

Trends and Knowledge Gaps In Fish-Based Fermented Foods: A Bibliometric Analysis From The Last Decade (2015-2024)

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Abstract.

Fish-based fermented foods are integral to traditional diets across Asia, Africa, and Europe, valued for both their nutritional role and cultural significance. Increasingly, they are also studied for potential functional properties such as probiotic activity and bioactive compounds, yet their global research landscape has not been systematically assessed. This study presents a bibliometric analysis of global research on fish-based fermented foods published between 2015 and 2024. Data were retrieved from the Scopus database and analyzed using the Bibliometrix R package and Biblioshiny interface. A total of 263 documents were identified across 145 sources, authored by 1,150 researchers. The field has shown rapid growth, with an annual publication increase of 27.01% and an average of 28.48 citations per article, indicating strong scholarly visibility. Most contributions originated from East and Southeast Asia, particularly China, South Korea, and Thailand, reflecting the cultural and culinary importance of fermented fish in these regions. Author productivity followed Lotka's law, with a small group of core researchers driving sustained output. Keyword co-occurrence and thematic mapping revealed dominant clusters around fermented fish sauce, lactic acid bacteria, and microbial diversity, alongside emerging themes related to fatty acids and bacterial communities. Despite these advances, the analysis highlighted notable gaps, including limited international collaboration and underrepresentation of research from Africa and parts of South Asia. These findings suggest that while the field is expanding and diversifying, greater cross-regional engagement and methodological innovation are needed to fully explore the nutritional, functional, and socio-economic dimensions of fish-based fermented foods.

Keywords: Bibliometric analysis; fermented fish; lactic acid bacteria; probiotics; food microbiology; research trends.

1. INTRODUCTION

Fish-based fermented foods have long been integral to traditional diets across Asia, Africa, and parts of Europe, where they serve not only as important sources of protein but also as carriers of cultural identity. Fermentation improves shelf life, modifies flavor and texture, and enhances nutritional accessibility, making these foods vital in both subsistence and culinary contexts. Well-known examples include *pla-ra* in Thailand, *bekasang* in Indonesia, *ngari* in India, and *surströmming* in Sweden, each reflecting localized practices and cultural heritage [1].

In recent years, research on fish-based fermented foods has shifted beyond product characterization to focus on their functional potential. Lactic acid bacteria (LAB) are key microorganisms in fermentation, converting carbohydrates into lactic acid and shaping the flavor, texture, and safety of many traditional foods [2]. In Asian cuisines, they are central to the fermentation of fish, rice, vegetables, and other staples [3,4]. Common genera include *Lactobacillus*, *Lactococcus*, *Leuconostoc*, *Pediococcus*, *Tetragenococcus*, and *Weissella*. In fish-based fermented foods, LAB not only suppresses spoilage organisms and pathogens but also reduces harmful biogenic amines, creating a safer product. At the same time, they drive acidification, enrich flavor complexity, and fine-tune product quality, making them indispensable in both traditional and modern fermented fish products [5]. Multiple LAB strains are now studied for their role in producing probiotics, antimicrobial agents, bioactive peptides, and essential fatty acids. These findings support the positioning of fermented fish within the broader category of functional foods, with implications for human health, nutrition security, and the valorization of traditional knowledge [6, 7].

Despite their benefits, these foods are not without challenges. Safety concerns persist regarding the accumulation of biogenic amines, heavy metals, and pathogenic bacteria during fermentation [8]. Furthermore, growing attention to environmental sustainability has encouraged exploration of fish fermentation as a means of reducing food waste and valorizing by-products, thereby linking traditional practices to modern concerns of resource efficiency and circular economy [9].

Although the field is growing, research on fish-based fermented foods remains fragmented across various domains, including microbiology, food chemistry, nutrition, and ethnobiology. Many studies are localized, focusing on specific products or practices, with limited synthesis across regions or disciplines. Contributions from regions such as Africa and parts of South Asia remain underrepresented, and cross-border collaborations are rare, leaving gaps in both thematic integration and geographic representation [10].

Bibliometric analysis offers a systematic approach to mapping such a field. By examining publication outputs, citation patterns, collaboration networks, and keyword dynamics, bibliometric methods enable the identification of research hotspots, knowledge gaps, and emerging themes [11]. To date, however, no bibliometric study has comprehensively analyzed the global research landscape on fish-based fermented foods. The present study addresses this gap by applying bibliometric techniques to publications from 2015 to 2024 indexed in the Scopus database. This study aimed to (i) describe publication and citation trends, (ii) identify the most influential authors, journals, institutions, and countries, (iii) map thematic evolution and collaboration networks, and (iv) highlight underexplored areas and future directions for research in this field.

II. METHODS

The bibliometric data were retrieved from the Scopus database in May 2025. Scopus is one of the largest repositories of peer-reviewed literature and is widely used in bibliometric research [12]. The search was designed to capture publications on fish-based fermented foods published during the last decade (2015–2024). The following query was applied to the Title, Abstract, and Keyword fields (TITLE-ABS-KEY): (*"fermented food"* AND fish*). This search initially yielded 353 records, which were refined by restricting the document types to articles, reviews, and conference papers and by limiting the language to English, resulting in a final dataset of 263 documents. The records were exported in BibTeX format, including citation data, abstracts, and keywords. The analysis combined descriptive and network-based approaches. The methodological framework followed established bibliometric procedures described in previous studies [13], combining descriptive and network-based analyses to explore publication trends, collaboration patterns, and thematic evolution. Descriptive indicators included annual scientific production, average citations per article, authors' productivity (Lotka's law), and the most prolific journals, countries, authors, and cited works. Keyword dynamics and collaboration patterns were examined through temporal keyword distribution, co-authorship networks, and keyword co-occurrence mapping. Data processing, visualization, and thematic mapping were conducted using the Bibliometrix R (version 4.1) package and Biblioshiny 5.0 interface [11], with Microsoft Excel (Office 365) for additional summaries.

III. RESULT AND DISCUSSION

The bibliometric search identified 263 documents on fish-based fermented foods published between 2015 and 2024, distributed across 145 different sources (Fig. 1). These publications involved 1,150 authors, with an average of 5.46 co-authors per document, reflecting the collaborative nature of research in this area. Only five single-authored articles were recorded, confirming that the field has moved away from individual efforts toward collective work. However, no instances of international co-authorship were observed. This suggests that while research is active within national or regional contexts, cross-border collaboration is still underdeveloped. The reason could be that fermented fish products are strongly tied to cultural traditions across Asia, Africa, and parts of Europe; the absence of global partnerships may represent a missed opportunity for comparative and integrative studies [13].

The dataset contained 3,257 author keywords, demonstrating wide thematic diversity and the presence of multiple research fronts. The average document age was 4.23 years, suggesting that most contributions are

relatively recent. With an average of 28.48 citations per document, the field shows a healthy level of academic visibility, indicating that fermented fish research has relevance beyond its niche domain. The annual growth rate of 27.01% reflects a sharp increase in scholarly attention over the past decade, likely driven by rising interest in traditional foods, probiotics, and the functional properties of fermentation. Two key points are evidenced: First, that research on fish-based fermented foods is experiencing rapid growth and strong citation performance [10]; and second, that the lack of international collaboration may represent a structural gap that limits the global development of this field [14].



Fig. 1. Descriptive bibliometric indicators of studies on fish-based fermented foods (2015–2024).

The annual scientific production on fish-based fermented foods has increased steadily over the past decade (Fig. 2). From only five publications in 2015, output grew consistently, reaching 30 articles by 2019 and peaking at 43 publications in 2024. A slight fluctuation was observed between 2020 and 2023, with annual counts ranging from 34 to 37 documents, yet the overall trajectory reflects strong and sustained growth. This upward trend aligns with the 27% annual growth rate observed in the dataset and demonstrates the increasing scholarly interest in the field. An analysis of citation patterns revealed clear differences in the visibility of publications across years (Fig. 3). The earliest articles in the dataset (2015) showed modest average citations (14 citations per article), reflecting their limited number ($n = 5$) and relatively narrow influence. A sharp peak was observed in 2016, with an exceptionally high mean citation rate of 104.1 citations per article, indicating that a few highly influential studies were published during this period. From 2017 to 2020, the average citations per article stabilized between 34 and 49, suggesting a steady but moderate impact. More recent publications (2021–2024) showed progressively lower citation averages, with values declining from 23.9 citations per article in 2021 to 7.4 in 2024. This decline is expected, given the shorter time window for citations to accumulate. Nevertheless, the consistent increase in the number of documents, from 5 in 2015 to 43 in 2024, demonstrates growing research activity despite the lag in citation accrual. Citation rates in this context remain low, likely due to the limited role of cross-institutional and international collaboration. Papers involving international co-authors, particularly from Northern Europe and other high-income countries, tend to receive more citations, whereas publications from East Asia, Southeast Asia, and Southern Europe are cited less often compared to those from North America [16].

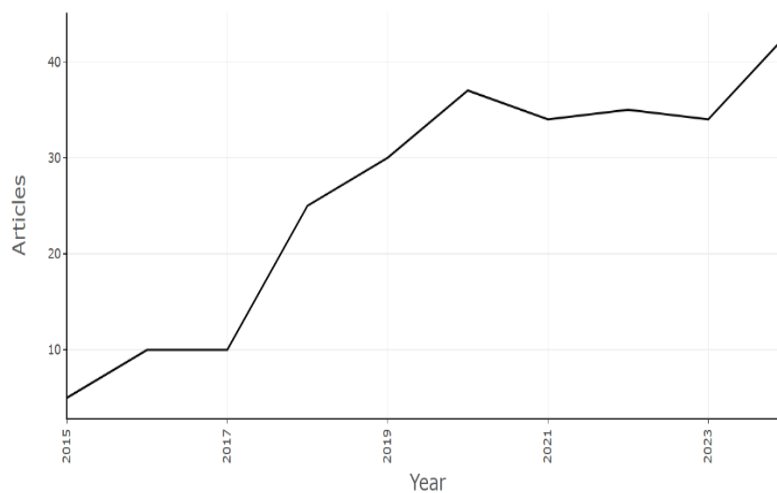


Fig. 2. Annual publication trend on published document for fish-based fermented foods (2015–2024).

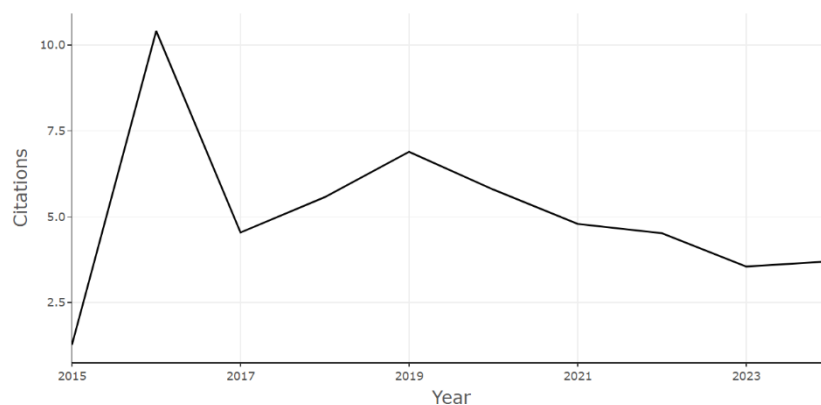


Fig. 3. Annual trends in average citations per article for published document on fish-based fermented foods (2015-2024)

Analysis of author productivity revealed that the majority of contributors in this field were associated with only a single publication (Fig. 4). Out of 1,150 authors, 987 (85.8%) published only once, while smaller proportions authored two (8.5%) or three (3.5%) documents. Only a handful of researchers contributed to four or more publications, with productivity decreasing sharply as the number of authored documents increased. This pattern aligns with Lotka's law of scientific productivity, which predicts that most authors publish infrequently, while a small group of core researchers drive sustained contributions in a given field [17]. The distribution showed good agreement with the theoretical model, confirming the presence of a highly skewed authorship pattern in fish-based fermented food research.

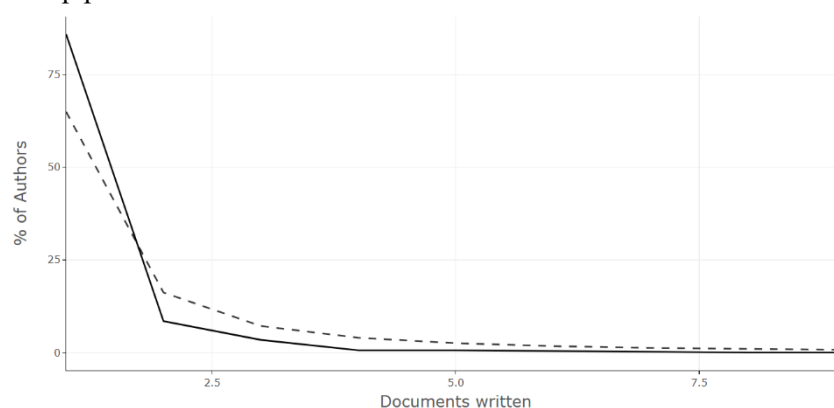


Fig. 4. Distribution of author productivity in research on fish-based fermented foods compared with the theoretical Lotka's law model.

Among the journals contributing to research on fish-based fermented foods, Food Research International was the most prolific, publishing 14 articles during the study period (Fig. 5). This was followed by Food Chemistry (10 articles), LWT and Nutrients (8 articles each), and the International Journal of Food Microbiology and the Journal of Ethnic Foods (7 articles each). Other journals with notable contributions included Food Research and Foods (5 articles each), as well as the IOP Conference Series: Earth and Environmental Science (5 articles). High-impact review outlets such as Critical Reviews in Food Science and Nutrition also featured in the dataset with 4 publications. These journals represent a balance between mainstream food science outlets, specialized journals on traditional and ethnic foods, and multidisciplinary venues, reflecting the broad relevance of fish-based fermented food research across domains of nutrition, microbiology, and food chemistry [18]. Among the contributing researchers, several authors emerged as particularly productive in the study of fish-based fermented foods over the last decade (Fig. 6). Li C led the field with nine publications, followed by Chen S with eight, and Li L, Park J with seven each. Some of the recently published works from the top three include flavor improvement of fermented tilapia sausage and surimi using LAB [19,20] and volatile compounds profile of *baechu-kimchi*, a traditional fermented food from *kimchi* cabbage (*Brassica rapa*) mixed with *jogi*, an Atlantic croaker (*Micropogonias undulatus*) [21]. The distribution of publications by country highlights clear regional patterns in research on fish-based fermented foods (Fig. 7). China led the field with 53 documents, accounting for the highest research output. This was followed by South Korea (37 documents) and Thailand (36 documents), both of which have strong traditions of fermented fish products in their food culture. India (34 documents) and Japan (26 documents) also contributed substantially, reflecting a mix of traditional food heritage and growing scientific interest. Among Southeast Asian nations, Indonesia (25 documents) and Malaysia (17 documents) emerged as active contributors, reflecting the significance of fermentation practices in the region. In contrast, contributions from Western countries were limited, with the United States (15 documents), Italy (8 documents), and Germany (7 documents) producing smaller outputs.

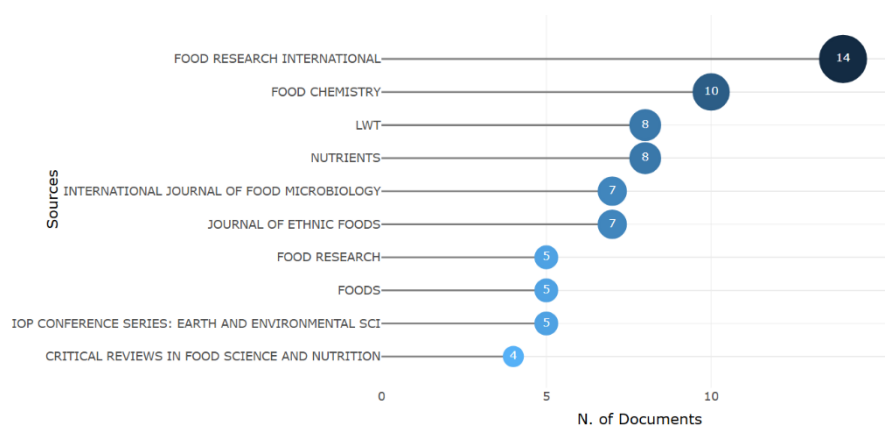


Fig. 5. Top ten journals publishing document on fish-based fermented foods between 2015 and 2024.

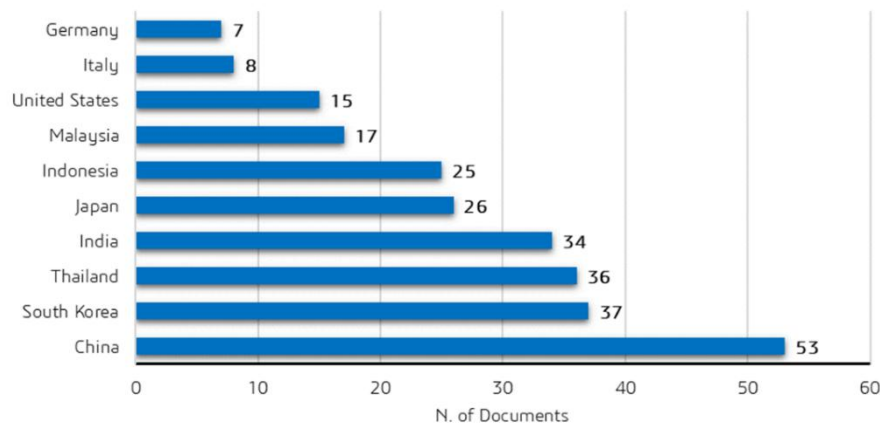


Fig. 6. Top ten countries publishing document on fish-based fermented foods between 2015 and 2024.

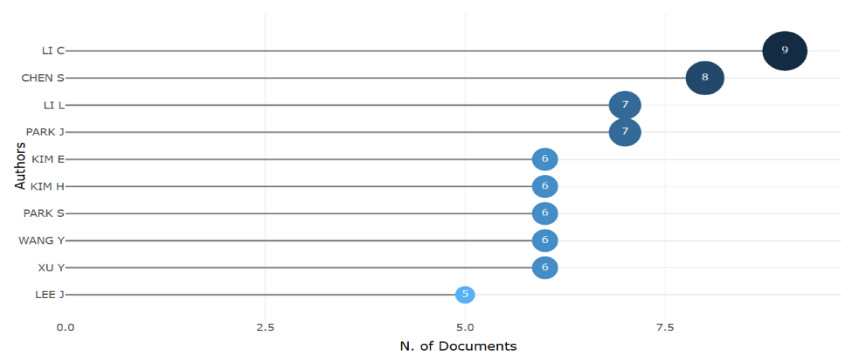


Fig. 7. Most productive authors in fish-based fermented food research between 2015 and 2024, ranked by number of publications.

The author network revealed several distinct clusters of collaboration, with varying levels of centrality and influence in the field of fish-based fermented food research (Fig. 8). Cluster 1 was dominated by Korean researchers (e.g., Kim E., Lee Y., Park J.), where Kim E. and Lee Y. exhibited relatively high betweenness and PageRank values, suggesting that they act as key connectors within their collaboration network. Cluster 2 was strongly represented by Chinese scholars, led by Li X. (betweenness = 49.7) and Xia W. (betweenness = 39.0), who occupy central positions in bridging multiple collaborations. Cluster 7 also demonstrated high network centrality, particularly for Yang X. (betweenness = 44.75) and Li C. (betweenness = 20.85), indicating their pivotal role in maintaining knowledge flow across research communities. Other clusters, such as those from Thailand (Cluster 10: Keeratipibul S., Lopetcharat K.), India and Nepal (Cluster 11: Tamang J.P., Jeyaram K.), and Indonesia/Africa (Cluster 9: Huda N., Adzitey F.), consisted of smaller but cohesive groups, often regionally bound and highly collaborative within their clusters. This network shows a concentration of research leadership in East Asia, with China and Korea producing the most influential authors, while Southeast Asian and South Asian scholars form smaller but thematically significant clusters. The absence of strong cross-regional linkages reflects limited international collaboration in this field, consistent with the earlier finding of 0% international co-authorship.

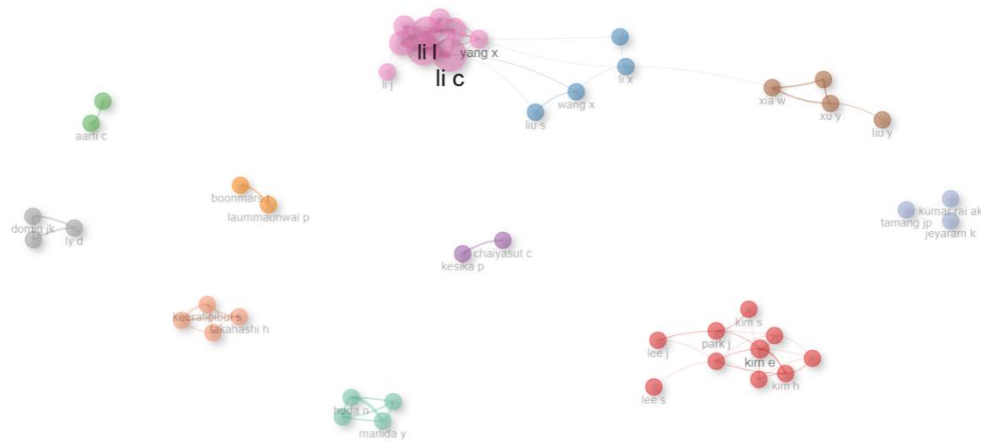


Fig. 8. Author collaboration network based on centrality measures. Node size represents PageRank (author influence), while edge thickness reflects co-authorship strength.

Among the retrieved publications, the most influential articles were identified based on citation performance (Fig. 9). The study by Tamang [1] published in *Frontiers in Microbiology* was the most cited, with 686 total citations, averaging 68.6 citations per year, and a normalized citation score of 6.59. This was followed by Behera [6] in *Biomed Research International* with 358 citations and a normalized score of 8.04, reflecting its strong annual impact relative to its publication year. Melini [7] in *Nutrients* ranked third with 318 citations and consistently high yearly citations (45.43 per year). The dominance of reviews among the top-cited papers suggests that the field of fish-based fermented foods is still consolidating knowledge, with reviews serving as foundational references [22]. The temporal distribution of author keywords provides insights into how research themes have emerged and shifted over the past decade (Fig. 10). Early studies (around 2016) were characterized by terms such as *fish dishes*, *heavy metal*, and *NaCl concentration*, reflecting a focus on product characterization and safety-related issues in traditional fermented fish. By 2017, attention had expanded to microbial aspects, with the appearance of terms like *strain BV*, *Aeromonas hydrophila*, and *fish pathogens*, indicating an increasing concern with pathogenic bacteria and microbial quality. From 2018 onward, the dataset shows a transition toward functional and probiotic perspectives. Keywords such as *FFO extract*, *mg/ml* (dose–response context), and *plantarum strains* became more frequent, while *Lactobacillus plantarum* emerged as a dominant and persistent theme (22 occurrences, median year 2019, extending to 2021).

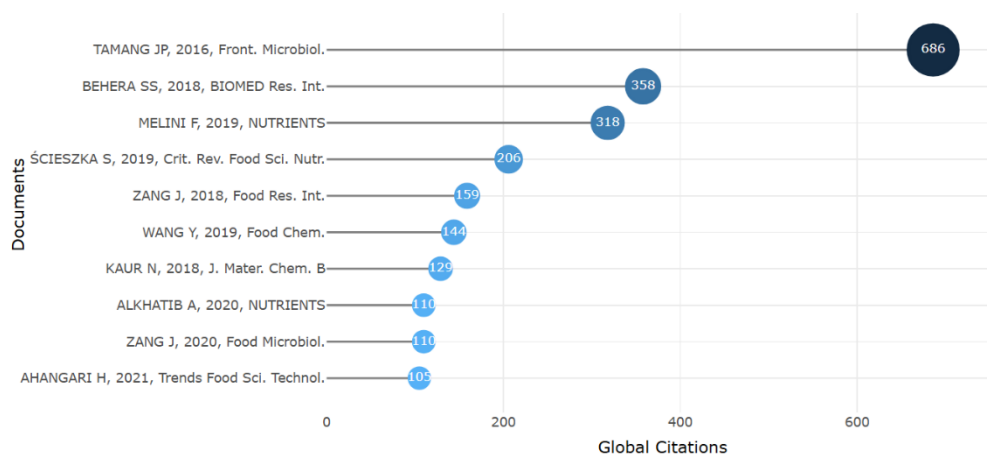


Fig. 9. Top 10 most cited documents on fish-based fermented foods (2015–2024), ranked by total citations.

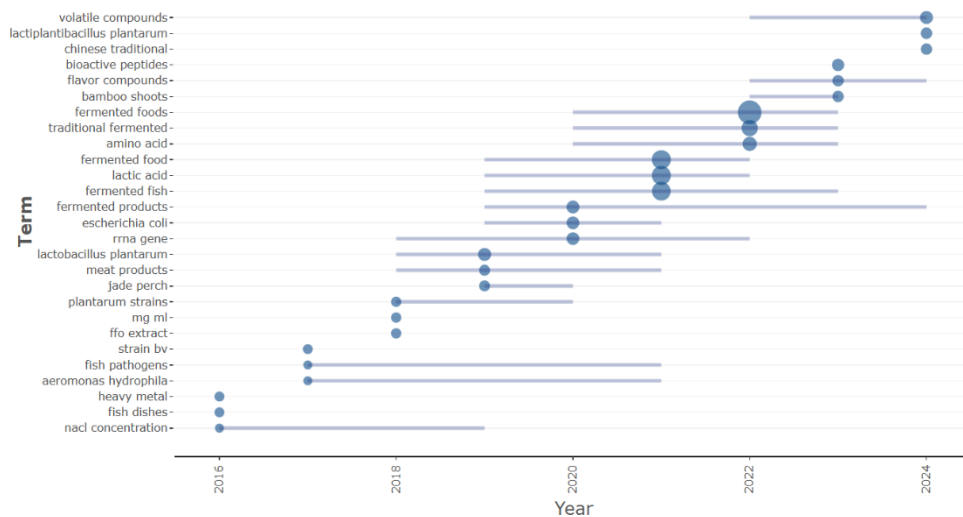


Fig. 10. Temporal distribution of selected high-frequency keywords in fish-based fermented food research.

Thematic mapping based on keyword co-occurrence identified several clusters that illustrate the intellectual structure of research in fish-based fermented foods (Fig. 11). The cluster with the highest frequency was *fermented foods* ($n = 613$), followed by *fish sauce* ($n = 408$) and *lactic acid* ($n = 473$), indicating strong emphasis on traditional products and the role of lactic acid bacteria in fermentation processes. The cluster *fermented food* ($n = 202$), while closely related, reflects broader discussions on fermented products beyond specific fish-based applications. Emerging clusters include *gut microbiota* ($n = 31$) and *fish fed* ($n = 23$), both characterized by relatively high density, suggesting focused but specialized research streams on the interaction between fermented foods, microbial ecology, and animal nutrition. The cluster *freshwater fish* ($n = 68$) highlights species-specific applications, particularly relevant to regions where freshwater fish are the main raw material for fermentation. Peripheral but thematically distinct clusters were also identified, such as *food waste* ($n = 18$), which shows the integration of sustainability concepts into fermentation studies, and *Aeromonas hydrophila* ($n = 9$), which reflects research on pathogenic risks. Smaller clusters such as *inhibitory peptides*, *ACEi activity*, and *korean food*, although low in frequency, appear as specialized, niche themes that may represent emerging directions or isolated studies. Based on the clustering dimensions, the thematic map shows a balance between core, well-established research areas (fermented foods, fish sauce, lactic acid bacteria) and emerging or specialized niches (gut microbiota, bioactive peptides, food waste), suggesting both consolidation of traditional knowledge and diversification into health- and sustainability-oriented research.

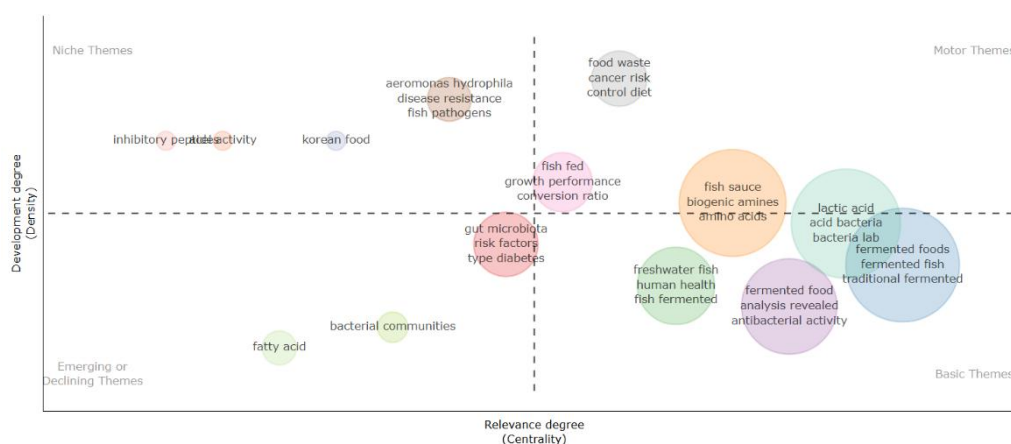


Fig. 11. Keyword co-occurrence network of publications on fish-based fermented foods (2015–2024). Node size represents frequency of occurrence, while colors indicate thematic clusters.

When classified into thematic quadrants, *fish sauce*, often associated with *biogenic amines* and *amino acids*, emerges as a motor theme, together with *food waste*, reflecting well-developed and highly relevant research directions that bridge tradition with modern sustainability and health concerns. Representative high-impact articles within the motor theme include a review on biogenic amines, which highlighted their role as precursors of carcinogenic N-nitroso compounds formed during microbial degradation of protein-rich foods in fermentation. Increasing research attention has been directed toward monitoring biogenic amine levels in fermented products [8]. Another example focused on the anti-cancer properties of fermented foods, summarizing evidence that their consumption may reduce cancer risk and improve patient outcomes. The proposed mechanisms involve multiple signaling pathways, including p38 MAPK, ERK1/2, energy deprivation, and death receptor-mediated processes. However, contradictory findings were also reported, with some studies showing no significant association between fermented food intake and cancer risk [23].

Basic themes include *fermented foods*, *fermented fish*, *lactic acid bacteria*, and *freshwater fish*, forming the backbone of the field but remaining broad and multidisciplinary. Some examples included Sarawak fermented foods that were found to be enriched with LAB and yeast strains, including dominant species such as *Weissella paramesenteroides* and *Candida magnoliae* [24]. Surya [25] published a review paper regarding fermented foods in Southeast Asia, with examples such as Indonesia, Malaysia, Thailand, Vietnam, and their neighbors. While international research has primarily focused on soybean- and fish-based products, his review highlighted the broader diversity of Southeast Asian fermented foods across seven categories, addressing their biochemical, microbiological, ethnic, and cultural dimensions.

Niche themes, such as *inhibitory peptides*, *ACE inhibitory activity*, *korean food*, and *Aeromonas hydrophila*, are internally cohesive but peripheral, reflecting specialized work on bioactive compounds and pathogen control. For instance, Meidong [26] reported that *Lactobacillus paraplantarum* L34B-2, isolated from a fermented food source, significantly enhanced growth performance, disease resistance, and innate immunity in *Pangasius bocourti*. In another study, Lestari [27] demonstrated the potential of *bekasam* powder derived from catfish (*Clarias batrachus*) as a natural flavor enhancer, while also reporting its angiotensin-I-converting enzyme (ACE) inhibitory activity across various food preparations. Meanwhile, Shin [2] compared the volatile aroma profiles and sensory attributes of traditional *doenjang* with Korean-style *doenjang*, fermented foods with fish aromatics, providing insights into how fermentation techniques and cultural practices influence flavor complexity and consumer perception.

Fatty acids and bacterial communities were identified as themes receiving limited attention, which may continue to decline or, if linked more closely to nutrition and microbiome research, could re-emerge as important areas of investigation. For instance, Ohshima [9] provided the first detailed characterization of bacterial communities in Thai fish sauce using 16S rRNA sequencing, revealing 7 phyla and 45 genera with distinct succession patterns across factories and fermentation stages. Their findings highlighted how raw materials and fermentation environments shape microbial diversity and ultimately influence product characteristics. In other aspect, Kang [29] demonstrated the biofunctional potential of mackerel-derived fermented fish oil (FFO), showing that FFO extract and its key component docosahexaenoic acid (DHA) stimulated dermal papilla cell proliferation and promoted hair growth by activating anagen-associated signaling pathways. Together, these studies showed how research has progressed beyond traditional product descriptions to encompass both microbial dynamics and bioactive functions of fermented fish products.

IV. CONCLUSION

This study conducted a bibliometric analysis of publications on fish-based fermented foods indexed in Scopus from 2015 to 2024. The results revealed a steady growth in publication output, strong citation performance, and a clear regional concentration in East and Southeast Asia. Core themes such as *fish sauce*, *lactic acid bacteria*, and *microbial diversity* remain dominant, while emerging topics, including *gut microbiota*, *bioactive peptides*, and *sustainability*, are gaining momentum. Despite this progress, the field is still limited by weak international collaboration, underrepresentation of regions such as Africa and South Asia, and a lack of advanced analytical approaches such as metagenomics and metabolomics. Strengthening

global research networks and applying modern analytical methods will be essential to advance scientific understanding of the nutritional, functional, and cultural aspects of fish-based fermented foods.

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