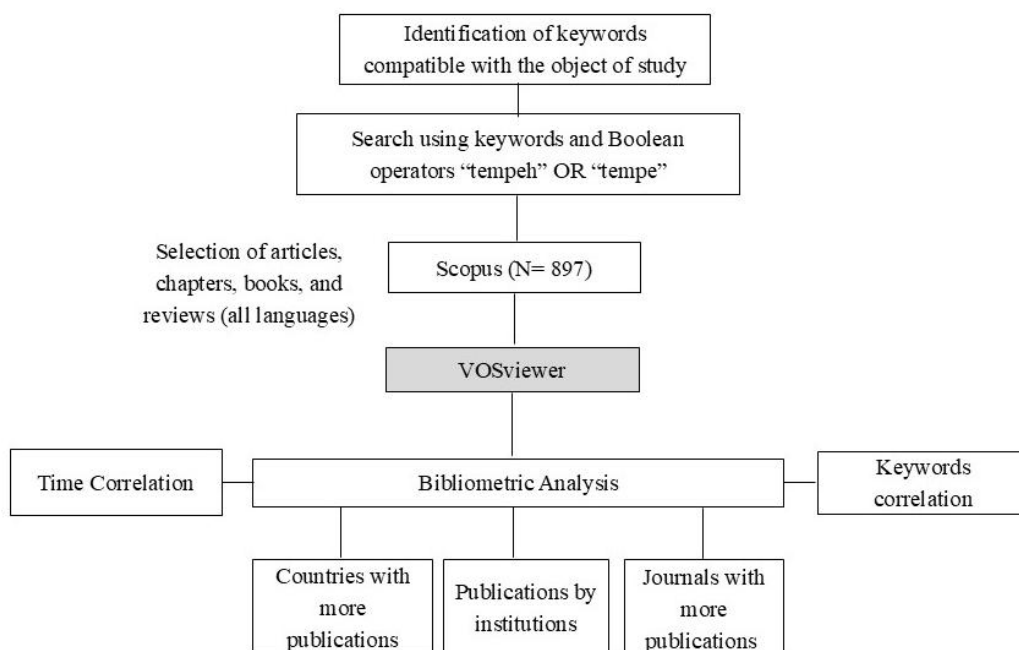


Figure 1. The methodological framework of the bibliographic analysis in the present study

search” function with the keywords “tempeh” OR “tempe” resulting in 897 records. This search strategy enabled the retrieval of publications containing the specified terms in the title, abstract, or keywords. No temporal restrictions were applied, allowing for comprehensive coverage across all publication years to facilitate chronological analysis of the topic. The retrieved documents were subsequently analyzed to identify research trends through keyword co-occurrence analysis, performed using VOSviewer software. This software was used to construct visual maps illustrating the relationships among keywords and journals. The methodological framework of the bibliographic analysis is presented in Figure 1.

Results and Discussion

Evolution of publications about tempeh

Tempeh is a traditional Indonesian fermented soybean product that has gained global recognition as a nutritious and sustainable protein source (Figure 2). The evolution of scientific publications on tempeh reflects growing interest in its health benefits and potential as an alternative protein. Figure 3 presents the distribution of scientific publications related to tempeh in the Scopus database from 1928 to 2025, illustrating how academic attention has shifted over time. From 1928 until the early 1980s, the number of publications was very low, indicating limited international scientific attention to tempeh.

An upward trend began to emerge in the late 1980s and continued into the 1990s. However, a substantial increase is evident after 2010, with a dramatic surge in publications observed post-2020. This growth indicates the rising global awareness of the importance of sustainable diets and alternative protein sources. Compared to animal-based proteins, tempeh has become recognizable for its high protein content, amino acid profile, probiotic potential, and

environmentally sustainable production (Marco et al., 2017; Ritchie et al., 2022).

In 2023, tempeh research reached its highest point, with a total of 105 published documents. The increased popularity of tempeh is also associated with its health-promoting properties, such as improving gut microbiota composition, enhancing nutrient bioavailability, and contributing to the prevention of non-communicable diseases (Granato et al., 2010; Ahnan-Winarno et al., 2021). The growing consumer interest in plant-based foods has further contributed to the acceptance of tempeh in Western markets, which is caused by product development advancements and rising consumer demand for minimally processed, high-protein, plant-based foods.

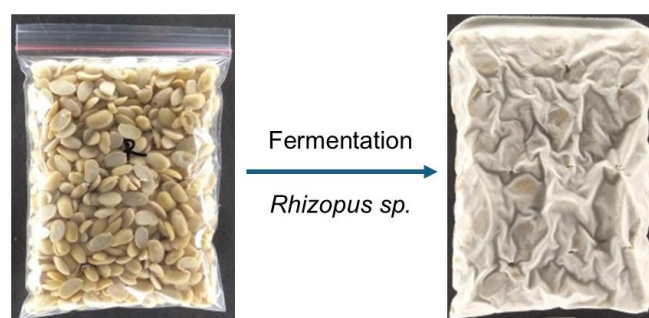


Figure 2. Tempeh fermentation

Bibliometric study of document types, countries, institutions, and journals

Figure 4 shows the distribution of document types retrieved from Scopus using the search terms “tempeh” or “tempe” over the period (1928–2025). A total of 897 documents were identified, including research articles (614 documents, 68.4%), conference papers

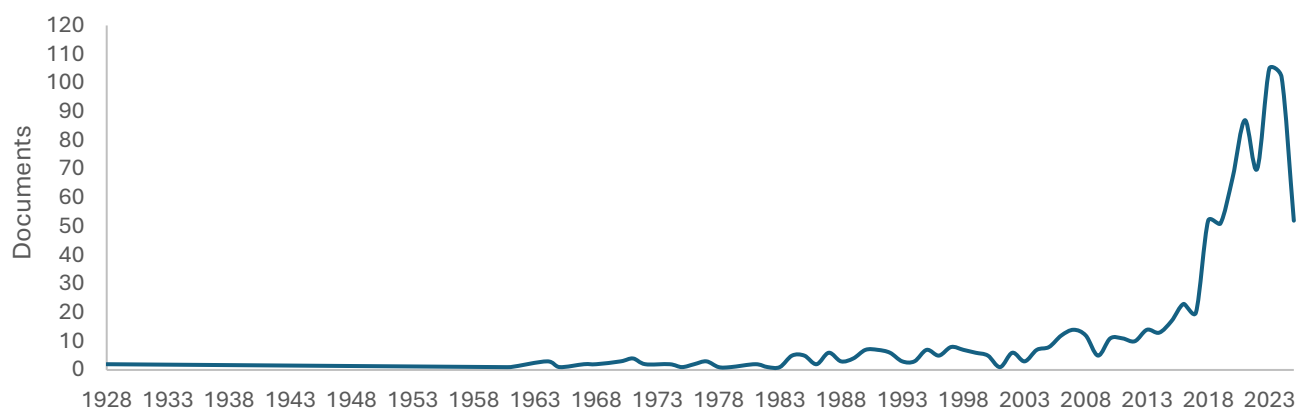


Figure 3. Evolution of publications “tempeh” in the period 1928-2025.

(178 documents, 19.8%), review articles (43 documents 4.8%), book chapters (38 documents, 4.2%), conference papers (13 documents, 1.4%), and less frequent categories including conference reviews, short surveys, errata, letters, and notes.

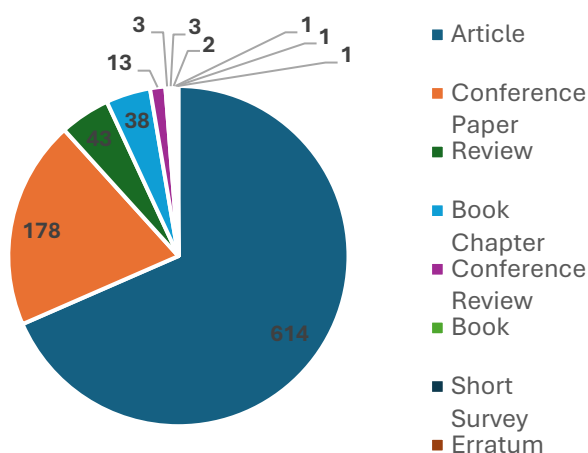


Figure 4. Distribution of document types retrieved using the terms “tempeh” or “tempe” in Scopus (1928–2025)

The large number of research articles demonstrates the growing interest of scientists in tempeh as an empirical study topic. The study of traditional fermented foods for their potential health benefits, microbiological profiles, and sustainability advantages is a growing interest in the domains of food science and nutrition (Marco et al., 2017). The substantial quantity of conference papers indicates tempeh has also been a subject of attention in scholarly forums and symposia, providing a forum for the exchange of innovative research and multidisciplinary discussions.

The relatively lower number of review articles may suggest that comprehensive syntheses of *tempeh*-related research are still limited, suggesting opportunities for future literature reviews to compile findings from different fields like public health nutrition, food technology, and microbiology. The presence of book chapters and data papers implies that tempeh is also considered relevant in academic textbooks and

research datasets.

According to the analysis of publication data, Indonesia is the dominant contributor to scientific literature involving the terms tempeh or tempe, with nearly 450 documents (Figure 5). This is significantly higher than any other country, reflecting Indonesia’s deep-rooted cultural and historical connection to tempeh as a traditional fermented soybean product indigenous to the region (Shurtleff and Aoyagi, 2011).

Following Indonesia, the United States, Malaysia, and Japan are the next most active in publishing documents related to tempeh, though with significantly lower counts, less than 100 publications each. Because of its expanding popularity as a plant-based protein source and increased knowledge of its nutritional advantages, tempeh has attracted considerable academic and commercial interest in these countries (Steinkraus, 1996; Kuswanto, 2004; Nout and Kiers, 2005).

Moderate publishing numbers are found in regions including the United Kingdom, Germany, China, India, Poland, the Netherlands, and Taiwan, indicating

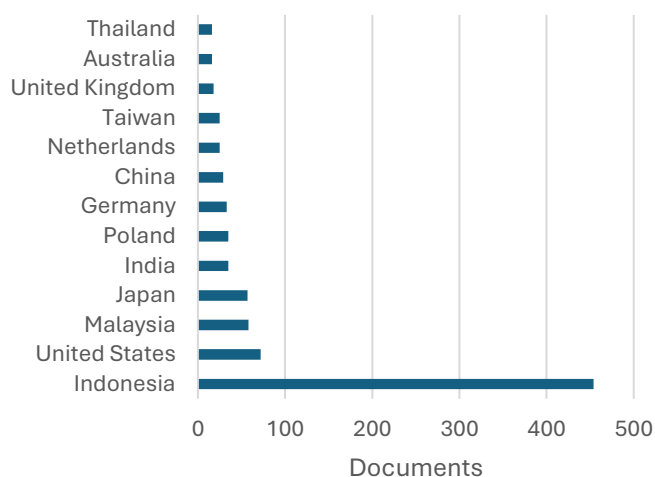


Figure 5. Main countries that most published documents using the terms “tempeh” or “tempe”

new or specialized research communities focused on plant-based diets, fermentation, or food sciences. The

increasing contributions from other nations highlight tempeh's globalization and its growing role in discussions related to functional foods and sustainable food systems (Bourdichon et al., 2012).

Figure 6 illustrates the leading academic institutions contributing to publications. The data clearly shows that IPB University showed the highest publication, with over 50 documents, followed by Universitas Gadjah Mada and Universitas Diponegoro. Other notable contributors include Universitas Indonesia, Universitas Katolik Indonesia Atma Jaya, Lembaga Ilmu Pengetahuan Indonesia (LIPI), and Bina Nusantara University, each with over 20 publications. The dominance of Indonesian institutions is expected, given tempeh's origin and widespread local consumption. Interestingly, Uniwersytet Przyrodniczy w Poznaniu (Poznań University of Life Sciences) from Poland is among the top 10, suggesting that there is some interest in tempeh research outside of Indonesia among scholars worldwide. This could be caused by Europe's rising recognition of tempeh as a healthy meat substitute and its applicability to sustainable food innovation, emerging global interest in integrating traditional fermented foods into modern dietary frameworks (Research and Markets, 2024). These institutions explore tempeh from the perspectives of food science, microbiology, nutrition, sustainability, and socio-economic impact.

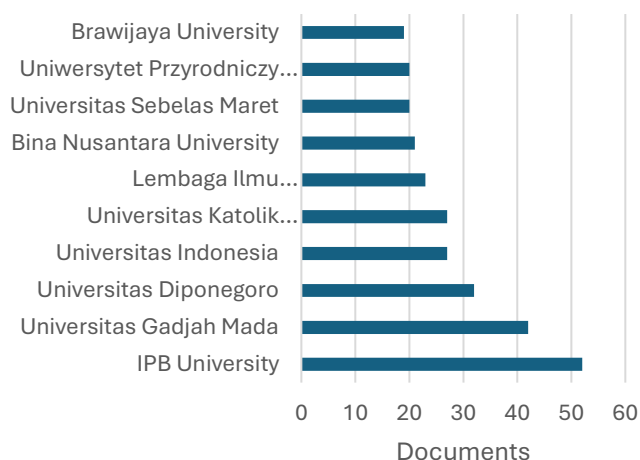


Figure 6. Main institutions that most published documents using the terms “tempeh” or “tempe”

The majority of journals and conference proceedings that have published documents with the terms tempeh or tempeh are displayed in Figure 7. With around 100 documents, the IOP Conference Series: Earth and Environmental Science is the most extensive source, followed by AIP Conference Proceedings and Food Research. This trend also implies that a large number of tempeh studies come from academic events, particularly in Southeast Asia, where tempeh is both extensively studied and culturally significant. Food Research, Journal of Food Science, Food Chemistry, Journal of Agricultural and Food Chemistry, and LWT are well-known peer-reviewed journals. These journals are well-regarded in food science and technology and frequently publish studies on functional foods and fermented foods. This distribution of publications

highlights that tempeh research is not only being recognized in food-specific journals but also in broader scientific discussions.

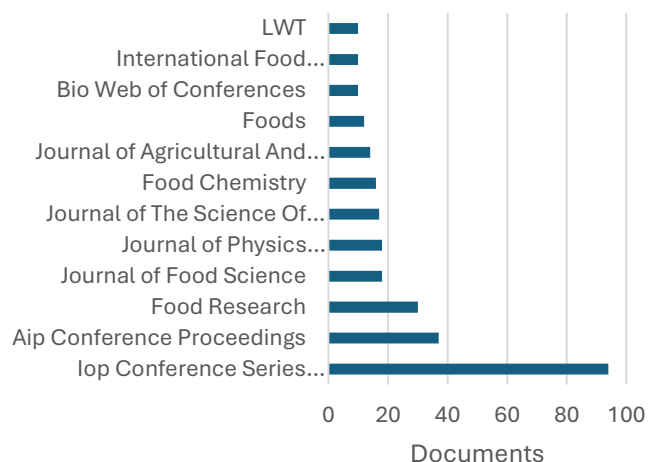


Figure 7. Main journals that most published documents using the terms “tempeh” or “tempe”

Study of the main keywords in the area of tempeh

The co-occurrence analysis of keywords, generated using VOSviewer, highlights the thematic distribution and research focus areas related to the terms “tempeh” or “tempe” (Figure 8). At the core of the network lies the term “tempeh,” indicating its central importance across publications. Surrounding it are five distinct color-coded clusters, each representing a major thematic domain within tempeh-related research while maintaining interconnectedness across topics. These clusters illustrate the research directions, ranging from microbiological processes to nutritional and functional applications. The green cluster represents microbiological and fermentation-related studies, with frequently co-occurring terms such as *Rhizopus*, *microbiology*, *lactic acid*, and *solid-state fermentation*. These terms imply a major emphasis on the microbial ecology involved in tempeh production, particularly the role of *Rhizopus oryzae*, a fungus commonly used as a starter culture in traditional tempeh fermentation (Nout & Kiers, 2005). Previous studies reported on the dynamics of yeast and fungal growth, β -glucan formation, and antibacterial activity against *Escherichia coli* during tempeh fermentation. The addition of *S. cerevisiae* to the traditional *R. oligosporus* fermentation process enhances the health benefits of tempeh by increasing β -glucan content and antibacterial activity against *E. coli* (Rizal et al., 2021).

In contrast, the red cluster focuses on the nutritional and technological aspects of tempeh, including terms like *nutritional value*, *proteins*, *amino acids*, *cooking*, and *food processing*. These studies aim to enhance the understanding of tempeh's nutrient content and its application in various food systems. Previous findings have demonstrated tempeh's high protein bioavailability (Steinkraus, 1996). According to Damanik et al. (2018), processing affected nutritional composition, showing both increases and decreases in

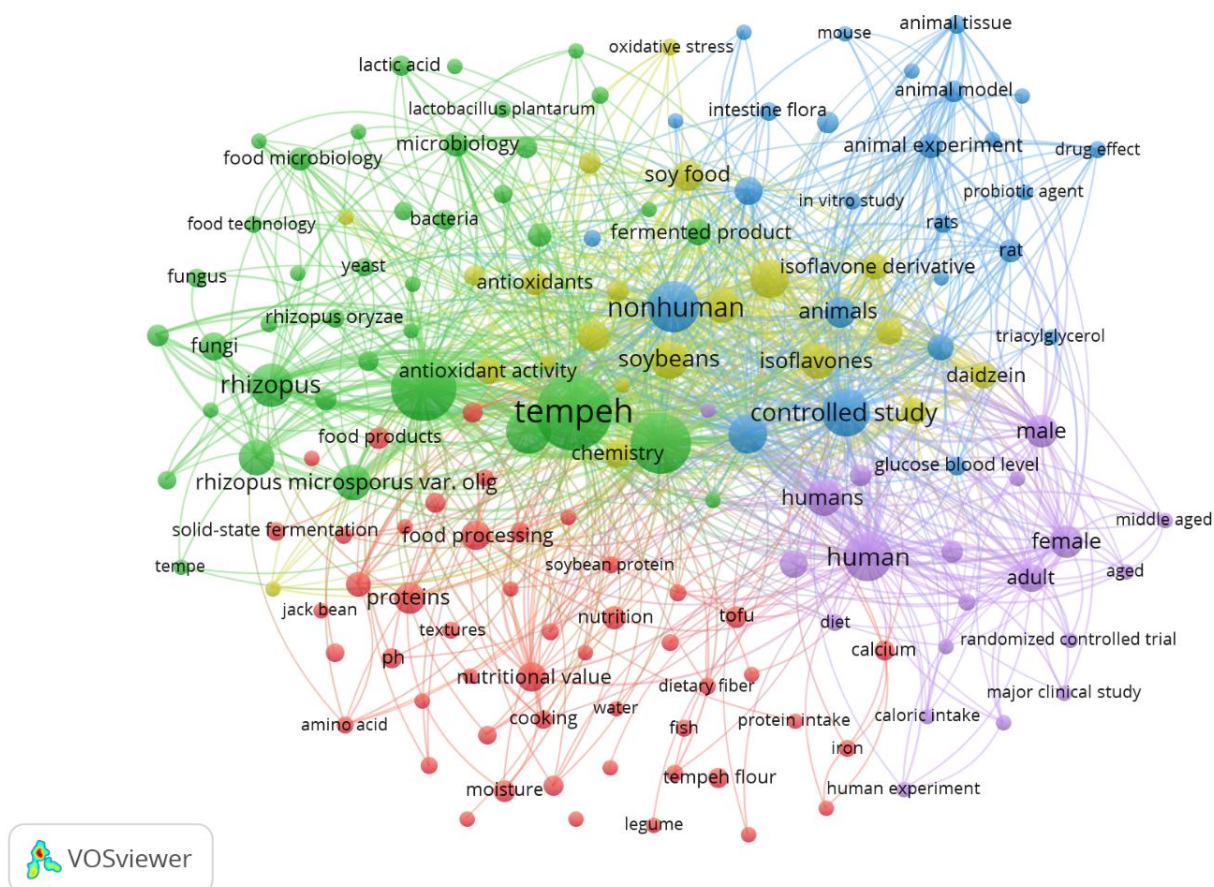


Figure 8. Network map showing correlations between the most used keywords in the articles based on the keywords and Boolean operators “tempeh” or “tempe”

various nutrients of tempeh gembus. These results are crucial for understanding how tempeh can be optimized for better nutritional value and its application in diverse food systems.

The blue cluster studies involve animal models and functional food evaluations. Keywords such as *animals*, *oxidative stress*, *probiotic agent*, and *animal experiment* indicate a focus on preclinical research investigating the health effects of tempeh, including its potential in reducing oxidative stress and improving gut microbiota. For instance, in a study by Ahmad et al. (2014), total isoflavones from soybean and tempeh were administered orally to different groups of rats. The findings revealed that tempeh isoflavones (TI) significantly increased acetylcholine levels and decreased acetylcholinesterase activity, which is crucial for improving memory and cognitive function.

The purple cluster centers on clinical and human health research using keywords like *human*, *controlled study*, *diet*, *glucose blood level*, and *randomized controlled trial*. This cluster highlights efforts to assess tempeh's impact on metabolic health, cardiovascular function, and hormonal regulation. The previous study reported that the presence of isoflavones in tempeh has attracted attention for its potential to alleviate menopausal symptoms and support cardiovascular health (Mani and Ming, 2017).

Lastly, the yellow cluster links several terms such as *soybeans*, *isoflavones*, and *fermented product*.

indicating a strong biochemical and phytochemical focus. One of the studies reported the emphasis on isoflavone derivatives reflecting their role in modulating physiological processes, as supported by research on soy-based foods (Zaheer and Humayoun Akhtar, 2017).

Overall, this co-occurrence analysis highlights the multidisciplinary nature of tempeh research, integrating microbiology, nutrition, food science, and health sciences. The rich interconnectivity between keywords points to a growing scientific interest in tempeh as a traditional food and modern functional ingredient with potential health benefits.

Future research directions

With the rising global popularity of tempeh among vegan and vegetarian communities, there is a timely opportunity to position tempeh research at the forefront of plant-based innovation. The growing interest in alternative substrates, functional properties, and health-related benefits suggests opportunities for developing non-soy tempeh variants and probiotic-enriched products. For future research on tempeh, the researchers should prioritize interdisciplinary exploration that correlates traditional knowledge with modern scientific innovation. Collaborative studies across countries and institutions, particularly between Southeast Asia, North America, and Europe, can accelerate innovation in processing, safety, industrial

scalability, and sustainability.

This study has proven valuable in visualizing thematic clusters and identifying underexplored intersections between keywords, which can inform novelty in future research. For instance, limited connections between tempeh and omics technologies, clinical nutrition, or environmental impact suggest fertile ground for innovation. Strengthening future research will support tempeh's development as a healthy, sustainable, and widely accepted food around the world.

Conclusion

Tempeh research has experienced substantial growth in the last decade, indicating global interest in sustainable and health-promoting diets. Bibliometric analysis reveals that Indonesia remains the primary contributor to tempeh research, followed by the United States, Malaysia, and Japan. Thematic clusters indicate a multidisciplinary landscape that encompasses microbiology, nutrition, animal studies, and clinical trials. The co-occurrence of keywords related to fermentation, isoflavones, and health outcomes underscores tempeh's potential. This study provides a research roadmap that can guide future investigations and foster international collaboration to advance tempeh innovation and its integration into sustainable food systems.

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