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KNOWLEDGE STRUCTURE OF NATURAL ANAESTHETICS IN AQUACULTURE: A BIBLIOMETRIC ANALYSIS

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Abstract

Aquaculture anaesthesia, particularly with natural agents, has gained increasing attention due to its relevance in fish welfare, stress management, and sustainable aquaculture practices. This study addresses the need to systematically assess the state of knowledge, gaps, and potential future trajectories in this dynamic field. We conducted a bibliometric analysis using Scopus to collect and analyse scholarly publications related to natural anaesthesia in aquaculture. Metrics such as citation counts, co-authorship networks, and keyword co-occurrence were employed to unveil the research landscape. The VosViewer tool was utilised for network visualisations, offering insights into collaboration patterns and thematic clusters. Preliminary findings indicate a prolific output of research, with specific authors and countries playing pivotal roles in shaping the discourse. The co-authorship network analysis reveals key figures and interdisciplinary collaborations, while the keyword co-occurrence analysis uncovers central themes and emerging topics. The country collaboration map provides a visual representation of regional clusters, emphasising the global nature of aquaculture anaesthesia research. This bibliometric study is poised to contribute a holistic understanding of the trends and patterns in natural anaesthesia research for aquatic species. The expected results will shed light on the interdisciplinary nature of the field, identify potential research collaborators, and pinpoint knowledge gaps for future exploration. The insights gained from this study aim to inform researchers, policymakers, and practitioners involved in aquaculture, paving the way for sustainable and welfare-centric practices in the field of aquaculture anaesthesia.

Keywords: anaesthesia, aquaculture, natural agents, fish welfare

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Introduction

In the dynamic realm of aquaculture and fisheries, the pursuit of sustainable practices has led researchers and practitioners to explore natural anaesthetic agents as alternatives to traditional chemical sedatives (Hoseini et al. 2015; Obirikorang et al. 2020). The use of natural compounds derived from plants, marine organisms, and other botanical sources in the sedation and immobilisation of aquatic species has gained increasing attention. This bibliometric analysis sets out to comprehensively map the scientific landscape of publications devoted to natural anaesthetic agents for aquatic species, providing an in-depth exploration of the trends, patterns, and key contributors in this burgeoning field. As the aquaculture industry continues to expand to meet global demands for seafood, the ethical and ecological implications of anaesthesia and stress mitigation in aquatic species are paramount (Ahmad et al. 2021; Cottrell et al. 2020; Waite et al. 2014). Natural anaesthetics present a promising avenue, offering the

potential to minimise the environmental impact associated with conventional anaesthetics while ensuring the welfare of the cultured organisms (Barreto et al. 2021). This bibliometric study aims to systematically assess and quantify the growth, impact, and dissemination of knowledge on natural anaesthetic agents, elucidating the intellectual structure of the field.

By employing bibliometric methodologies, including citation analysis, co-authorship networks, and thematic mapping, we seek to uncover the seminal research contributions, influential authors, and collaborative networks that have shaped the discourse on natural anaesthetics in aquatic environments. The temporal evolution of research themes and the identification of emerging areas of interest will be crucial in guiding future research directions and fostering interdisciplinary collaboration. The outcomes of this bibliometric analysis are anticipated to contribute significantly to the understanding of the current state of research on natural anaesthetic agents for aquatic species. Such insights are essential for researchers, practitioners, and policymakers involved in aquaculture, fisheries management, and aquatic veterinary science. As we embark on this bibliographic exploration, we aspire to provide a valuable resource that informs and inspires further advancements in the sustainable and ethical handling of aquatic organisms in diverse aquatic environments. .

The application of anaesthesia agents in aquaculture is a pivotal aspect of fish welfare and overall aquaculture management. Numerous studies, have explored the intricacies of anaesthesia efficacy, considering factors like water temperature, body weight, and lipid content (Santos et al. 2015; Skår et al. 2017; Zotte et al. 2020) . Diverse anaesthesia agents have been investigated for their effects on various fish species, including zebrafish and marbled rabbitfish, emphasising the importance of tailored protocols to ensure the welfare of aquatic species (Readman et al. 2013; Schroeder et al. 2021) The impact of anaesthesia has been further probed through electroencephalographic responses in juvenile fish (Lima Araújo et al. 2023). Procedures like stunning and killing fish in aquaculture, studied in sea bass and rainbow trout, underscore the practical implications of anaesthesia application (Zampacavallo et al. 2014; Zotte et al. 2020).

The development of anaesthesia protocols for specific fish species, exemplified by lumpfish, showcases the ongoing efforts to refine anaesthesia practices in aquaculture (Skår et al. 2017). Beyond welfare considerations, the use of anaesthesia extends to diverse applications such as phytoremediation and biochemical composition analysis (Cardoso et al. 2022). The literature also delves into microalgae cultivation, exploring the effects of unfiltered water from recirculating aquaculture systems on microalgae growth (Egloff et al. 2018). Anaesthesia research in aquaculture is not confined to fish alone; it extends to considerations of balanced anaesthesia in equine inhalation anaesthesia, providing broader insights into anaesthesia across different animal species, including aquatic animals (Gozalo-Marcilla et al. 2014).

The comprehensive understanding of anaesthesia agents and their effects on aquatic species is fundamental for sustainable and ethical aquaculture management. Research in this domain also encompasses the evaluation of stunning and killing methods for humane practices, societal considerations such as substance use disorder in professionals working with anaesthesia, and investigations into intravenous lipid emulsion effects on recovery from anaesthesia, showcasing the multifaceted nature of anaesthesia research in aquaculture (Baird, 2021; Li et al., 2014) Overall, the literature on anaesthesia agents in aquaculture spans diverse topics, including welfare implications, practical applications, and societal considerations, highlighting the interdisciplinary nature of research in this field.

Research Question: i. What are the trends in research related to anaesthesia applications in aquaculture?, ii. Who writes most of the articles related to anaesthesia application in aquaculture?, iii. Who writes the most cited articles related to anaesthesia application in aquaculture?, iv. What is the number of citations by research?, v. What are the maps of co-authorship about anesthesia in aquaculture?, vi. What are the popular keywords related to the study?, and vii. What are co-authorship countries' collaborations?.

Methodology

Bibliometric analysis, a quantitative method employed in scholarly research, systematically evaluates literature to discern patterns, trends, and the impact of research within a specific field (Dervis, 2019; Donthu et al. 2021) . Employing statistical and mathematical techniques, this method analyses diverse bibliographic data, including citation counts, authorship patterns, journal impact factors, and collaboration networks. The primary objective is to assess research productivity, influence, and interconnections, providing a profound understanding of knowledge evolution and identifying key contributors and pivotal works. The involvement of influential databases and indices enhances the rigor of bibliometric analyses (Ninkov et al. 2022).

The first step involves identifying relevant literature from reputable sources such as Scopus or WoS. Scopus, developed by Elsevier, is a key player offering a comprehensive abstract and citation database across academic disciplines (Kumpulainen & Seppänen 2022). Providing broad content coverage, advanced citation tracking, and tools for evaluating author and journal impact, Scopus facilitates collaboration network exploration and aids in identifying key research trends (Martín-Martín et al. 2018; Martín-Martín et al. 2021). The search strategy includes keywords related to anaesthesia agents and aquaculture. Relevant articles were selected based on their topic and publication type. For instance, articles focusing on the application of anaesthesia agents in aquaculture and published in high-impact journals were included. Additionally, VosViewer was utilised for data analysis, visualisation, and mapping of bibliometric data. By leveraging the Scopus database and VosViewer for analysis, this bibliometric review aimed to provide a holistic understanding of the trends, comprehensive literature search, data extraction, challenges, and potential future research directions in this domain.

Data search strategy

Study employed a screening sequence to determine the search terms for article retrieval. Study was initiated by querying Scopus database with online TITLE-ABS-KEY (anaesthesia AND fish) AND (LIMIT-TO (PUBYEAR , 2013) OR LIMIT-TO (PUBYEAR , 2014) 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)) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (PUBSTAGE , "final")) AND (LIMIT-TO (SRCTYPE , "j")) AND (LIMIT-TO (LANGUAGE , "English"))which was inputted in order to exclude publications that does not meet the criteria. Comprehensively, a total of 763 valid sample documents, including research and the full-text data of articles in the online version and articles in press categories from 2013 to 2023, were retrieved from the Scopus database (accessed on Jan 10, 2024) (Table 1 and Table 2).

Table 1. The search string

Database	Search string
Scopus	TITLE-ABS-KEY (anesthesia AND fish) AND (LIMIT-TO (PUBYEAR , 2013) OR LIMIT-TO (PUBYEAR , 2014) 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)) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (PUBSTAGE , "final")) AND (LIMIT-TO (SRCTYPE , "j")) AND (LIMIT-TO (LANGUAGE , "English"))

Table 2. The selection criterion in searching

Criterion	Inclusion	Exclusion
Language	English	Non-English
Time-line	2013 - 2023	< 2013
Literature type	Journal (Article)	Conference, Book, Review
Publication stage	Final	In Press

Data analysis

VOSviewer is a specialised software tool designed for bibliometric analysis, offering researchers the capability to visually explore and analyse complex networks within scholarly literature. Developed at Leiden University, VOSviewer excels in creating network visualisations, particularly in depicting co-authorship and collaboration networks. Researchers can identify key contributors, research clusters, and thematic structures within a specific field, enhancing their understanding of scholarly interactions. The tool facilitates keyword co-occurrence maps, aiding in the identification of prevalent themes and emerging trends. It supports citation analysis, helping researchers pinpoint influential publications and understand knowledge flow. With customisation options and an interactive interface, VOSviewer provides flexibility and user-friendly functionalities for dynamic exploration of bibliographic datasets, making it an indispensable resource for those aiming to conduct comprehensive bibliometric analyses.

In summary, VOSviewer's strength lies in its ability to generate clear and intuitive visualisations of bibliometric data, enabling researchers to uncover patterns, collaborations, and thematic structures in scholarly literature. Its user-friendly features, customisation options, and support for various analyses make it a valuable tool for those seeking deeper insights into the intellectual landscape of their research domain. Data sets encompassing information on the publication year, publication title, author name, journal, citation, and keywords in PlainText format were obtained, covering the timeframe from 2013 to December 2023. These datasets underwent analysis using VOSviewer software version 1.6.19, which was employed for both analysis and the generation of maps through the application of VOS clustering and mapping methods. VOSViewer, an alternative to the Multidimensional Scaling (MDS) approach introduced by Van Eck and Waltman in 2010, shares a similar objective with MDS, focusing on positioning items in a low-dimensional space to accurately reflect the relatedness and similarity between them (Appio et al. 2014; Van Eck & Waltman 2010). In contrast to MDS, which primarily computes similarity measures like Jaccard indexes and cosine, VOS implements a more suitable technique for normalising co-occurrence frequencies, specifically the association strength (ASij), calculated according to the methodology by an Eck and Waltman (Van Eck & Waltman 2007):

$$AS_{ij} = \frac{C_{ij}}{\omega_i \omega_j}$$

This is expressed as being "proportional to the ratio between, on the one hand, the observed number of cooccurrences of i and j, and on the other hand, the expected number of co-occurrences of i and j under the assumption that co-occurrences of i and j are statistically independent" (Van Eck & Waltman, 2010). Utilising this index, VOSviewer arranges items into a map by minimising the weighted sum of squared distances between all pairs of items. The same study also noted that the LinLog/modularity normalisation was implemented. Additionally, leveraging visualisation techniques through VOSviewer on the dataset revealed patterns based on mathematical relationships, facilitating analyses such as keyword co-occurrence, citation analysis, and co-citation analysis.

Therefore, utilising this index, VOSviewer arranges items into a map by minimising the weighted sum of squared distances between all pairs of items. Another studies suggested for the implementation of LinLog/modularity normalisation that will further refines this process (Appio et al., 2016). Employing visualisation techniques through VOSviewer on the dataset reveals patterns based on mathematical relationships, enabling analyses such as keyword co-occurrence, citation analysis, and co-citation

analysis. The evolution of a research area over time can be explored through keyword co-occurrence analysis (Zhao 2022), successfully identifying popular topics in various fields (You et al. 2021). Meanwhile, citation analysis proves useful in identifying key research issues, trends, and techniques, along with exploring the historical relevance of a discipline's primary focus area (Mejia et al. 2021). Document co-citation analysis, a frequently applied bibliometric method produces results dependent on network theory to identify the relevant structure of data (Appio et al. 2016; Trujillo & Long 2018).

Result and Discussion

What are the trends in research related to anaesthesia applications in aquaculture?

The Figure 1 presents a chronological overview of the number of publications related to a specific topic over the past decade. In 2021, the highest number of publications was recorded, with a total of 115, constituting 15% of the total publications. The previous year, 2022, also saw a substantial contribution with 102 publications, making up 13% of the total. The year 2019 follows closely with 84 publications, representing 11% of the total output. The years 2018 and 2017 contributed 72 and 73 publications, respectively, each constituting 9% and 10% of the overall publications. There is a noticeable fluctuation in the publication numbers, with the lowest figures in 2016 and 2014, both recording 49 and 46 publications, respectively, each accounting for 6% of the total. The remaining years, from 2015 to 2013, show a relatively consistent range of 50 to 45 publications, representing 7% to 6% of the total each year. This analysis provides insights into the temporal distribution and trends in the research output on the specified topic over the specified time frame.

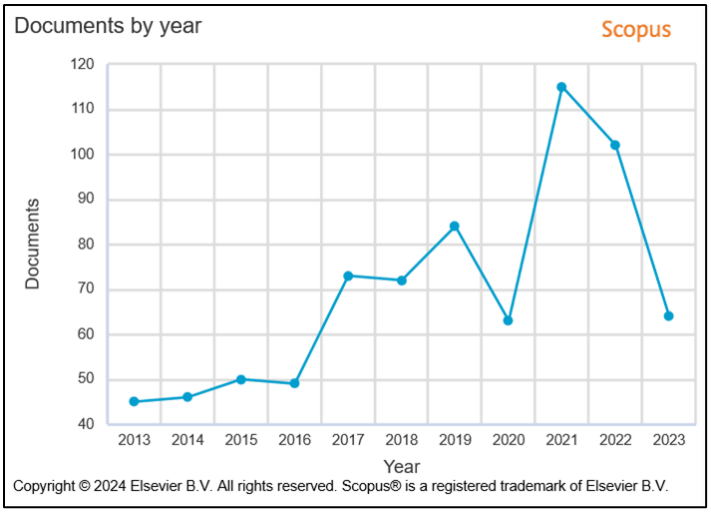

Figure 1. The trends in research related to anaesthesia applications in aquaculture per year.

Who writes most of the articles related to anaesthesia application in aquaculture?

Figure 2 illustrated the bibliometric analysis of authors in the field of natural anaesthetic agents for aquatic species reveals a diverse and active scholarly landscape. Baldisserotto, B., emerges as a prominent figure with the highest document count of 52, indicative of extensive and sustained contributions to the field. This prolific output suggests a leadership role in shaping the discourse and signifies a wealth of knowledge that has likely influenced the trajectory of research in natural anaesthetic agents. Following closely is Heinzmann, B.M., with 43 documents, demonstrating a notable commitment to advancing knowledge in this domain. The consistent publication output suggests a substantial impact on the evolving literature, reinforcing the significance of their research endeavours. Barbas, L.A.L., Luz, R.K., Hoseini, S.M., Garlet, Q.I., Hamoy, M., and Torres, M.F. contribute significantly with 16, 13, and 11 documents each, respectively. Their contributions underscore a collective effort in exploring the diverse facets of natural anaesthetic agents for aquatic species. While their document counts may be lower than the top contributors, the substantial output signifies substantial involvement in the scholarly conversation and adds valuable perspectives to the broader discourse.

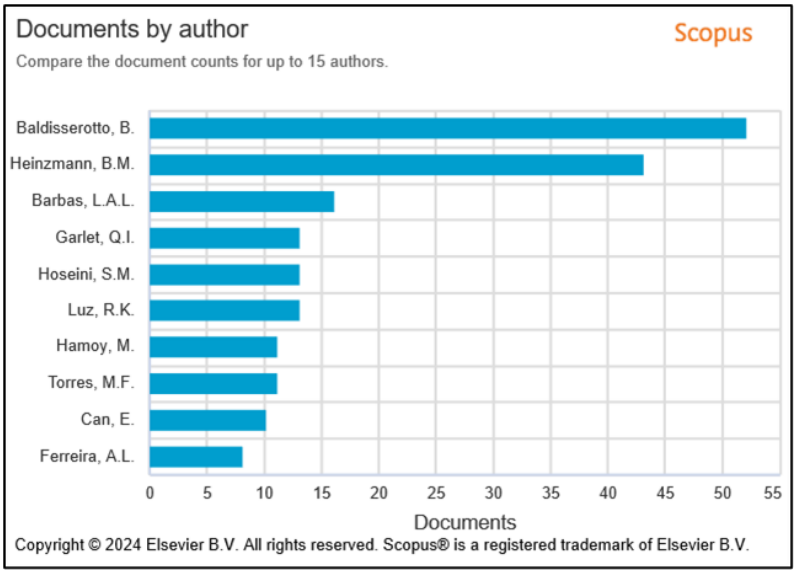

Figure 2. Number of documents related to application of anaesthesia in aquaculture published by the author

Can, E., and Ferreira, A.L., each with 10 and 8 documents respectively, further contribute to the richness of the literature. Though their individual publication counts are slightly lower, their consistent commitment is evident. Collectively, these authors represent a community of scholars engaged in collaborative efforts, contributing to the multidisciplinary nature of research on natural anaesthetic agents. The varying document counts highlight the collaborative and distributed nature of research efforts in this dynamic field, where multiple voices contribute to a comprehensive understanding of the subject. The distribution of publications among these authors emphasises the collaborative nature of research on natural anaesthetic agents for aquatic species. The varied perspectives and expertise brought forth by each contributor contribute to the holistic exploration of this critical topic.

Who writes the most cited articles related to anaesthesia application in aquaculture?

The analysis of the most cited publications in the field of anesthesia application in aquaculture provides valuable insights into the key research areas and impactful studies shaping the discourse (Table 3). A study by Marvin in 2019 (Marvin et al. 2019) entitled "A genetically encoded fluorescent sensor for in vivo imaging of GABA," stands out as the most cited, with 176 citations. This suggests a significant interest in the development and application of advanced molecular tools, particularly fluorescent sensors, for in vivo imaging of neurotransmitters like GABA in aquatic organisms. The emphasis on molecular techniques reflects a trend toward exploring the neurobiological aspects of anesthesia in fish, shedding light on the physiological responses and mechanisms involved.

Other highly cited works on antibiotic-resistant bacteria prevalence in various environments and investigation into fish perception of anesthetics, highlight the multidisciplinary nature of research in this field (Boonyasiri et al. 2014; Readman et al. 2017). The diverse range of topics, from antibiotic resistance to the psychological aspects of fish anesthesia, demonstrates the holistic approach taken by researchers in understanding the complexities of anesthesia application in aquaculture. Additionally, publications focusing on using skin mucus to evaluate stress in gilthead seabream and a study on the anesthetic activity of essential oils in silver catfish, contribute significantly to the welfare aspect of aquaculture practices (Guardiola et al. 2018). This bibliometric analysis indicates a growing interest in both the molecular and applied aspects of fish anesthesia, emphasising the need for well-rounded research to address the diverse challenges in the field and promote sustainable aquaculture practices.

Table 3. The most cited articles related to anaesthesia application in aquaculture

Authors	Document Title	Citation
Marvin et al. 2019	A genetically encoded fluorescent sensor for in vivo imaging of GABA	176
Boonyasiri et al. 2014	Prevalence of antibiotic resistant bacteria in healthy adults, foods, food animals, and the environment in selected areas in Thailand	115
Readman et al. 2014	Do Fish Perceive Anaesthetics as Aversive?	110
Guardiola et al. 2016	Using skin mucus to evaluate stress in gilthead seabream (*Sparus aurata* L.)	99
Parodi et al. 2014	Anaesthetic activity of the essential oil of Aloysia triphylla and effectiveness in reducing stress during transport of albino and gray strains of silver catfish, Rhamdia quelen	98
Collymore et al. 2014	Efficacy and safety of 5 anaesthetics in adult zebrafish (*Danio rerio*)	92
Gressler et al. 2014	Silver catfish Rhamdia quelen immersion anaesthesia with essential oil of *Aloysia triphylla* (L'Hérit) Britton or tricaine methanesulfonate: Effect on stress response and antioxidant status	91
Fernandes et al. 2016	The efficacy of clove oil as an anaesthetic and in euthanasia procedure for small-sized tropical fishes.	85
Crook et al. 2014	Nociceptive sensitisation reduces predation risk	85
Toni et al. 2014	Fish anaesthesia: Effects of the essential oils of *Hesperozygis ringens* and *Lippia alba* on the biochemistry and physiology of silver catfish (*Rhamdia quelen*)	83

What are the most subject published?

The bibliometric analysis of anaesthesia application in aquaculture, categorised by subject area, reveals the interdisciplinary nature of research in this field (Figure 3). Most publications fall within the subject area of Agricultural and Biological Sciences, constituting a substantial 35.8%. This dominance aligns with the inherent connection between aquaculture and biological sciences, emphasising the profound impact of anaesthesia on the health and well-being of aquatic organisms. Researchers in this subject area likely explore various aspects, including the development of new anaesthetic agents, assessment of their impact on aquatic species, and advancements in aquaculture practices to ensure sustainable and humane procedures.

The distribution across other subject areas further highlights the multifaceted nature of anaesthesia in aquaculture. Notably, Medicine, Biochemistry, Genetics, and Molecular Biology, as well as Veterinary sciences collectively account for a significant portion, indicating the relevance of aquaculture anaesthesia to broader biomedical and veterinary research. The inclusion of subject areas such as Environmental Science, Immunology and Microbiology, and Neuroscience underscores the holistic approach researchers adopt to understand the environmental and physiological implications of anaesthesia in aquatic environments. The diversity across subject areas reflects the collaborative efforts of scientists, spanning traditional boundaries to address the intricate challenges associated with aquaculture anaesthesia. This comprehensive analysis illustrates that advancements in aquaculture anaesthesia not only contribute to the optimisation of aquaculture practices but also intersect with various scientific disciplines, making it a vibrant and evolving field with broader implications for aquatic and biomedical sciences.

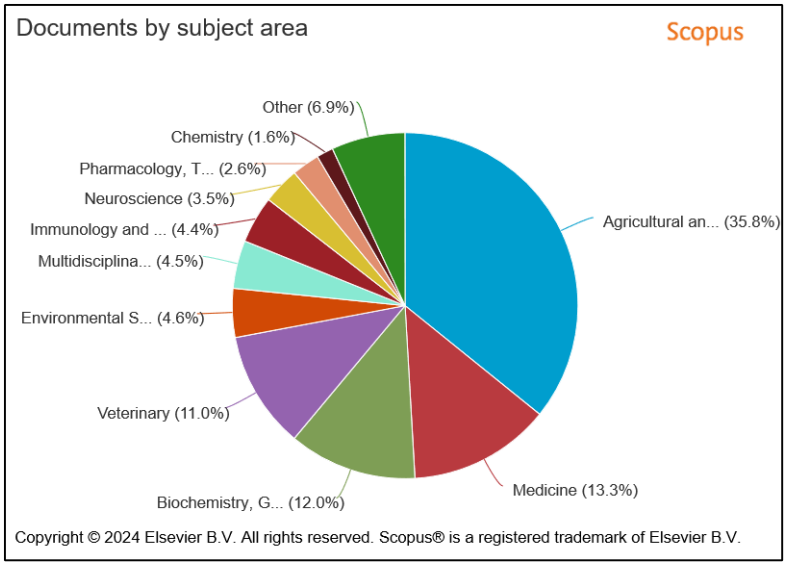

Figure 3. Number of documents related to application of anaesthesia in aquaculture published by the subject area

What are the maps of co-authorship about anaesthesia in aquaculture?

The network map of co-authorship in the field of anaesthesia for aquaculture, depicted in Figure 4, provides a comprehensive overview of collaborative research dynamics. In this visual representation, nodes symbolise individual researchers, while edges signify co-authorship connections. The size of nodes corresponds to the researcher's publication output, and the color reflects the average citation count of their publications. Notably, the figure unveils distinct clusters of researchers engaged in co-authorship, with the central and largest cluster prominently featuring contributors from Brazil, Portugal, and Spain. Esteemed researchers like A.L. Ferreira, R.K. Luz, and M.D. Baldissera emerge as pivotal figures within this influential cluster, underscoring their substantial impact on the field.

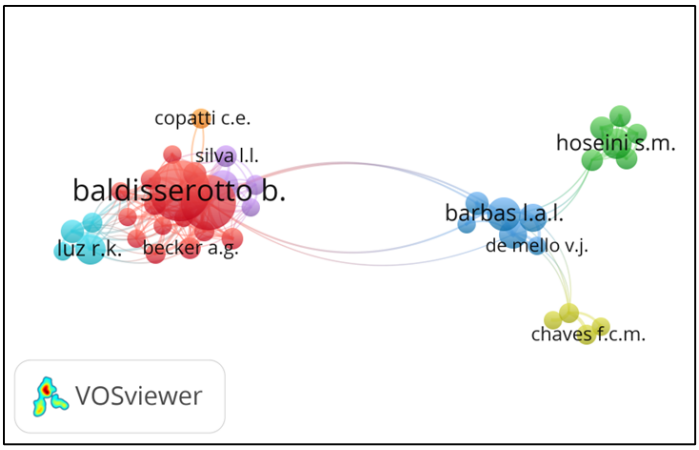

Figure 4. Network visualization map of Co-Authorship for publication on the topic of anaesthesia application in aquaculture

Furthermore, the figure highlights additional clusters involving researchers from countries such as China, Iran, and Italy, indicative of a burgeoning trend in international collaboration within the realm of anaesthesia for aquaculture. The ability to identify these collaborative clusters through the map offers valuable insights for researchers seeking potential collaborators and facilitates the exploration of shared research interests. Moreover, the figure aids in pinpointing the most productive and highly cited researchers in the field, enabling a focused exploration of cutting-edge research and innovative anaesthetic developments for aquatic species. The presence of distinct clusters with specific focuses, such as the central cluster's emphasis on clove oil and the left-side cluster's focus on AQUI-S, highlights diverse research interests within the broader field of anaesthesia for aquaculture. Overall, the

collaborative nature depicted in the figure underscores the collective effort aimed at advancing the field and advancing the development of improved anaesthetics for fish.

What are the popular keywords related to the study?

The nodes in the network represent the keywords, and the edges between the nodes represent co-occurrence relationships. The size of the nodes is proportional to the number of times that a keyword appears in the papers, and the colour of the nodes represents the cluster to which a keyword belongs. The Figure 5 shows that there are several clusters of keywords that co-occur frequently in anaesthesia research for aquaculture. The largest cluster is in the centre of the figure, and it includes keywords such as "fish welfare", "stress", "recovery", and "mortality". This cluster is focused on the negative impacts of anaesthesia on fish.

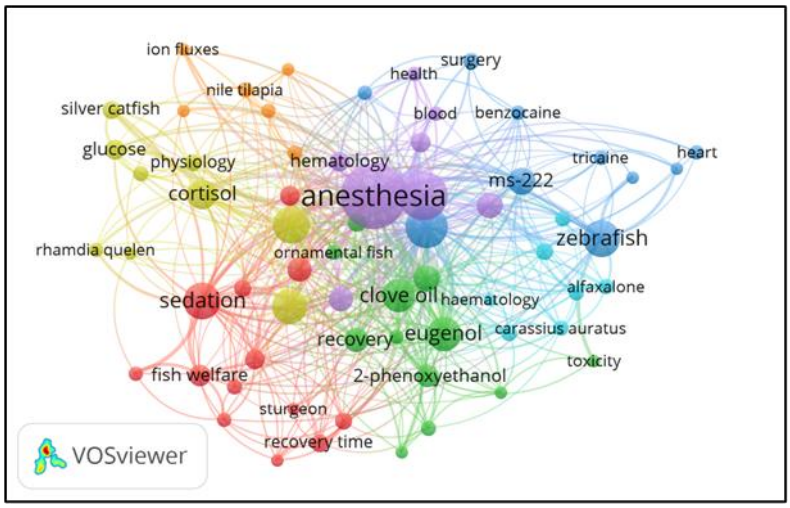

Figure 5. Network visualization map of popular keywords on the topic of anaesthesia application in aquaculture

Another cluster is on the left side of the figure, and it includes keywords such as "AQUI-S", "MS-222", "tricaine", and "clove oil". This cluster is focused on the different types of anaesthetics that are used in aquaculture. The figure also shows that there are a few keywords that co-occur with keywords from other clusters. These keywords are represented by the nodes that are in between the clusters. For example, the keyword "physiology" co-occurs with keywords from both the "fish welfare" cluster and the "anaesthetics" cluster. This suggests that there is a link between the physiological effects of anaesthesia and fish welfare. Overall, the figure shows that there are several important topics that are being studied in anaesthesia research for aquaculture. These topics include the negative impacts of anaesthesia on fish, the different types of anaesthetics that are used, and the physiological effects of anaesthesia.

What are co-authorship countries' collaboration?

The Figure 6 reveals two main clusters of countries that are collaborating on research in anaesthesia for aquaculture. The larger cluster on the left-hand side of the map consists of countries from Europe and South America, including Brazil, Portugal, Spain, and Italy. This cluster is focused on the use of clove oil as an anaesthetic for fish. Clove oil is a natural product that is readily available and relatively inexpensive, making it an attractive option for use in aquaculture. However, clove oil can also have negative effects on fish, such as causing tissue damage and respiratory distress. The smaller cluster on the right-hand side of the map consists of countries from North America and Australasia, including the United States, Canada, Chile, and Australia. This cluster is focused on the development and use of synthetic anaesthetics for fish. Synthetic anaesthetics can be more precisely controlled than clove oil and may have fewer negative side effects. However, they can also be more expensive and difficult to obtain.

The figure also shows a few countries that have co-authored papers with countries from both clusters. These countries are represented by the nodes that are in between the clusters. This suggests that there is some collaboration between researchers who are interested in clove oil and those who are interested in synthetic anaesthetics. Overall, the figure shows that there is a lot of active research being done on anaesthesia for aquaculture, and that there is a global effort to develop new and better anaesthetics that can be used to improve the welfare of fish during surgical and other procedures. Researchers from different countries are collaborating to share knowledge and expertise, which is helping to accelerate the development of new and improved anaesthesia methods for aquaculture.

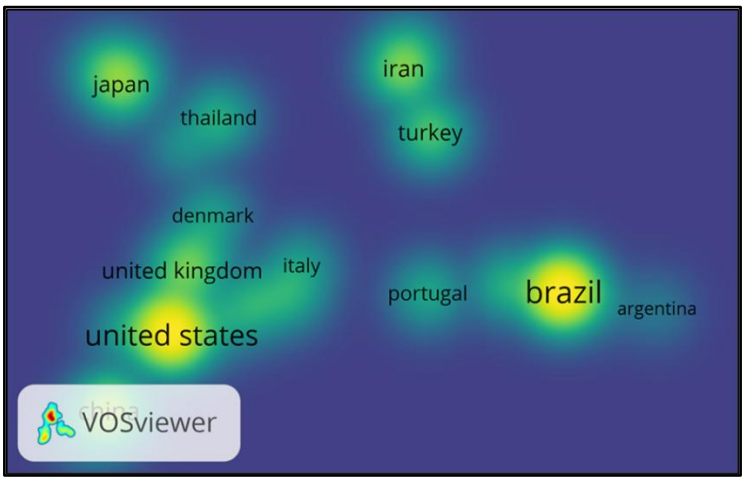

Figure 6. Density map of co-authorship by countries of collaboration.

The bibliometric analysis provides a comprehensive overview of the temporal distribution, key contributors, citation impact, and collaborative dynamics in the field of anaesthesia for aquaculture. In 2021, there was a peak in publications with 115, constituting 15% of the total output, followed by 102 publications in 2022 (13%). The analysis showcases fluctuating trends, with 2016 and 2014 recording the lowest figures (6% each). Notably, Baldisserotto, B., emerges as a leading contributor with 52 documents, indicating significant influence and sustained contributions. Heinzmann, B.M., follows closely with 43 documents, showcasing consistent commitment. Authors like Barbas, L.A.L., Luz, R.K., Hoseini, S.M., Garlet, Q.I., Hamoy, M., and Torres, M.F. contribute substantially, emphasising a collaborative community exploring diverse aspects of natural anaesthetics. Further analysis of highly cited publications reveals a diverse range of research areas, including molecular tools for in vivo imaging of neurotransmitters, antibiotic-resistant bacteria prevalence, and fish perception of anaesthetics. Notably, Marvin et al. (2019) stands out as the most cited publication, emphasising interest in molecular techniques for studying anaesthesia in aquatic organisms.

Subject area distribution underscores the interdisciplinary nature of aquaculture anaesthesia research, with a dominance in Agricultural and Biological Sciences (35.8%). Noteworthy contributions also extend to Medicine, Biochemistry, Genetics, Molecular Biology, and Veterinary sciences, highlighting broader implications for biomedical and veterinary research. Additionally, subject areas such as Environmental Science, Immunology and Microbiology, and Neuroscience emphasise the holistic approach researchers adopt to understand the environmental and physiological implications of anaesthesia in aquatic environments (Martins et al., 2019; McGain et al., 2020). Co-authorship network analysis reveals distinct clusters of researchers, with Baldisserotto, B., Luz, R.K., and Ferreira, A.L. emerging as pivotal figures in influential clusters. The map demonstrates international collaboration trends, with clusters involving countries like China, Iran, and Italy. The visual representation aids in identifying potential collaborators and productive researchers, facilitating focused exploration of cutting-edge research in aquaculture anaesthesia. Keyword co-occurrence analysis unveils clusters focused on fish welfare, stress, recovery, mortality, and anaesthetics. Clove oil and synthetic anaesthetics form distinct clusters, while keywords like "physiology" bridge multiple clusters,

indicating links between physiological effects of anaesthesia and fish welfare (Ehrlich et al., 2019; López-Cánovas et al., 2020; Pattanasiri et al., 2017).

Conclusion

In conclusion, the thorough analysis highlights the dynamic and progressive nature of research in aquaculture anaesthesia. A wide array of subjects is investigated by a collaborative international community, showcasing its trends and evolution. The research not only contributes to optimising aquaculture practices but also intersects with various scientific disciplines, making it a dynamic and impactful field for aquatic and biomedical sciences.

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Author Contribution

SA Arifin - Conceptualization, Investigation, Data Analysis, Project Administration, Writing -original draft, review and editing; MF Yusof - Supervision, Investigation, Project Administration, Writing -review and editing; MZ Jaapar - Investigation, Project Administration, Writing -review and editing; MA Amatul-Samahah - Investigation, Project Administration, Writing -review and editing; MZ Lani – Supervision, Investigation, Project Administration, Writing -review and editing.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Declaration on the Use of Generative AI

Authors declare that AI tools such as ChatGPT and Grammarly were used only to improve the language and grammar of this manuscript. They were not used to generate content, analyze data, or make scientific decisions. All ideas, analysis, and conclusions are the authors' own work.

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