Research Landscape of Tempeh: A Bibliometric Study of Research Focus, Applications, and Product Development Opportunities

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ABSTRACT

Tempeh, a traditional Indonesian fermented soybean product, has gained increasing global recognition for its nutritional value and functional health benefits. Characterized by high protein bioavailability, essential vitamins, minerals, and bioactive compounds such as isoflavones and peptides, tempeh plays an important role in plant-based and functional food innovations. This study aims to systematically map the research landscape on tempeh over the past decade (2015–2025) using bibliometric analysis. Data were exclusively retrieved from the ScienceDirect database and analyzed using VOSviewer (version 1.6.20). A total of 9,338 publications were examined to identify trends in research themes, publication dynamics, and keyword co-occurrence networks. Three types of visualization network, overlay, and density maps were generated to illustrate the intellectual structure and thematic evolution of tempeh-related research. The network analysis revealed six major thematic clusters: (1) plant-based meat alternatives and consumer preferences, (2) fermentation processes and Rhizopus oligosporus, (3) antioxidant and bioactive compound studies, (4) plant-based dietary strategies, (5) isoflavones and bone health, and (6) microbial identification and antimicrobial activity. The overlay visualization highlighted a temporal shift from microbial and biochemical studies (2021–2022) towards market-driven and consumer-focused research (2023–2024), particularly emphasizing sensory evaluation and plant-based food product development. Meanwhile, the density map pinpointed emerging research hotspots in market trends, antioxidant studies, and microbial functionality. In conclusion, this bibliometric study demonstrates a clear evolution in tempeh research, moving from fundamental microbiological and nutritional analyses towards applied food technology and market acceptance studies. These findings provide valuable insights for researchers, industry stakeholders, and policymakers in guiding future research priorities and supporting the development of innovative, sustainable, and health-promoting tempeh-based food products.

Keywords: Bibliometric, fermented soybean, science direct, tempeh, vosviewer

INTRODUCTION

Tempeh is a traditional Indonesian food product derived from soybeans and widely consumed as a key source of dietary protein. According to the Indonesian National Standard (SNI 3144:2015), tempeh is defined as a compact, white, solid product obtained from dehulled soybeans that have been cooked and fermented with Rhizopus spp. mold starter (BSN, 2015). Compared to unfermented soybeans, tempeh offers enhanced nutritional benefits due to the fermentation process, which breaks down soybean proteins into smaller peptides and free amino acids. This degradation significantly improves the protein bioavailability, as the resulting compounds have lower molecular weights and higher solubility, making them easier for the human body to absorb.

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Tempeh, a traditional Indonesian fermented soybean product, has gained increasing scientific attention due to its exceptional nutritional and functional properties. The fermentation process not only enhances its protein digestibility, amino acid profile, and protein quality score, but also significantly reduces anti-nutritional factors, making its nutrients more bioavailable. Rich in vitamins (including B-complex and B12) and essential minerals such as calcium, iron, magnesium, and zinc, tempeh is also a valuable source of essential fatty acids, particularly linoleic and linolenic acids, along with beneficial monounsaturated (MUFA) and polyunsaturated fatty acids (PUFA). Importantly, tempeh contains high levels of bioactive compounds like isoflavones, peptides, and saponins, which exhibit strong antioxidant properties. These bioactives contribute to various health benefits, including the prevention and management of cardiovascular diseases, obesity, diabetes, osteoporosis, cancer, neurodegenerative disorders, and menopausal symptoms. Tempeh also supports digestive health, enhances immune response, and offers cosmetic benefits for skin health. Given its nutritional richness and functional health potential, tempeh is increasingly recognized as a superfood and holds significant promise for functional food innovation, public health nutrition, and sustainable plant-based dietary strategies.

Bibliometric analysis provides critical insights into the evolving research landscape on tempe, enabling the identification of publication trends, keyword patterns, authorship networks, and institutional contributions. This method quantitatively assesses scholarly output, highlighting thematic hotspots, emerging research areas, and technological developments, while minimizing the risk of research redundancy and supporting more strategic resource allocation (Abdullah et al., 2023; Şenyapar, 2023; Xiao et al., 2024). Despite the increasing global interest in tempe as a functional food and plant-based protein source, a comprehensive bibliometric mapping of tempe-related research has been lacking. Therefore, this study applies bibliometric analysis, using tools such as VOSviewer, to systematically explore research trends, thematic evolution, and knowledge gaps over the last decade, as visualized through network, overlay, and density mapping outputs.

MATERIALS AND METHOD

Data Sources and Searching Strategy

The data for this bibliometric analysis were exclusively retrieved from the ScienceDirect database, which was selected for its comprehensive collection of peer-reviewed journal articles and its recognized reliability in providing high-impact scientific publications. ScienceDirect is widely acknowledged as a reputable source for scholarly literature in the fields of food science, microbiology, nutrition, and food technology, making it well-suited for the scope of this study.

ScienceDirect is recognized as one of the largest and most reputable platforms for accessing and publishing scientific literature globally. Managed by Elsevier, a leading publisher in the fields of science, technology, and medicine, ScienceDirect serves as an online service offering access to an extensive collection of scholarly resources. The platform hosts over 12 million pieces of content, encompassing more than 3,500 peer-reviewed academic journals and approximately 34,000 electronic books (Sukirno et al., 2018). Covering a broad spectrum of disciplines—including natural sciences, technology, medicine, social sciences, and humanities—ScienceDirect provides researchers worldwide with authoritative and high-quality research publications originating from various prestigious publishers.

A systematic search was conducted by applying a combination of relevant keywords such as *"tempe," "fermented soybean," "plant-based protein," "Rhizopus oligosporus," "functional food,"* and *"soy-based meat alternatives."* The search was limited to research and review articles published between 2015 and 2025, ensuring the inclusion of the most recent and relevant publications.

To facilitate further analysis, all bibliographic data were exported in RIS file format, which allowed for efficient processing and visualization using VOSviewer software (version 1.6.20). This tool was utilized to perform network mapping, identify keyword co-occurrence patterns, and explore the intellectual and thematic structure of the research landscape surrounding tempe-based innovations, microbial functions, functional food development, and consumer preferences in plant-based nutrition.

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Data Extraction and Analysis

Bibliographic data comprising article titles, abstracts, author keywords, and full-text content were systematically extracted and compiled. The dataset was stored in "RIS" format to ensure compatibility with bibliometric software. Subsequent analysis was conducted using VOSviewer (v1.6.20), with a focus on mapping publication dynamics, identifying contributing sources, examining keyword co-occurrence networks, and generating overlay visualizations to elucidate thematic structures within the research corpus.

Term map

Bibliometric analysis is a widely adopted quantitative method across various academic disciplines for evaluating scientific literature and uncovering patterns of knowledge production, such as research trends, author collaborations, and topic development. One of the most commonly used tools in this field is VOSviewer, a software specifically designed to visualize bibliometric networks involving co-authorship, co-citation of journals, article titles, keywords, and publications. VOSviewer supports multiple types of mapping, including collaboration networks, thematic mapping, and temporal visualizations, with outputs that are clearly labeled and easy to interpret. These features enable researchers to identify both well-established research areas and those that remain relatively underexplored. In particular, keyword mapping with VOSviewer offers valuable insights into the direction and focus of existing research, while also informing potential pathways for future investigation.

RESULTS AND DISCUSSION

Publication Trends

The most recent research literature was sourced from ScienceDirect and systematically compiled on June 15, 2025. A total of 9.338 publications were identified, covering a ten-year span from 2015 to 2025. Figures 1 and 2 present the outcomes of the bibliometric analysis, which was conducted by filtering relevant terms extracted from the reference data. The network diagrams generated consist of 270 items organized into 6 thematic clusters, with a total link strength of 9.338, reflecting the intensity of co-occurrence among the identified terms.

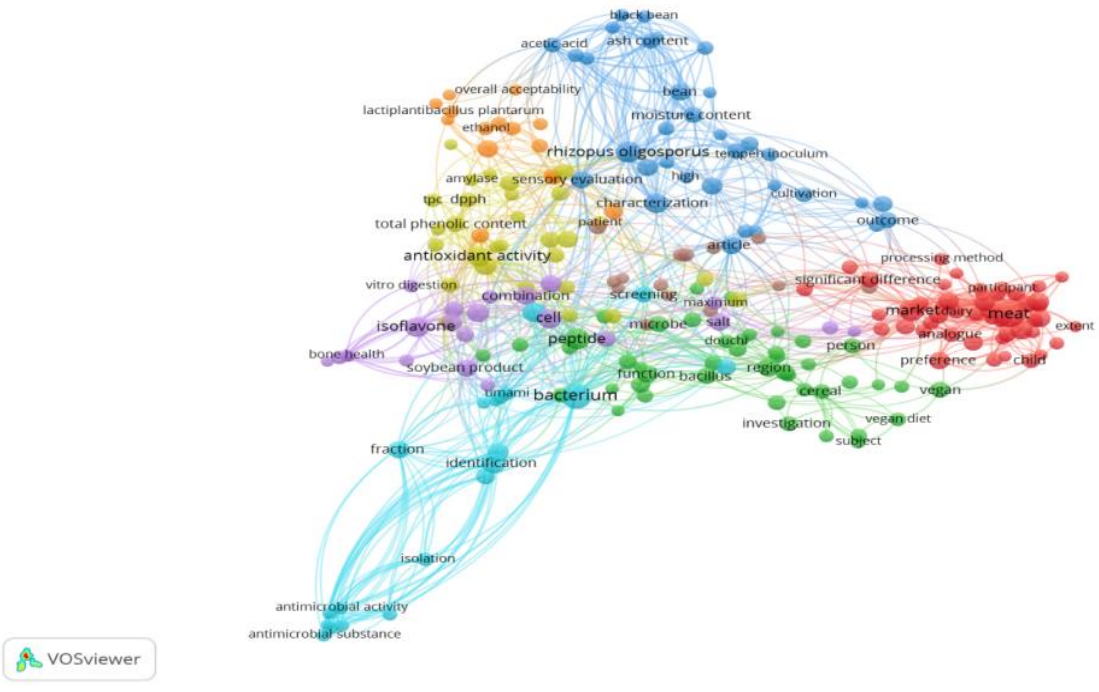

Fig. 1 Network Visualization

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Figure 1 The network visualization presented in Figure X was generated using VOSviewer software to illustrate the co-occurrence relationships among key terms identified in the literature dataset. Each node represents a specific term, with the size of the node indicating the frequency of occurrence, and the distance between nodes reflecting the strength of their co-occurrence. Terms that frequently appear together in the same documents are positioned closer, suggesting a strong thematic association. The analysis revealed a total of six distinct clusters, each visualized in a different color red, green, blue, yellow, purple, and light blue.

The red cluster highlights a strong research focus on meat alternatives, consumer preferences, and market acceptance of plant-based foods, particularly within the context of vegan and vegetarian diets. This cluster also encompasses studies on sensory evaluation, consumer behavior, and market analysis of novel food products. Key terms frequently appearing in this cluster include *meat, market, dairy, analogue, preference, participant, child, vegan, vegan diet, significant difference*, and *processing method*. The prominence of terms such as *meat*, *analogue*, and *dairy* indicates a concentrated interest in the development of plant-based substitutes for animal-derived products. Meanwhile, terms like *market*, *preference*, and *participant* suggest that many studies investigate consumer responses, sensory testing, and market trends for these products. The appearance of the term *child* points to a subtheme focused on child-targeted sensory or acceptance studies, which is crucial for creating family-friendly commercial formulations. Furthermore, the presence of *significant difference* and *processing method* reflects the application of statistical analysis and technological innovations to assess product quality and acceptance. Collectively, this cluster underscores a growing interest in sustainable food research, particularly in the development and optimization of plant-based dairy and meat analogues, aligning with shifts in dietary patterns. These insights are valuable not only for researchers but also for the food industry, as they help in formulating products with the desired texture, taste, and consumer appeal.

The green cluster represents a research domain centered on plant-based nutritional strategies, particularly the role of vegan diets and cereal consumption, as well as the behavioral and demographic factors influencing dietary choices. This cluster reflects a broader interest in sustainable, health-promoting food systems and the social dynamics shaping food preferences in diverse populations. Other research on sugar palm is represented by the yellow, light blue, and red clusters, located on the right side of the diagram. These clusters focus more on the utilization of sugar palm fiber and starch, their material properties, and the physical characteristics of the plant.

The blue cluster focuses on fermented food products, with particular attention to *Rhizopus oligosporus* and the examination of their physicochemical properties, such as moisture content, ash content, and inoculum characteristics.

The yellow cluster is primarily associated with studies on antioxidant activity**,** total phenolic content**,** and sensory evaluation, reflecting a growing interest in the health-promoting properties of functional foods**.**

Meanwhile, the purple cluster emphasizes research on isoflavones and other soybean-derived bioactive compounds, particularly in relation to their potential benefits for bone health.

The light blue cluster comprises investigations into microbial identification**,** antimicrobial activity, and the isolation of bioactive substances produced during fermentation processes. Together, these clusters illustrate the of the field, offering a comprehensive overview of the diverse but interconnected intellectual structure domains of research, and facilitating a deeper understanding of emerging trends and knowledge gaps.

The bibliometric network analysis identified six distinct thematic clusters. These clusters represent key research areas including consumer preferences and plant-based meat alternatives (red cluster), fermented food products and their physicochemical properties (blue cluster), antioxidant activity and functional food evaluation (yellow cluster), plant-based diets and cereal-based nutrition (green cluster), soybean-derived bioactive compounds and bone health (purple cluster), and microbial identification and antimicrobial activity from fermentation processes (light blue cluster). Together, these clusters reflect the diverse and multidisciplinary research landscape surrounding food science, nutrition, and functional food development.

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Overlay Visualization Using VOS Viewer

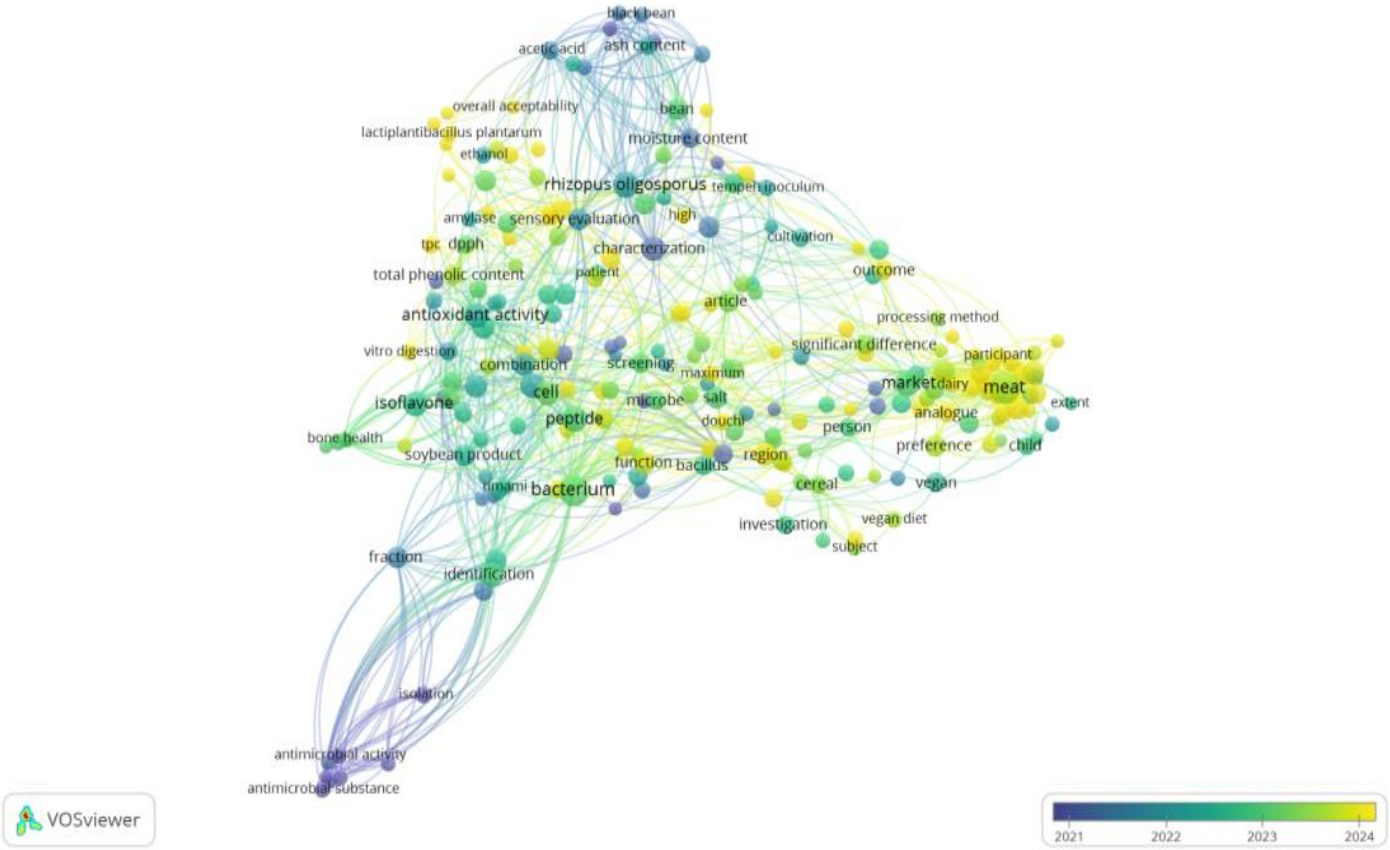

Fig. 2 Overlay Visualization

Figure 2 presents the overlay visualization generated using VOSviewer, illustrating the temporal progression of research themes within the analyzed literature dataset. The color gradient, ranging from purple (earlier years, ~2021) to yellow (most recent years, ~2024), highlights the evolution of research priorities over time.

During the early research phase (around 2021), studies were predominantly centered on microbial identification, antimicrobial activity, and bioactive compound isolation, as indicated by the concentration of purple and blue nodes in the lower-left area of the map. This reflects the initial scholarly interest in microbiological aspects and functional bioactivity of fermentation-related substances.

As the research field progressed into 2022 and 2023 (green-toned nodes), there was a noticeable shift towards exploring peptide characterization, bacterial functions, antioxidant activity, and physicochemical properties of fermented products, such as those involving *Rhizopus oligosporus* and soy-based food systems. This phase marked an increasing emphasis on nutritional quality assessment and functional food development.

In the most recent years (late 2023 to 2024, represented by yellow nodes), research trends further evolved towards consumer-focused studies, with growing attention on market preferences, sensory evaluation, plant-based meat analogues, and vegan dietary patterns. This temporal shift suggests a significant move from laboratory-based bioactive and microbiological investigations toward product development, consumer acceptance research, and market-driven innovations.

Overall, the overlay visualization clearly demonstrates how the research landscape has transitioned from fundamental microbiology and bioactivity studies to more application-oriented research that integrates sensory science, consumer behavior, and plant-based food product innovation, in line with global trends in sustainable food systems and functional nutrition.

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Density Visualization Analysis

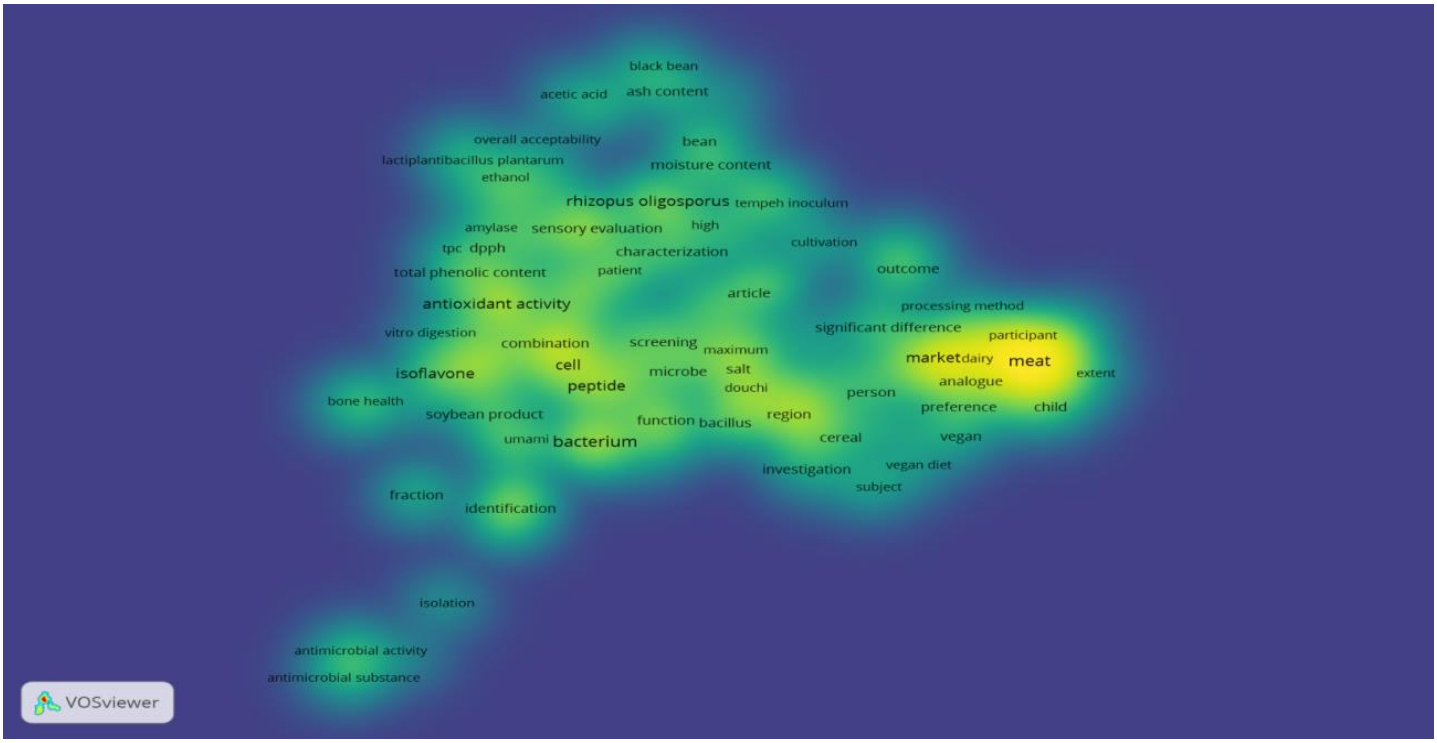

Fig. 3 Density Visualization

Figure 3 presents the density visualization map generated using VOSviewer, which illustrates the frequency and intensity of keyword occurrences within the selected literature on tempe research. In this visualization, areas with higher research concentration appear in warmer colors, ranging from green to yellow, while regions with lower keyword density are represented in cooler tones, such as blue and purple**.**

The most prominent hotspot is observed around the keywords “market,” “dairy,” and “meat,” indicating that recent research in the field has shown a heightened focus on topics related to plant-based meat alternatives, consumer markets, and dairy-free innovations. This suggests an increasing scholarly interest in tempe as a functional ingredient in meat analogues and vegan food products**.**

Moderate density zones are visible around keywords like “antioxidant activity,” “Rhizopus oligosporus,” “sensory evaluation,” “peptide,” “bacterium,” and “isoflavone,” reflecting substantial but comparatively lower levels of research activity in these areas. These regions represent topics on microbial fermentation processes, functional bioactive compounds, and nutritional evaluations of tempe and soy-based products**.**

On the periphery, cooler blue and purple areas such as “antimicrobial activity,” “isolation,” and “identification” indicate emerging or less intensively studied research themes. These keywords suggest a growing but still limited body of work on microbial characterization and bioactive substance discovery from fermentation processes**.** Overall, this density visualization highlights the research hotspots and thematic gaps within the tempe research landscape, providing valuable guidance for identifying potential areas for future investigation**.**

CONCLUSION

The bibliometric analysis conducted using VOSviewer provides a comprehensive overview of the research landscape on tempe over the past decade. The network visualization revealed six distinct thematic clusters, highlighting major research focuses such as fermentation processes and Rhizopus oligosporus (blue cluster), antioxidant and bioactive properties (yellow cluster), isoflavone and bone health (purple cluster), microbial and antimicrobial activity (light blue cluster), consumer market preferences (red cluster), and nutritional evaluations (green cluster).

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The overlay visualization, with its chronological color gradient, illustrates the temporal evolution of research themes. Earlier studies (2021–2022), shown in darker colors, predominantly concentrated on fermentation techniques, microbial characterization, and nutritional assessments. In contrast, more recent publications (2023–2024), depicted in brighter yellow tones, demonstrate a growing research emphasis on market acceptance, sensory evaluation, consumer preferences, and the development of plant-based meat analogues.

Additionally, the density visualization map highlights research hotspots, with the highest concentration of studies focusing on market-oriented topics such as “meat,” “market,” and “preference.” Meanwhile, areas such as antimicrobial substance identification and bioactive compound isolation remain relatively underexplored, representing important opportunities for future research.

In summary, the research trajectory in the field of tempe has gradually shifted from microbial and nutritional studies toward product innovation, consumer behavior, and functional food development. This trend reflects the increasing global interest in plant-based foods and sustainable protein alternatives, signaling a critical need for continued multidisciplinary collaboration to support both scientific advancement and industrial application.

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