Emerging Threats In Aquaculture: Bibliometric Analysis Of *Aeromonas Sps.* As An Emerging Pathogen

Dr. Nupur Joshi[1]*, Dr. Geeta Bhandari[2], Dr Archna Dhasmana[3], Dr Vikash Singh Jadon[4], Dr. Sanjay Gupta[5]

[1]*,2,3,4,5*Himalayan School of Biosciences, Swami Rama Himalayan University, Dehradun, Uttarakhand, 248016.*[1]*Email: nupurjoshi@srhu.edu.in,* [2]*Email: geetabhandari@srhu.edu.in,*
[3]*Email: archnadhasmana@srhu.edu.in,* [4]*Email: vsjadon@srhu.edu.in,* [5]*Email: sanjaygupta@srhu.edu.in*

*Corresponding Author: *Dr. Nupur Joshi*
*Himalayan School of Biosciences, Swami Rama Himalayan University, Dehradun, Uttarakhand, 248016
Email: nupurjoshi@srhu.edu.in

Article History	Abstract
	The concern regarding emerging diseases in aquaculture has received considerable global interest. This research focuses on the recent emergence of Aeromonads as a possible zoonotic pathogen that can impact both human and aquatic organisms. Therefore, it is crucial to evaluate the current state of this issue. Bibliometric analysis is employed to evaluate the prevalence of Aeromonas in the field of aquaculture during the period spanning from 2004 to 2023. The investigation was performed with the VOSviewer software and the Dimension database. The present study investigates the patterns of publishing output and global collaboration throughout the last ten years. The results demonstrate a substantial and steady rise in the quantity of scholarly articles, accompanied by a noteworthy degree of collaboration among academics hailing from various nations. This research investigates the global distribution of scholarly articles, with a specific emphasis on the countries of China and India, which have the highest levels of representation. The Chinese Academy of Fishery Science has attained the most substantial publication output among academic institutes. This study also examines the prominent academic journals, specifically Fish & Shellfish Immunology, Aquaculture, and Aquaculture Research, which serve as crucial platforms for the dissemination of scholarly information.

1. Introduction

The aquaculture revenue has experienced significant growth in recent years. It has emerged as the fastest-growing agricultural sector worldwide and currently accounts for over 50% of global seafood production (Soltani *et al.,*2021). Intensification of aquaculture practices and the expansion of worldwide trade in aquatic goods led to an increase in the occurrence and resurgence of infectious diseases, posing substantial economic and ecological challenges for society (Gatta, 2022). *Aeromonas* species are classified as Gram-negative and non-sporulating bacteria. They are facultative anaerobes, meaning they can survive in both aerobic and

anaerobic environments. These bacteria have a rod-shaped morphology and are mesophilic. They are commonly found in water and food sources and are zoonotic pathogens that can infect humans. This microorganisms in have been identified as a prominent factor in the development of severe dysentery, bacteremia, and diarrhea. Aeromonas strains have been identified as opportunistic pathogens in both veterinary and human medicine (Igbinosa *et al.,*2017). The ability of Aeromonas spp. to establish an infection is influenced by multiple factors and exhibits a complex nature. The phenomenon encompasses the potential for the production or secretion of many pathogenic determinants, which may work in concert or autonomously (Joseph *et al.,*2013; Jacobs & Chenia, 2007 and Duarte *et al.,*2018).

Bibliometrics is a methodological approach that involves the quantitative examination of academic publications within a defined scientific field. This methodology employs mathematical and statistical methodologies to clarify historical progressions, research trends, and notable subjects within the discipline. Bibliometrics endeavours to predict the future research and development trajectory of the subject (Liang *et al.,*2021 and To, 2022). The program possesses the capacity to effectively analyse many characteristics of a significant quantity of publications, including the publication year, place of origin, affiliations, journal distribution, keywords, and other relevant information. Furthermore, it has the capability to utilize other methodologies to visually depict the spatial distribution of authors, the collaborative relationships between nations and institutions, and the co-citation tendencies of keywords (Zhu *et al.,*2022 and Uysal, 2009). The utilization of bibliometrics has been widely applied in many fields owing to its complete methodology, impartiality, and precision. In recent years, there has been a growing interest among scholars in conducting bibliometric analyses to analyse various research topics (O'Leary, 2021 and Grillo, 2021). The primary aim of this research was to employ VOSviewer visualization software as a bibliometric instrument for examining the relevant scholarly literature in the domain of arsenic remediation from groundwater. The study focused on utilizing the dimensions database to examine publications published between 2014 and 2023. The objective of this study was to analyse the existing research environment, identify areas of significant interest, and evaluate potential prospects, so providing valuable insights for future investigations.

## 2 Methodology and data

2.1 Data collection

A bibliometric investigation was carried out utilizing the Dimensions database to assess the emergence of *Aeromonas sps.* as a potential pathogen in aquaculture. The investigation was conducted within the temporal span of 2004-2023. The incorporation of keywords in combination with Boolean operators enabled the creation of a relevant dataset. The search query comprised the phrases "Aeromonas" AND "pathogen" AND "aquaculture". The process of collecting data was carried out on October 13, 2023, to minimize potential inconsistencies in the dataset. The materials were categorized into four discrete categories, namely publications (768), datasets (64), grants (99), patents (11), with zero clinical trials and policy documents. All the search results that were obtained were imported and included important bibliometric information, such as the title, abstract, journal name, year of publication (including volume, issue, and page numbers), author details (including affiliation and country), number of citations, and references cited. These details were subsequently cleaned manually and used for conducting bibliometric analysis.

Leiden University created the bibliometric software tool known as VOSviewer, which has recently gained widespread adoption and popularity. The key function of this tool is to assess the developments in research while simultaneously identifying hot topics within a certain field of study. This software facilitates a thorough examination of published literature by incorporating many aspects, such as country, research institution, and keyword, among other factors. The current study highlights the distinct benefits of utilizing this methodology for visual representation, namely by grouping networks through co-occurrence patterns. The software application referred to as VOSviewer uses automated semantic clustering methodologies to examine the associations among various entities and produce graphical depictions of co-occurrence networks (Oyewala & Dada, 2022). In the current study, the analysis of articles was conducted using Microsoft Excel and VOSviewer. Further, the study involved a comprehensive analysis of publication volume, including many factors such as publication year, place of origin, institutional affiliation, and journal of publication. Moreover, the current study investigated the yearly variation pattern of publications in relation to both the year and contributing countries.

3 Result and Discussion

3.1 Growth Trends

The assessment of recent trends and patterns can be estimated by analyzing the annual growth rate derived from the publication volume within a specific field. The linear relationship depicted in Figure 1 illustrates the progression of publications in the dimensions database over the period from 2004 to 2023. The quantity of publications exhibited a consistent increase, ascending from 9 in 2004 to 85 in 2023, demonstrating an annual growth rate of 15.2%. The year 2019 saw the highest number of citations within two decades, with a dataset volume of 75. The observed pattern indicates that emergence of *Aeromonas sps.* as pathogenic bacteria can garner the attention of researchers worldwide in coming future.
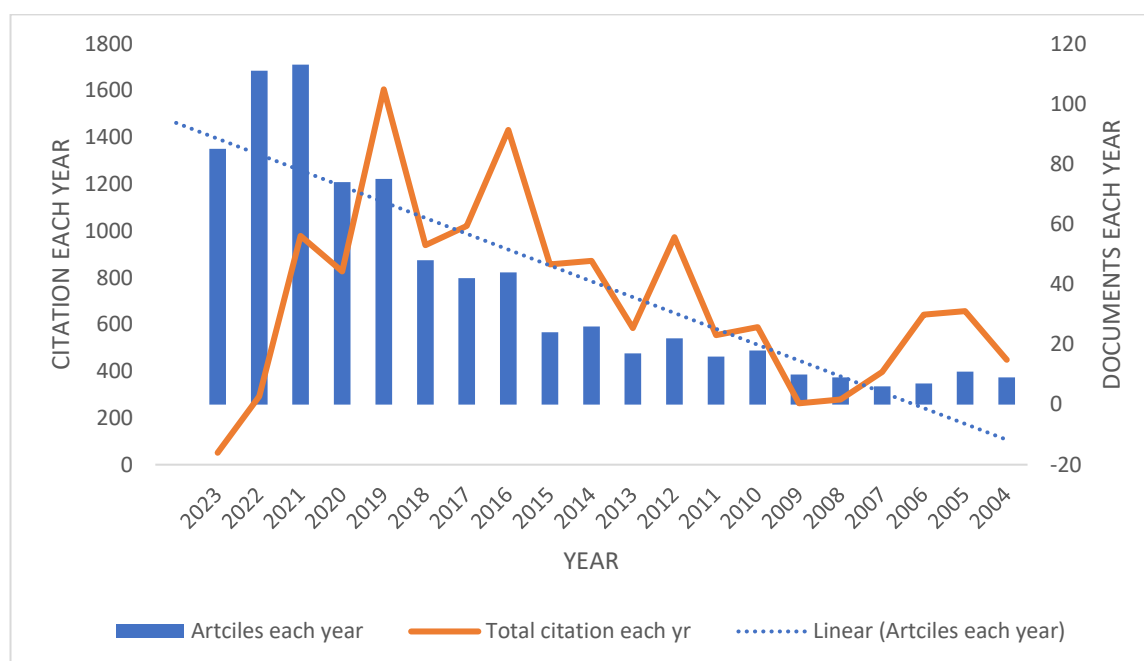
Figure 1: Growth patterns of publications throughout the course of past two decades (2004-2023)

3.2 Publication Distribution

A comprehensive examination of the publication distribution within the dimension database indicates that 36 nations or regions have majorly contributed to topic *Aeromonas sps.* as emerging pathogen. Figure 2 illustrates the countries that made the most significant progress in terms of article production throughout the period spanning from 2004 to 2023. The publication production was predominantly contributed by the top 10 countries, which collectively accounted for 68.42% of the total output.
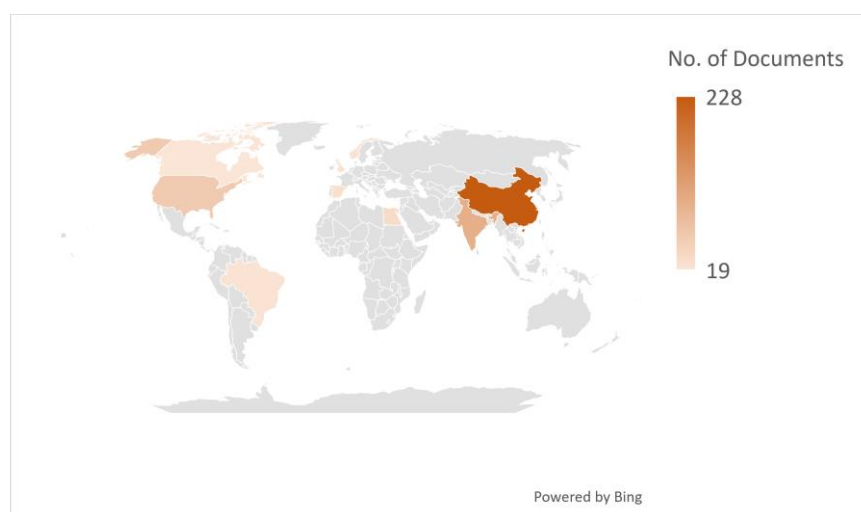
Figure 2: Distribution of publication across different nations (2004-23)

Furthermore, Table 1 presents a comprehensive analysis of citations, shedding light on the leading ten nations that are actively involved in studies regarding Aeromonads as emerging pathogens in aquaculture. Based on the available data, it can be concluded that the mean year for the top 10 countries was 2018.008.

Country	No. of Documents	Citations	Avg. pub. Year
China	228	3677	2019.2719
India	98	2105	2018.102
United States	58	1316	2016.3966
Egypt	33	700	2018.9394
Spain	26	418	2018.2692
Brazil	22	624	2017.6364
Norway	22	354	2016.5909
United Kingdom	22	588	2018.5909
Canada	19	367	2016.8947
Indonesia	18	170	2019.3889

Table 1: Top 10 countries with publication on *Aeromonas* as a potential pathogen in aquaculture along with average publication year

China and India have been major contributors in the field of aquaculture for a considerable period, exerting significant influence. In fact, their combined efforts accounted for a substantial 91.6% share of the global production of aquatic animals and algae in the year 2020 (Gatta, 2022). China demonstrates a significant impact in terms of the quantity of publications and citations, a trend that can be related to the growing emphasis on aquaculture. According to the Food and Agriculture Organization (FAO) in 2022, the aquaculture industry yielded a total of 49.90 million tons of fish, or 57.03% of the global production. Nevertheless, this escalation has resulted in recurrent occurrences of disease outbreaks caused by diverse pathogenic bacteria, such as aeromonads. These outbreaks could perhaps be attributed to the overutilization of conventional culture methods, such as ponds and cages, as well as environmental contamination (Chen and Gao, 2023).

To enhance the analytical process, VOSviewer software was employed to visually represent the collaborative linkages across notable countries and regions in terms of their performance over the period spanning from 2004 to 2023. The findings of the current study are depicted in Figure 3. The circular element portrayed in the image functions as a symbolic depiction of distinct countries or areas, with the size of each circle correlating to the number of articles originating from that nation. The arc that links the two circles represents a symbiotic and interconnected association between the two countries. A positive relationship can be observed between the degree of collaboration among nations and the magnitude of the curve's thickness. The level of collaboration among different geographic locations can be deduced by examining the spatial proximity between circles.

Figure 3 provides additional insight by illustrating that China demonstrates a significant number of connections with various countries, resulting in a cumulative link strength of 3480.0152. Subsequently, India demonstrated a link strength of 2742.3893, so securing the second position. On the other hand, it is noteworthy that the United States occupies the third rank, with a link strength of 1449.0892.
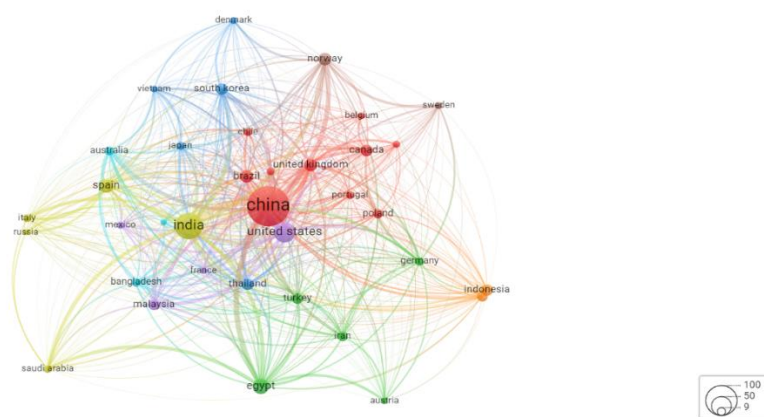
Figure 3: Network of nations with significant research contribution on *Aeromonas* as an emerging pathogen in aquaculture

3.3 Distribution of Publications Across Organizations

The collaboration of 62 organizations was found in studies pertaining to the emergence of *Aeromonas* as a pathogen in the field of aquaculture. Figure 4 depicts the top ten organizations that are actively involved in undertaking research related to pathogenic aeromonads. The China Academy of Fishery Science contributes 5.95% of the total published documents, indicating a substantial proportion of the overall publications.

Figure 4: Top 10 organization involved in studies pertaining to emergence of Aeromonads as emerging pathogens in aquaculture

Furthermore, VOSviewer was employed to visually represent the linkages between various institutions in relation to their cooperation. Figure 5 depicts four complex and interrelated networks, each represented by specific colors. The red cluster has 43 organizations that have a strong link, whereas the blue cluster consists of 53 organizations. The green cluster includes 9 organizations, and there are 5 organizations in both the blue and yellow clusters. The Chinese Academy of Fishery Science is recognized for its extensive collection of 29 documents, which have an average citation score of 12 and an average publication year of 2019.75. Additionally, it demonstrates a high level of collaboration with other institutions, as indicated by its impressive link strength of 934.11.

**Figure: 5** Organizational Landscape on *Aeromonas* as a prominent pathogen in aquaculture

3.4 Co-cited Author Publication

The co-citation analysis of authors was conducted using VOSviewer, which unveiled that Zhang, Lei possessed the highest count of documents, followed by Qian, Aidong and Shan, Xiaofeng. The article authored by Liles, Mark R. received the highest number of citations, with an average citation score of 37.625.
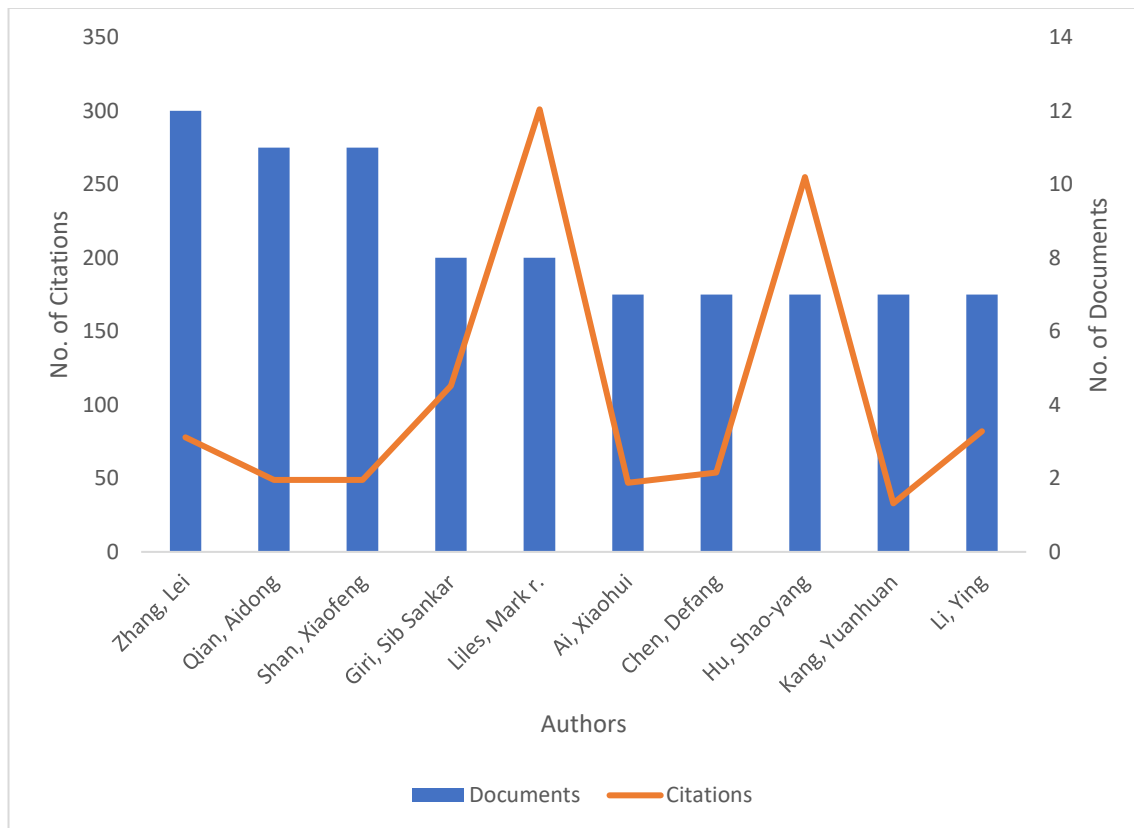
Figure 6: Co-citation analysis of prominent authors on *Aeromonas* as pathogen in aquaculture (2004-2023)

Figure 7 depicts the co-citation network, which is characterized by nine distinct clusters, each denoted by a unique color. The size of the circle corresponds to the frequency of citation, while the line connecting two points indicates that the authors referenced in each article are the same. The degree of proximity between the two authors is shown by the length of the line (Huang *et al.,*2020).
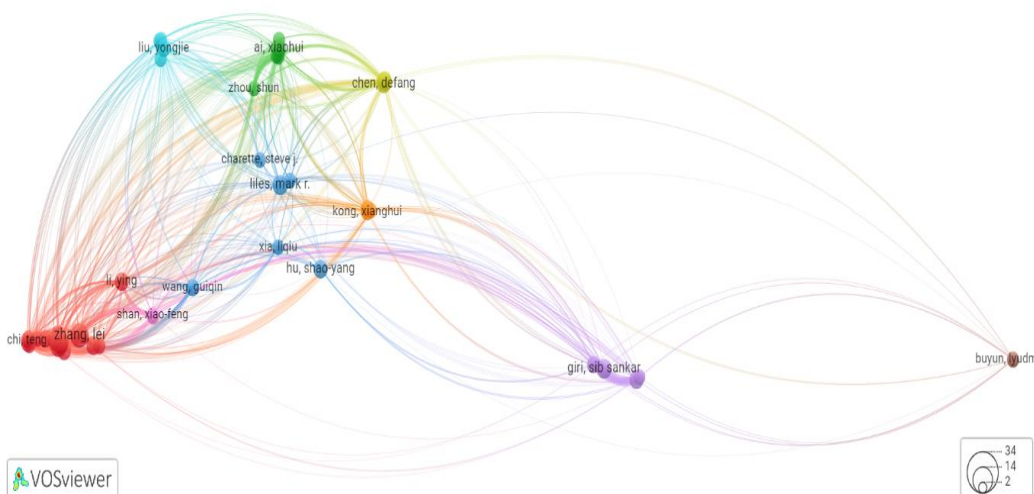

Figure 7: Co-citation network of authors represented by nine distinct cluster

| Cluster	No. of Authors	No. of Documents
1	16	107
2	6	33
3	6	36
4	4	25
5	4	26
6	4	21
7	3	17
8	2	10
9	2	10

Table 2: Co-citation network analysis with different clusters with corresponding number of authors and documents

3.5 Academic Publishing Landscape

The analysis of journal publications spanning from 2004 to 2023 encompassed a corpus of 378 articles. Among these, the cumulative contribution of the top 10 journals accounted for 74.87% of the total publications and 73.25% of the overall citations. Most published publications are credited to three renowned academic journals, namely Fish & Shellfish Immunology, Aquaculture, and Aquaculture Research. The journal Fish & Shellfish Immunology comprises 21.43% of the overall publications, with an average citation score of 31.92 and a total link strength of 930.2137. The Aquaculture exhibits a strong correlation with a link strength of 799.15 and an average year of publication of 2018.7857. Aquaculture Research exhibits a cumulative link strength of 451.90, accompanied by an average year of publication of 2017.42.
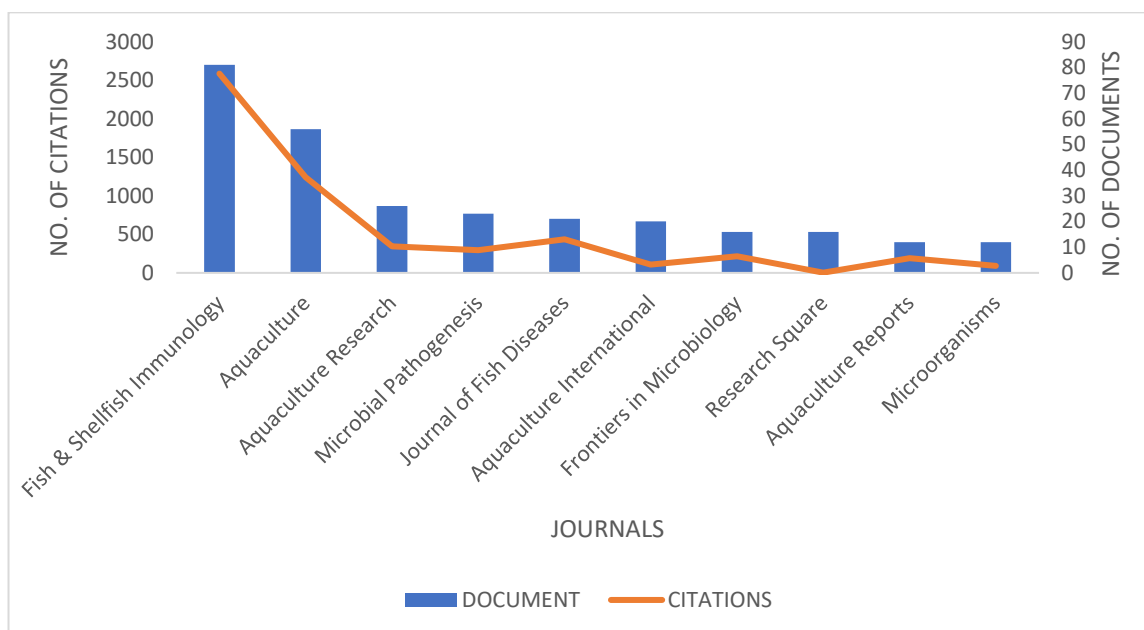
Figure 8: Distribution of journals pertaining to the emergence of *Aeromonas* as pathogen in aquaculture
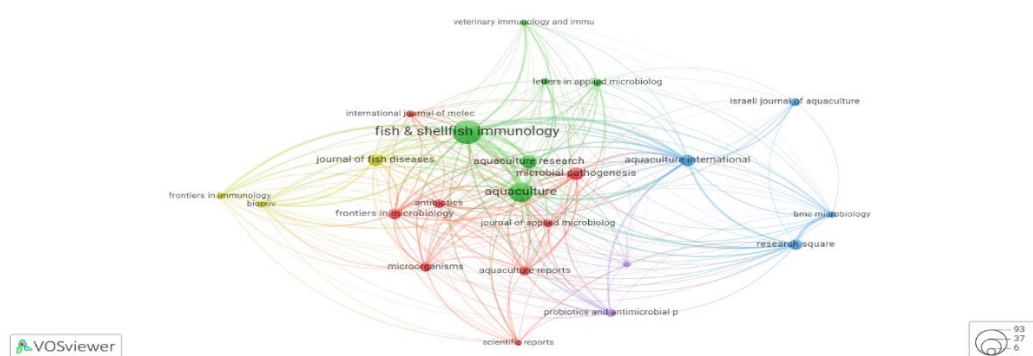
Figure 9: Distribution of journals pertaining to the emergence of *Aeromonas* in aquaculture as a pathogen visualized using VOSviewer

Upon closer analysis, it becomes evident that several academic journals, specifically Antibiotics, Biorxiv, Microorganisms, Frontiers in Immunology, and Aquaculture International, demonstrate an increase in user involvement in their recent articles (refer to Table 2).

JOURNAL	DOCUMENT	CITATIONS	AVG. PUB. YEAR
Antibiotics	11	73	2021.4545
Biorxiv	7	8	2021.2857
Microorganisms	12	93	2021.25
Frontiers in Immunology	6	76	2021.1667
Aquaculture International	20	108	2021

Table 3: Recent publications involved in dissemination of articles

3.6 Keyword Analysis

The use of keywords in research documents is of paramount importance as they serve to align with the main findings of the study. The application of statistical analysis on keywords provides significant insights into the current trends within a particular study domain, facilitating the monitoring of the advancement and development of the subject at hand (Tamala *et al.,*2022). In the current investigation, out of the total number of publications that were evaluated, only 591 items were found to meet the set threshold value. Moreover, out of this selection, a total of only 355 keywords were selected for subsequent study. To enhance the potential for future research, terms that had semantic and contextual similarity were excluded. Keywords that do not have scientific implications were omitted. The diagram depicted in Figure 8 presents the top 10 terms that demonstrate the highest link strength, together with their associated frequency of occurrence.
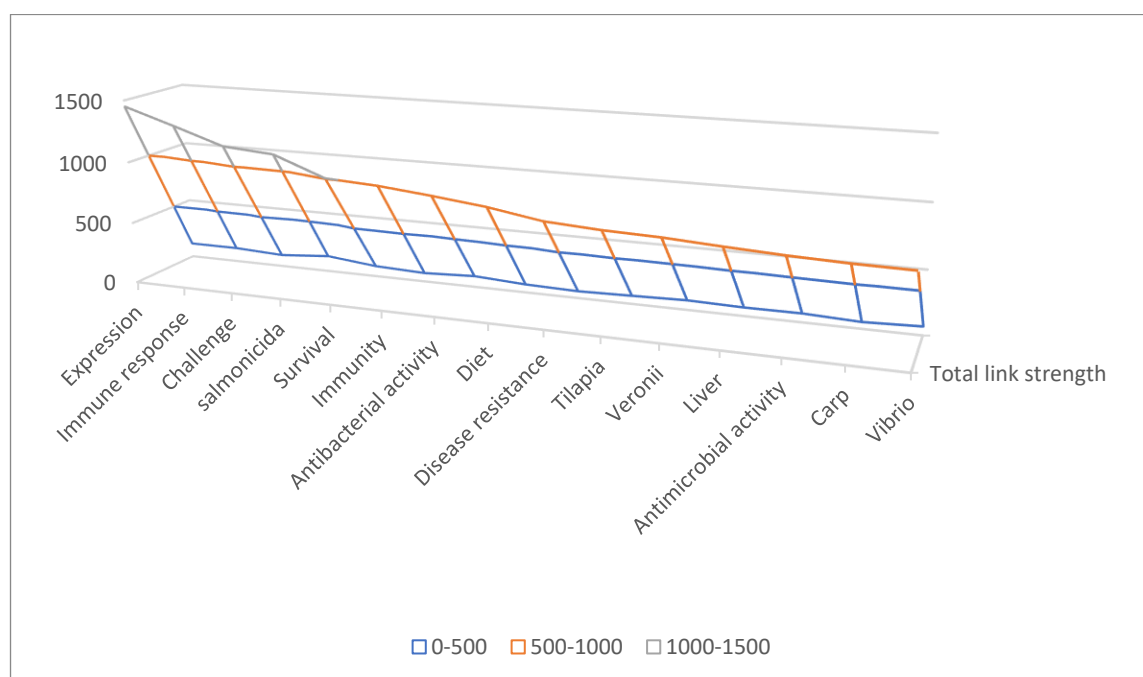
Figure 10: Top 10 keywords that exhibit the highest total link strength

The VOS viewer software was employed to create a keyword concurrence network, which visually depicts the relationships between terms and their corresponding link strengths. The magnitude of the circle exhibits a direct proportionality to the frequency of the keyword. The findings of the study indicate that a variety of keywords were classified into six discrete clusters, wherein each cluster is denoted by a certain color.

The first cluster has keywords that delineate a range of bacterial strains that are widely recognized as pathogens, encompassing *Vibrios, Pseudomonas*, and *Aeromonas* and many more. Since ages aquaculture has been severely impacted by vibriosis disease, which is caused by antibiotic-resistant strains of *Vibrio spp*. (Sheikh *et al.,*2022). One of the prominent bacterial species that negatively impacts the aquaculture sectors in terms of economic losses. *Vibrio* species, *including V. cholerae, V. parahaemolyticus, V. vulnificus, V. alginolyticus, V. funissii, V. fluvialis, V. damselae, V. mimicus, V. hollisae, V. cincinatiencis, V. harveyi,* and *V. metchnikovii*, are frequently encountered pathogens that can be transmitted through the consumption of contaminated water or

food (Zhang *et al.,*2020). Aquatic environments serve as the native habitats for these species, where they exist either in symbiotic or pathogenic relationship with eukaryotic organisms. They pose a significant risk to both human people as they are zoonotic in nature. Arunkumar et al. (2020) and Dalsgaard (1998) have documented that these microorganisms can induce a range of infections, varying from mild to severe, including but not limited to cholera, vibriosis, gastroenteritis, and septicemia.

Although *Pseudomonas spp*. have been characterized as opportunistic pathogens, numerous species have also been identified as the primary causative agents of various diseases in farmed fish. These are known to induce stress-related illnesses in freshwater fish, particularly in aquaculture settings (Duman *et al.,*2021). Several species of *Pseudomonas* have been well documented as pathogens, including *P. aeruginosa, P. anguilliseptica, P. baetica, P. chlororaphis, P. fluorescens, P. koreensis, P. luteola, P. plecoglossicida, P. pseudoalcaligenes,* and *P. putida* (Liu *et al.,*2022; Ricahards, 2014 and Gołaś *et al.,*2019).

Aeromonas, which falls under the class γ-Proteobacteria, is a widely distributed bacterium found in both terrestrial and aquatic environments. In Salmonids they are widely recognized as enteric pathogens that induce haemorrhagic septicaemia, fin rot, soft tissue rot, and furunculosis. According to the study conducted by Fečkaninová et al. (2017), several pathogenic motile *Aeromonas* species, including *A. hydrophila, A. veronii, A. jandaei, A. caviae, A. sobria, A. bestiarum, A. dhakensis,* and *A. schubertii*, have been documented in aquaculture as pathogenic organism. These species have been associated with disease outbreaks, resulting in mortality rates of up to 100% (Nhinh *et al.,*2021; Dien *et al.,*2022; Park *et al.,*2020 and Mallik *et al.,*2020).
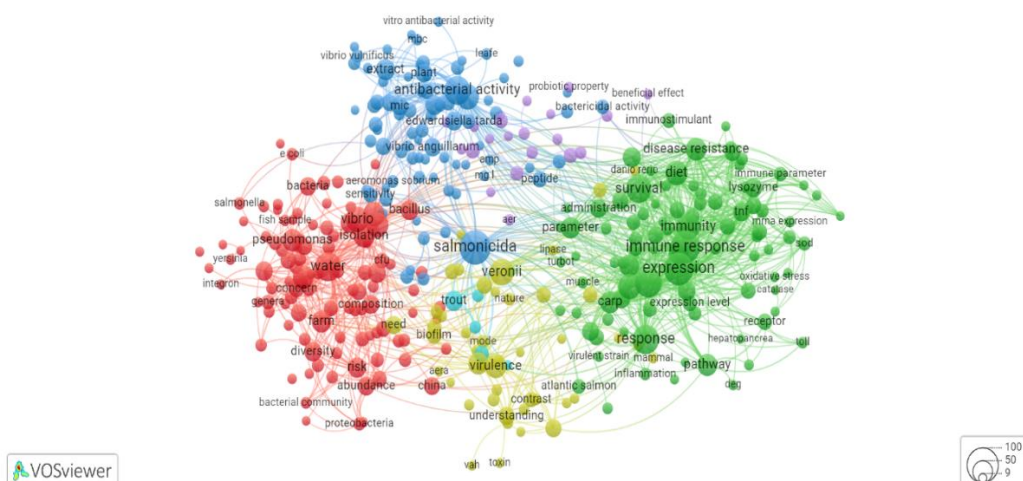
Figure 11: A visual representation of a keyword concurrence network showcasing the connections between various keywords.

Cluster two is centred on the examination of immunological responses elicited by aquatic species in response to different diseases. The three primary keywords identified inside cluster 2 are "expression," "immune response," and "challenge." Challenge experiments are a crucial component of studies aiming to establish Koch's Postulates, which serve to validate the pathogenicity of a given pathogenic organism (Shahi *et al.,*2020). When an organism is exposed to a pathogen, it exhibits diverse defence mechanisms and activates genes associated with immunity in fish (Maekawa *et al.,*2019). Additional keywords present in the cluster encompass SOD, Lysozyme, and alkaline phosphatase. Superoxide dismutase (SOD) is a very significant enzyme that plays a crucial role in the physiological response to oxidative stress. The primary role of this is to facilitate the conversion of toxic superoxide anions into hydrogen peroxide.

The enzyme alkaline phosphatase plays a pivotal role in metabolic regulation by directly participating in the transfer of phosphate groups and the regulation of calcium phosphorus metabolism. The enzymatic activity of alkaline phosphatase possesses the capability to alter the surface architecture of pathogens, hence augmenting the mechanisms involved in pathogen identification and engulfment by phagocytes. Similarly, the function of lysozyme plays a significant role in non-specific humoral immunity, giving it precedence over cellular defence mechanisms (Hu *et al.,*2017 and Zhao *et al.,*2022).

Cluster 3 primarily encompasses keywords such as minimum inhibitory concentration, antibacterial activity, antimicrobial activity, plants, and nanoparticles. This suggests that this segment primarily centres around

various substances that can be employed for the management of pathogenic organisms in aquaculture. The global popularity of different plants as anti-microbials has surged due to their convenient preparation, affordability, and minimal impact on animals and the environment (Van Hai, 2015).

According to Reverter et al. (2014), it has been documented that plant-derived products possess the ability to improve fish health. Additionally, these products have been found to exhibit immunostimulatory effects and demonstrate antibacterial and anti-parasitic properties in the context of fish and shellfish aquaculture. These beneficial effects can be attributed to the presence of bioactive compounds such as alkaloids, terpenoids, saponins, and flavonoids which exert various effects, ranging from direct actions on aquatic pathogens and intestinal flora to influences on nutrient consumption, metabolism, oxidative state, and immunology (Hernández-Contreras & Hernández, 2020).

The utilization of nanotechnology, specifically nanoparticles, is a promising strategy in addressing infections. Nanotechnology is an emerging and rapidly expanding interdisciplinary domain that encompasses the integration of various scientific disciplines (Pratik *et al.,*2012). There is a wealth of current literature available that elucidates the pivotal function of nanoparticles in antibacterial strategies. Nanoparticles possess enhanced capabilities, such as increased permeability across cellular membranes and the ability to target various areas inside an organism. These attributes render them more efficacious in combating drug-resistant bacteria compared to traditional antibiotics, as supported by studies conducted by Nithya *et al.,* (2017), Dhasmana *et al.,*2021 and Swain *et al.,* (2014).

Cluster 4 encompasses various virulent components, such as biofilm formation, adhesins, hemolysins, quorum sensing, lipases, and proteolytic enzymes, which are crucial for the pathogen to exert its pathogenic effects (Defoirdt, 2013; Zhang & Li, 2021). The virulence of microorganisms that infect aquaculture systems is intricately linked to the secretion of virulence factors and the development of biofilms, both of which are governed by a phenomenon known as quorum sensing (QS) (Zhao *et al.,*2014; Arunkumar 2020; Chenia and Duma, 2016).

The adherence of bacteria to mucus appears to be a necessary condition for the onset of infection, therefore can be regarded as fundamental virulence determinants (Hamed *et al.,*2018; Sakai *et al.,*2009 and Ellul *et al.,*2021). Bacterial hemolysins are cytolytic toxins that are commonly regarded as virulence factors. The toxicity of these substances extends beyond erythrocytes and affects various other cell types (Rodkhum *et al.,*2005; Pessoa *et al.,*2020; Sarkar *et al.,*2021).

The presence of keywords such as probiotics, lactic acid bacteria, and Bacillus subtilis suggests that cluster 5 focuses on the utilization of different probiotics to enhance fish health and modulate the immune system, hence offering defence against various harmful organisms. The production of bacteriocins, siderophores, lysozymes, proteases, and hydrogen peroxides by probiotic microbes has been found to effectively suppress the growth of pathogenic microorganisms (El-Saadony *et al.,*2021; Dawood *et al.,*2018; Govindaraj *et al.,*2021). Bacillus species are commonly employed as probiotics in various aquatic organisms. There are now various probiotic species from the Bacillus genus being utilized, with Bacillus subtilis being one such probiotic. Additionally, Lactic Acid Bacillus, which has antagonistic activity against fish infections, holds promise as a prospective candidate probiotic in the field of aquaculture in the future (Nayak, 2020 and Ringø *et al.,*2005).

Cluster 6 comprises several frequently cultivated fish species, such as salmonid, trout, and Oncorhynchus mykiss.

Figure 12 illustrates the temporal distribution of various keywords, including aerolysin, *Aeromonas*, and toll-like receptors.

4. Conclusion

The present study utilized bibliometric analysis to examine the growth of Aeromonads as pathogens in the field of aquaculture from the years 2004 to 2023. Over the course of the previous 20 years, there has been a discernible and steady increase in the output of scholarly publications, which has been accompanied by a significant degree of international collaboration. Based on the available statistics, it can be observed that China has emerged as the nation with a substantial share of articles, closely trailed by India. The Chinese Academy of Fishery Science has been identified as the academic institution with the highest number of published papers. The key academic journals involved in the transmission of information on *Aeromonas* as a pathogen in aquaculture includes Fish & Shellfish Immunology, Aquaculture, and Aquaculture Research.

Despite the important findings of the study, it is crucial to highlight the presence of various limitations. Instead of employing many sources, we exclusively relied on a single database for the purpose of retrieving information. The potential omission of several essential articles may have occurred due to the exclusion and lack of study of publications beyond the Dimensions database. Therefore, it is essential that future research endeavours incorporate a wide array of databases to retrieve publications and utilize text mining tools to enhance the accuracy and precision of the results. This methodology would serve to augment the accuracy and scholarly rigor of the analysis. In brief, the results obtained from the bibliometric study provide insights into the global research trends on emergence of Aeromonas as emerging pathogens in aquaculture.

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