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Review Article

Status of aquaponics systems in Brazil: A systematic literature review

Gabriela de Moraes-Viana[1]*, Otilene dos Anjos Santos[2], Edinaldo Nelson dos Santos-Silva[1], André Moreira Bordinhon[2]

[1]Instituto Nacional de Pesquisas da Amazônia – Programa de Pós-Graduação em Biologia de Água Doce e Pesca Interior – Manaus (AM), Brazil.

[2]Universidade Federal do Amazonas – Manaus (AM), Brazil.

*Corresponding author: gabimoraes88@gmail.com

ABSTRACT

Aquaponic systems have gained prominence in Brazil, attracting researchers from aquaculture, agriculture, ecology, and other similar fields. This study reviewed Brazilian publications to assess the national status of aquaponics, focusing on research approaches, key authors, and institutions. A systematic review of 148 works (2008–2022) from Scopus, SciELO Brasil, Web of Science, and Google Scholar revealed that most prominent researchers and institutions are concentrated in the Southeast and South, primarily in established aquaculture research groups. Key topics include operation of aquaponic systems and selection of species of plants and aquatic organisms. The nutrient film technique was the most cited hydroponic system, with tilapia and lettuce showing the best performance and economic value. The study highlights the need for further research on the bioeconomic of commercial-scale aquaponics and consumer perceptions of aquaponic products in Brazil. Identified gaps include experimental design and project management, with a call for standardization of key experimental parameters. Future investigations should explore the co-occurrence network and intellectual structure of aquaponics research to better understand its development and integration into sustainable practices.

Keywords: Aquaculture; Integrated agri-aquaculture systems; Responsible production and consumption.

Situação atual dos sistemas aquapônicos no Brasil: Uma revisão sistemática da literatura

RESUMO

Os sistemas aquapônicos estão ganhando destaque no Brasil, atraindo pesquisadores da aquicultura, agricultura, ecologia e outras áreas afins. Este estudo revisou publicações brasileiras para avaliar o *status* nacional da aquaponia, com foco em abordagens de pesquisa, autores-chave e instituições. Uma revisão sistemática de 148 trabalhos (2008–2022) da Scopus, SciELO Brasil, Web of Science e Google Acadêmico revelou que a maioria dos pesquisadores e instituições proeminentes está concentrada nas regiões Sudeste e Sul, principalmente em grupos de pesquisa em aquicultura estabelecidos. Os principais tópicos incluem operação de sistemas aquapônicos e seleção de espécies de plantas e organismos aquáticos. A técnica de filme de nutrientes foi o sistema hidropônico mais citado, com tilápia e alface apresentando os melhores desempenho e valor econômico. O estudo destaca a necessidade de mais pesquisas sobre a bioeconomia da aquaponia em escala comercial e as percepções do consumidor sobre produtos aquapônicos no Brasil. As lacunas identificadas incluem delineamento experimental e gerenciamento de projetos, com apelo à padronização dos principais parâmetros experimentais. Investigações futuras devem explorar a rede de coocorrência e a estrutura intelectual da pesquisa em aquaponia para entender melhor seu desenvolvimento e integração em práticas sustentáveis.

Palavras-chave: Aquicultura; Sistemas integrados de agroaquicultura; Produção e consumo responsáveis.

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INTRODUCTION

Aquaponics integrates three fundamental components: aquaculture, hydroponics, and microorganisms (Baganz et al., 2022; Rakocy et al., 2006). Aquaculture involves cultivating aquatic organisms such as fish, while hydroponics focuses on growing plants without soil, either through a single (coupled) or two-cycle (decoupled) process. Microorganisms, particularly bacteria, play a crucial role by converting fish waste into nutrients essential for plant growth. In this system, water circulates between the fish tank, biofilters, and hydroponic beds, with microorganisms transforming organic matter into macronutrients and micronutrients absorbed by plants (Gichana et al., 2018; Kasozi et al., 2021).

Aquaponics is recognized for its efficient water use in producing fish and crops intensively (Mauricieri et al., 2018). It minimizes reliance on synthetic fertilizers, eliminates pesticides and antibiotics, and has a minimal environmental footprint while simultaneously cultivating plants and fish (Greenfeld et al., 2021; Lennard & Goddek, 2019; Love et al., 2015). Originally implemented as small-scale backyard systems, aquaponics has evolved into industrial-scale technology, enabled by design improvements that have enhanced productivity for both plants and fish (Pattillo et al., 2022).

Recent scientometric studies have highlighted global trends and challenges in aquaponics. Yep and Zheng (2019) reported a preference for decoupled systems over coupled ones and identified deep water culture (DWC) as the dominant method in commercial applications, while media-based growing beds (MBGB) were common in research. They also noted the success of tilapia and leafy vegetables in aquaponics, contrasting with the challenges of cultivating fruit-bearing plants due to nutrient deficiencies. Both Hao et al. (2020) and Yep and Zheng (2019) emphasized the need for more research on microbial communities and their biochemical roles in nutrient management and system optimization.

Basumatary et al. (2022) expanded these findings by analyzing research trends from 2004 to 2021. They observed advancements in system performance, wastewater treatment, nutrient management, and species selection, while also identifying leading researchers and institutions.

Despite global progress, Brazil lags in aquaponics development. Although the country has abundant freshwater resources and suitable climates (Valenti et al., 2021), inefficient data collection and fragmented statistics have hindered its aquaculture sector. Castellani (2008) documented the first Brazilian aquaponics experiment, but subsequent studies often involved small systems with limited trials and experimental rigor (Colt et al., 2021). Addressing these limitations through systematic reviews, as suggested by Basumatary et al. (2022), could help researchers, policymakers, and funders optimize resources and foster large-scale research and innovation.

This review sought to identify knowledge gaps, challenges, and trends in Brazilian research that may encourage further research and help define established and emerging research areas. Its specific objectives were to review publications in Brazil to determine the status of aquaponics; determine the leading authors and organizations conducting research in aquaponics; identify the most used research approaches; identify trends in experimental studies regarding the cultivation techniques used in aquaponics; and analyze the intellectual structure of experimental studies.

RESEARCH METHODOLOGY

A systematic review of Brazilian publications on aquaponics was carried out by accessing the Scopus (Elsevier), SciELO Brasil, Web of Science (Clarivate Analytics) and Google Scholar databases through the Periódicos CAPES virtual library. Search results were used to compile a list of studies carried out in Brazil between 2008 and 2022. Studies published in 2023 were excluded from this investigation, because at the date of the review the publications list for this year was not definitive yet. The initial search for information was undertaken in September 2022 and subsequently updated in February 2023. The search covered all studies that contained (in the title, abstract, and keywords) the word *aquaponics*, as well as the words for similar or associated practices (aquaponic* OR flocponic* OR bioflocs* AND Brazil). All matching studies were identified and downloaded. Studies in both Portuguese and English were included, and Boolean truncation (*) was used to capture all variations of the words.

The search returned a total of 1,098 studies from the four databases:

- Web of Science: 306;
- Scielo Brazil: 32;
- Scopus: 529;
- Google Scholar: 231.

The studies were screened by first using the web-based review application Rayyan to facilitate classification and sharing with co-collaborators, and then the criteria described in Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Page et al., 2021). A total of 950 studies was excluded based on the following criteria:

- Duplicate studies appearing in more than one database;
- Studies that were not available in their entirety in the databases;
- Studies that only discussed other subjects and that did not include aquaponics (*e.g.*, bioflocs, water recirculation, hydroponics);

• Studies on aquaponics published by Brazilian researchers but based in and on other countries;
• Gray literature that included research and committee reports, government reports, conference papers, undergraduate course completion work, summaries of events and seminars, book reviews, and ongoing research.

Following this screening, the refined search identified the total of 148 studies (Moraes-Viana, 2025b). The process described and the related results are in Fig. 1.

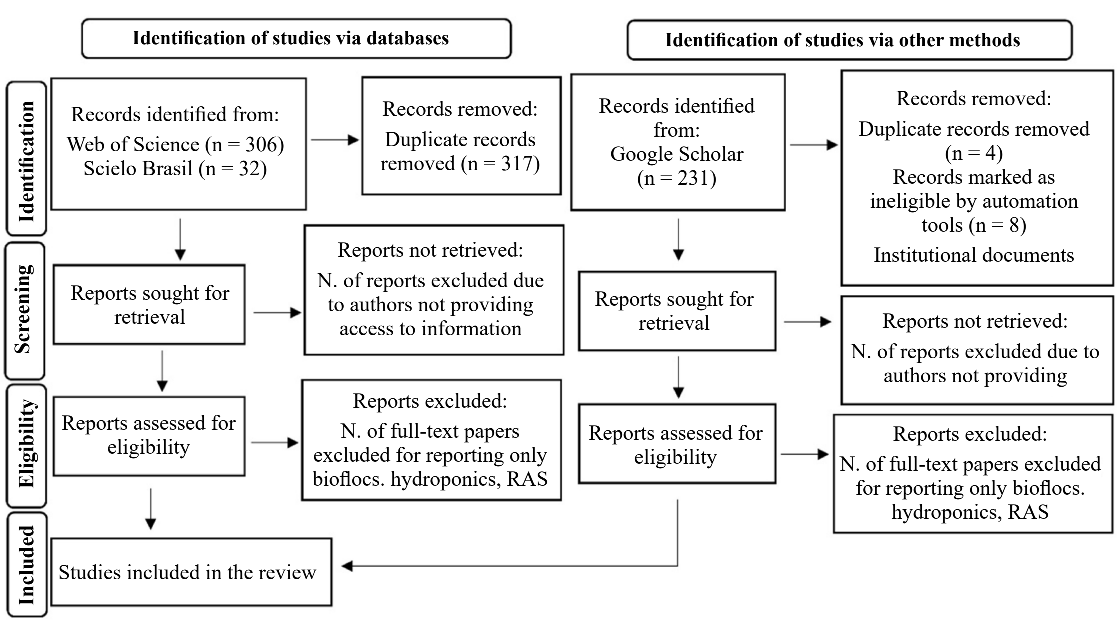
The 148 publications identified were further screened with predefined criteria including:
• Peer-review articles;
• Gray literature (only theses and dissertations);
• Chapters of theses and dissertations that involved experiments.

The experimental studies were analyzed in more details and are organized in a table in Moraes-Viana (2025a). Each study was then categorized using the criteria in Table 1.

The specification of system size and details of physical and chemical parameters were tabulated as either present or absent in the studies. The interactions between authors/regions and organizations were graphed using bipartite graphs generated based on proportional data (number of studies conducted by authors in different regions and number of studies attributed to each organization in different regions). This analysis was performed using R software, specifically employing the bipartite package (R Core Team, 2020).

Table 1. Summary of the criteria used to evaluate each study on aquaponics in Brazil, 2008–2022.

Item	Sub-item
Type of research paper	Article, dissertation, and thesis
Type of study	Reviews, case studies, and experimental studies
Study location	Region (Northern, North-Western, Central-Western, South-Eastern, Southern)
Topics studied (not mutually exclusive)	Plant and fish selection
	System structure and mechanics
	Economics and management
	Fish and plant health
	Water chemistry and microbiology
Hydroponic components	Deep-water culture or floating raft technique, media-based growing bed, and nutrient film technique
Species studied	Plant and aquatic organisms
System design	Total volume of water
	Hydraulic retention time
	Water flow rate
	Total grow bed area
	Plant density (plant/m^2)
	Feeding rate ratios
	Fish tank water volume
	Fish stocking density
Water quality parameters	Dissolved oxygen (mg/L)
	pH
	Temperature
	Electrical conductivity
	Total suspended solids (mg/L)
	Ammonia (mg/L)
	Nitrite (mg/L)
	Nitrate (mg/L)
	Orthophosphate (mg/L)



Source: Adapted from Page et al. (2021).

Figure 1. Preferred Reporting Items for Systematic Reviews and Meta Analysis (PRISMA) protocol with the criteria for identification, selection, eligibility, inclusion and exclusion of studies on aquaponics.

RESULTS

Chronology and types of study of aquaponics research in Brazil

A total of 148 studies (reviews, experimental studies, and case studies) on aquaponics were published between 2008 and 2022, and the majority (70.3%) of them was published in Portuguese. The most common types of publication were peer-reviewed scientific articles (58.1%), followed by dissertations (31.7%) and theses (10.1%). Experimental studies accounted for 62.8%, followed by case studies, with 22.9%, and reviews, with 14.2%. The percentage of dissertations and theses that were converted into articles was 14.9 (n = 7) and 20% (n = 3), respectively.

According to the distribution of publications in the period 2008–2022 (Fig. 2), the first published scientific work was Castellani's (2008) thesis. This was the evaluation of an integrated system for the production of Amazon river prawn (*Macrobrachium amazonicum*) and the hydroponic cultivation of lettuce (*Lactuca sativa* L.) and watercress (*Rorippa nasturtium aquaticum*), which led to a scientific article the following year (Castellani et al., 2009). The production of scientific works only increased significantly in 2017 (Fig. 2), peaking in 2020, and declining over the following years.

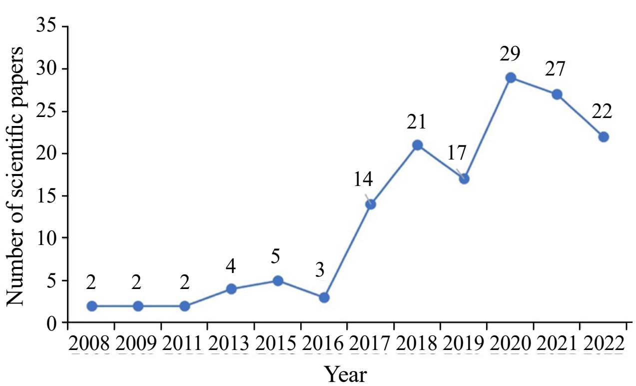


Figure 2. Research studies on aquaponics carried out in Brazil from 2008 to 2022.

Leading authors, organizations and regions

Figure 3 shows the distribution of scientific papers across the five regions of Brazil. The South-Eastern region is the most prominent and prolific one (27%), followed by the Southern (24.3%), Central-Western (20.9%), North-Eastern (14.1%), and Northern (13.5%) regions. Although the data shows the Northern region to be the least prolific, research on aquaponics in this region started later, with the first

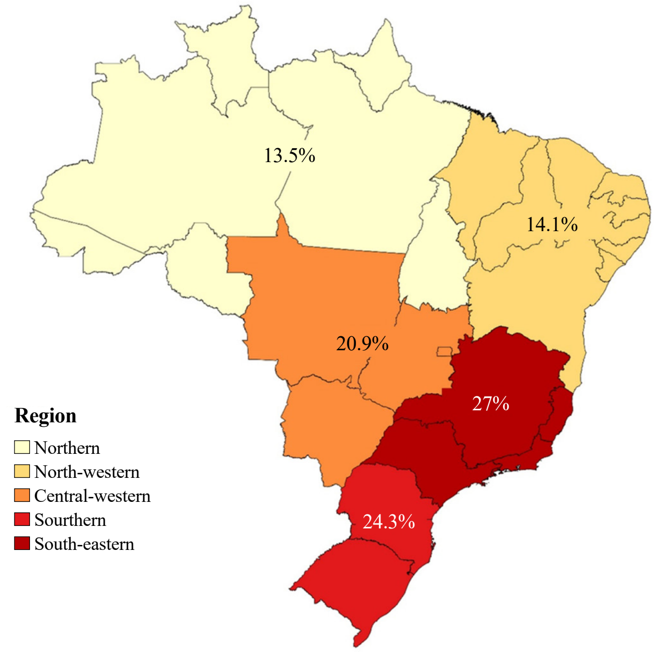


Figure 3. Percentage of studies on aquaponics according to the regions of Brazil. Maps were generated using Mapchart.net, licensed under CC BY 4.0.

publications seen only in 2019. The region also has a smaller number of research institutions.

In Table 2, the most prominent authors and institutions were ranked according to the total number of published articles. The highest-ranked authors are S. Pinho and M. C. Portella, both of

Table 2. Ten most prolific authors on aquaponics research in Brazil from 2008 to 2022.

Rank	Authors	Organization	Region	Publications
1	Pinho, S. M.	UNESP	South-Eastern	13
2	Portella, M. C.	UNESP	South-Eastern	9
3	David, L. H. C.	UNESP	South-Eastern	8
4	Emerenciano, M. G. C.	UDESC	Southern	5
5	Jordan, R. A.	UFGD	Central-Western	5
6	Seiffert, W. Q.	UFSC	Southern	5
7	Oliveira, F. C.	UTFPR	Southern	5
8	Lenz, G. L.	UFSC	Southern	4
9	Corrêa, B. R. S.	UnB	Central-Western	4
10	Vieira, F. N.	UFSC	Southern	4

UNESP: Universidade Estadual Paulista "Júlio de Mesquita Filho"; UDESC: Universidade do Estado de Santa Catarina; UFGD: Universidade Federal da Grande Dourados; UFSC: Universidade Federal de Santa Catarina; UTFPR: Universidade Tecnológica Federal do Paraná; UnB: Universidade de Brasília.

whom linked to the Universidade Estadual Paulista "Júlio de Mesquita Filho" (UNESP). These authors' publications mainly focus on the topics biofloc technology with plant production, economic feasibility, environmental assessment, sustainability, water quality, and plants and fish.

Table 3 also shows that UFSC and UNESP are the leading institutions in the field in Brazil. All four institutions that have the ten most prolific authors on aquaponics research in Brazil from 2008 to 2022 are based in the Southern and South-Eastern regions of Brazil.

Table 3. The ten most prolific institutions on aquaponics research in Brazil from 2008 to 2022.

Rank	Organization	Region	Publications
1	UFSC	Southern	21
2	UNESP	South-Eastern	18
3	UnB	Central-Western	10
4	IFGO	Central-Western	7
5	UFGD	Central-Western	7
6	USP	South-Eastern	6
7	UFC	North-Western	6
8	UFRA	Northern	6
9	IFAM	Northern	4
10	UDESC	Southern	2

UFSC: Universidade Federal de Santa Catarina; UNESP: Universidade Estadual Paulista "Júlio de Mesquita Filho"; UnB: Universidade de Brasília; IFGO: Instituto Federal de Educação, Ciência e Tecnologia de Goiás; UFGD: Universidade Federal da Grande Dourados; USP: Universidade de São Paulo; UFC: Universidade Federal do Ceará; UFRA: Universidade Federal Rural da Amazônia; IFAM: Instituto Federal do Amazonas; UDESC: Universidade do Estado de Santa Catarina.

Research development areas

As shown in Fig. 4, the main topic addressed in the studies was system structures and their mechanisms (43%). Some of these studies compared aquaponics with hydroponics, bioflocs, and traditional cultivation (soil), while others addressed the effect of different fish or shrimp densities on the productive performance of plants and the use of alternative substrates for plant cultivation. The second most-discussed topic was selection of plant and fish species (28%), with studies investigating the types of plants that are most suitable for aquaponic systems and comparing the performance of different species of fish in aquaponic systems. The results showed limited interest in areas as water chemistry and microbiology (5%) and fish and plant health (2%).

Trends in cultivation techniques used on aquaponics experimental studies

Hydroponic components

In terms of preference for certain hydroponic systems, the nutrient film technique (NFT, 51.1%) was the most used system in studies on aquaponics in Brazil, followed by DWC (25%) and MBGB (23.9%).

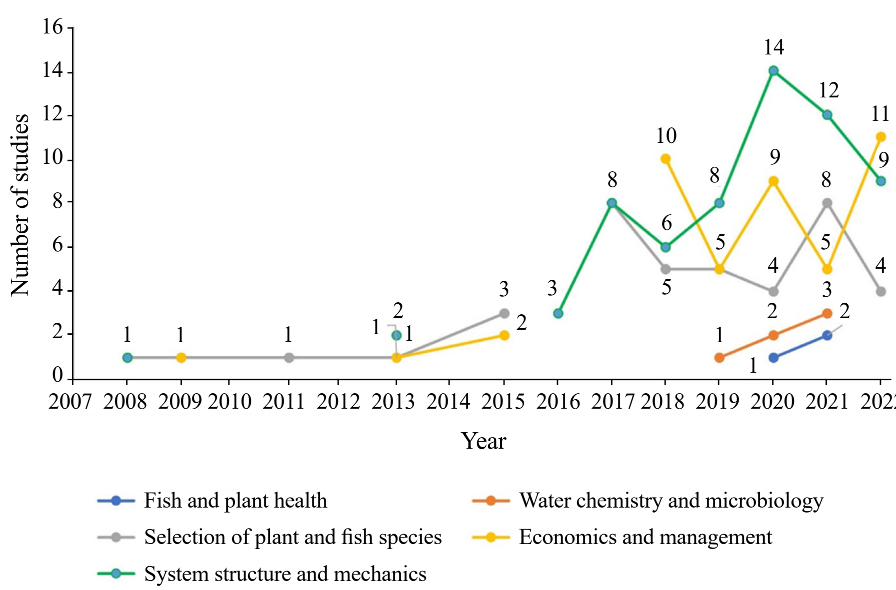


Figure 4. Trending research topics on aquaponics in Brazil by year (2008–2022).

Plant species

Lettuce (*Lactuca sativa* L.) was the plant species most used in experimental studies in Brazil (72.8%). The second most-studied plant was *Sarcocornia ambigua* (14.1% of the studies). It can be seen in the pareto graph of Fig. 5 that most research was concentrated among the first 12 species in the list, which accounted for 80% of the total.

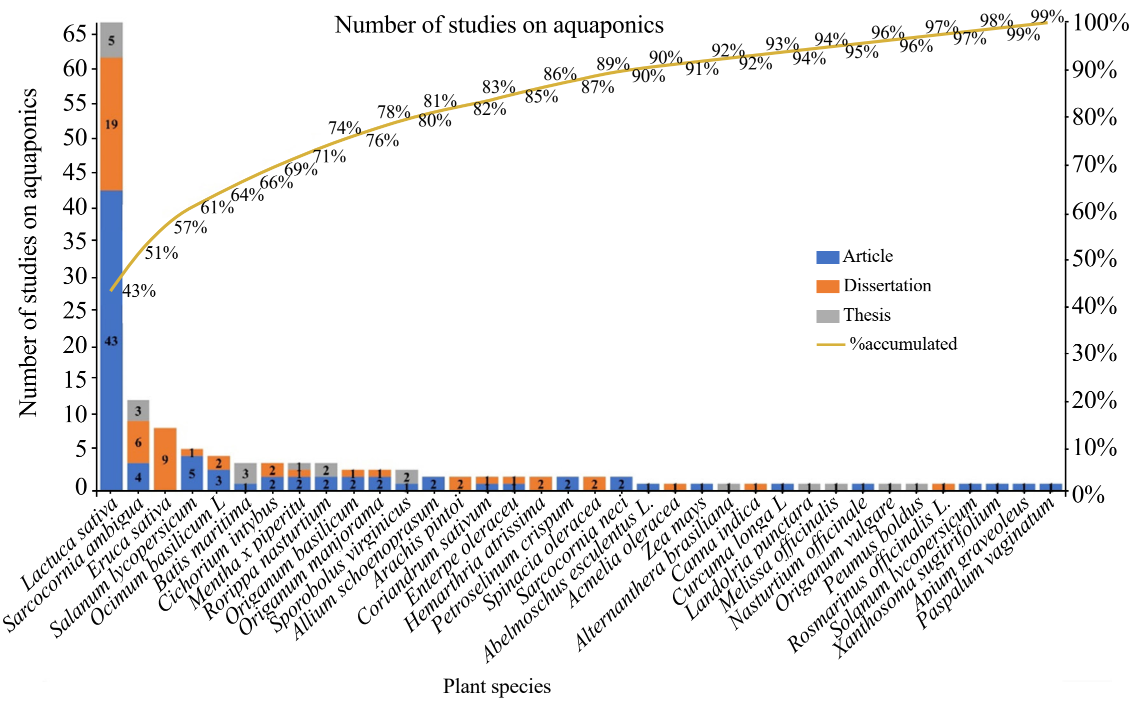


Figure 5. Accumulated percentage of plant species used in aquaponic systems for each type of academic work in Brazil between 2008 and 2022.

Aquatic organisms

A total of 16 different aquatic organisms was observed in the studies on aquaponics. Tilapia (*Oreochromis niloticus*) was the predominant species in the studies (47.8%), followed by whiteleg shrimp (*Litopenaeus vannamei*) (16.3%), tambaqui (*Colossoma macropomum*) (9.7%), Amazon river prawn (*Macrobrachium amazonicum*) (8.6%), and catfish (*Rhamdia quelen*) (4.3%) (Fig. 6).

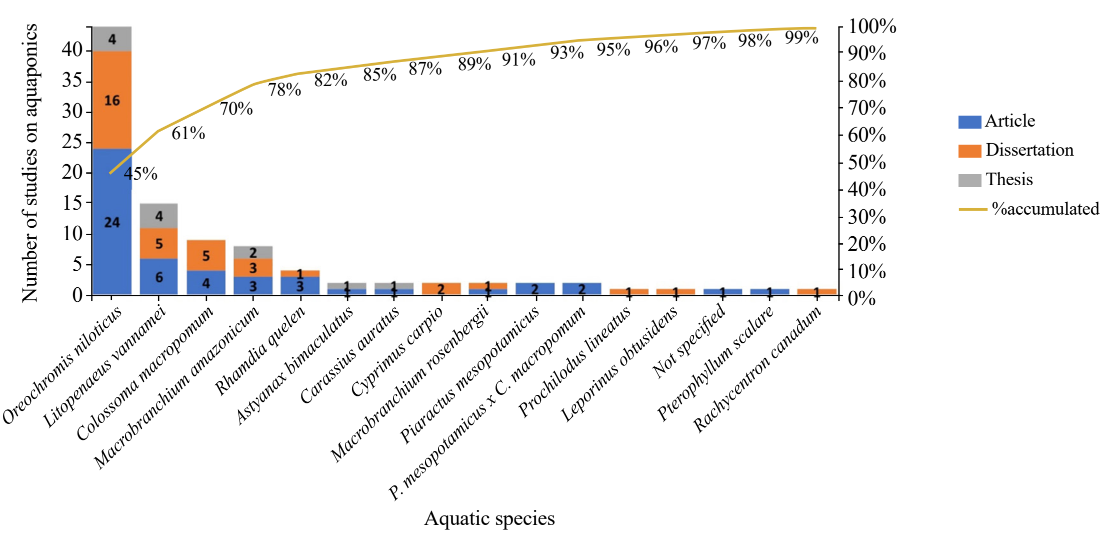
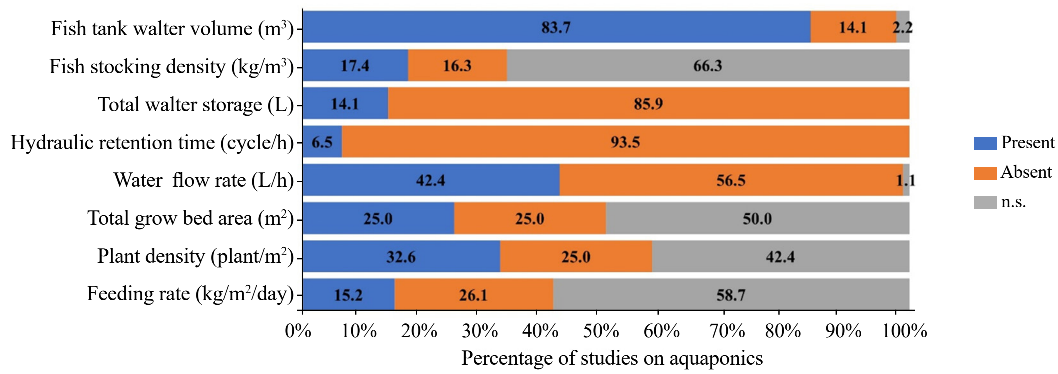


Figure 6. Fish species used in aquaponic systems for each type of research work.

Intellectual structure of experimental studies

System sizing

Among the 93 experiments listed in Moraes-Viana (2025a), only 18 incorporated all eight essential parameters (Colt et al., 2021) during the development of an aquaponic system (Fig. 7). In several other cases, not enough information was presented to accurately evaluate some of the parameters (Conrado et al., 2021; Geisenhoff et al., 2016; Jordan et al., 2020), and, in four papers, none of the items was cited at all (Bianchini et al., 2020; Martins, 2021; Souza et al., 2017; Tonet et al., 2011).



n.s.: not specified.

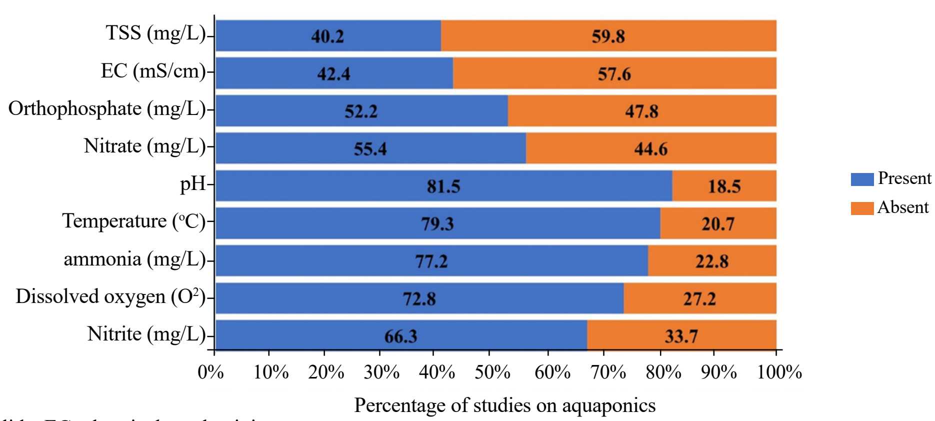
Figure 7. The essential technological parameters for designing an aquaponic system. The numbers present in the bars represent the percentage of studies.

The parameter fish tank water volume was the most reported one in the system design (83.6%), while fish stocking density was only mentioned in 17.3% of the studies. Fifteen studies (16.3%) provided only the number of fish/m^3 and not the fish stocking density as kg/m^3. The items total volume of water in the system, hydraulic retention, and flow rate were the parameters most often omitted by authors, being absent in 85.9, 93.5, and 56.50% of these studies, respectively.

The feeding rate was also neglected in most studies. It was mentioned in only 14 studies (15.2%), and 24 of the studies (26%) failed to provide exact values of feed provided daily. For example, some studies reported fish feeding as *ad libitum* (Cani et al., 2013), while others reported only the percentage of live weight used for feeding (Carvalho et al., 2017; Castellani et al., 2009) without precisely recording the fish stocking density.

Water quality parameters

Among the nine water quality parameters examined, the total suspended solids one was the least reported, with 55 out of 92 studies (59.7%) omitting this measurement. This was followed by the parameters electrical conductivity, omitted in 53 studies (57.6%); orthophosphate, omitted in 44 studies (47.8%); and nitrate, omitted in 41 studies (44.6%) (Fig. 8). The most



TSS: total suspended solids; EC: electrical conductivity.

Figure 8. The nine water quality parameters used in research on aquaponics in Brazil between 2008 and 2022. The numbers in the bars give the percentage present and absent in the studies reviewed.

frequently evaluated parameters were pH (81.5%), temperature (79.3%), ammonia (77.7%), dissolved oxygen (72.8%), and nitrite (66.3%).

Only six studies evaluated all water quality parameters, namely: Carneiro (2019); Carvalho et al. (2017); Lima (2016); Lima et al. (2022); Pinho et al. (2021b); and Ros (2017). The studies by Castellani et al. (2009), Castilho-Barros et al. (2018), Franchini (2019), Martins (2021), Mendes et al. (2021), Mendonça et al. (2020), Pinho (2018), Soares (2021), and Tonet et al. (2011) had research objectives that did not require the water quality analysis. In these cases, therefore, there were no water parameters to analyze and no implications regarding the quality of the research developed.

DISCUSSION

Following the literature review, it was seen a significant increase in the number of scientific studies in the aquaponics field in Brazil between 2008 and 2022. During this period, 148 studies were published, including articles, theses and dissertations, with a predominance of studies being undertaken in the Southern and South-Eastern regions of Brazil. The prevalence of studies in these regions may be partly due to an historical regional concentration of research and development investment in the Southeast and South regions, as they receive most financial incentives from development agencies (Andrade, 2021; CGEE, 2021).

Whether regionally or nationally, investment in collaborative networks is important. In a scientometric study on the global growth and advancement of aquaponics, Basumatary et al. (2022) stated that investing in such networks among authors and organizations can help researchers achieve common goals more effectively and make them more impactful. According to data from Academia Brasileira de Ciências (2022), Brazil's growth depends on the level of investment in science and innovation and the quantum of science produced in the country, with more than 90% of the investment being made by public universities via graduate programs.

When analyzing the research topics by year of publication, between 2008 and 2015, research was more focused on the topics structures of systems and their mechanisms and selection of plant and fish species (Fig. 4). Since 2018, interest in economics and management has increased, reflecting a recognition that improved knowledge of the economic and environmental benefits of these systems is an important determinant for the viability of commercial aquaponics (Greenfeld et al., 2018; Greenfeld et al., 2021). Greenfeld et al. (2018) and Greenfeld et al. (2021) considered that, for aquaponics to become a significant part of global food production and realize its potential environmental benefits, it must generate profit. They suggested there should be a greater focus on three under-studied aspects important for the success of commercial aquaponics:

- Grower considerations, such as financial planning and risk management, which affect the initial involvement of potential growers in aquaponics;
- Consumer perception of aquaponics products, including willingness to pay more for their added value;
- The economic value of the environmental benefits of aquaponic systems and ways to internalize them for profit.

As in other countries, the interest in studies about aquaponics is due in no small part to consumer demand for healthier and sustainably produced food. There are several studies on consumer perception of aquaponic products in various parts of the world, including Spain, Austria, the United States of America, and some countries in South America (Eichhorn & Meixner, 2020; Pollard et al., 2017; Miličić et al., 2017; Suarez-Carceres et al., 2021). However, there is a gap in these studies when it comes to Brazilian consumers, which can be partly explained by the fact that aquaponics is an emerging practice using a new paradigm of sustainable agriculture in Brazil.

Eichhorn and Meixner (2020) considered that successful implementation of aquaponics in the market requires the provision of accurate information to consumers with an emphasis on the value of aquaponics as a sustainable food production system. Therefore, producers need to understand the factors that influence the consumer's decision to purchase products grown via aquaponics and whether they are willing to pay a premium for these products (Greenfeld et al., 2018; Miličić et al., 2017). In Europe, studies into consumer awareness and knowledge of aquaponics and acceptance of aquaponics produce showed that, when consumers have access to these products, acceptance is generally good, while a willingness to pay a premium is mostly present with respect to products that are free of antibiotics, pesticides and herbicides, and are associated with well-known local producers (Miličić et al., 2017). Certification is also considered a necessary step to enable growth in ventures in the field and to help spread awareness of the system and its environmental and social benefits (The Aquaponics Association, 2020).

The first technical reports in aquaponics (released in the late 1990s and early 2000s), mainly focused on small-scale aquaponics (in backyards and apartment balconies) (Love et al., 2014). However, with an increase in public interest and encouraging results obtained in aquaponics-based farms in other countries, the interest of Brazilian institutions has increased in the last decade. Figure 2 shows that, between 2017 and 2020, the number of scientific studies increased in Brazil in line with global trends. It is also the case that, at the same time as numerous research reports were being published, large commercial aquaponic systems were established (Pattillo et al., 2022; Villarroel et al., 2016). However, the Brazilian aquaponics market remains at an early stage of development, with few businesses established in the field and most of them still in the process of developing and refining their business models.

Producers have found it difficult to price aquaponic products to make them economically viable (Greenfeld et al., 2021). This is partly due to the large number of different systems (DWC, MBGB, and NFT) working in different locations under different environmental conditions (Brewer et al., 2021; David et al., 2022). The lack of specific knowledge on marketing and selling products from aquaponic systems may also hinder the establishment of aquaponics in the Brazilian market.

The current review revealed a growing interest in integrating aquaponics into the biofloc system. Among the 93 experimental studies, 25% were based on bioflocs. This suggests that aquaponics has the potential to be deployed in conjunction with other methods of cleaning fish waste and that both biofloc and aquaponics systems have an approach that is considered ecologically friendly for food production. It also offers the advantage of producing aquatic animals in a controlled environment, with a high degree of water reuse and predictability in harvests (Pinho et al., 2021b). Rahman (2010) was one of the first authors to use the biofloc system in aquaponics cultivation, now known as FLOCponics. FLOCponics is a recent term that is defined as the integration of aquaculture based on bioflocs with hydroponics, which focuses on nutrient recycling and water savings, in addition to reducing the accumulation of nitrate and phosphorus in the system (Pinho et al., 2022). In a recently published global review, Basumatary et al. (2022) found an increase in interest in this area, and the authors consider that this may be a response to the global demand for sustainably produced, quality food employing cutting-edge methods and technologies. Pinho et al. (2022) considered that the integration of aquaponics with biofloc systems could make commercial aquaponics a reality in Brazil.

In relation to the most-used hydroponic components, Mauricieri et al. (2018) reviewed 122 papers published between 1979 and 2017 and observed that MBGB was the main hydroponic system used in scientific research (43%), followed by DWC (33%), and NFT (15%). In a more recent study (Pattillo et al., 2022), DWC was cited as the main choice in research carried out in the United States of America (71%), followed by MBGB (64%), and NFT (26%). They pointed out that MBGB is the most viable option for small-scale research, as the media itself serves as a substrate for bacterial growth, thus bypassing the use of a separate biological filter. In addition, it provides systems with greater stability to support larger plants. Mauricieri et al. (2018) considered that NFT seems to be, in several aspects, less efficient than DWC or MBGB. This is mainly because the yield of some plants may be impaired in places with abrupt temperature changes during day and night, although there are other problems, such as clogging of the system. On the other hand, Lennard (2017) considers that NFT is an appropriate technology for aquaponics considering capital cost and ease of use.

There is a need to direct research towards other plant species, as most studies focus on the use of leafy vegetables such as *L. sativa*. Yep and Zheng (2019) pointed out that leafy plants seem to be the most successful species in aquaponics because they have low nutrient requirements, grow quickly, are generally in high demand, and have good economic value. The second most-used species, *S. ambigua*, is a halophyte species that is common in the coastal region of Brazilian South-Eastern, where most of the studies with this species were carried out. It was also noted that there were fewer fruit crops and no root crops in the studies.

Different approaches have been used in research on tilapia. Cani et al. (2013) verified the viability of the interaction between lettuce and tilapia for improving the wastewater quality, noting that the greater the number of plants, the greater the amounts of nitrite and orthophosphate removed, while Pinho et al. (2021b) evaluated the cultivation of tilapia in a biofloc system, which makes it possible to use less protein in the fish diet. In addition to being one of the most-cultivated species globally (FAO, 2014), the greater use of tilapia in scientific studies on aquaponics is justified by Lennard (2017) because of the characteristics of the species (fast growth, ability to withstand stress and diseases, and for being omnivorous).

However, the use of non-native species, especially invasive ones like tilapia, can represent a threat to global biodiversity, in addition to any social and economic impacts (Gozlan et al., 2010; Latini et al., 2021; Gilles et al., 2023). One of the concerns with the use of non-native fish species (NNF) in the Amazon basin, for example, is their introduction into fish farms without escape barriers, because these fish farms suffer from seasonal flooding by rivers in their vicinity (Sousa et al., 2022). Doria et al. (2021) carried out a specific NNF review for the Amazon region and found that Brazil is in second place in terms of occurrence of NNF species and tilapia is one of the most invasive fish. The Amazon basin has the greatest variety of fish species in the world, which should suggest greater investment in studies of native species integrated with innovative systems, as is the case for aquaponics.

Recently, native species *versus* non-native species has been a common theme in aquaponics. Pinho et al. (2021b) suggested that some South American fish species, such as *Colossoma macropomum*, *Rhamdia quelen*, and *Piaractus mesopotamicus*, have the potential to replace tilapia in aquaponic systems. According to the authors, these species have very similar characteristics to tilapia in terms of fish stocking density and high levels of suspended solids, a high market value, good nutritional quality and reach large sizes when produced in conventional systems. Despite the small number of studies on aquaponics in the Northern region (11.9%), the use of native species was universal, which suggests a great interest in investigating innovative and sustainable alternatives for fish production with an already established market in the region.

The current review also highlighted that 16.3% of the studies involved saltwater species. Mariscal-Lagarda et al. (2012) showed that whiteleg shrimp (*Litopenaeus vannamei*) can be incorporated into tomato production when using groundwater, with a water consumption of 2.1 m^3/kg of harvested products. Pinheiro et al. (2017) used biofloc technology to integrate brine shrimp and marine asparagus (*Sarcocornia ambigua*) and were able to improve the use of nutrients in the culture, producing up to 2 kg of plants for each 1 kg of shrimp. More recently, Chu and Brown (2020) evaluated the effect of salinity on the growth performance of whiteleg shrimp and three halophyte plants in a marine aquaponic system with bioflocs and suggested a salinity of 15 parts per thousand for the integrated cultivation.

Overall, results indicated a high degree of success in the integrated cultivation of plants and fish in saltwater (marine aquaponics). Marine aquaponics offers many of the same advantages as freshwater aquaponics, with the additional benefit that marine animals generally grow faster than freshwater fish, and mollusks may have a higher market value (Quagrainie et al., 2018).

Regarding system sizing, it is important to plan a precise system in order to find the correct balance between the size of the fish component in relation to the plant component (Buzby & Lin, 2014). Liebig's Law, which emphasizes that the yield of a plant is determined by the most limiting micronutrient, is being replaced by more complex algorithms that consider the interactions between chemical nutrients. These methods make evaluating the effects of changes in nutrient concentrations a more complex task (Baxter, 2015).

The eight parameters generally used for system sizing (Fig. 7) are important because they aid in the calculation of overall nutrient masses within the system (based on measured nutrient concentrations) and in understanding the rate of water flow through the bed/channel, including retention time (Lennard, 2017). Hydraulic retention time is important because it defines how long water remains in the system and how quickly it responds to changes in inputs. Flow rate is used to determine how often water is changed per hour and is an important component in agricultural production via aquaponics since it determines the flow of nutrients into the root zone, which affects spatial and temporal water characteristics and, subsequently, determines the growth and yield of crops (Yang & Kim, 2020).

The feeding rate (*i.e.*, the amount of daily fish feed based on plant growing area and plant type) has often been used as the key parameter in system sizing (Rakocy et al., 2006; Somerville et al., 2014). To determine the daily amount of feed provided, the fish stocking density (kg/m^3) and the percentage of live weight used for feeding must be considered. In addition to the amount of feed, feeding rate also considers the total area of plant cultivation. However, the cultivation area was reported in only 25% of the 92 studies, and the plant stocking density (number of plants/m^2) was not specified in others. Together with the total cultivation area, this measure helps determine the amount of daily feed that is necessary to meet the nutritional needs of the plants (Colt et al., 2021; Yildiz et al., 2017).

Rakocy et al. (2006) established a feeding rate ratio in the range 60–100 grams of feed (UVI system/model/method) supplied to the fish every day for each m^2 of plant cultivation area (60–100 g/m^2/day) when using DWC. Lennard (2017) used another method that requires 15 g/m^2/day, *i.e.*, a quarter of the feed required for the UVI method for the same plant production area. The main reason for this difference is that Lennard's method (Symbioponic™ Aquaponic Method) remineralizes all solid waste from the fish farming (aerobic mineralizer), which reduces the amount of input (fish food) (Lennard, 2021). Despite the difference, both authors agree that no matter which method is used, the daily fish feed (feed rate – kg/day) and number of cultivated plants (plants/m^2) are the most important parameters, because they provide the data needed to plan the size of the two main components of the aquaponic system (*i.e.*, the fish and plant components). Therefore, it is important that experimental studies produce valid results that can be used to design systems on a commercial scale. The lack of well-designed experiments can raise doubts about the productive performance of the aquaponic system and, therefore, generate uncertainty for producers seeking to invest in commercial systems (Colt et al., 2021; Lennard, 2021).

In relation to the water quality parameters, there is some debate in the academic community about the use of electrical conductivity as a necessary test in the context of aquaponics (Colt et al., 2021; Lennard & Goddek, 2019), because nutrients in aquaponics are organic and unloaded. Therefore, testing the electrical conductivity does not show the total nutrient load in the system (Lennard, 2017; Rakocy et al., 2006). In hydroponic systems, the electrical conductivity provides a measure of the total amount of nutrients in the water, and since all nutrients are added as salts, they dissolve and turn into charged ions. These charged ions are read by the electrical conductivity meter, and since all nutrients in hydroponics are derived from salt, the electrical conductivity reading provides a measure of total nutrient load output. However, in aquaponics most of the nutrients required by plants come from fish waste that comprises complex organic molecules with no associated charge. Therefore, although it can still be a valuable management tool in aquaponics, electrical conductivity only represents a proportion of the total amount of nutrients in the water.

The current review also highlighted that nitrate and orthophosphate parameters were analyzed in only 52.2 and 54.5% of the studies, respectively (Fig. 8). The absence of these analyses in many of the studies reveals a lack of scientifically based methodology in the development of research experiments. Colt et al. (2021) attributed this to the fact that many studies evolved from small-scale experimental systems, short growth trials, and weak experimental designers. Total suspended solids were another parameter missing in many studies (approximately 60%). This parameter is intrinsically linked to water turbidity, since the more solids suspended in the water, the greater its turbidity. The accumulation of solid waste in the root zone can result in the production of anaerobic conditions. Low dissolved oxygen issues are predicted to be more serious in aquaponic systems (compared to hydroponic systems) due to the high levels of suspended solids and biochemical oxygen demand, which further reduce dissolved oxygen in the root zone (Palm et al., 2018).

Perspectives for aquaponics in Brazil

Brazil has significant potential for aquaponics, but its use is still limited and there is little dissemination of the technique at national level. In a survey conducted by Emerenciano et al. (2016) to classify the groups working in the research area, a questionnaire was administered to understand the current state of research, science, and innovation in aquaponic systems implemented in Brazil. A total of 55 responses was obtained from individuals involved in the sector who had previously participated in technical-scientific events during the period in question. It was reported that in many cases systems were implemented by local farmers and were of limited scope. Commercial operators were distributed across the North-Eastern region (38%), the South (29%), South-East (23%), Central-West (6%), and North (4%). Among the total responses, 63% carried out research into aquaponics and a little more than half went on to develop some type of scientific production.

Recently, the challenges faced by aquaponics farmers in Brazil have caught the attention of Brazilian researchers (ABA, 2021). Paulo Carneiro, a researcher with Embrapa Tabuleiros Costeiros, reported various difficulties farmers have in developing realistic business plans that consider the provenance of inputs. The lack of consumer awareness of the advantages of aquaponics is also referenced as a latent/cultural issue. He suggested that producers must find ways to disseminate information on the products, allowing appropriately for cultural issues, since in some places freshwater fish is not part of the local or indigenous diet (ABA, 2021).

Carneiro and Emerenciano agreed that with respect to the prospects for aquaponics research in Brazil, the search for economic partners in research, especially in the private sector, is critical. According to their research, this is because of a reduction in public funding for scientific research, and the desirability of directing research to focus on specific regional needs. In addition, there is a need to ensure that findings generated by research carried out at national level reach interested producers, and in language that is appropriate for each audience (ABA, 2021).

Dialogue between institutions has not become common yet, and for future collaborative effort to be feasible, it is necessary to look to the global scene to guide future action. For example, the 2021 (Virtual) Annual Aquaponics Congress aimed to stimulate discussion about what theme research is necessary for aquaponics industry. It highlighted several issues including the need to understand the nutrient dynamics of the system and its optimization, avoid the tilapia-lettuce combination, invest in value-added aquaculture and plant species, and develop more accessible aquaculture recirculation systems. It also noted the importance of performing sensitivity analyses that are specific to the relevant system model (NFT, DWC, MGMB). The desirability of developing economic models with marketing strategies that enable the implementation of specific certifications for aquaponics was also discussed (Emerenciano, 2022).

CONCLUSION

Brazil's growing interest in sustainable agricultural systems like aquaponics is evident from the rising number of studies over the past decade. Research is concentrated in the Southeastern and Southern regions, highlighting the need for deeper analysis of co-occurrence networks and the intellectual structure of aquaponics research. Mapping collaborations among authors, institutions, and regions is crucial for future investments, particularly in the North and Northeast, where research is fragmented, groups are smaller, and funding is limited.

This study provided an overview of species selection and system types. Tilapia dominates due to its tolerance to high nitrate and low oxygen levels, though native species show potential in established markets. Lettuce prevails in plant selection for its low nutrient demand, consumer appeal, and economic value. The prevalence of NFT systems is likely due to their low cost and ease of management compared to other soil-less methods.

Despite increasing research, key gaps remain, particularly in commercial-scale feasibility. Studies on the economic and environmental benefits of aquaponics, as well as consumer perception, are essential for advancing the field. Additionally, experimental design inconsistencies hinder data interpretation and system scalability. Addressing these gaps will aid standardization, improving commercial viability and research accuracy.

CONFLICT OF INTEREST

Nothing to declare.

DATA AVAILABILITY STATEMENT

The data are available in the repositories: https://doi.org/10.6084/m9.figshare.29508782.v1 and https://doi.org/10.6084/m9.figshare.29506079.v3

AUTHORS' CONTRIBUTION

Conceptualization: Moraes-Viana, G., Santos, O.A., Santos-Silva, E.N.; **Funding Acquisition:** Moraes-Viana, G., Santos, O.A., Santos-Silva, E.N., Bordinhon, A.M.; **Writing – original draft:** Moraes-Viana, G.; **Data curation:** Moraes-Viana, G.; **Methodology:** Moraes-Viana, G., Santos, O.A., Santos-Silva, E.N.; **Investigation:** Moraes-Viana, G., Santos, O.A.; **Project administration:** Moraes-Viana, G., Santos, O.A.; **Validation:** Moraes-Viana, G.; **Software:** Moraes-Viana, G.; **Formal Analysis:** Moraes-Viana, G., Santos, O.A., Santos-Silva, E.N.; **Writing – review & editing:** Moraes-Viana, G., Santos, O.A., Santos-Silva, E.N.; **Resources:** Santos, O.A., Santos-Silva, E.N., Bordinhon, A.M.; **Supervision:** Santos, O.A.; **Validation:** Santos-Silva, E.N.; **Visualization:** Bordinhon, A.M.; **Writing – review:** Bordinhon, A.M.; **Final approval:** Moraes-Viana, G.

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