integrity Research Journals

Global Journal of Fisheries Science
Volume 6(3), pages 70-85, August 2024
Article Number: 02C619123
ISSN: 2782-750X
https://doi.org/10.31248/GJFS2024.058
https://integrityresjournals.org/journal/GJFS

Full Length Research

Mapping the research landscape: A bibliometric analysis of Tilapia Lake Virus disease worldwide

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Received 9th July 2024; Accepted 18th August 2024

ABSTRACT: Tilapia Lake Virus (TiLV) poses a significant threat to global tilapia populations, impacting food security and the aquaculture industry. This comprehensive bibliometric assessment scrutinizes TiLV disease research publications between 2012 and 2023 from 46 countries, sourced from the Scopus database. Utilising Scopus and VOSviewer for qualitative and quantitative analyses, the study evaluated 168 publications, accumulating 3718 citations at an average of 22.1 citations per article across 71 journals. Key contributions came from journals like Aquaculture and Journal of Fish Diseases, while prolific authors associated with Thai institutions spearheaded robust international collaborations. More than 70% of TiLV publications originated from ten countries, notably Thailand, India, the US, China, and Germany, indicating their significant interests in aquaculture. The study identifies pivotal trends, noteworthy contributors and institutions, research themes, geographical research distribution, and future research directions. The publication trajectory signals the heightened recognition of TiLV disease's importance in tilapia aquaculture. Profiling prolific authors and institutions provides insights into the evolving research landscape. Analysis of term co-occurrence delineates predominant research themes, traversing diagnosis, epidemiology, pathogenesis, and control strategies in TiLV disease. Global dissemination of research contributions signifies a strong global network of scientists engaged in TiLV research. Nevertheless, discernible disparities in research output among regions underscore the necessity for capacity building and enhanced collaboration, particularly in developing nations. This assessment identifies critical future research directions, stressing the urgency for improved diagnostic tools, understanding pathogenesis, vaccine development, enhanced biosecurity measures, regional collaboration, sustainable aquaculture practices, public awareness and education, continuous monitoring and surveillance, research funding, and a multidisciplinary approach. Addressing these research paths could significantly advance efforts to combat TiLV disease and fortify the global tilapia aquaculture industry against this dangerous pervasive pathogen.

Keywords: Bibliometric analysis, food security, research trend, tilapia, tilapia lake virus infection, tilapia lake virus disease

INTRODUCTION

Tilapia, scientifically known as *Oreochromis spp*., is one of the most widely farmed fish species, thriving in over 140 countries. Tilapia's popularity stems from its exceptional attributes, including high protein content, high fecundity, rapid growth, adaptability to diverse geographical regions, and substantial size. This aligns with the surging global demand for aquaculture-derived protein. As a result, intensified tilapia farming systems have increased the incidence of diseases, attributed to bacteria, viruses, parasites, and fungi, causing considerable economic losses within the tilapia industry and its related sectors (FAO, 2022).

Tilapia Lake Virus (TiLV) has continued to emerge as a global viral pathogen responsible for massive episodes of mortality in cultured and wild tilapia (*Oreochromis spp.* and hybrids) across Asia, Africa, Central America, South

America (Fathi *et al.,* 2017; Jansen *et al*., 2018; OIE, 2018a) and North America. Since 2014, instances of TiLV disease have been reported globally, causing mortality rates ranging from 10% to 90% among tilapia fry, juveniles, grow-out and adults, thus imposing substantial economic losses (Fathi *et al*., 2017; Jansen *et al.,* 2018). Presently, the disease has been confirmed in several countries, including Colombia, Ecuador, Egypt, India, Indonesia, Israel, Malaysia, Mexico, the Philippines, Peru, Tanzania, Thailand, Bangladesh, Uganda, and the U.S. While TiLV has become a recurring threat, it has not been identified in Canada (Eyngor *et al*., 2014; Ferguson *et al*., 2014; Kembou -Tsofack *et al.,* 2017; Koesharyani *et al.,* 2018; Mugimba *et al*., 2018; Nicholson *et al*., 2017; OIE, 2018a; OIE, 2018b; Subramaniam *et al*., 2019; Tattiyapong *et al.,* 2023).

Timely diagnosis and reporting of TiLV are vital. Naturally infected tilapia displays clinical signs, including anorexia, exophthalmia, skin abrasions, and haemorrhages, with accompanying histopathological findings, such as syncytial giant cells formation, intracytoplasmic inclusion bodies, and hepatic, myocardial and renal tubular necrosis (He *et al*., 2023). Experimental infections with TiLV are associated with high mortality rates exceeding 90% in healthy Nile tilapia, demonstrating clinical signs and tissue lesions similar to those found in naturally infected tilapia. These infections result in various tissue lesions, including vacuolation and necrosis in the brain, inclusion bodies and necrosis in the heart, and megalocytes and necrosis in the intestine. The presence of TiLV has been confirmed in multiple organs, with the liver, kidney, spleen, and brain being the primary target tissues (He *et al.,* 2023).

Aquaculture plays a pivotal role in securing food supplies and livelihoods, particularly in low and middle-income countries (LMICs). Regrettably, the emergence of the Tilapia Lake Virus (TiLV) has negatively impacted this industry, representing a substantial threat to food production and economic stability for countless individuals (Behera *et al*., 2018; Lakshmi *et al*., 2023). Compounding the issue, there is currently a notable absence of established treatments or commercially available vaccines to effectively counteract TiLV infections (Kembou-Ringert *et al*., 2023). This lack of remedies further exacerbates the challenges faced by aquaculture stakeholders in their battle against this viral pathogen.

Additionally, TiLV poses a significant peril to the global tilapia industry, valued at approximately US $7.5 billion annually (Chong, 2022). It has a devastating impact on tilapia populations, with mortality rates reaching as high as 90% in certain instances (Bacharach *et al.,* 2016). Given the profound implications of TiLV, this bibliometric study underscores the imperative need for collaborative, multidisciplinary efforts within the scientific community. By addressing critical research gaps and advocating for enhanced scientific cooperation (Surachetpong *et al*., 2020).

Consequently, this study is designed to offer a comprehensive understanding of the global research landscape related to Tilapia Lake Virus Disease (TiLVD). Recognizing the significant implications of TiLVD for tilapia populations worldwide, our goal is to assess the current state of TiLVD research, identifying trends, key contributors, research themes, gaps, and areas that require further exploration.

Bibliometric analysis is a valuable methodology for objectively assessing scientific literature by quantifying publication patterns and identifying influential works, authors, and research institutions. In this context, it enables us to explore the multifaceted dimensions of TiLVD research systematically (Pendlebury, 2010).

By addressing some of these questions, this bibliometric analysis will serve as an invaluable resource for researchers, policymakers, and stakeholders in the field of TiLVD. It is intended to provide insights into the current state of TiLVD research and offers directions for future investigations, ultimately contributing to our collective efforts to combat this global challenge.

MATERIALS AND METHODS

Data source

Relevant documents were obtained from the Scopus database, which is hosted by Elsevier in the Netherlands. The retrieval was conducted on October 4th, 2023. The search employed specific strings including “Tilapia Lake Virus,” “TiLV,” “Tilapia Tilapinevirus,” “Tilapia Lake Virus Disease,” and “Tilapia Lake Virus Infection.” These searches were performed within the Title-Abstract-Keyword field. The search covered articles from the period 2012 to 2023. Initially, 187 publications were retrieved. Subsequently, these documents underwent manual screening to eliminate duplications, non-English communications, and topics that did not align with the scope of the investigation. Following this process, 168 relevant documents were saved as a *.csv file and later exported to VOSviewer for bibliometric analysis.

Data analysis

The bibliometric methodologies employed by Elisha and Viljoen (2021), and further enhanced in their subsequent work in Elisha *et al*. (2023) were applied with specific adaptations in this study. To scrutinize the acquired documents, Scopus' inherent "data analysis" feature was utilized. Moreover, VOSviewer, a tool for analyzing term co-occurrence within all keyword fields, was employed to construct term maps. These maps facilitated the examination of prevalent research themes within the bibliographic data. While predominantly adhering to default settings, certain adjustments were made to

parameters, enabling the generation and analysis of network maps and other visual representations.

Reasoning behind the selection of the Scopus database

Scopus database was chosen due to its extensive repository of scholarly literature spanning various disciplines which includes science, technology, medicine, social sciences, and the arts and humanities (Falagas and Pitsouni, 2008). This broad spectrum of publications provides researchers with access to a diverse array of relevant literature and research outputs. Furthermore, Scopus aggregates content from worldwide sources including journals, conference proceedings, and patents, allowing for comprehensive international-scale analyses of trends, collaborations, and research impact (Pendlebury, 2010). Regular updates ensure that Scopus remains current, granting users access to the latest research findings, which is vital for staying abreast of recent advancements in specific fields (Harzing, 2007; Kwanya, 2021). Its citation analysis capabilities are invaluable for tracking the impact of articles, authors, or institutions over time, thereby facilitating a deeper understanding of scholarly interactions (Van Raan, 2004).

The author profiles available in Scopus furnish comprehensive information on an author's publications, affiliations, citation metrics, and collaborations. This feature aids in constructing a holistic view of an author's research contributions and network connections (Thelwall and Kousha, 2016). Additionally, Scopus' broad coverage across disciplines promotes interdisciplinary research, fostering innovative collaborations and discoveries across seemingly disparate fields (Bornmann and Leydesdorff, 2014).

RESULTS AND DISCUSSION

Publication summaries, growth patterns and research emphasis on TiLV disease retrieved from Scopus database, 2012 – 2023. From 2012 to 2023, the global discourse on TiLV disease witnessed significant contributions from forty-six (46) nations, resulting in the compilation of 168 publications. These publications collectively amassed 3718 citations, averaging 22.1 citations per article (CPA), see Figure 1. These 168 documents were distributed across various categories, covering research articles (88.1%), reviews (7.7%), book chapters (1.2%), conference papers (1.2%), letters and notes (1.8%) respectively.

The corpus of literature emerged from a total of 71 journals. Notably, only 7.0% of these publications originated from sources that published five or more articles during the reviewed period. The Aquaculture demonstrated significant involvement, contributing 41 documents (57.7%) and amassing 1180 citations. Following closely, the Journal of Fish Diseases contributed 28 publications (39.4%) and accrued 598 citations. Additional sources included Fish and Shellfish Immunology (9 publications: 126 citations), Viruses (8 documents: 109 citations), and Transboundary and Emerging Diseases (5 publications: 49 citations). Visual representation in Figure 2 showcases the top contributing sources, with node size directly correlating with publication output (Van Eck *et al*., 2010). The proximity or thickness of connecting lines, such as the link between Aquaculture and the Journal of Fish Diseases (Figure 2), indicates a strong correlation in their utilization of similar references or co-citation within their publications, potentially reflecting similarities in their thematic scope.

A total of 675 researchers participated in the writing of 168 publications, leading to an average of four authors per publication. Merely 6.5% of these authors had a record of contributing five or more papers (Figure 3). The top contributor, Surachetpong W, affiliated with Kasetsart University in Thailand, stands out prominently with 44 publications. The author's publications span the domains of immunology, microbiology, and biological sciences. Surachetpong exhibits robust collaborative partnerships with co-authors hailing from various countries including the USA, Germany, Poland, Switzerland, Brazil, Spain, the United Kingdom, Bangladesh, Belgium, Canada, China, France, Italy, Singapore, South Africa, and Taiwan. It is noteworthy that Tattiyapong P, also affiliated with Kasetsart University, co-authored a significant 52.3% of Surachetpong's publications, likely stemming from their shared institutional affiliation and common research areas.

Another prolific contributor in the field of TiLV disease research is Tattiyapong P, having authored 23 publications. The subject areas covered in the author's publications include immunology, microbiology, and biological sciences, with affiliations from Kasetsart University in Thailand. Co-authorship connections extend to countries such as the USA, Switzerland, China, Germany, Italy, South Africa, and the United Kingdom.

Senapin, affiliated with the Thailand Center for Genetic Engineering and Biotechnology in Pathum Thani, Thailand, emerged as the third most productive author, contributing to 21 papers. The author's expertise revolves around veterinary and biological sciences, fostering international collaborations with authors from Thailand, Malaysia, Bangladesh, Vietnam, Norway, the United Kingdom, Australia, Japan, New Zealand, and Nigeria (Figure 3).

Thailand's scholarly contributions proved substantial across the 168 publications, as depicted in Figure 4**,** showcasing the nation's collaborative ties with authors from other countries. The growth witnessed in TiLV disease publications could be attributed to the robust research collaboration among all contributing nations.

A total of 515 institutions participated in collaborative efforts leading to the publishing of 168 publications across

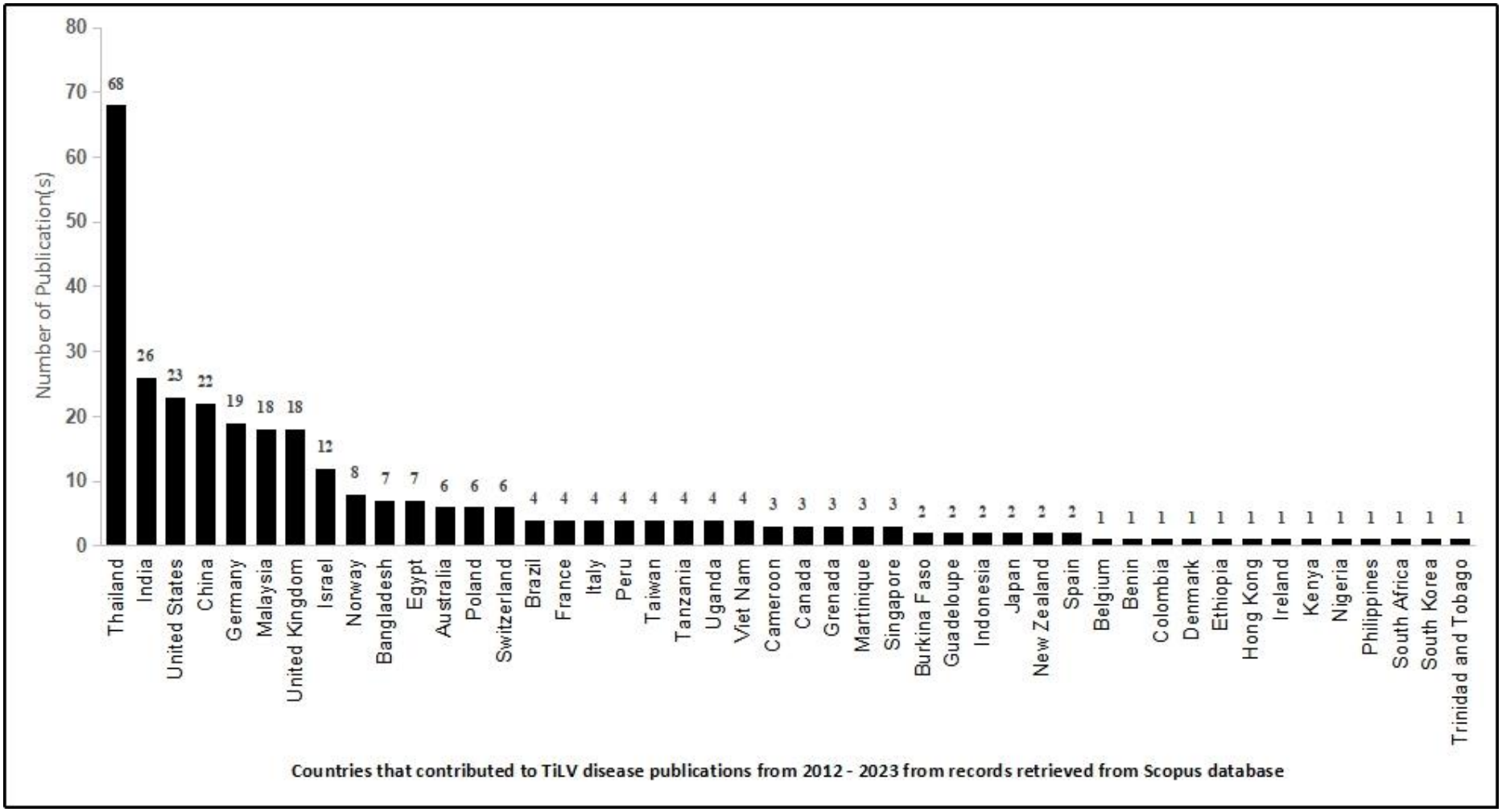

Figure 1. Bar chart of the 46 countries that contributed to TiLV disease publication(s) from 2012 -2023. Records retrieved from Scopus database, N = 168.

46 countries. It is noteworthy that a mere 1.7% of these institutions significantly contributed to publications numbering five or more.

Examining the top institutional contributors in the research landscape, Kasetsart University stands out with 52 publications accumulating 1105 citations. This institution's expertise spans agricultural and biological sciences, immunology, microbiology, and veterinary science. Following closely is the Thailand National Science and Technology Development Agency, which contributed 22 publications and garnered 501 citations, focusing on agricultural and biological sciences, as well as veterinary science. Additionally, the Thailand National Center for

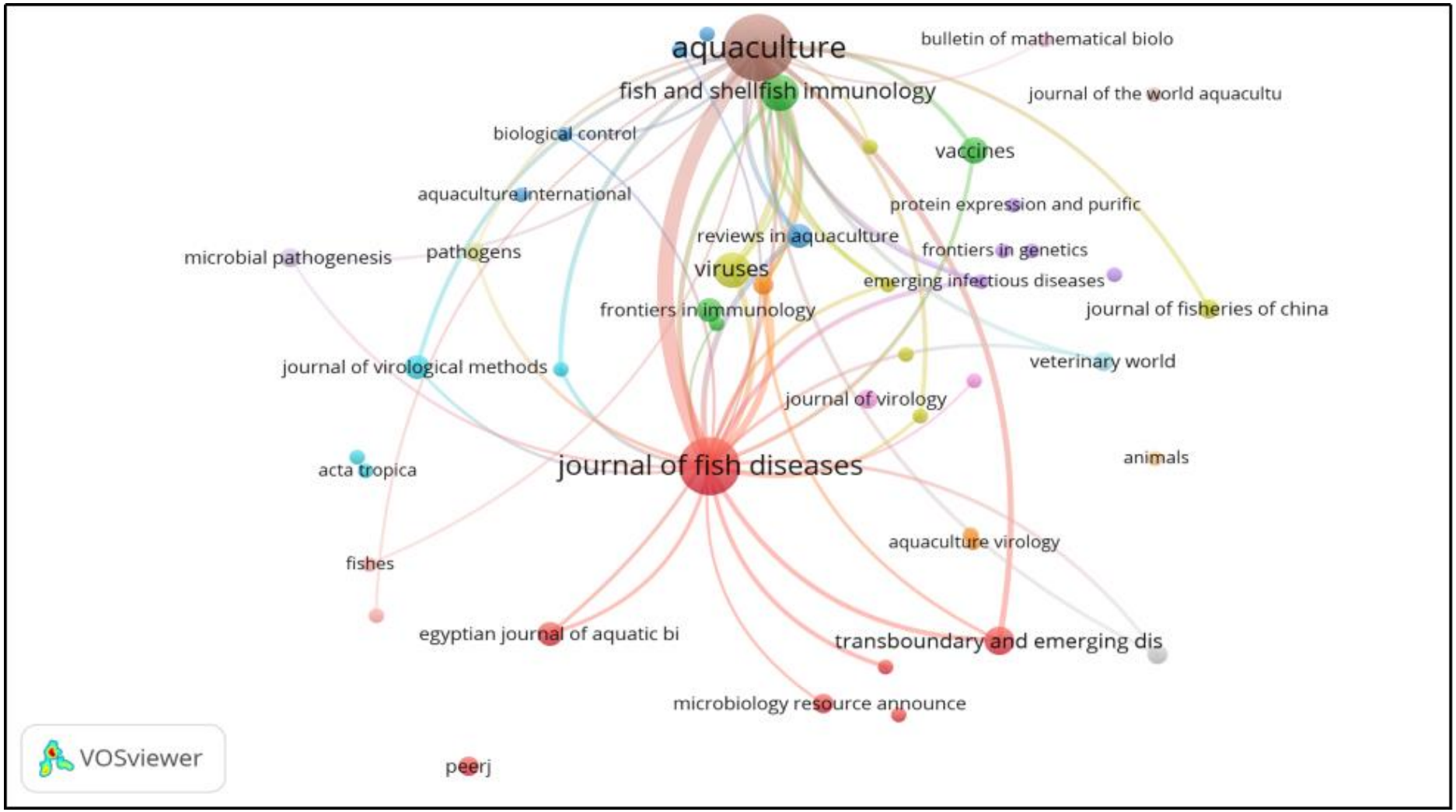

Figure 2. Network visualization of sources of TiLV disease publications retrieved from Scopus database, from 2012 – 2023, N = 168 documents.

Genetic Engineering and Biotechnology contributed 21 papers accumulating 490 citations, showcasing strengths in biological sciences, veterinary science, biochemistry, genetics, and molecular biology. Mahidol University in Thailand also made a significant impact with 20 publications and 488 citations, with expertise in biological and veterinary science. Rounding up the top five contributors is Chulalongkorn University with 19 papers and 458 citations, encompassing agricultural and biological sciences, veterinary science, immunology, microbiology, and environmental

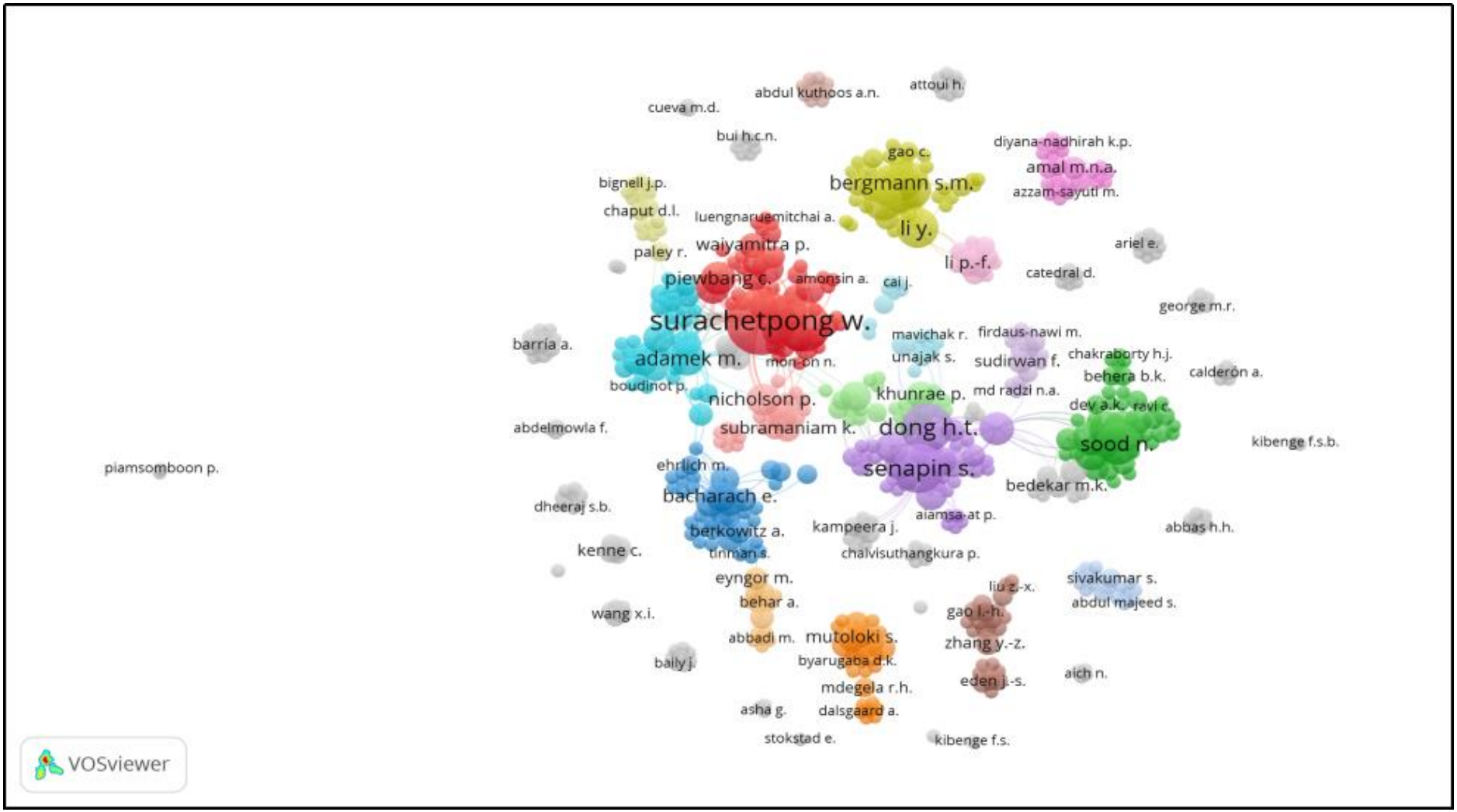

Figure 3. Network visualization of co-authorship association of all contributing researchers in 168 articles related to TiLV Disease retrieved from Scopus database during 2012 – 2023.

science.

An intriguing observation is the dominance of Thai funding bodies in the TiLV disease research landscape. Notably, the National Research Council, Chulalongkorn University, and the Center for Advanced Studies for Agriculture and Food, KU Institute for Advanced Studies at Kasetsart University, Thailand emerged as top contributors, representing 8.9%, 7.7%, and 7.1% of the total

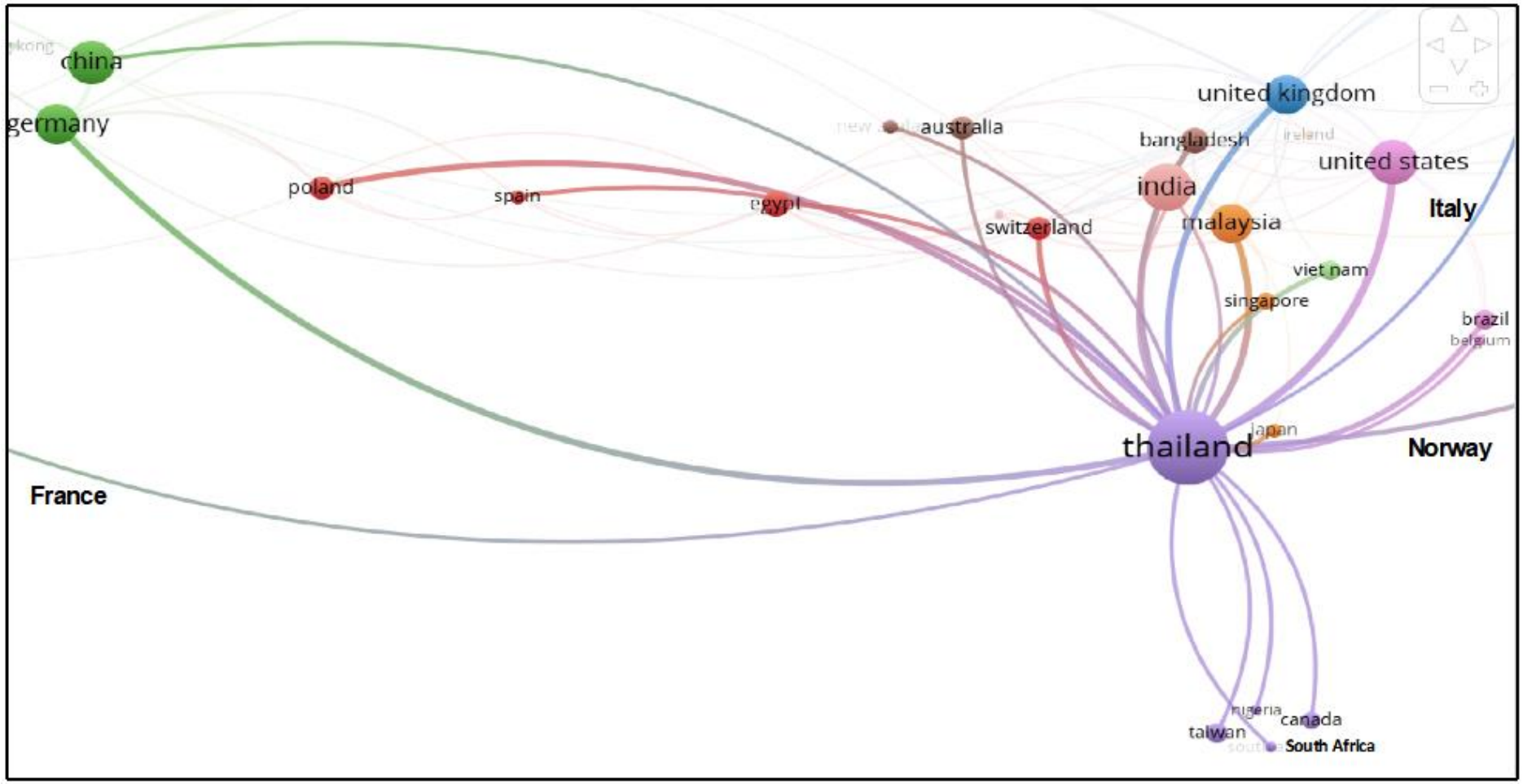

Figure 4. Network visualization of publication co-author links between Thailand, the top publication contributor with 26 other countries, (n = 68).

publications, respectively.

The concentration of contributions from a small fraction of institutions highlights the significant role played by select academic entities in advancing TiLV disease research. Kasetsart University's prominence, evident from both publication volume and citations, underscores its leading position in this domain. Moreover, the prevalence of Thai institutions among the top contributors and funding bodies signifies the regional focus and commitment to addressing TiLV, showcasing the collaborative efforts within Thailand's scientific community.

These findings emphasize the necessity for further international collaborations to broaden the research scope and enhance the global understanding of TiLV disease, ensuring a comprehensive approach towards its prevention and management. Additionally, while these institutions have made

substantial contributions, fostering diversity in research partnerships and widening the participation of institutions globally can enrich the knowledge pool and drive innovation in combating TiLV disease (Dong *et al*., 2017b; Senapin *et al*., 2018; Ahasan *et al*., 2020).

Multidisciplinary landscape of TiLV disease research: subject area analysis of 168 publications from Scopus database

The analysis of 168 publications on Tilapia Lake Virus (TiLV) diseases retrieved from the Scopus database reveals a diverse spectrum of subject areas that cover this research domain. These publications primarily converge within the realms of agriculture and biological sciences, constituting the largest share at 64.3 per cent. This emphasizes the substantial attention and focus dedicated to understanding TiLV disease from an agricultural and biological standpoint, likely centred around its impact on aquaculture and the ecological aspects concerning affected aquatic environments (Figure 5).

Following agricultural and biological Sciences, immunology and microbiology represent a significant portion at 30.4 per cent. This substantial contribution underscores the exploration of TiLV disease mechanisms, including immunological responses and microbial factors influencing the disease's pathogenesis and spread. The veterinary field accounts for 23.8% of the publications, indicative of a concentrated effort to comprehend the disease concerning its effects on fish health and the veterinary aspects associated with TiLV infections in Tilapia. Furthermore, medicine (17.3%) and biochemistry, genetics, and molecular biology (12.5%) denote a crossover into areas potentially examining the disease's implications on human health, genetic predispositions, and molecular mechanisms underlying TiLV infections. Environmental science (11.3%) reflects the concern for the ecological impact of TiLV, including studies exploring how the disease affects the surrounding environment and its inhabitants beyond direct host organisms (Figure 5).

However, it is noteworthy that neuroscience (3.0%), pharmacology, toxicology, and pharmaceutics (3.0%) fields constitute a smaller yet non-negligible portion of TiLV-related research, suggesting potential investigations into neurological aspects of the disease and pharmacological interventions. The "others" category (9.5%) signifies additional subject areas beyond the delineated classifications, showcasing the multidisciplinary nature and diverse research approaches applied in comprehending TiLV diseases (Figure 5).

The diverse distribution of subject areas across TiLV-related publications underscores the multidimensional nature of research undertaken in understanding and addressing TiLV diseases. The preponderance of studies within agriculture and biological sciences highlights the critical focus on the disease's impact on aquaculture and the biological intricacies surrounding TiLV infections in Tilapia populations. Moreover, the inclusion of immunology, microbiology, veterinary, medicine, biochemistry, genetics, and molecular biology indicates a comprehensive approach towards unravelling TiLV's multifaceted nature, spanning from the molecular and immunological underpinnings to its veterinary and potential human health implications (Adamek *et al.,* 2022; Wang *et al*., 2023).

The presence of environmental science underscores the holistic approach to comprehending the broader ecological ramifications of TiLV infections, recognizing the interconnectedness between disease, aquatic environments, and other organisms. However, the relatively limited representation of neuroscience, pharmacology, toxicology, and pharmaceutics areas suggests potential avenues for further exploration and collaboration, highlighting the need for interdisciplinary research to comprehensively address TiLV diseases and their impacts across various scientific domains.

Analysis of the global annual publications on Tilapia Lake Virus Disease (TiLV) from 2012 to 2023

The annual global publication growth rate on Tilapia Lake Virus Disease is 47.5 per cent. It can be inferred as a positive trajectory during the period under review. Figure 6 shows that the number of publications on TiLV disease has increased steadily over time, from 1 in 2012 to 33 in 2021 and 2022. However, there is a noticeable gap in publications between 2013 and 2015, with no publications recorded during those years. There are a few possible explanations for this gap. One possibility is that TiLV was not yet widely recognized as a major threat to the tilapia industry during this period. Another possibility is that research on TiLV was still in its early stages, and there were not yet many researchers working on the field. The publication pattern from 2016 to 2021 shows a steady increase in publications, with the number of publications doubling each year. Firstly, advancements in diagnostic techniques and tools may have facilitated easier detection and identification of Tilapia Lake Virus Disease. As researchers gain access to improved methods for studying pathogens, they are more likely to investigate and publish their findings on emerging diseases like the Tilapia Lake Virus. Additionally, increased awareness about the economic impact of Tilapia lake virus disease on aquaculture industries may have motivated researchers to focus their efforts on understanding its etiology, transmission dynamics, and potential control measures (Surachetpong *et al*., 2020).

Furthermore, international collaborations and networking among researchers may have played a role in the increased publication output. As scientific communities become more interconnected, researchers are exposed to a broader range of research topics and are encouraged to collaborate on global health issues. This collaboration can lead to more comprehensive studies and subsequently

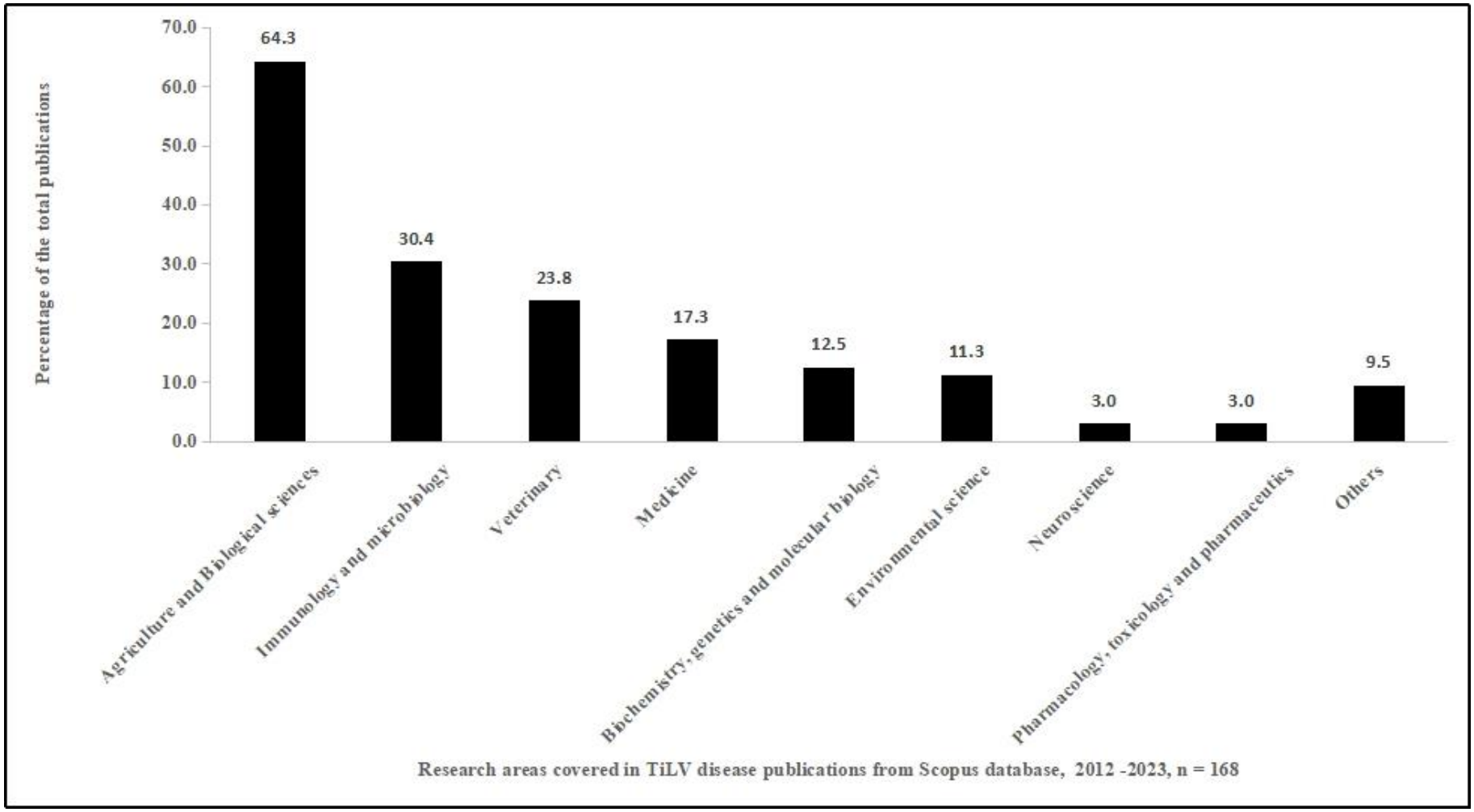

Figure 5. Graph showing the different research areas covered by the 168 publications related to Tilapia lake virus disease from 2012 -2023, from the Scopus database.

more publications. This suggests that TiLV research is a rapidly growing field and that there is increasing interest in this field. The plateau in publications between 2021 and 2022 (Figure 6) could be due to a number of factors, such as the COVID-19 pandemic, which disrupted research activities around the world. It is also possible that researchers are taking more time to publish their work, as they are conducting more complex and sophisticated studies on TiLV. It is also worth considering that the plateau in publications between 2021 and 2022 may simply be an anomaly or a temporary fluctuation rathe than a significant trend. Research output can vary from year to year due to various factors such as funding availability, individual research projects, or changes in researcher priorities.

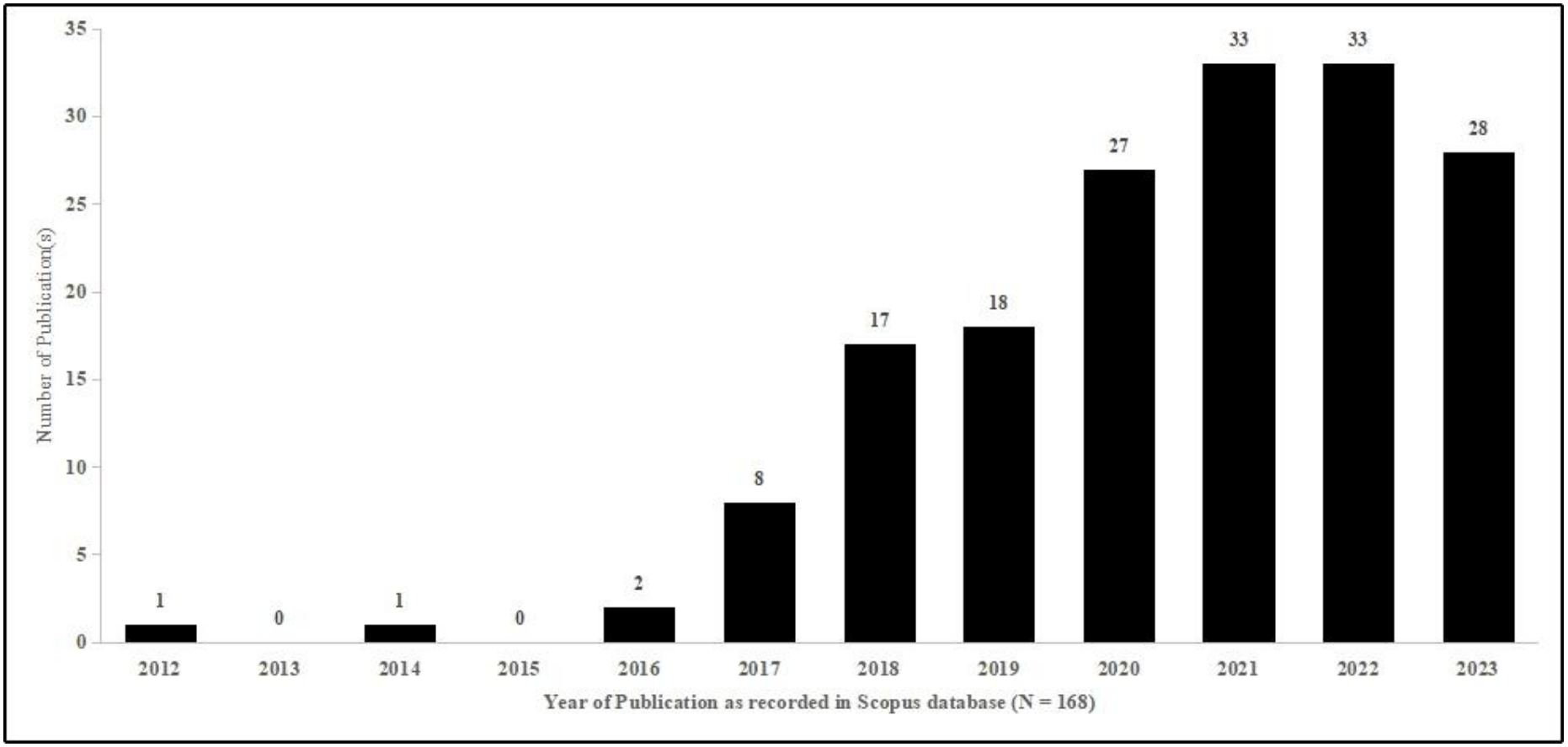

Figure 6. Annual global publication patterns on Tilapia Lake Virus diseases as recorded in the Scopus database, (N = 168).

Global landscape of Tilapia Lake Virus (TiLV) research: A comprehensive analysis of top 10 high-producing countries

These top 10 high publishing countries account for over 70% of all TiLV publications during this period. It is worth noting that all of the countries in the top 10 are either major producers or consumers of tilapia, or have significant research interests in aquaculture diseases. Thailand is the leading country in terms of TiLV research, with 40.5% of all publications (Figure 1)**.** This high publication output suggests that Thailand has been at the forefront of research on TiLV disease. The country's strong presence in aquaculture and its significant tilapia farming industry likely contribute to its active research efforts in this field (Dong *et al.,* 2017a; *Surachetpong et al*., 2020). India ranks second in terms of TiLV disease publications, with 26 articles identified. The country's substantial contribution to aquaculture and its large tilapia farming sector makes it an important player in TiLV disease research. The Indian government's initiatives to promote sustainable aquaculture practices and address emerging diseases like TiLV may have also influenced research activities in this area (Chong, 2022). The United States holds the third

position with 23 TiLV disease publications. As a major player in global aquaculture, including tilapia farming, it is not surprising that the U.S. has made significant contributions to TiLV research. The country's advanced research infrastructure and expertise in aquatic animal health likely contribute to its active engagement in studying TiLV disease. China, known for its extensive aquaculture industry and being the largest producer of tilapia, ranks fourth with 22 TiLV disease publications. Given the country's significant tilapia farming sector, it is crucial for China to understand and mitigate the impact of TiLV on its aquaculture production (Rabeh, 2022). The research output reflects China's commitment to addressing this emerging disease. Germany demonstrates a notable presence in TiLV disease research, with 19 publications identified. Although not a major tilapia producer, Germany's strong research institutions and expertise in aquatic animal health contribute to its active involvement in studying TiLV disease. Collaboration with other countries and international research networks may also play a role in Germany's research output. Malaysia, known for its aquaculture industry and tilapia farming, ranks sixth with 18 TiLV disease publications. The country's research efforts likely stem from the need to protect its aquaculture sector from the negative impacts of TiLV. Malaysia's geographical location and climate make it susceptible to diseases like TiLV, necessitating active research and surveillance (Adamek *et al*., 2022). The United Kingdom shares the sixth position with Malaysia, also contributing 18 TiLV disease publications. Despite not being a major tilapia producer, the UK's strong research infrastructure and expertise in aquatic animal health contribute to its active engagement in TiLV research. Collaboration with international partners and participation in global research networks may further enhance the UK's research output. Israel has made significant contributions to TiLV disease research, with 12 publications identified during the study period (Figure 1). The country's advanced aquaculture industry and expertise in fish health management likely drive its active involvement in studying TiLV. Israel's experience in dealing with viral diseases in aquaculture may also contribute to its research output. Norway, known for its expertise in salmonid aquaculture, has also shown interest in TiLV disease research, with 8 publications identified. Although tilapia farming is not a major industry in Norway, the country's experience in fish health management and virology may have influenced its research activities in this area. Collaboration with other countries and knowledge exchange within the aquaculture community likely contribute to Norway's research output. Bangladesh ranks tenth with 7 TiLV disease publications. The country's significant tilapia farming sector and growing aquaculture industry make it important to understand and manage TiLV disease. Bangladesh's research output reflects its commitment to addressing emerging diseases that pose a threat to its aquaculture production (Surachetpong *et al*., 2020).

Term analysis using the keyword frequencies

The examination of terms across 168 documents involved utilizing a comprehensive approach, employing all keyword fields, and adopting the full counting technique. This methodology involves tallying all occurrences of keywords within each document. From this analysis, a total of 1924 terms or keywords were initially identified. However, only a fraction, approximately 9.6% comprising 185 keywords, met the predefined criterion of appearing five times or more within the documents. Subsequently, for these 185 keywords, the cumulative link strength from co-occurrence connections with other keywords was computed. The selection of keywords was based on those demonstrating the highest total link strength. A careful manual screening process was followed to ensure the inclusion of only pertinent terms relevant to our bibliometric analysis. This rigorous selection process yielded a final set of 173 important keywords intended for network mapping and visualization. The resultant visualization revealed four distinct clusters, each distinguished by a unique colour (Figure 7). These clusters serve as visual representations of different research or publication emphases observed over twelve years concerning publications related to Tilapia Lake Virus (TiLV) disease.

Cluster 1 coloured red is comprised of 33% of the selected keywords. The red cluster in the term analysis of Tilapia Lake Virus (TiLV) disease research underscores pivotal facets within this scientific domain. Key terms such as "virus infection", "virus load", "gene expression", and "real-time polymerase chain reaction" illustrate a focused exploration of TiLV's virological aspects. These terms highlight a significant emphasis on understanding the dynamics of TiLV infection, including its prevalence, replication dynamics, and the molecular mechanisms regulating gene expression during the course of infection. Moreover, terms like "immune response", "immunology", and "antiviral activity" denote a substantial interest in dissecting the host immune reactions, potential antiviral mechanisms, and immunological aspects concerning TiLV (Adamek *et al*., 2022). This reflects an in-depth investigation into the immune system's response against TiLV infection, aiming to elucidate potential avenues for therapeutic interventions or vaccine development (Kembou-Ringert *et al*., 2023). Additionally, the inclusion of "RNA extraction" signifies the methodological focus, highlighting the significance of precise RNA isolation techniques in TiLV research, crucial for downstream analyses and understanding the virus-host interaction (Dong *et al*., 2017b). The terms "pathology" and "Tilapia Lake Virus infection" suggest an exploration into disease manifestation, pathological changes, and specific attributes related to TiLV infection within Tilapia populations. This indicates an interest in understanding the clinical presentation and pathological effects of TiLV on Tilapia fish (Rabeh, 2022).

Cluster 2 is represented in green colour and comprised

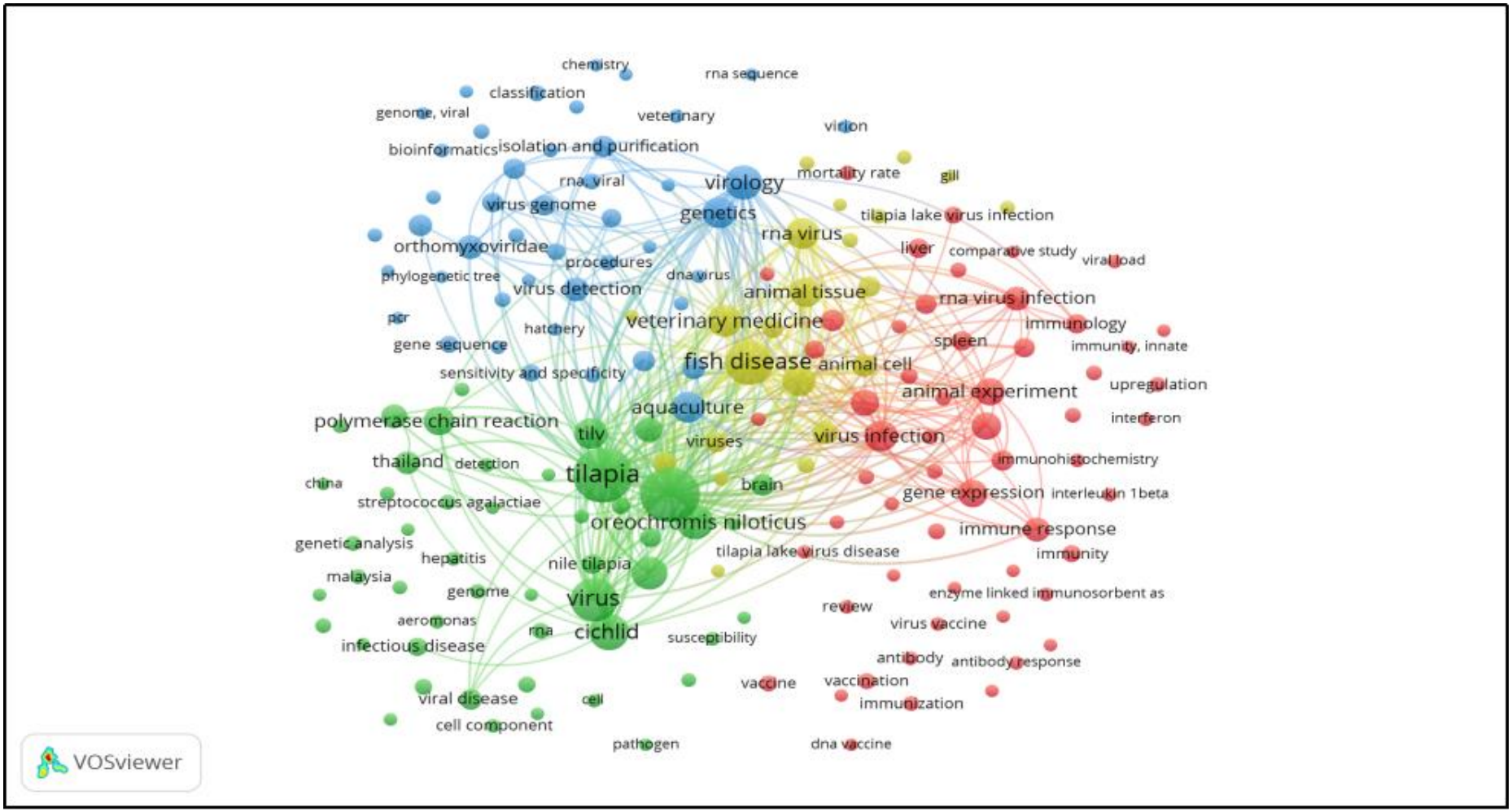

Figure 7. Network visualization of keyword occurrences from publications related to TiLV disease from publications retrieved from the Scopus database from 2012 – 2023.

of 28.3% of the relevant keywords. The cluster is better captioned ‘Exploration of Tilapia-specific aspects and pathogen interactions in Tilapia Lake Virus Disease Research’. The green cluster in the term analysis of Tilapia Lake Virus (TiLV) disease research centres around Tilapia-specific aspects and the interplay between Tilapia and the virus. Key terms such as "Tilapia" and "Tilapia Lake Virus" showcase a primary focus on Tilapia as the host species and the specific virus impacting this aquatic population. This emphasis suggests a dedicated examination of the interactions between Tilapia and TiLV, elucidating aspects related to infection dynamics, disease outcomes, and host-virus relationships. Moreover, terms such as

"*Oreochromis niloticus*", the scientific name for Nile Tilapia, underscore a species-specific investigation, likely focusing on understanding TiLV's impact on this particular Tilapia species and its relevance in the context of TiLV infections. The term "mortality" indicates a notable interest in assessing disease outcomes and the impact of TiLV infections on Tilapia populations, emphasizing the severity and implications of the virus on fish survival rates (Wang *et al*., 2023). Additionally, "polymerase chain reaction", "genome", and "genetic analysis" signify a methodological inclination towards molecular techniques and genetic investigations (Senapin *et al.,* 2018). This suggests efforts directed at understanding TiLV's genetic makeup, its evolution, and possible genetic variations among different strains, crucial for comprehensive disease management strategies. The inclusion of terms like "disease control" and "disease severity" highlights a focused inquiry into mitigation strategies and disease progression, indicating an interest in developing control measures and assessing the severity of TiLV infections in Tilapia. Furthermore, terms such as "co-infection", "*Aeromonas hydrophilia*", and "*Streptococcus agalactiae*" suggest an examination of potential interactions between TiLV and other pathogens. This indicates a broader investigation into co-infections and potential synergistic effects, recognizing the complex microbial ecology within Tilapia populations (Amal *et al*., 2018).

Cluster 3 is coloured blue and made up of 26% of the key-relevant words. The blue cluster in the term analysis of Tilapia Lake Virus (TiLV) disease research accentuates key domains which includes virology, genetics, and aquaculture-specific aspects related to TiLV infections. Terms such as "virology", "genetics", and "aquaculture" underscore a substantial emphasis on exploring the virological aspects of TiLV, including its structure, replication dynamics, and interactions within Tilapia aquaculture systems (Machimbirike *et al.,* 2019). The term "virus detection" highlights efforts in developing methods for identifying and detecting TiLV within Tilapia populations, crucial for timely disease management and surveillance within aquaculture settings (Aich *et al.,* 2022). Moreover, "phylogeny" and "virus genome" suggest an interest in genetic and evolutionary studies, focusing on TiLV's phylogenetic relationships, genetic variations, and the evolutionary trajectory of the virus. This genetic insight is fundamental in understanding the diversity of TiLV strains and their implications for disease control strategies. The inclusion of terms such as "isolation and purification", "diagnosis", and "bioinformatics" signifies a methodological orientation, emphasizing the development of techniques for virus isolation, purification, and diagnostics (Dong *et al.,* 2017b). Furthermore, bioinformatics approaches are likely to contribute to genomic analyses and sequence-based studies, aiding in unravelling TiLV's genetic makeup and functional aspects. Additionally, terms like "virus protein", "sequence alignment", and "orthomyxoviridae" indicate a finer exploration of TiLV at the molecular level, including investigations into viral proteins, sequence alignments for genetic comparisons, and situating TiLV within its viral family, Orthomyxoviridae. The term "transmission" hints at efforts directed toward understanding the routes and modes of TiLV transmission within aquaculture systems, crucial for implementing preventive measures and biosecurity protocols (Rabeh, 2022).

Cluster 4 is coloured olive and it is made up of 12.7% of the relevant words. The cluster is defined as the "Exploration of Veterinary Medicine and Fish Disease Aspects in Tilapia Lake Virus Research". The olive cluster in the term analysis of Tilapia Lake Virus (TiLV) disease research converges on significant themes within veterinary medicine and fish disease aspects, particularly focusing on the implications of TiLV infections in Tilapia populations. Terms such as "veterinary medicine" and "fish disease" highlight a prominent emphasis on veterinary aspects and the disease pathology specifically observed in Tilapia affected by TiLV infections (Surachetpong et al., 2017). The term "RNA viruses" signifies a specific focus on the characteristics and behaviour of RNA viruses, with a particular spotlight on TiLV's genomic structure, replication mechanisms, and viral dynamics within Tilapia. Moreover, the inclusion of terms such as "Tilapia tilapine virus" denotes a specific focus on TiLV itself and its impact on Tilapia populations, likely pertaining to understanding its pathogenesis, clinical manifestations, and effects on fish health. Terms like "animal cell", "cell culture", and "cell line" suggest an inclination towards experimental studies involving cell-based models, indicative of efforts to study TiLV replication dynamics, viral behaviour in specific cell types, and potential cell responses to TiLV infections. Furthermore, "virus replication" signifies a concentrated exploration into the mechanisms and dynamics of TiLV replication within Tilapia hosts, elucidating the viral lifecycle and essential processes influencing disease progression. The terms "lethargy" and "exophthalmos" refer to specific clinical signs observed in Tilapia affected by TiLV infections, indicating a focus on understanding disease presentation and associated symptoms in infected fish populations (Rabeh, 2022). Additionally, terms such as "disease predisposition" and "disease susceptibility" hint at investigations into factors influencing the vulnerability of Tilapia to TiLV infections, shedding light on potential predisposing factors and underlying mechanisms affecting disease susceptibility (Adamek *et al.,* 2022; Wang *et al*., 2023).

Conclusion

The bibliometric assessment conducted between 2012 and 2023 on Tilapia Lake Virus Disease (TiLVD) publications reveals the growing significance of this viral pathogen within the global context of tilapia aquaculture. TiLVD, caused by the Tilapia Lake Virus (TiLV), has

emerged as a substantial threat to the global tilapia industry due to its widespread presence and severe economic impact. The alarming mortality rates ranging from 10% to 90% in affected tilapia populations have led to significant financial losses, endangering food security and challenging the sustainability of aquaculture practices. This study employed a robust bibliometric approach involving data extraction from the Scopus database and subsequent analysis using both Scopus' data analysis functionality and VOSviewer software. The comprehensive assessment allowed for quantitative and qualitative exploration of publication trends, prolific authors, influential countries, and key research themes within TiLVD research. The analysis illuminated critical areas that warrant attention within TiLVD research. Firstly, the absence of established treatments or commercially available vaccines to combat TiLV infections remains a challenge, exacerbating the plight faced by the aquaculture industry. Secondly, the clinical manifestations and tissue lesions observed in naturally and experimentally infected tilapia highlight the urgency for accurate diagnosis and effective control measures to mitigate the spread and impact of TiLV. Moreover, the bibliometric assessment revealed the global scope of TiLVD research, with the disease being reported in numerous countries across Asia, Africa, Central America, South America, and North America. This widespread distribution emphasizes the need for concerted international efforts and collaborative research endeavours to address the multifaceted challenges posed by TiLVD.

Moving forward, this bibliometric study calls for interdisciplinary collaboration, focusing on innovative research strategies to fill existing knowledge gaps, enhance disease surveillance, develop effective therapeutic interventions, and devise preventive measures such as vaccines. By fostering collaborative research networks, facilitating knowledge exchange, and leveraging advancements in diagnostic technologies, the scientific community can strive towards a more comprehensive understanding of TiLVD and ultimately contribute to mitigating its detrimental effects on global tilapia aquaculture.

Future perspectives

Future investigations into TiLVD should prioritize multidisciplinary approaches, encompassing virology, immunology, pathology, and aquaculture sciences. Collaborative efforts between researchers, policymakers, and industry stakeholders are crucial for fostering knowledge exchange and developing innovative strategies to combat TiLV infections. The bibliometric assessment of TiLV disease research points to several important future directions. These include and are not limited to the following -developing more sensitive and rapid diagnostic tools, elucidating molecular mechanisms of TILV pathogenesis, developing safe and efficacious vaccines, implementing stringent biosecurity measures, fostering regional collaboration and knowledge exchange, promoting sustainable aquaculture practices, raising public awareness and educate stakeholders, continuously monitor and surveillance of TILV prevalence and distribution, increasing research funding, and the adopting an interdisciplinary approach.

Potential limitations

In this research endeavour, our primary focus is on English-language articles, a selection that potentially limits our exploration and may overlook valuable insights available in other languages. This restricted scope might inadvertently exclude significant contributions from non-English-speaking researchers, thereby potentially skewing the comprehensive understanding of TiLV disease research. The decision to concentrate solely on English articles introduces a possible bias, hindering the inclusion of diverse perspectives and findings from various linguistic and cultural backgrounds. The exclusive reliance on Scopus as the sole data source could present limitations, offering only a partial view of the landscape of TiLV disease research. This approach might inadvertently disregard relevant studies housed in untracked databases, possibly omitting critical research outcomes essential for a comprehensive assessment of TiLV.

Furthermore, when utilizing VOSviewer for network map generation, certain notable challenges have surfaced. An apparent issue involves larger nodes covering smaller ones and their associated labels, which may obscure vital connections and details within the network. Additionally, the appearance of terms such as countries, author names, and institutions in lowercase or abbreviated forms presents obstacles to a thorough examination of the network's intricacies. As a result, these challenges could potentially limit the reader's ability to comprehend the full spectrum of relationships and connections embedded within the data.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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