

Review Article

A Comprehensive Bibliometric Analysis of Fish Drying Techniques for Preservation: Trends, Innovations, and Future Directions

Nicky Rahmana Putra^{1*}, Iman Mukhaimin², Sarah Aisyah Khurun Hizar³, Jumardi Roslan³, Fan Hui Yin³, Norliza Julmohammad³, Norazlina Mohammad Ridhwan³, Hasmadi Mamat³, Abdul Aziz Jaziri⁴, Ahmad Hazim Abdul Aziz^{3*}

¹Faculty of Engineering Technology and Science, Higher College of Technology, 25026 Ruwais, United Arab Emirates

²Polytechnic of Marine Affairs and Fisheries, Karawang, 41315 West Java, Indonesia

³Food Security Research Laboratory, Faculty of Food Science and Nutrition, Universiti Malaysia Sabah, 88400 Kota Kinabalu, Sabah

⁴Program of Fisheries Product Technology, Faculty of Fisheries and Marine Science, Universitas Brawijaya, 65145 East Java, Indonesia

*nickyrahman1309@gmail.com ; hazim.aziz@ums.edu.my

ABSTRACT

This bibliometric study analyses global research trends on fish drying techniques for preservation, based on 243 Scopus-indexed documents published between 2000 and 2024. The data, extracted on June 1, 2024, using the search string TITLE-ABS-KEY (drying AND fish AND preservation), were limited to English-language publications. Results show a steady increase in annual output, peaking at 18 publications in 2022. India (28 documents), the United States (21), and China (17) emerged as the top contributing countries, while Spain led in citations with 870. Co-authorship analysis revealed six distinct international collaboration clusters, with strong linkages between India, Egypt, and Bangladesh. Among authors, Fito P. (44 citations, 1047 link strength) and Barat J.M. (45 citations, 925 link strength) were most influential. Source co-citation analysis identified Food Chemistry and the Journal of Food Engineering as central journals. Keyword co-occurrence mapping highlighted themes around preservation quality, lipid oxidation, shelf life, and solar drying. Notably, there remains limited integration between nutritional, microbial, and sustainability aspects, suggesting critical research gaps. This study provides a comprehensive overview of the evolution, collaboration, and thematic focus in fish drying preservation literature, guiding future research directions in sustainable and efficient preservation technologies.

Received: 15 July 2025

Accepted: 27 February 2026

Published: 31 March 2026

DOI: <https://10.5120/ijf.v3i1.6623>

Keywords: aquatic food systems; dehydration processes; food quality assessment; preservation efficacy; seafood shelf-life enhancement; thermal and non-thermal processing

1. Introduction

Fish is one of the most abundantly produced food commodities worldwide, playing a crucial role in the diet of millions of people and contributing significantly to the economy of many countries. According to the Food and Agriculture Organization (FAO) (2020), global fish production reached approximately 179 million tonnes

in 2018, with aquaculture accounting for nearly half of this total. This abundance, however, presents a challenge in terms of preservation and storage, as fish are highly perishable due to their high moisture content and the presence of enzymes and microorganisms that rapidly degrade the flesh (Sampels, 2015). Without proper preservation techniques, a substantial portion of this valuable resource is lost due to spoilage, leading to economic losses and reduced food availability (Huang *et al.*, 2019). Thus, developing and implementing efficient preservation methods is imperative to ensure food security and economic stability.

Drying is one of the oldest and most widely used methods for the preservation of fish. This process involves removing moisture from the fish, thereby inhibiting the growth of spoilage microorganisms and enzymes that cause decay (Osae *et al.*, 2020). Various drying techniques have been developed and refined over the years, including traditional methods like sun drying and smoking, as well as modern methods such as mechanical drying, freeze drying, and solar drying (Adeyeye, 2019). Each of these methods has its own set of advantages and limitations. For instance, sun drying is cost-effective but dependent on weather conditions, while mechanical drying provides consistent results but requires significant energy input (Ran *et al.*, 2024). Understanding these processes and their impact on the quality, shelf life, and nutritional value of dried fish is essential for optimising preservation methods to meet the demands of different markets and consumers.

The preservation of fish through drying not only extends the shelf life but also enhances the economic value of the product, particularly in regions where fish is a major export commodity. Dried fish products are easier to transport, and store compared to fresh fish, reducing post-harvest losses and ensuring a stable supply during off-seasons (Huang *et al.*, 2019). This stability can lead to improved food security and provides opportunities for fishers and processors to access international markets, thereby boosting local economies. For example, countries like Norway, Iceland, and several Southeast Asian nations have developed robust dried fish industries that contribute significantly to their export earnings (Golmohammadi *et al.*, 2023). Additionally, dried fish is a culturally important food in many regions, and maintaining its availability supports traditional diets and culinary practices. This study supports Sustainable Development Goal 12 (Responsible Consumption and Production) by promoting efficient, low-waste fish preservation techniques that extend shelf life, reduce post-harvest loss, and improve food security in aquatic food systems.

Bibliometric analysis is a valuable tool for understanding the research landscape in the field of fish drying techniques for preservation. By analysing scientific publications, citations, and research trends, bibliometric studies provide insights into the development and dissemination of knowledge within this field (Ikhwani *et al.*, 2024). This approach allows researchers to identify key areas of innovation, influential studies, and emerging trends. For instance, bibliometric analysis can reveal which drying techniques are most studied, which countries and institutions are leading in research, and how collaborative networks are formed. Moreover, it plays a pivotal role in identifying gaps within the existing body of knowledge, thereby directing future research to address practical industrial challenges. Such analysis is vital for aligning academic investigations with the evolving needs of the fish processing industry and fostering innovation in preservation technologies.

The objective of this study is to conduct a comprehensive bibliometric analysis of fish drying techniques for preservation. This analysis aims to identify trends, innovations, and future directions in the research on fish drying by examining scientific literature from various databases.

2. Methodology of Review

A comprehensive bibliometric analysis of fish drying techniques for preservation was conducted using data retrieved from the Scopus database on June 1, 2024. Scopus was selected due to its extensive coverage of peer-reviewed literature and powerful citation analysis tools, ensuring a high-quality and relevant dataset. Publications from 2000 to 2024 were identified using a targeted search query that included the terms "drying," "fish," and "preservation" in the title, abstract, or keywords, limited to English-language articles. The resulting records were cleaned and prepared for analysis, with duplicate and inconsistent

entries removed. VOSviewer was then used to visualise and analyse the data, generating co-authorship, keyword co-occurrence, and citation networks to reveal trends, key themes, influential authors, and research growth patterns in the field of fish drying and preservation.

3. Exploring Research Trends in Fish Drying Techniques for Preservation: A Data-Driven Analysis and Discussion

3.1 Trends in Annual Research Output on the Fish Drying Techniques for Preservation

The bar chart as shown in Figure 1 illustrates a clear upward trend in research activity related to fish drying and preservation techniques from 2000 to 2024. In the early 2000s (2000–2006), publication output remained relatively low and stable, ranging from 1 to 4 documents per year, indicating a nascent stage in scholarly attention toward this field. A modest increase began around 2007–2010, peaking at 13 documents in 2010, suggesting growing interest likely due to emerging preservation innovations and food security concerns.

From 2011 to 2016, output fluctuated between 4 and 8 publications annually, reflecting a period of steady, but not accelerated, research output. However, from 2017 onward, the trend shows a substantial rise. Notably, 2019 marked a sharp increase with 17 documents published, followed by a sustained high-output phase through 2024. The highest output was recorded in 2022 with 18 publications, indicating peak scholarly activity and possibly reflecting increased global concern over food preservation, post-harvest losses, and sustainable drying technologies. The slight drop in 2023 (11 documents) may be attributed to shifts in research focus or publication delays, but the rebound in 2024 to 15 documents suggests continued momentum.

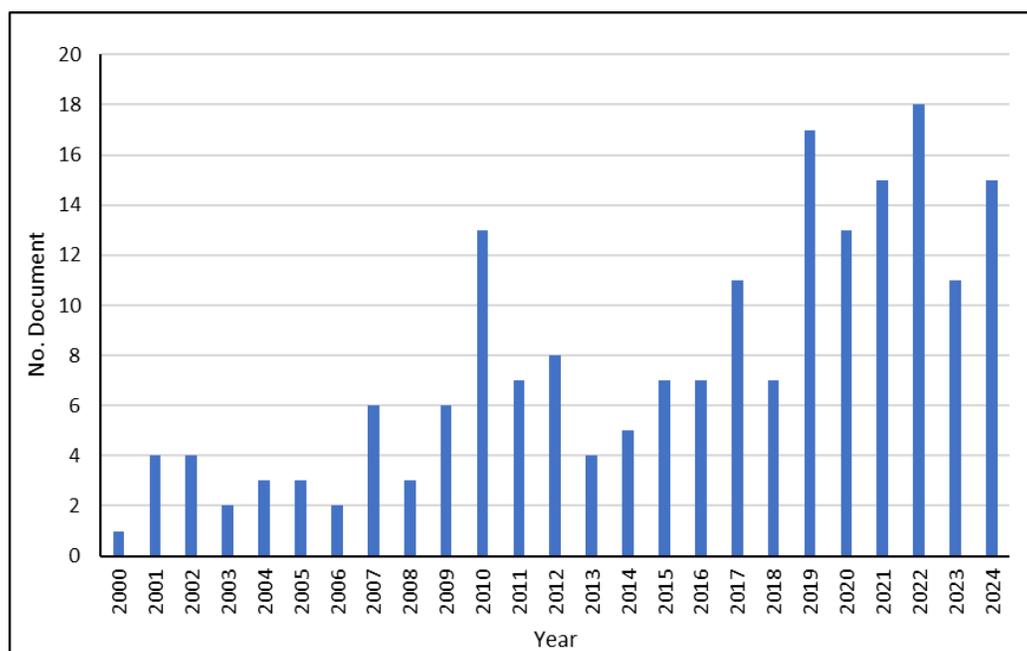


Figure 1 Yearly trends in research output on fish drying techniques for preservation

3.2 Geographical Analysis and Collaboration Countries of Research Publications

Figure 2 illustrates the regional dispersion of publications on fish drying techniques for preservation across the globe, using colour coding and numerical indicators to represent the number of publications from each country. The map reveals that India leads the research output with 29 publications, indicating a significant

focus on fish drying techniques within the country. This high level of research activity can be attributed to India's extensive fishery industry and the importance of fish preservation for both domestic consumption and export. The United States follows with 21 publications, reflecting its substantial contributions to innovations in fish drying techniques. This level of research activity is likely driven by the U.S.'s diverse fisheries and seafood markets, as well as its strong academic and technological research infrastructure. China, with 17 publications, also shows a considerable focus on fish drying techniques, consistent with its large and diverse fishery sector and emphasis on food security and technological advancements.

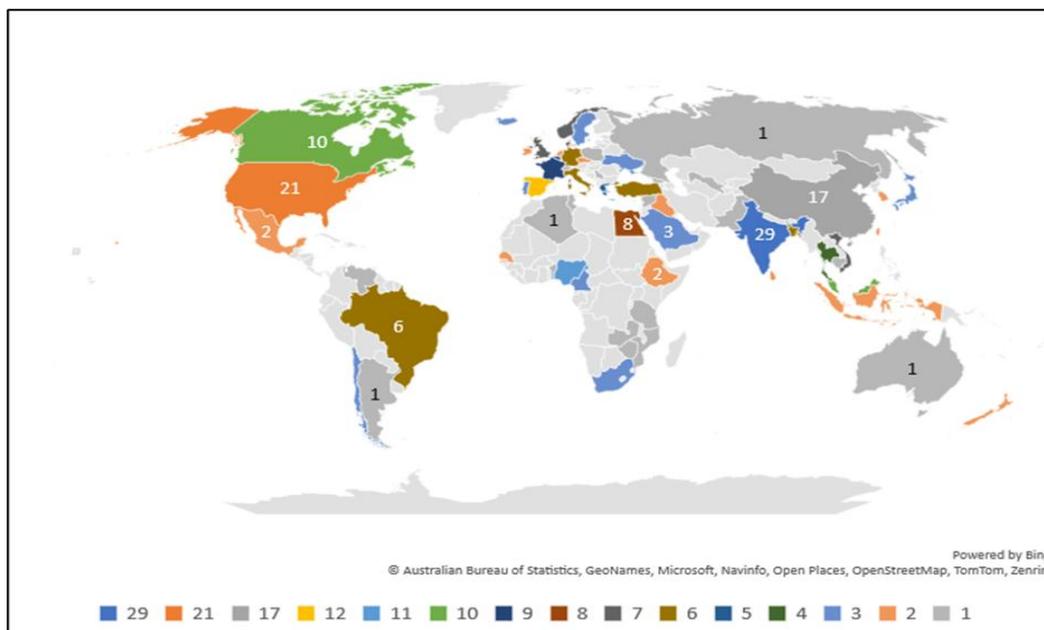


Figure 2 The regional dispersion of publications on fish drying techniques for preservation

Other notable contributors include Canada with 10 publications and Brazil with 6 publications, both of which have significant fisheries industries that necessitate effective preservation methods. Europe, Italy and Norway stand out with 12 and 11 publications, respectively, highlighting their historic and economic ties to fisheries. Egypt's 8 publications emphasise the importance of fish preservation in a country that relies heavily on both marine and aquaculture resources. Additionally, Saudi Arabia and Mexico contribute with 3 and 2 publications, respectively, aligning with their local fishery practices and preservation needs.

The map also shows scattered contributions from various countries, each with fewer publications (ranging from 1 to 7), including nations from every continent. This global presence reflects a widespread interest in fish drying techniques for preservation, with countries such as Australia, Chile, South Korea, Vietnam, and several European nations like Germany, Spain, and the UK contributing to the diverse research landscape. Overall, the map indicates a broad international interest and participation in research on fish drying techniques for preservation. The distribution of publications suggests that countries with significant fishery industries and those facing challenges related to food security and preservation are more actively engaged in this research domain. The dominance of India, the United States, and China highlights their leadership roles in advancing the technology and methods used in fish preservation. This global dispersion underscores the universal need for effective preservation methods to reduce spoilage, enhance food security, and support economic development through fisheries.

Figure 3 provides a visualisation of the co-author network for countries involved in research on fish drying techniques for preservation, generated using VOSviewer with a threshold set at three co-authored publications. This network comprises 61 links and six distinct clusters, illustrating the collaborative efforts and interconnectedness among countries in this research domain. India emerges as the central and most prominent node in the network, highlighting its substantial collaborative efforts and leading role in research on fish drying techniques. The numerous connections from India to other countries reflect its extensive

international collaborations, underscoring India's significant influence and active participation in global research efforts.

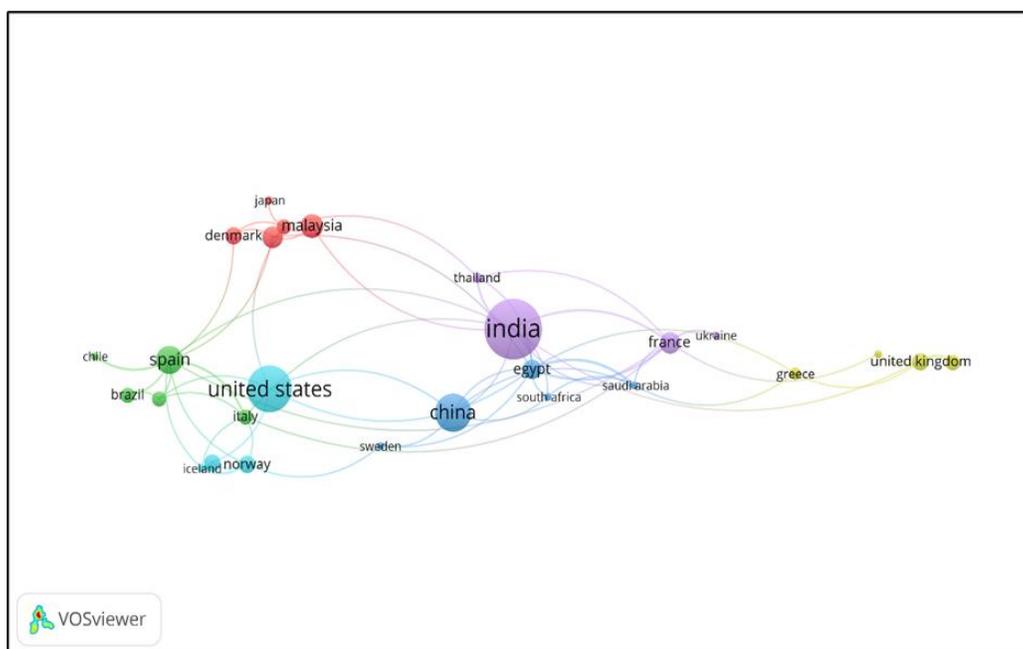


Figure 3 Illustration of the co-author network for countries, with a threshold set at 3, a total of 61 links and 6 cluster, within the domain of fish drying techniques for preservation

The United States and Spain are also key nodes in the network, with robust connections to multiple countries. The United States shows strong links with Spain, Italy, and Norway, indicating a collaborative network primarily within Western countries. Spain's connections extend to South America, including Brazil and Chile, demonstrating its role in bridging research efforts between Europe and Latin America. Malaysia and China are notable nodes with substantial connections as well. Malaysia exhibits strong links with Denmark and Japan, indicating collaborative research efforts with countries known for their technological advancements in food preservation. China's connections with the United States, India, and Italy reflect its broad collaborative reach and significant role in the global research landscape.

The network comprises six distinct clusters, each representing regional collaborations and specialised research networks. Cluster 1 (green) includes the United States, Spain, Brazil, Chile, and Norway, suggesting strong transatlantic collaborations. Cluster 2 (blue), featuring India and China, highlights extensive collaborations within Asia and connections with Western countries. Cluster 3 (red) includes Malaysia, Denmark, and Japan, indicating a focus on advanced preservation technologies. Cluster 4 (purple) involves India, Egypt, and France, suggesting collaborations spanning South Asia, North Africa, and Europe. Cluster 5 (yellow) links the United Kingdom, Greece, and Ukraine, reflecting European regional collaborations. Cluster 6 (light blue) includes countries like Sweden and South Africa, representing additional collaborative links. Notable links within the network include the strong connection between India, Egypt, and France, which suggests significant collaborative research activities. The robust collaboration between the United States and Spain indicates shared research interests and strong academic ties, while the connections between Malaysia, Denmark, and Japan likely reflect a focus on technological advancements in fish drying techniques.

Table 1 provides a comprehensive summary of the research output, citation counts, and total link strength for various countries involved in the study of fish drying techniques for preservation. The table highlights the contributions and influence of each country in this research domain. India leads with the highest number of documents (28) and a substantial number of citations (460), reflecting its significant research output and impact in this field. The total link strength of 13 indicates strong collaborative ties with

other countries. Spain, with 12 documents, stands out with the highest number of citations (870), suggesting its research contributions are highly influential and widely recognised. Spain's total link strength of 12 also highlights its extensive collaboration network. The United States has a high number of documents (21) and citations (451), indicating active participation and influence in fish drying research. However, the total link strength of 5 suggests a relatively lower level of international collaboration compared to other leading countries. China, with 17 documents and 258 citations, reflects substantial research output and influence, with a total link strength of 6 indicating moderate collaborative efforts with other countries.

Table 1 Summary of research output, citations, and total link strength for countries involved in fish drying techniques for preservation research

Country	Documents	Citations	Total link strength
Egypt	8	133	14
India	28	460	13
Spain	12	870	12
France	9	166	11
Saudi Arabia	6	36	8
Italy	6	70	7
Bangladesh	8	113	6
China	17	258	6
Iceland	3	59	6
Norway	7	117	6
Canada	9	465	6
Thailand	7	98	6
United Kingdom	7	120	5
United States	21	451	5
Germany	6	388	4
South Africa	6	214	4
Vietnam	7	90	4
Denmark	7	85	3
Greece	5	60	3

France and Canada, both with 9 documents each, have notable research contributions. France has 166 citations, while Canada has a higher citation count of 465, highlighting the impact of Canadian research. Both countries have strong collaboration networks, with total link strengths of 11 and 6, respectively. Egypt, with 8 documents and 133 citations, has the highest total link strength (14) among the countries listed, suggesting a strong collaborative network crucial for advancing research in this field. Other notable countries include Saudi Arabia and Italy, both with 6 documents but differing significantly in citations (36 for Saudi Arabia and 70 for Italy) and total link strength (8 for Saudi Arabia and 7 for Italy). Bangladesh and Thailand each have 8 and 7 documents, respectively, with moderate citation counts and total link strengths of 6 each. Germany and South Africa, both with 6 documents, show Germany having a higher citation count (388) compared to South Africa (214). Both have a total link strength of 4. Vietnam, Denmark, and Greece, with fewer documents and citations, still contribute to the research landscape, with total link strengths ranging from 3 to 4.

3.3 Author Co-Citation Analysis in the Fish Drying Techniques for Preservation

Table 2 provides a detailed summary of the number of citations and total link strength for various authors involved in the research on fish drying techniques for preservation, highlighting the contributions and influence of individual researchers within this domain. Fito P. stands out with 44 citations and the highest

total link strength of 1047, indicating significant influence and extensive collaborative networks. Similarly, Barat J.M. has 45 citations and a total link strength of 925, reflecting substantial impact and collaborative reach. Andres A. and Bala B.K. are also notable, with Andres A. having 35 citations and a total link strength of 879, and Bala B.K. leading in citations with 49 and a total link strength of 765. These figures suggest that their work is widely recognised and influential in the field.

Other notable researchers include Banjai S. and Chiralt A., with 35 and 21 citations respectively, and total link strengths of 671 and 607. Their significant contributions and strong collaborative ties are evident. Wang Y., with 45 citations and a total link strength of 566, indicates a high level of impact and collaboration. Sarason S. and Zhang Y. show substantial contributions with 22 and 30 citations, respectively, and total link strengths of 477 and 432, highlighting their importance in the research network. Additional influential authors include Vorobiev E., who has 39 citations and a total link strength of 404, demonstrating significant research influence and collaboration. Li J. and Lebovka N.I. both have 25 citations, with total link strengths of 400 and 398, respectively, indicating their collaborative efforts and impact. Zhang X. and Tiwari G.N. contribute with 23 and 21 citations, respectively, and total link strengths of 372 and 363, reflecting their active participation in the research community. Li X., Benjakul S., Liu Y., Zhang M., and Rahman M.S. all have notable citations and total link strengths, further emphasising their contributions and collaborative efforts within the field.

Table 2 Summarization of the number of citations and total link strength for each author involved in the research on fish drying techniques for preservation

Author	Citations	Total link strength
Fito P.	44	1047
Barat J.M.	45	925
Andres A.	35	879
Bala B.K.	49	765
Banjai S.	35	671
Chiralt A.	21	607
Wang Y.	45	566
Sarason S.	22	477
Zhang Y.	30	432
Vorobiev E.	39	404
Li J.	25	400
Lebovka N.I.	25	398
Zhang X.	23	372
Tiwari G.N.	21	363
Li X.	20	358
Benjakul S.	31	357
Liu Y.	24	342
Zhang M.	32	330
Rahman M.S.	23	311

Figure 4 illustrates the co-citation network for cited authors in the domain of fish drying techniques for preservation, generated with a threshold set at 20 co-citations. This network comprises a total of 232 links and five distinct clusters, highlighting influential authors and their co-citation relationships. Vorobiev E. stands out as a distinct node, separate from the main cluster, indicating significant influence but fewer direct co-citations with the other prominent authors in this domain. Bala B.K., in the yellow cluster, has strong connections to multiple authors, demonstrating high influence and frequent co-citations within the network. Central figures like Barat J.M., Wang Y., and Fung D.Y.C. form the core of the red and blue clusters, showcasing their extensive co-citation links and central roles in the research community.

The network consists of five clusters, each representing specialised research areas. The yellow cluster, centred around Bala B.K., indicates a focused area of research with strong internal co-citation links. The blue cluster, dominated by Barat J.M., reflects a cohesive group of frequently cited authors, suggesting collaborative or related research themes. The red cluster, featuring Wang Y. and Fung D.Y.C., highlights a well-connected and influential group of authors. The green cluster includes Gomez-Guillen M.C., indicating a specialised area of research with strong internal ties. The purple cluster, with Vorobiev E., suggests unique contributions that are recognised but less integrated with the main network.

Notable connections include dense co-citation links among authors like Barat J.M., Wang Y., and Fung D.Y.C., indicating their frequent citation together and contributions to overlapping research topics or methodologies. The separate positioning of Vorobiev E. suggests unique contributions or a different focus area within the domain, recognised by citations from distinct sets of research works. This visualisation highlights the influential authors and the co-citation relationships within the research domain of fish drying techniques for preservation. The presence of distinct clusters indicates specialised research areas and collaborative networks among frequently cited authors. Authors like Bala B.K., Barat J.M., and Wang Y. are central figures with extensive co-citation links, reflecting their significant contributions and influence in the field. The co-citation network provides valuable insights into the intellectual structure of the field, helping to identify key contributors and the relationships between their works. Overall, Figure 4 underscores the importance of collaboration and the interconnected nature of research within the domain. It also highlights the contributions of individual authors and their roles in advancing the understanding and development of fish drying techniques for preservation.

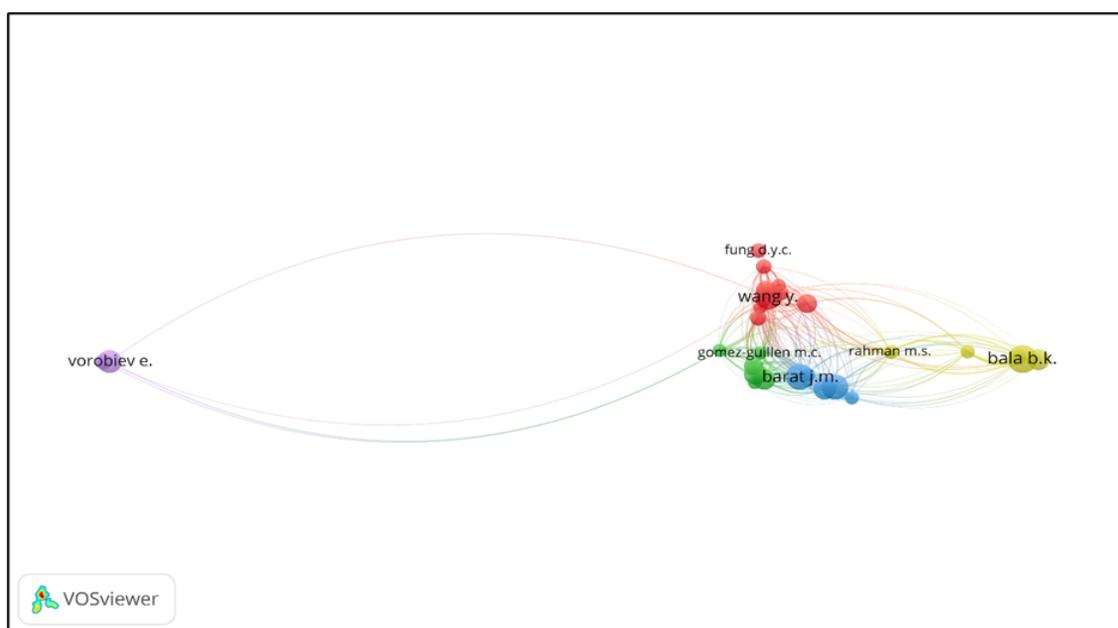


Figure 4 Illustration of the co-citation network for cited authors, with a threshold set at 20, a total of 232 links and 5 cluster, within the domain fish drying techniques for preservation

3.5 Co-occurrence of authors' Keywords in the Fish Drying Techniques for Preservation

Based on Table 3, the most frequently occurring keyword in the research on fish drying techniques for preservation is "drying", with 16 occurrences and the highest total link strength of 33, indicating its central role and strong connectivity with other keywords. Closely following are "fish" and "preservation", each appearing 15 times, although their total link strengths (21 and 17, respectively) are lower, suggesting they are important but perhaps not as extensively connected to diverse research themes as "drying."

On the other end of the spectrum, the keywords with the lowest total link strength include "salt,"

“tilapia,” and “solar air dryer”, each with a total link strength of 4 despite having 4–5 occurrences. This implies that while these topics appear in the literature, they are less integrated into the broader research network. Similarly, terms such as “fatty acids,” “lipid oxidation,” and “spoilage” also exhibit low connectivity (link strength of 5), highlighting underexplored or less connected areas that could benefit from more focused research to strengthen their link to core preservation and drying themes.

Table 3 Keyword occurrences and total link strength in research on fish drying techniques for preservation

Keyword	Occurrence s	Total link strength
drying	16	33
fermentation	8	21
fish	15	21
smoking	6	18
preservation	15	17
salting	7	14
quality	9	13
fish muscle	3	6
shelf life	4	6
storage	3	6
vacuum	3	6
fatty acids	5	5
fish preservation	4	5
lipid oxidation	3	5
spoilage	3	5
volatile compounds	4	5
salt	5	4
tilapia	4	4
solar air dryer	4	4

Figure 5 illustrates the co-occurrence network of authors’ keywords in the application of fish drying techniques for preservation, generated with a minimum keyword threshold of 3, resulting in 78 links and five distinct clusters. The visualisation highlights the relationships and thematic groupings among frequently used keywords within this research domain. Drying is the most prominent keyword, centrally positioned with numerous connections, indicating its fundamental role in the research. It forms the core of the network, reflecting its high co-occurrence with other keywords. Preservation and Quality are also significant keywords, with strong connections to various other terms, highlighting their importance in the context of fish drying techniques.

The network is organised into five distinct clusters. Cluster 1 (Green) includes keywords like Drying, Fermentation, Smoking, and Fish Preservation, representing various methods and techniques used in the preservation process. Cluster 2 (Blue) features keywords such as Preservation, Fermentation, Storage, and Tilapia, indicating a focus on different preservation methods and specific fish species. Cluster 3 (Red), centred around Quality, includes keywords like Shelf Life, Sun Drying, Solar Drying, and Food Preservation, emphasising the quality aspects and different drying techniques used. Cluster 4 (Yellow) contains keywords like Fatty Acids and Antioxidants, focusing on the chemical and nutritional aspects related to fish preservation. Cluster 5 (Purple) includes keywords like Salt, Lactic Acid Bacteria, and Colour, indicating a focus on additives and microbial aspects in the preservation process.

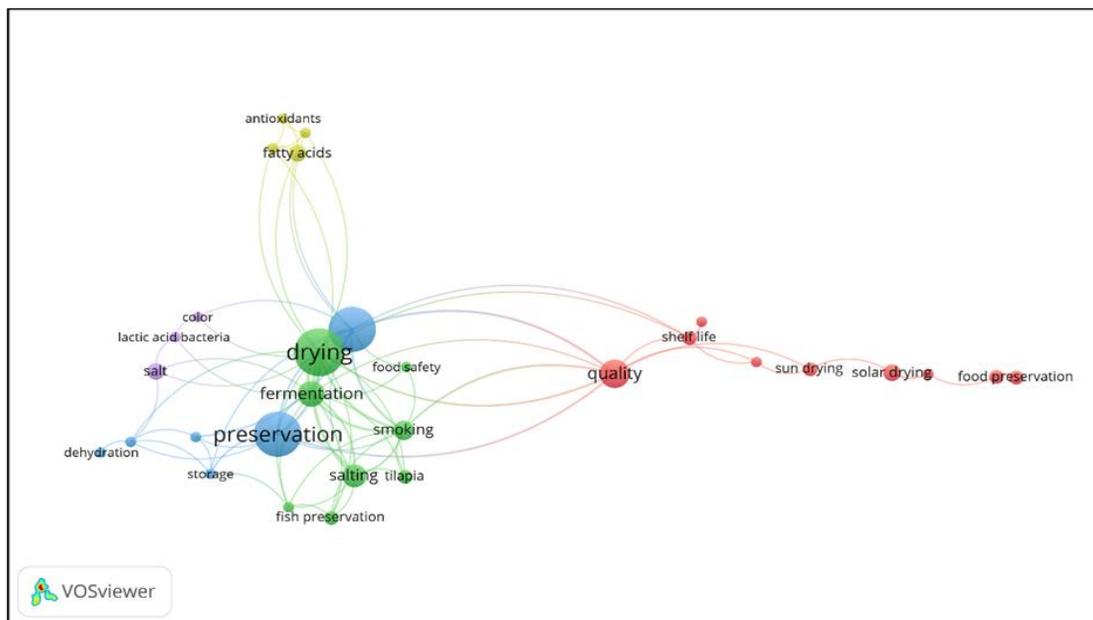


Figure 5 Co-occurrence of authors' keywords on application of fish drying techniques for preservation: minimum keywords threshold of 3 and 78 link with 5 cluster

4. Deep Analysis of the Top Cited Documents in Fish Drying Techniques for Preservation

The top-cited documents on fish drying techniques for preservation highlight influential research that has shaped current practices as described in Table 5. Leading the list is the highly cited review by Ghaly *et al.* (2010), which discusses fish spoilage mechanisms and preservation techniques, underscoring its foundational role in the field. Following closely is Gómez *et al.*'s (2019) work on pulsed electric fields, reflecting the growing relevance of non-thermal preservation methods. Micklin's (2016) study on the Aral Sea, though environmental in focus, contributes to the broader understanding of aquatic preservation and its ecological implications.

Further contributions include Kaehler & Pakhomov (2001), who examined the effects of preservation on stable isotope signatures in marine organisms, and Gutiérrez *et al.* (2010), who introduced the use of deep-eutectic solvents and freeze drying for bacterial preservation—showcasing methodological innovation. Chiralt *et al.* (2001) explored vacuum impregnation for food salting, while Ortiz *et al.* (2002) advanced mercury speciation techniques, reinforcing the connection between preservation and food safety. These studies demonstrate both fundamental and applied advancements that have influenced preservation science.

Lastly, Fan *et al.* (2014) analysed biogenic amines in lightly salted fish, while Jain and Pathare (2007) provided insights into traditional open sun drying kinetics. Kolanowski *et al.* (2004) contributed to fish oil stabilization via microencapsulation, reflecting efforts to enhance product shelf life. Collectively, these documents emphasise the evolution of fish preservation methods, blending traditional approaches with emerging technologies and highlighting the field's multidisciplinary nature.

Table 5 Top cited documents on fish drying techniques for preservation

Title	Year	Source Title	Cited by	Ref.
Fish spoilage mechanisms and preservation techniques: Review	2010	American Journal of Applied Sciences	420	(Ghaly <i>et al.</i> , 2010)
Application of pulsed electric fields in meat and fish processing industries: An overview	2019	Food Research International	198	(Gómez <i>et al.</i> , 2019)
The future Aral Sea: hope and despair	2016	Environmental Earth Sciences	187	(Micklin, 2016)
Effects of storage and preservation on the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ signatures of selected marine organisms	2001	Marine Ecology Progress Series	186	(Kaehler & Pakhomov, 2001)
Bacteria incorporation in deep-eutectic solvents through freeze drying	2010	Angewandte Chemie - International Edition	165	(Gutiérrez <i>et al.</i> , 2010)
Use of vacuum impregnation in food salting process	2001	Journal of Food Engineering	164	(Chiralt <i>et al.</i> , 2001)
Evaluation of different sample pre-treatment and extraction procedures for mercury speciation in fish samples	2002	Journal of Analytical Atomic Spectrometry	129	(Ortiz <i>et al.</i> , 2002)
Biogenic amine and quality changes in lightly salt- and sugar-salted black carp (<i>Mylopharyngodon piceus</i>) fillets stored at 4 °C	2014	Food Chemistry	125	(Fan <i>et al.</i> , 2014)
Study the drying kinetics of open sun drying of fish	2007	Journal of Food Engineering	118	(Jain & Pathare, 2007)
Fish oil stabilisation by microencapsulation with modified cellulose	2004	International Journal of Food Sciences and Nutrition	116	(Kolanowski <i>et al.</i> , 2004)

5. Future Research in Fish Drying Techniques for Preservation Determined by VOSviewer

The network map generated by VOSviewer highlights several research gaps in fish drying techniques for preservation. One area needing attention is the integration of chemical and nutritional aspects, such as fatty acids and antioxidants, which currently show weak linkages in the bibliometric network. Future studies should explore how drying methods affect nutrient retention and how fortification strategies can be incorporated to enhance the nutritional quality and stability of dried fish. Similarly, the microbial and additive cluster—including keywords like salt and lactic acid bacteria—shows limited connectivity with drying techniques, suggesting a need for research on how these additives interact with various drying methods to optimise product safety, quality, and shelf life.

Additionally, sustainable drying techniques, such as solar and sun drying, exhibit promising yet underexplored potential. Future research should focus on enhancing the efficiency, scalability, and environmental impact of these green methods, particularly through the development of renewable energy-based systems. Finally, while quality and safety remain central themes, further optimisation is required to understand the effects of drying on sensory, nutritional, and microbiological attributes. This includes developing real-time monitoring systems and integrating advanced antimicrobial treatments and smart packaging to ensure the long-term quality and safety of dried fish products.

6. Conclusion

This bibliometric analysis provides a comprehensive overview of the global research landscape on fish drying techniques for preservation, encompassing a total of 236 documents published between 2000 and 2024. The trend analysis revealed a clear escalation in research interest, with a significant rise observed after 2017, peaking at 18 publications in 2022, and maintaining high output levels in 2020 (17 publications) and 2024 (15 publications). Keyword co-occurrence mapping identified “drying”, “preservation”, and “quality” as dominant research clusters, underscoring their centrality in the field. Citation analysis highlighted the seminal work of Ghaly *et al.* (2010) with 420 citations, followed by Gómez *et al.* (2019) with 198 citations, reflecting their foundational impact. The VOSviewer network visualisation exposed fragmentation among chemical, microbial, and sustainability-related keywords, suggesting research silos. Future studies should aim to bridge these gaps by integrating nutritional science, microbial safety, and green energy approaches into fish preservation technologies. By doing so, researchers can contribute not only to food quality and shelf life but also to SDG 12: Responsible Consumption and Production, promoting sustainable post-harvest practices aligned with both industry demand and environmental objectives.

Author Contributions: All authors contributed equally to the preparation of this review paper.

Funding: Not applicable.

Data Availability Statement: Data available on request from the authors.

Acknowledgements: The authors would like to Badan Riset dan Inovasi Nasional, Indonesia and Institut Teknologi Sepuluh Nopember.

References

- Adeyeye, S. A. O. (2019). An overview of fish drying kinetics. *Nutrition & Food Science*, 49(5), 886-902. <https://doi.org/10.1108/NFS-10-2018-0296>
- Chiralt, A., Fito, P., Barat, J., Andres, A., González-Martínez, C., Escriche, I., & Camacho, M. (2001). Use of vacuum impregnation in food salting process. *Journal of Food Engineering*, 49(2-3), 141-151. [https://doi.org/10.1016/S0260-8774\(00\)00219-3](https://doi.org/10.1016/S0260-8774(00)00219-3)
- Einarsson, Á., & Óladóttir, Á. D. (2020). *Fisheries and Aquaculture: The Food Security of the Future*: Academic Press.
- Fan, H., Luo, Y., Yin, X., Bao, Y., & Feng, L. (2014). Biogenic amine and quality changes in lightly salt-and sugar-salted black carp (*Mylopharyngodon piceus*) fillets stored at 4 C. *Food Chemistry*, 159, 20-28. <https://doi.org/10.1016/j.foodchem.2014.02.158>
- Ghaly, A. E., Dave, D., Budge, S., & Brooks, M. (2010). Fish spoilage mechanisms and preservation techniques. *American Journal of Applied Sciences*, 7(7), 859. <https://doi.org/10.3844/ajassp.2010.859.877>
- Golmohammadi, A., Razavi, M. S., Tahmasebi, M., Carullo, D., & Farris, S. (2023). Cinnamon Essential-Oil-Loaded Fish Gelatin–Cellulose Nanocrystal Films Prepared under Acidic Conditions. *Coatings*, 13(8), 1360. <https://doi.org/10.3390/coatings13081360>
- Gómez, B., Munekata, P. E., Gavahian, M., Barba, F. J., Martí-Quijal, F. J., Bolumar, T., Lorenzo, J. M. (2019). Application of pulsed electric fields in meat and fish processing industries: An overview. *Food Research International*, 123, 95-105. <https://doi.org/10.1016/j.foodres.2019.04.047>
- Gutiérrez, M. C., Ferrer, M. L., Yuste, L., Rojo, F., & del Monte, F. (2010). Bacteria incorporation in deep-eutectic solvents through freeze-drying. *Angewandte Chemie International Edition*, 49(12), 2158-2162. <https://doi.org/10.1002/anie.200905212>
- Huang, Z., Jia, S., Zhang, L., Liu, X., & Luo, Y. (2019). Inhibitory effects and membrane damage caused to fish spoilage bacteria by cinnamon bark (*Cinnamomum tamala*) oil. *LWT*, 12, 108195. <https://doi.org/10.1016/j.lwt.2019.05.093>
- Ikhwan, I., Rahayuningsih, S., Yuniarti, E., Kusuma, H. S., Darmokoesoemo, H., & Putra, N. R. (2024). Mapping the trend of evolution: a bibliometric analysis of biopesticides in fruit crop protection. *Journal of Plant Diseases and Protection*, 131(3), 645-664. <https://doi.org/10.1007/s41348-024-00879-0>
- Jain, D., & Pathare, P. B. (2007). Study the drying kinetics of open sun drying of fish. *Journal of Food Engineering*, 78(4), 1315-1319. <https://doi.org/10.1016/j.jfoodeng.2005.12.044>
- Kaehler, S., & Pakhomov, E. (2001). Effects of storage and preservation on the d13C and d15N signatures of selected marine organisms. *Marine Ecology Progress Series*, 219, 299-304. <https://doi.org/10.3354/meps219299>
- Kolanowski, W., Laufenberg, G., & Kunz, B. (2004). Fish oil stabilisation by microencapsulation with modified cellulose. *International Journal of Food Sciences and Nutrition*, 55(4), 333-343. <https://doi.org/10.1080/09637480410001725157>
- Micklin, P. (2016). The future Aral Sea: hope and despair. *Environmental Earth Sciences*, 75, 1-15. <https://doi.org/10.1007/s12665-016-5614-5>
- Ortiz, A. I. C., Albarrán, Y. M., & Rica, C. C. (2002). Evaluation of different sample pre-treatment and extraction procedures for mercury speciation in fish samples. *Journal of Analytical Atomic Spectrometry*, 17(12), 1595-1601. <https://doi.org/10.1039/B207334J>
- Osa, R., Essilfie, G., Alolga, R. N., Akaba, S., Song, X., Owusu-Ansah, P., & Zhou, C. (2020). Application of non-thermal pretreatment techniques on agricultural products prior to drying: a review. *Journal of the Science of Food and Agriculture*, 100(6), 2585-2599. <https://doi.org/10.1002/jsfa.10284>
- Ran, R., Xiong, Y., Zheng, T., Tang, P., Zhang, Y., Yang, C., & Li, G. (2024). Active and intelligent collagen films containing laccase-catalyzed mulberry extract and pickering emulsion for fish preservation and freshness indicator. *Food Hydrocolloids*, 147, 109326. <https://doi.org/10.1016/j.foodhyd.2023.109326>
- Sampels, S. (2015). The effects of storage and preservation technologies on the quality of fish products: A review. *Journal of Food Processing and Preservation*, 39(6), 1206-1215. <https://doi.org/10.1111/jfpp.12337>