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A DECADE OF PROBIOTIC AQUACULTURE PRACTICE: BIBLIOMETRIC INSIGHTS INTO TRENDS, PLAYERS, AND EMERGING TOPICS

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ABSTRACT

Probiotics in aquaculture gain research interest due to their potential to improve production and promote sustainable aquaculture. This study aims to systematically identify the trend, topic of interest, key players and collaboration in probiotic aquaculture research field for past 10 years. We conducted a bibliometric analysis using Scopus to collect and analyse scholarly publications related to probiotic in aquaculture. The sample is composed by 1467 articles in total with increase trends pattern in number of publications per year. Metrics such as citation counts, co-authorship networks, and keyword co-occurrence were employed to unveil the research landscape. The VOSviewer tool was utilized for network visualizations, offering insights into collaboration patterns and thematic clusters. Preliminary findings indicate increasing trend in terms of documents per year, with countries such as China, India, Spain and US playing pivotal roles in number of publications. Keyword co-occurrence analysis uncovers central themes is probiotic and aquaculture, while emerging topics such as intestinal health, Penaeus vannamei, bacteria, and water quality start to be explored. Citation analysis discovers most contributing authors, countries, institution, and journals in this research area. The co-authorship network analysis reveals clustering of collaborations between countries, emphasizing the global interest research of probiotic in aquaculture. We concluded that global theme will remain the major focus with new collaborations focus on specific niche in this research will emerge as it benefits the contributing countries.

KEYWORDS: Probiotic; aquaculture; gut microbiota; immune response; growth

INTRODUCTION

Probiotics are live microorganisms that, when administered in adequate amounts, confer health benefits to the host (Shebat *et al*., 2022). They play a crucial role in maintaining or improving the intestinal microbial balance, contributing to the health and well-being of their hosts (Bogus³awska-Was *et al*., (2022). Probiotics have become a promising approach to improving aquaculture production due to their numerous benefits, including enhanced fish health, boosted immunity, and improved growth of cultured species.

Various bacterial genera have been utilized as probiotics in aquaculture, including *Bacillus* species, *Lactobacillus*, and yeast. Among these, *Bacillus subtilis* has been extensively studied and applied in aquaculture due to its wide range of benefits (Nayak (2020). *Lactobacillus* species in particular have been shown to enhance fish health and protect against viral infections in shrimp farming (Naiel *et al*., 2020). Additionally, yeast and other probiotic bacteria have demonstrated positive effects in aquaculture systems (Vasyliuk *et al*., 2023). The functionality of these probiotics varies; for instance, *Bacillus* species are recognized for their antimicrobial properties against *Vibrio* species (Chau *et al*., 2021), while *Lactobacillus* species are known to improve survival rates and overall health in shrimp (Mayor *et al*., 2019; Zheng *et al*., 2020). Moreover, probiotics, along with bacteriocins, are increasingly regarded as viable alternatives to antibiotics in aquaculture (Pereira *et al*., 2022).

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Probiotics in aquaculture work through various mechanisms, including improving growth, boosting immunity, competing with pathogenic bacteria, enhancing disease resistance, improving water quality, and aiding in nutrient absorption (Alagawany *et al.*, 2020; Noshair, 2023; Zaloilo *et al.*, 2021). Additionally, they modulate the host's immune system, normalize intestinal microflora, and produce beneficial metabolites (Refeld *et al.*, 2020). Importantly, probiotics contribute to reducing the environmental impact of aquaculture by mitigating fish farm waste and improving water quality (Nathanailides *et al.*, 2021). Furthermore, the use of probiotics in aquaculture has been shown to have a healing effect on fish, normalizing tissue structure, activating the immune response system, and reducing oxidative stress (Romanova *et al.*, 2022). Overall, probiotics play a crucial role in promoting fish health, improving aquaculture productivity, and reducing the environmental impact of fish farming. Moreover, application of probiotics in aquaculture has been associated with mitigation of environmental impact of aquaculture, further indicating their potential in contributing towards sustainable aquaculture practice. A meta-analysis by Gabadage *et al.* (2023) reveals effectiveness of Bacillus as a potential probiotic in aquaculture by significantly lowering FCR, higher body weight in fish, crustaceans, freshwater and marine fish. The purpose of this study is to systematically analyse the trends, key themes, and collaboration patterns in research on probiotics in aquaculture over the past decade. By doing so, we aim to provide a comprehensive understanding of the current state of research in this field and identify emerging areas of interest.

RESEARCH QUESTIONS

This study aims to analyse the research trends related to the application of probiotics in aquaculture over the past decade. It further seeks to determine the countries that have made the greatest contributions to this field of research, as well as to identify the predominant research themes and focal areas. In addition, the study evaluates the most influential authors and publications, together with the journals and institutions that have contributed significantly to the dissemination of research on probiotics in aquaculture. Moreover, the study examines co-authorship networks to understand patterns of scholarly collaboration within this field.

MATERIALS AND METHODS

Bibliometric Analysis

Bibliometric analysis is a quantitative method used in scholarly research to systematically evaluate literature to discern patterns, trends, and the impact of research within a specific field (Ying *et al.*, 2022). This method allows the extraction of quantitative information on distribution by author, time, country, keywords, and journal, providing a comprehensive analysis of the current status and developing trends in publications related to specific research topics. This allows for systematic and visual assessment of previous research hotspots and development trends in the field of interest (Li *et al.*, 2022). Furthermore, it also integrates information visualization techniques with mathematical and statistical analyses to assess institutions performing research, contributing authors, journals publishing a specific area of research, and countries/regions with a research area of interest (Su *et al.*, 2022).

Scopus, is a web database developed by Elsevier, play pivotal roles in offering a comprehensive abstract and citation database across academic disciplines. Its utilization of Scopus aid bibliometric analyses, contributing to evidence-based decision-making in research evaluation and policy development (Leder *et al.*, 2023; Novihoho *et al.*, 2022).

Data Search Strategy

The study implemented a systematic screening sequence to identify search terms for article retrieval. Initial querying of the Scopus database employed the string

TITLE-ABS-KEY (probiotic AND aquaculture) AND LIMIT-TO (PUBYEAR , 2015) OR LIMIT-TO (PUBYEAR , 2016) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2022) OR LIMIT-TO (PUBYEAR , 2023), LIMIT-TO (PUBYEAR , 2024) AND (LIMIT-TO (DOCTYPE , "ar") AND (LIMIT-TO (PUBSTAGE , "final") AND (LIMIT-TO (LANGUAGE , "English") AND (LIMIT-TO (SRCTYPE , "j"), retrieving 2119 articles.

These results were additionally scrutinized to include only research articles at final publication stage in English language. The final search string refinement included 1467 articles which was used for bibliometric analysis (Table 1). As of January 2025, all articles from Scopus database relating to probiotic application in aquaculture fish growth, were incorporated in the study (Table 2).

Data Analysis

Data sets containing the study publication year, publication title, author name, journal, citation, and keyword in PlainText format were acquired from SCOPUS database covering the period 2015 to De-

Table 1. Search string for the probiotic roles in fish growth

Scopus	TITLE-ABS-KEY (probiotic AND aquaculture) AND OR LIMIT-TO (PUBYEAR , 2015) OR LIMIT-TO (PUBYEAR , 2016) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2022) OR LIMIT-TO (PUBYEAR , 2023) OR LIMIT-TO (PUBYEAR , 2024)) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (PUBSTAGE , "final")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (SRCTYPE , "j")

Table 2. Selection criterion in searching

Criterion	Inclusion	Exclusion
Language	English	Non-english
Timeline	2015-2024	< 2015, > 2024
Literature type	Journal (article)	Review, Book
Publication stage	Final	In press

cember 2024 was analysed in VOSviewer software version 1.6.15. Keyword co-occurrence and citation analysis were analysed using visualisation techniques through VOSviewer to the data set. Minimum citation of a document was limited to 50 for citation analysis. Keyword co-occurrences analysis was done by limiting a minimum of 10 number of occurrences of author keywords.

Development of research area during a period can be explored by keyword co-occurrence analysis (Zhao, 2022) and is successful in identifying popular topics in different fields (Li *et al.*, 2016). Citation analysis was performed to identify key research issues, trends, and techniques, along with exploring the historical relevance of a discipline's main area of focus (Allahverdiyev & Yucesoy, 2017). Document co-citation analysis is one of the frequently applied bibliometric methods (Appio *et al.*, 2016; Fahimnia *et al.*, 2015; Liu *et al.*, 2015) and its result is mapping dependent on the network theory to identify relevant structure of data (Liu *et al.*, 2015).

RESULTS

Research Trends

Result showed increasing pattern in documents from year 2015 to 2024 (Figure 1). This trend suggests an increasing interest and activity in research in probiotic for aquaculture. In 2015, a total of 74 articles, representing 5.1% of total articles published, and this pattern showed gradual increment in 2015 (78 articles, 5.3%) until 2018 (82 articles, 5.6%). We noticed that the recent past 5 years, since 2019 marks notable increase in number of publication (117 articles, 9.0%) and year 2024 was the highest with 283 articles (19.3%).

Country and Institutions Contributions

It was shown in the data analysis (Figure 2) that publications related to probiotic in aquaculture covering 89 countries, mainly China (29.1%), India (11.6%), US (6.3%), Spain (5.7%), Egypt (5.0%) and Malaysia (4.7%). This showed that over a decade, the research on probiotic use in aquaculture has regain popularity and attention. Ministry of Agriculture of the People's Republic of China is the main contributor for articles (68 documents) followed by Ministry of Education of the People's Republic of China, Chinese Academy of Fishery Sciences, Chinese Academy of Sciences, Centro de Investigaciones Biologicas Del Noroeste, Ocean University of China, Universiti Putra Malaysia, Pilot National Laboratory for Marine Science and Technology, and Shanghai Ocean University, and Ningbo University, each 60, 56, 42, 28, 28, 27, 27, 26 and 24 documents respectively (Figure 3).

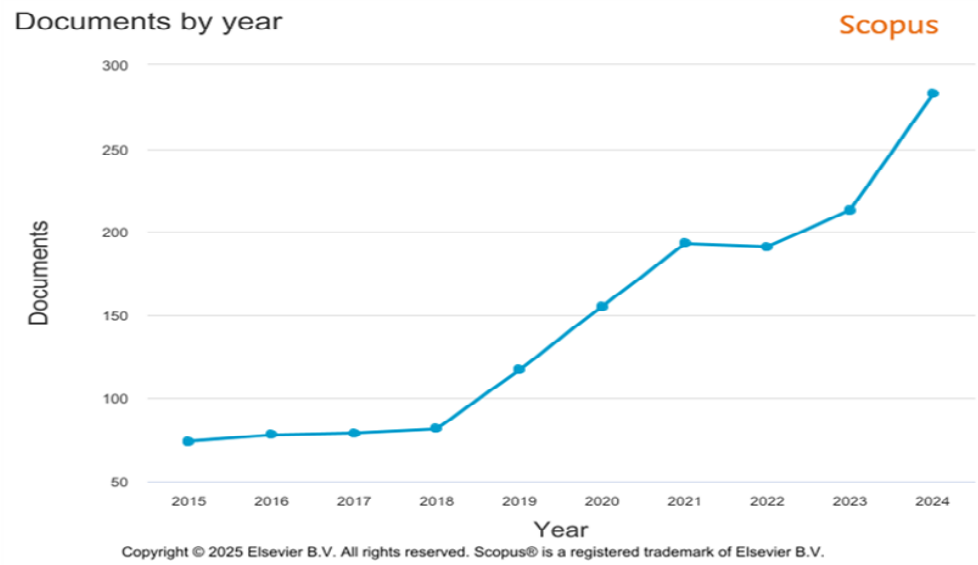

Figure 1. Number of documents published on probiotic aquaculture according to years.

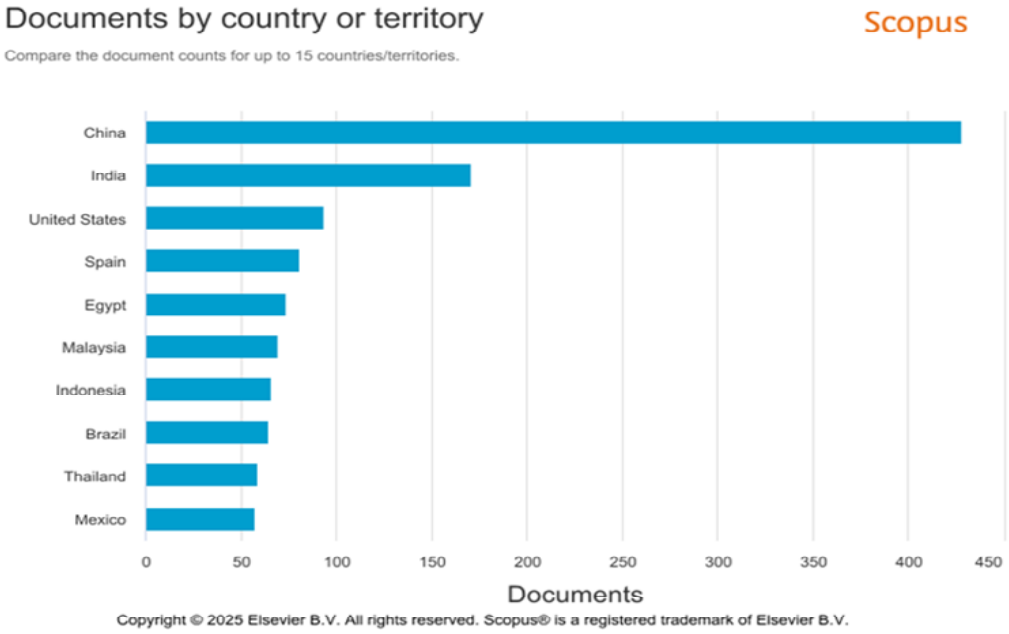

Figure 2. Publications on probiotic in aquaculture according to country affiliation.

Research Topics and Focus

Co-occurrences of a keyword showed 8594 keywords, in which 133 meet the threshold of minimum 50 occurrences in the studies. These keywords were visualized as network (Figure 4) and clustered into four clusters:

C1: *Aeromonas hydrophila*, alkaline phosphatase, amylase, analysis, animal cell, animal experiment, animal feed, animal food, animal model, animal tissue, antioxidant, antioxidant activity, body weight gain, carp, catalase, chemistry, colony forming unit, controlled study, diet, diet supplement, diet supplements, disease resistance, drug effect, enzyme activity, fish disease, fish diseases, gene expression, growth, development and aging, immune response, immune, innate, immunology, innate immunity, interleukin 1beta, intestine, intestines, lysozyme, metabolism, oxidase stress, physiology, real time polymerase chain, superoxide dismutase, survival rate, triacylglycerol lipase, tumor necrosis factor, unclassified drug, upregulation, veterinary medicine.

C2: Actinobacteria, antibiotics, aquaculture, aquaculture system, *Bacillus subtilis*, bacteria (microorganism), bacterium, bacteroidetes, cyprinid, decapoda (crustacea), digestive system, dna extraction, feeding, firmicutes, fish, gastrointestinal

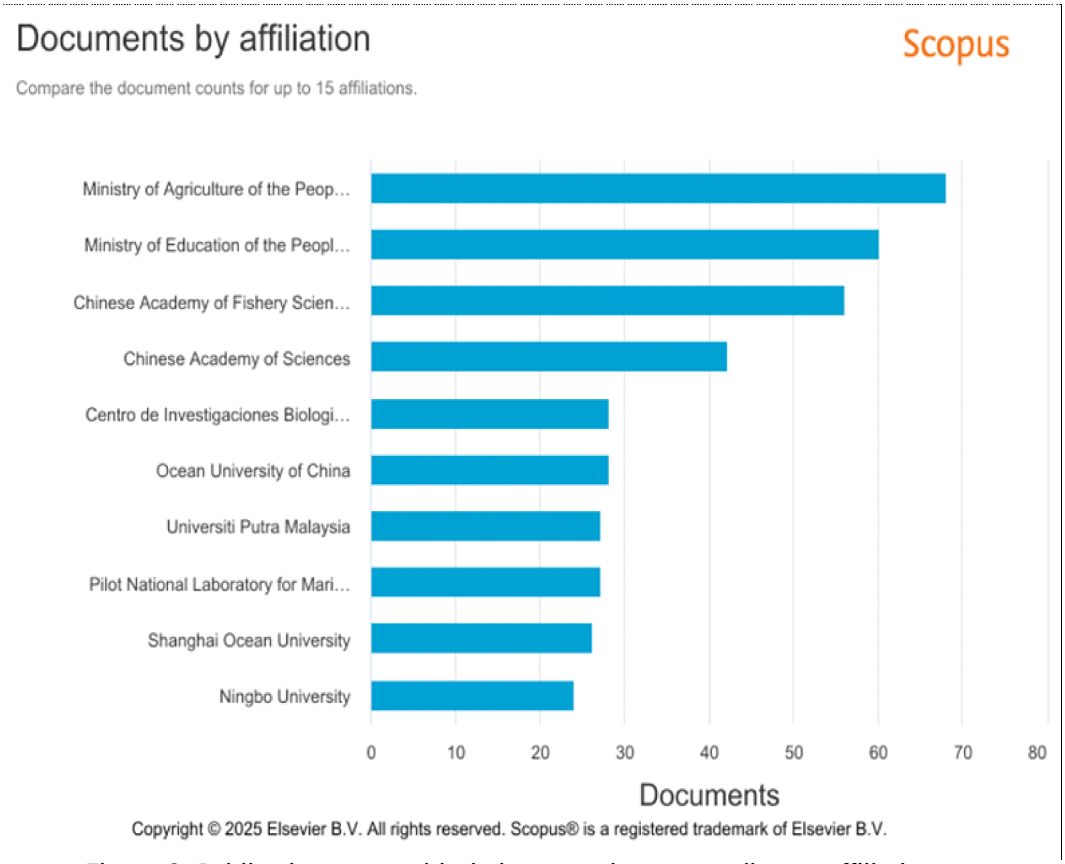

Figure 3. Publications on probiotic in aquaculture according to affiliations.

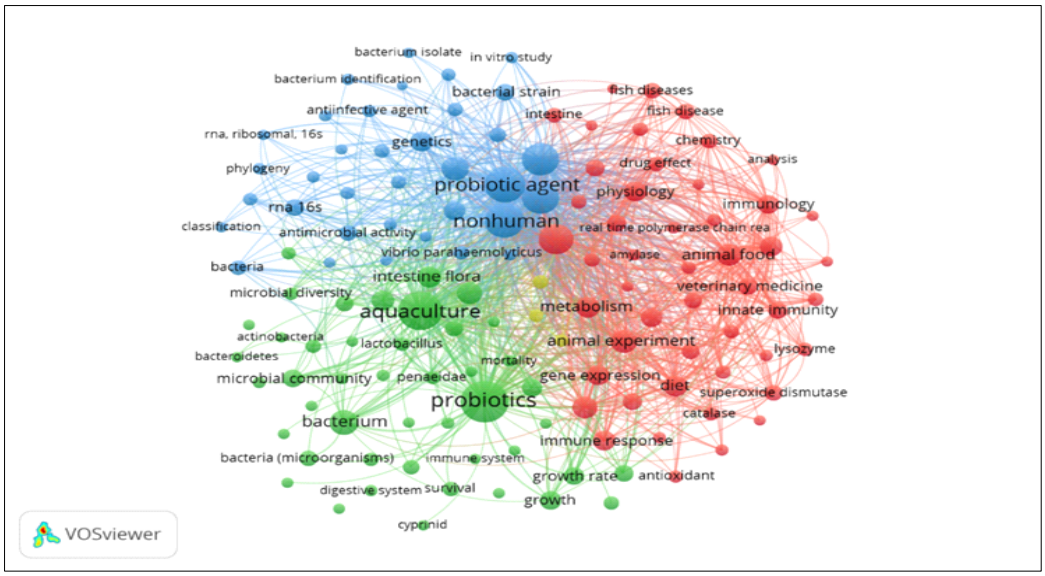

Figure 4. Co-occurrence between keywords.

microbiome, growth, growth performance, growth rate, gut microbiota, immune system, immunity, intestinal microbiota, intestine flora, lactobacillus, larva, *Litopenaeus vannamei*, microbial community, microbial diversity, microbiome, microbiota, mortality, *Oncorhynchus mykiss*, pathogen, penaeidae, *Penaeus monodon*, probiotic, probiotics, protein, proteobacteria, shrimp, survival, tilapia, vibrio, water quality.

C3: Animal, animals, anti-bacterial agents, antibacterial activity, antibiotic resistance, antibiotic sensitivity, anti-infective agent, antimicrobial activity, bacillus, bacteria, bacterial growth, bacterial strain, bacterium growth, bacterial identification, bacterium isolate, bacterium isolation, classification, gene sequence, genetics, human, in vitro study, isolation and purification, lactic acid bacteria, microbiology, nonhuman, ph, phylogeny, polymerase chain reaction,

probiotic agent, rna 16s, rna, ribosomal, 16s, *Vibrio harveyi*, *Vibrio parahaemolyticus*, vibriosis

C4: Cichlid, *Lactobacillus plantarum*, *Oreochromis niloticus*

The central cluster of the network is dominated by terms related to the benefits of probiotics for aquaculture, such as probiotic agent, intestine flora, metabolism, growth, immunity, and disease resistance. This suggests that these are the most studied and well-established benefits of probiotics in this field. The other cluster of the figure includes terms related to microbial communities, microbiota, and the microbiome, suggests growing interest in understanding the complex interactions between probiotics and the gut microbiome of fish. Another cluster include terms related to specific probiotic strains and species, suggesting increasing focus on identifying the most effective probiotic strains for different aquaculture applications.

Overlay visualization map of keyword co-occurrence analysis explain the trending research topics (Figure 5). Several keywords that are gaining interest are intestinal health, immunology, animal food, bacteria and immune response.

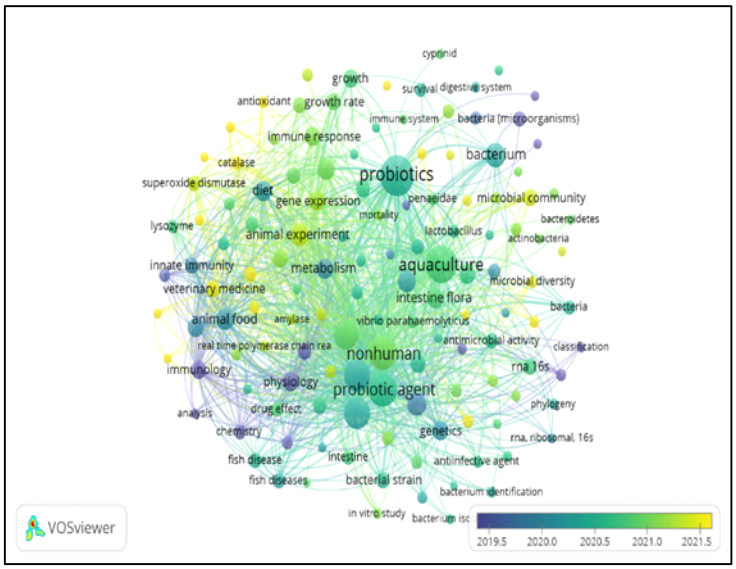

Figure 5. Overlay visualization of keywords.

Top contributing authors and articles

Citation analysis disclosed authors that have significantly contributed to research in probiotic usage in aquaculture (Table 3). Dawood is the most cited author but has weak total link strength (TLS) compared to other high citation authors such as Gram, Hoseinifar, Esteban, Hu, Zhang and Ran. Citation analysis of documents was conducted to explore most influential research articles in probiotic aquaculture study. Out of 1247 documents, 111 were cited more than 50 times.

Top 10 contributing studies are presented in Table 4 with article published by Fetzner (2015) showed highest citations (284). The article studied various approaches for disrupting quorum sensing, including the use of signal-degrading bacteria as probiotics in aquaculture. Meanwhile, the study by Nagappan *et al.* (2021) investigated the potential of microalgae-based fish feed to enhance fish health, including its possible probiotic effects. Study by Guardiola *et al.* (2016), showed that plant extract-derived immunostimulant has potential to improve innate immune response and immune-related gene expression in fish. According to Dawood *et al.* (2016) proven that *Lactobacillus* and *Lactococcus* bacteria help improve growth, gut microbiota and immune response in marine fish. Apart from that, study by Yi *et al.* (2018) explore about potential of probiotics that showed antimicrobial activities against fish pathogenic bacteria.

Contributing Journals and Institutions

Citation analysis was also carried out to investigate journals that contributed to publishing research in this field. Many journals have contributed to probiotic in aquaculture research. Out of 914 journals, it is observed that 139 journals have published at least 5 articles in this field with 15 most favourable journals in probiotic aquaculture studies as in Table 5. Aquaculture has the highest number of articles and citation, followed by Journal of Fish and Shellfish Immunology, Aquaculture Research, Aquaculture Reports, and Aquaculture International.

Citation analysis also revealed the top 10 institutions that are most prolific in terms of research pub-

Table 3. Top contributing authors

Author	Documents	Citations	Total link strength
Dawood, M.	15	942	9
Esteban, M.A.	15	931	24
Hossein Hoseinifar, S.H.	10	778	11
Van Doan, H.V.	10	694	16
Ringo, E.	7	672	21
Gram, L.	11	669	12
Chang, X.	13	573	30
Ran, C.	13	559	42
Hu, S.	7	540	3
Wang, G.	8	489	12

Table 4. Top contributing articles

Authors/Year	Article title	Journal	Times cited
Fetzner (2015)	Quorum quenching enzymes	*Journal of Biotechnology*	284
Nagappan *et al*. (2021)	Potential of microalgae as a sustainable feed ingredient for aquaculture	*Journal of Biotechnology*	270
Ringø *et al.* (2020)	Probiotics, lactic acid bacteria and bacilli: interesting supplementation for aquaculture	*Journal of Applied Microbiology*	265
Chauhan & Singh (2019)	Probiotics in aquaculture: a promising emerging alternative approach	*Symbiosis*	253
de Souza Valente & Wan (2021)	Vibrio and major commercially important vibriosis diseases in decapod crustaceans	*Journal of Invertebrate Pathology*	246
Yi *et al.* (2018)	Probiotic potential of *Bacillus velezensis* JW: antimicrobial activity against fish pathogenic bacteria and immune enhancement effects on *Carassius auratus*	*Fish & Shellfish Immunology*	239
Martinez-Cordova *et al.* (2015)	Microbial-based system for aquaculture of fish and shrimp: an updated review	*Reviews in Aquaculture*	218
Guardiola *et al*. (2016)	Impact of date palm fruits extracts and probiotic enriched diet on antioxidant status, innate immune response and immune-related gene expression of European seabass (*Dicentrarchus labrax*)	Fish & Shellfish Immunology	214
Dawood *et al*. (2016)	Effects of dietary supplementation of *Lactobacillus rhamnosus* or/and *Lactococcus lactis* on the growth, gut microbiota and immune responses of red sea bream, *Pagrus major*.	Fish & Shellfish Immunology	212
Bentzon-Tilia *et al*. (2016)	Monitoring and managing microbes in aquaculture – towards a sustainable industry.	*Microbial Biotechnology*	206

lications in this research field. The analysis shows that a total of 2956 institutions from 66 countries have conducted research in this area. 18 organisations at least produced research articles in this area with 10 of them are from China, Spain, Thailand, Egypt, Portugal, and Taiwan. The Universidad de Murcia along with University of Chinese Academy of Sciences and Gorgan University of Agricultural Sciences and Natural Resources, stand out as the leading organizations contributing to this field of study (Table 6). The diagram shows that research articles came from 91 countries with 55 countries produced at least 5 research articles about probiotics in aquaculture. The citation analysis also indicates that nations like China, India, Spain, USA, Egypt, Thailand, Iran, Norway, Denmark, and South Korea lead the charge in research focused probiotics in aquaculture (Figure 6). Geographically, China is the most of the prominent institutions contributing to this sector, highlighting their pioneering role in this research domain.

Table 5. Top contributing journals for probiotic aquaculture research

Journal title	Number of articles	Citations	Total link strength (TLS)
Fish and Shellfish Immunology	135	6594	310
Aquaculture	136	4033	479
Probiotics and Antimicrobial Proteins	43	1567	15
Aquaculture Research	74	1429	102
Aquaculture Reports	49	1386	34
Aquaculture International	47	851	48
Frontiers in Microbiology	29	784	13
Journal of Applied Microbiology	12	672	62
PLOS One	15	510	47
Scientific Reports	17	489	46
Applied Microbiology and Biotechnology	11	430	21
Microorganisms	27	425	19
Microbial Pathogenesis	20	358	29
Aquaculture Nutrition	14	348	62
Animals	25	328	11

Table 6. Top 10 contributing organisations

Organization	No of published articles	Citations	Country
University of Chinese Academy of Sciences	20	958	China
Universidad de Murcia	13	912	Spain
Gorgan University of Agricultural Sciences and Natural Resources	10	778	Iran
Kafr El-Sheikh	13	718	Egypt
Chiang Mai University	9	679	Thailand
Interdisciplinary Centre of Marine and Environmental Research	19	676	Portugal
National Pingtung University of Science and Technology	7	540	Taiwan
Jilin Agricultural University	21	500	China
Guangdong Ocean University	8	489	China
Pilot National Laboratory for Marine Science and Technology	19	449	China

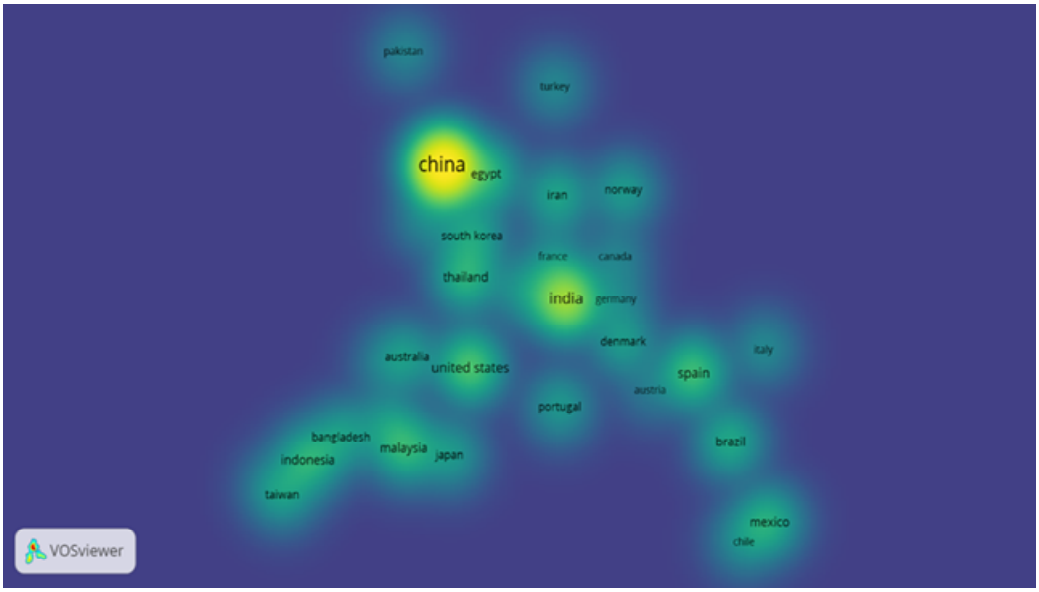

Figure 6. Density map of top contributing countries.

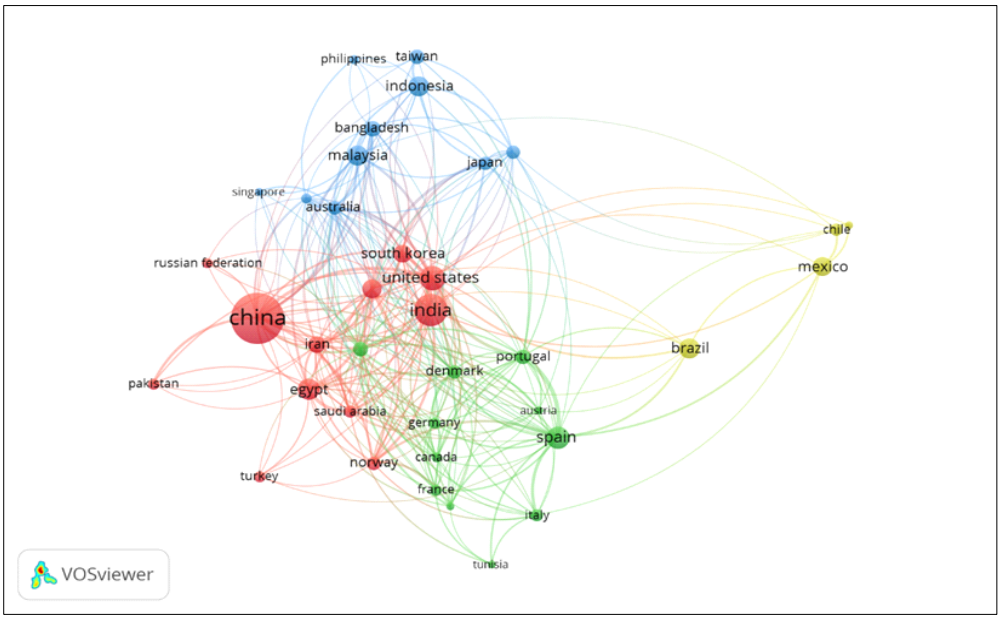

Figure 7. Co-authorship between countries.

Co-authorship

A total of 37 out of 91 countries has published at least 10 documents in this field and clustered into 4 clusters (Figure 7) in which Cluster 1 (C1) has 12 countries, C2, C3 and C4 has 11, 10 and 4 countries respectively;

C1: China, Egypt, India, Iran, Norway, Pakistan, Russian, Saudi Arabia, South Korea, Thailand, Turkey, USA

C2: Australia, Canada, Denmark, France, Germany, Ireland, Italy, Portugal, Spain, Tunisia, United Kingdom.

C3: Austria, Bangladesh, Belgium, Indonesia, Japan, Malaysia, Philippines, Singapore, Taiwan, Vietnam

C4: Brazil, Chile, Ecuador, Mexico

DISCUSSION

We performed the analysis on 1467 publications on probiotics in aquaculture between 2015 and 2024 which represent 69.2% of the documents published between 2015 until 2024 on probiotics in aquaculture. Trends in term of number of articles published shown to increase over the years with China, India, Spain and US as top contributors. In concurrent, China,

Malaysia and Thailand also the most influential country as they host most top 10 cited institutions in this research field. However, Egypt, Bangladesh are not in top 10 producer but among the top 10 cited countries.

Ministry of Agriculture of the People's Republic of China, Ministry of Education of the People's Republic of China, Chinese Academy of Fishery Sciences, Chinese Academy of Sciences, Centro de Investigaciones Biologicas Del Noroeste, Ocean University of China, Universiti Putra Malaysia, Pilot National Laboratory for Marine Science and Technology, Shanghai Ocean University and Ningbo University are the institutions with significant contributions. However, none of these institutions is listed the most cite institutions as only University of Chinese Academy of Sciences, Universidad de Murcia, Gorgan University of Agricultural Sciences and Natural Resources, Kafr El-Sheikh, Chiang Mai University, International Centre of Marine and Environmental Research, Jilin Agricultural University, National Pingtung University of Science and Technology, Guangdong Ocean University, and Pilot University Laboratory for Marine Science were listed. It is noticeably that not all highest producer of research articles are the most cited institutions (Table 6).

Keyword co-occurrence analysis shows that 4 clustering of keywords, indicating 4 niches in this research area, mainly microbial community, immunity and disease resistance, growth performance, gut microbiota, antibiotic resistance and antagonism. Yet, the main theme in keyword remains "probiotics" and "aquaculture". Overlay map (Figure 5) showed new emerging keywords such as intestinal health, zebrafish, *Penaeus vannamei*, bacteria and water quality. These keywords recently used to indicate exploration of new area with potential research and applications.

Top five authors with most publications in the field are Dawood, Esteban, Chang, Ran, and Gram with 15,15,13,13 and 11 publications respectively. They are also the top ten authors with highest citation (Table 3). Dawood with only 15 documents were the most cited author for this research. This indicate that these authors are prominent in term of producing an amount of relevant and good articles for the scientific community, enable them to be most influential authors in this research field.

The most influential research documents are generally those in the *Journal of Fish and Shellfish Immunology,* in which the theme focusing on immunology in aquaculture. The journal also the most contributing and influential journal for probiotic in aquaculture with highest citation and total link strength (Table 5). Top 10 institutions mostly are from China, and other developing countries (Thailand, Egypt, Portugal, Spain, and Taiwan). This may be due to the importance of sustainable aquaculture for these countries.

CONCLUSION

This study, based on bibliometric analysis, reveals a significant increase in research on probiotics in aquaculture over the past decade. This may due to its importance towards aquaculture industry thus gain more interest from huge nation towards sustainable aquaculture. Keyword co-occurrence also showed new topics emerging from this research area. Thus, is predicted that this new niche will expand and gain more attention for research in future.

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