Pertanika J. Trop. Agric. Sci. 49 (5): 2499 - 2522 (2026)

PERTANIKA JOURNALS

TROPICAL AGRICULTURAL SCIENCE

Journal homepage: http://www.pertanika.upm.edu.my/

Aquaponics as a Sustainable Food Security Solution: Global Scholarly Trends and Intellectual Structure Analysis

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ASBTRACT

This study presents a comprehensive bibliometric analysis of 328 peer-reviewed journal articles retrieved from the Dimensions AI database to examine the intellectual structure, research trends, and thematic evolution of aquaponics research, with a specific focus on food security. Using a structured Boolean search strategy and defined inclusion criteria, performance analysis and science mapping techniques, including bibliographic coupling and keyword co-occurrence analysis, were employed to identify influential contributors, research networks, and emerging themes. The findings reveal substantial publication growth between 2019 and 2025, reflecting increasing scholarly interest in sustainable and resource-efficient food production. Performance analysis identifies influential authors, institutions, journals, and countries, highlighting the international development of aquaponics research. Bibliographic coupling reveals interconnected research streams addressing technological innovation, environmental sustainability, and regional food security applications. Keyword co-occurrence analysis identifies prominent themes involving water efficiency, hydroponic integration, climate resilience, community implementation, and smart agriculture. Two major knowledge domains emerge: technology-driven aquaponics optimisation and community-based food security implementation. These findings suggest a gradual shift from experimental system development towards scalable, digitally supported, and socio-economically relevant applications. Unlike previous reviews examining aquaponics broadly, this study specifically maps the intersection between aquaponics and food security, providing a more focused understanding of its intellectual and thematic development. The findings identify emerging research priorities and offer useful insights for

ARTICLE INFO

Article history:
Received: 17 July 2026
Accepted: 20 October 2026
Published: 30 October 2026

DOI: https://doi.org/10.47836/pjtas.49.5.20

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policymakers, researchers, and practitioners seeking to strengthen sustainable food production, resource efficiency, and long-term food security.

Keywords: Aquaponics, bibliometric analysis, bibliographic coupling, food security, science mapping, sustainable food production

INTRODUCTION

The world's food systems are increasingly challenged by rapid urbanisation, climate change, resource scarcity, and supply chain disruptions. Such pressures have increased the exploration of novel and effective solutions to agriculture, ensuring food security in the longer term. While the world is facing the issue of food insecurity, resilient and practical options in food production are much needed, especially in densely populated areas (Khan et al., 2020). In a broader framework of circular resource utilisation, aquaponics integrates a production system that focuses on resource efficiency by linking aquaculture and hydroponics. Using this system, good microorganisms convert nutrients from fish waste into forms absorbable by plants. Plants remove nutrients from the water before it is recirculated to the fish tanks. The integrated process reduces water consumption, minimises nutrient discharge and enables productive resource use, rather than being treated as waste. By incorporating circular economy principles, aquaponics transforms waste streams into valuable inputs, reducing reliance on external resources and offering an effective approach to sustainable urban food production. The overall sustainability of aquaponics systems is also dependent on crucial factors such as energy consumption, system design, nutrient management and operational costs. Singapore is using technological innovation in the application of smart food system strategies in resource-challenged settings (Mok et al., 2020). One of the emerging technologies in fish and crop production is the combination of aquaculture and hydroponics that utilises water and nutrients in the system. The research indicated that this crop could enhance sustainable food production in dry and resource-limited regions (Abusin & Mandikiana, 2020).

The increasing need for sustainable food production is largely due to the growing scarcity of natural resources, especially water and agricultural land. In circular food production, recycling and resource recovery practices reuse materials rather than discard them, offering practical ways to reduce waste and enhance resource efficiency. Exemplifying this approach, aquaponics provides a system that combines fish farming and plant cultivation, recycling water and nutrients. It offers meaningful benefits for food security, environmental protection and sustainability, although future research is required to understand its contributions, identify knowledge gaps and determine further research directions to ensure ecosystem practicality in attaining the desired outcome. Recent studies have demonstrated the potential of innovative recycling and waste-valorisation approaches to enhance resource recovery

while minimising environmental impacts. The reuse of nutrient-rich aquaculture effluent in aquaponic systems promotes water conservation, reduces dependence on synthetic fertilisers and supports sustainable agricultural production (Abd Aziz et al., 2026). The integration of aquaculture and hydroponics facilitates continuous nutrient recycling in a closed-loop production environment, highlighting the effectiveness of aqua beds in enhancing nutrient cycling, supporting plant growth, and reducing environmental impacts (Abd Aziz et al., 2025). Furthermore, their study identified alternative growing substrates, such as carbonised rice husk and cocopeat, as innovations for enhancing resource efficiency and sustainability in aquaponic farming.

The latest developments also enhance the feasibility of aquaponics due to digitalisation and precision agriculture. The use of models of artificial intelligence (AI) and machine learning has proven to be effective in controlling nutrients and irrigation processes to achieve efficiency (Dhal et al., 2022), while AI-based forecasting can be employed to boost productivity and resilience of the supply chain (Dhal & Kar, 2024). Smart systems based on IoT enable real-time monitoring of water quality and environmental parameters (Dutta et al., 2025; Kok et al., 2024). Furthermore, the use of crop diagnostic technologies (Abbasi et al., 2023) supports the detection of diseases and plant health management in aquaponic systems. The application of integrated nutrient management (INM) techniques and bio-stimulants is also used to optimise soilless cultivation systems (Ali et al., 2024). Climate resilience is increasingly emerging as a critical issue, and climate change is impacting sustainable food production systems due to technological developments (Mešić et al., 2024). Despite these changes, the previous bibliometric mapping of aquaponics was quite general and did not focus specifically on aquaponic farming and food security, with the need for a bibliometric analysis of those two areas to track the research and intellectual trends and emerging themes at that intersection. This study addresses the gap in the aquaponics literature. Basumatary et al. (2023) examined the broader development and intellectual structure of global aquaponics research, while Kushwaha et al. (2025) reviewed aquaponic configurations, operational parameters, and microbial dynamics.

These studies provide valuable foundations for understanding the technological development and scientific evolution of aquaponics. On the other hand, this study positions aquaponics within specific context of food security, zooming into the research landscape through a food-system and sustainability perspective instead of just technological or operational considerations. Bear in mind that this distinction is significant as the advancement in aquaponics technology does not necessarily translate into demonstrable improvements in food security. Challenges in technological efficiency, system productivity and operational optimisation are only part of the broader challenges, and to understand aquaponics' contribution to food security demands attention to issues of food availability, accessibility, nutritional outcomes, economic feasibility, resource sustainability, and the potential adoption by vulnerable communities.

METHODOLOGY

Bibliometric analysis examines research trends, publication patterns, and the contributions of authors, institutions, and countries, while science mapping identifies and visualises relationships among research topics and their intellectual structures. Contrastively, a systematic literature review critically examines and summarises previous studies to answer specific research questions. Therefore, this study adopts bibliometric analysis supported by science mapping techniques, including bibliographic coupling and keyword co-occurrence analysis. By examining 328 journal articles, the study identifies global research trends, key contributors, major research themes, and emerging directions in aquaponics and food security. This approach provides a clearer understanding of how research in this field has developed. This study used a bibliometric research design to conduct a systematic review of the academic literature on aquaponic farming and food security. The decision to use bibliometric analysis was based on its ability to quantify research trends, high-impact publications, and topic frameworks within a particular body of literature. In addition, the methodological framework was developed based on the previous study on sustainability and aquaponics, a concept of unity between urban agriculture, technological development and food system resilience (Khan et al., 2020; Mok et al., 2020; Pulighe & Lupia, 2020). The dataset was retrieved from the Dimensions AI database using a structured Boolean search that combined aquaponics-related terms with food security concepts. Peer-reviewed journal articles published in the specified time frame were used to achieve academic rigor and relevance.

The collected data were analysed for performance analysis and science mapping, including bibliographic coupling and occurrence of keywords. By analysing performance indicators, citations, total link strength, authorship pattern, institutional contribution and country productivity, the impact of research and collaboration networks was identified. Bibliographic coupling detected intellectual connections among studies with common references, and co-occurrence analysis revealed prevailing and emerging research topics. Network analyses were conducted using VOSviewer (version 1.6.20) (van Eck & Waltman, 2010). Our study combined performance analysis (identifying top-performing documents, authors, institutions, journals, and countries) with science mapping (bibliographic coupling and co-occurrence analyses). To ensure that only the most significant and highest-quality data were included, we set a target benchmark of 60 items as the maximum threshold for each analysis. For analyses where 60 items were available, we applied a threshold of 60; for others where fewer items met the criteria, we adjusted the threshold accordingly, down to a minimum of 36. Across all analyses, these threshold values ranged from 36 to 60. This approach allowed us to filter out weak connections and focus solely on the most impactful contributions to the field (Donthu et al., 2021). The analytical technique used herein is similar to previous empirical and review studies on aquaponics that focused on

the sustainability, water efficiency, microbiology, and feasibility of aquaponics adoption (Abisha et al., 2022; Abusin & Mandikiana, 2020; Kasozi et al., 2021).

In addition, literature covering water management (Calone et al., 2019), system adoption issues (Okomoda et al., 2022), food sovereignty (Ibrahim et al., 2023), and applications of food security in the region was employed to give theme to the clusters (Obirikorang et al., 2021). This methodological process ensured the transparency, reproducibility, and comprehensive evaluation of the knowledge base on aquaponic farming as part of the elements supporting the establishment of sustainable food systems.

Search Strings

The inclusion criteria were also formulated meticulously to ensure the bibliometric data thoroughly considers the existing scholarly input on the links between aquaponic farming and food security outcomes. The retrieval of all records was limited to the Dimensions AI database, an all-encompassing index of peer-reviewed scientific publications across multidisciplinary fields. Consistency in metadata, citation tracking, and indexing quality was achieved by using only one validated database. The time period was limited to publications from 2019-2025 to account for recent changes and advancements in aquaponic technology, sustainability practices, and food systems resilience (Table 1). This is a particularly timely issue because, in the past decade, aquaponics has emerged as an area of interest in the field of agriculture that utilises climate-friendly solutions.

Table 1
Inclusion Criteria

Dimension Database	**ALL**
Time Period	2019 to 2025; searched on 11 July 2025
Search Keywords	("aquaponic*" OR "aquaponics system*" OR "aquaponics farm*" OR "integrated aquaculture hydroponic*" OR "aquaculture-hydroponic integration" OR "recirculating aquaculture system) AND ("food security" OR "food secur*" OR "food availability" OR "food access" OR "nutrition security" OR "food self-sufficiency" OR "sustainable food production")
Publication Type	Article
Language	English
Open Access	All OA

The selection of keywords included technical and outcome-based terms. The system-oriented descriptors were combined with concepts about food security, such as “food security,” “food availability,” “food access,” “nutrition security,” “food self-sufficiency,” and “sustainable food production.” This logical approach guaranteed the conceptual compatibility of production technologies and food security effects. The inclusion criteria

included Journal articles; open-access categories were accepted to ensure maximum accessibility and transparency. These filters helped narrow the next 550 records to 328 relevant studies most suitable to the research objectives. This systematic approach to editing minimised peripheral and/or irrelevant material while preserving key empirical and theoretical contributions.

RESULTS

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework was used to offer a clear and replicable screening procedure for the final selection of the literature. PRISMA is a set of instructions that help researchers report the identification, selection, screening, and inclusion of research for systematic reviews and meta-analyses in a transparent and clear way. It ensures the research process is easy to understand, repeatable and unbiased by showing all steps of the research selection process (Moher et al., 2009; Page et al., 2021).

It began with an identification step, in which the 550 publications were identified using the given search string in the Dimensions AI database. The aim at this stage was not to be precise but to capture broadly so as not to miss potentially relevant studies. In the screening phase, non-article sources and publications that did not directly reference both aquaponic systems and food security outcomes were excluded. The eligibility phase included further screening of the remaining records, where the inclusion criteria included: the type of publication (articles only), open access (only), and time period (defined). Lastly, the inclusion stage produced 328 articles that met all the requirements. This process of identifying the final inclusion is visually displayed in the PRISMA flowchart, which shows a decrease from 550 to 328 publications (Figure 1). This transparency of the methods enhances the credibility of the bibliometric analysis and enables the researcher to conduct a similar process in the future with confidence.

Performance Analysis

Performance analysis measures the productivity and the contribution of the research outputs. It quantifies such indicators as publications, documents, citations, authors, institutions, and countries. This critique shows the most instrumental ones, up-and-coming research centers, and the scholarly impact in a given field or subject.

Publication Trend Analysis

The trend analysis provides insight into how scholars' interest in aquaponic farming as an option for improving food security has changed. With the analytical overview provided by Dimensions AI, 328 publications were reviewed within the 2019 to 2025 period (Figure 2).

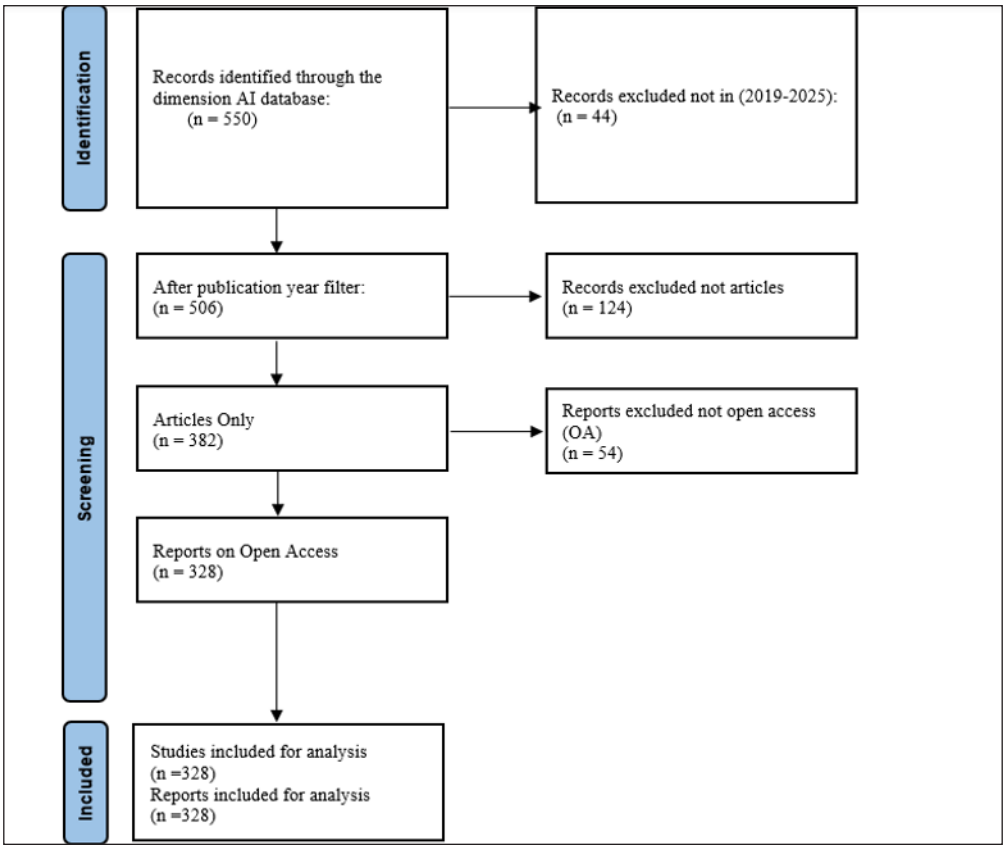

Figure 1. PRISMA flowchart

This period is when sustainable food production, urban agriculture and resource efficiency are gaining global momentum. The number of publications is slowly increasing, suggesting the experimental system of aquaponics has moved beyond the niche and has become an established area of research with possible policy and development outcomes.

The initial years of the period involved exploration, feasibility studies, and technical evaluations of the feasibility of combining aquaculture and hydroponics. As the field matures, studies moved into a variety of directions such as maximising yield, improving use of water, recycling nutrients and optimising costs. Subsequent studies focused on broader impacts, such as access to food, climate change adaptation, and participation in local food production. The rise in citation counts may represent an actual growth in production, and the influence and dissemination of knowledge within the scientific community.

The world's interest in sustainable agriculture, especially in urban and resource-limited settings, could also be a representation of the positive trend because aquaponics provides year-round production using minimal land area. The multidisciplinary collaboration of environmental scientists, agricultural engineers and food policy researchers is highlighted

in the growing literature. The fact that the publications and citations have been steadily increasing suggests that aquaponic farming is being regarded as a viable pathway to better food security and sustainable food systems.

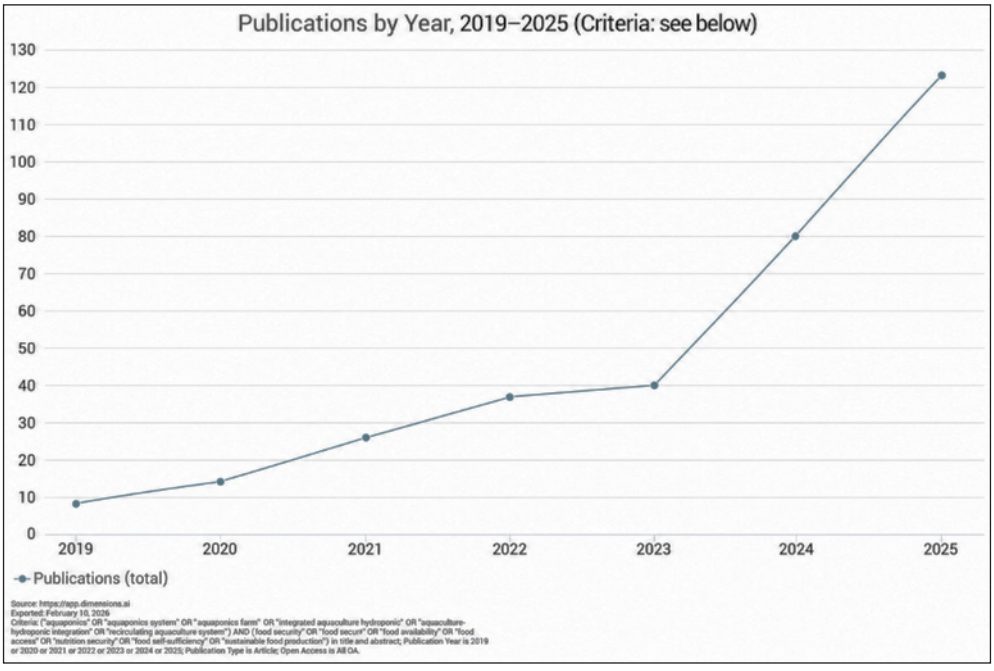

Figure 2. Quantity of publications and citations between 2019 to 2025

Documents

Document-level analysis provides information on the most influential publications in the research fields of aquaponics and food security. The number of citations reflects the impact and knowledge sharing of a study. The interest in urban agriculture during the COVID-19 crisis is evident in the most-cited journal article, which has been cited 214 times: "Food First: COVID-19 Outbreak and Cities Lockdown a Booster on a Wider Vision on Urban Agriculture," by Pulighe and Lupia (2020). It is followed by Technology Innovations in Food Security in Singapore: A Case Study of Future Food Systems in a More Natural Resource-Scarce World (141 citations), which demonstrates how technology can strengthen a country's food resilience. Similarly, during and in the aftermath of COVID-19, Urban Horticulture to Food Secure Cities emphasises the role of production systems that are city-based.

Containing more sources of reference, the other studies are in the field of aquaculture resilience and microbial ecology in aquaponics, and regional feasibility assessments. These demonstrate a balanced approach towards technical optimisation and sustainability

outcomes. The prominence of review articles is also notable, implying that synthesis papers can be crucial in terms of consolidating knowledge and establishing the path of future research. Document dissemination indicates that in many cases, the influential contributions relate aquaponics to more general topics like climate adaptation, urban agriculture, and resource efficiency. This shows that the most influential scholars in the field are not limited to systems design but rather focus on approaches to food system transformation and policy relevance (Table 2).

Table 2
Performance analysis by documents (Threshold 60)

Rank	Authors	Title	Citations
1	Pulighe and Lupia (2020)	Food First: COVID-19 Outbreak and Cities Lockdown a Booster for a Wider Vision on Urban Agriculture	214
2	Mok et al. (2020)	Technology innovations for food security in Singapore: A case study of future food systems for an increasingly natural resource-scarce world	141
3	Khan et al. (2020)	Urban Horticulture for Food Secure Cities through and beyond COVID-19	126
4	Abisha et al. (2022)	Sustainable development of climate-resilient aquaculture and culture-based fisheries through adaptation of abiotic stresses: a review	88
5	Kasozi et al. (2021)	The complex microbiome in aquaponics: significance of the bacterial ecosystem	85
6	Abusin and Mandikiana (2020)	Towards sustainable food production systems in Qatar: Assessment of the viability of aquaponics	70
7	Calone et al. (2019)	Improving water management in European catfish recirculating aquaculture systems through catfish-lettuce aquaponics	69
8	Okomoda et al. (2022)	Aquaponics production system: A review of historical perspective, opportunities, and challenges of its adoption	66
9	Ibrahim et al. (2023)	Aquaponics: A Sustainable Path to Food Sovereignty and Enhanced Water Use Efficiency	63
10	Obirikorang et al. (2021)	Aquaponics for Improved Food Security in Africa: A Review	53

Sources

With 12 publications and 442 citations, the Sustainability Journal is the first to top the list, establishing it as a site of interdisciplinary sustainability research. Other well-known journals are The Science of the Total Environment, Water, Aquaculture International, and Frontiers in Sustainable Food Systems, which have a higher citation performance with a smaller number of publications. The variety of sources establishes the interdisciplinary nature of the subject that covers environmental science, aquaculture engineering, and food

systems research. Technical publications address water management and recirculation, whereas sustainability-focused publications discuss social and policy repercussions. The total link strength values indicate that these journals have active citation networks which depict cross-disciplinary exchange of knowledge. Patterns of publication indicate that the research on aquaponics is not a niche in the aquaculture journals, but it is becoming a part and parcel of sustainability and food security studies. This extensive distribution increases exposure and speed of dissemination of research results in scientific and policy circles (Table 3).

Table 3
Performance analysis by sources (Threshold 44)

Rank	Journals	Documents	Citations	Total Link Strength
1	Sustainability	12	442	10
2	The science of the total environment	2	87	1
3	Water	3	68	12
4	Aquaculture International	4	57	11
5	Frontiers in Sustainable Food Systems	3	57	6
6	Agriculture	3	56	4
7	Annals of Animal Science	2	47	0
8	Journal of the World Aquaculture Society	2	44	10
9	Aquaculture research	3	43	1
10	Artificial Intelligence in Agriculture	2	38	3

Authors

The studies by Simon Goddek, Karel J. Keesman, R. Abbasi, R. Ahmad, and P. Martinez all resulted in three papers with relatively high citation rates and high collaboration linkage values. They tend to contribute to the optimisation of systems, their modelling, and the sustainable integration of aquaponics, implying technical leadership in the field. Large values of total link strength also indicate large co-authorship networks, which indicate collaborative and interdisciplinary research practices. This type of collaboration is necessary in aquaponics, a field that combines biology, engineering, and environmental management. The identical citation counts and link-strength values shared within the Abbasi/Ahmad/Martinez and Jaleel/Nair/Nishanth groups in Table 4 reflect tightly co-authoring teams that consistently publish together rather than a data artifact.

The other authors with moderate citations also broaden the thematic scope as they work with socio-economic adoption and regional implementation. They create centers of knowledge together, and they inform the methodological strategies and shape the future research directions. The presence of recurrent authors of various research studies with high impact suggests the development of a stable and steadily moving research community in

the domain of theoretical knowledge and practical application of aquaponics as a food security production approach.

Table 4
Performance analysis by authors (Threshold 47)

Rank	Authors	Documents	Citations	Total Link Strength
1	Goddek, Simon	3	64	5
2	Kessman, Karel J.	3	61	8
3	Abbasi, R.	3	58	11
4	Ahmad, R.	3	58	11
5	Martinez, P.	3	58	11
6	Jaleel, Abdul	3	47	10
7	Nair, Chythra Somanathan	3	47	10
8	Nishanth, Drishya	3	47	10
9	Rharrhour, Haytam	3	5	0
10	Styawati, Styawati	3	5	0

Organisations

Institutional analysis helps highlight the leading institutions for the study of aquaponics and food security. The number of citations is the highest at Sultan Qaboos University, and the involvement in sustainable agriculture in arid environments is high in the region. Other key players include Texas A&M University, University of Bologna and Wageningen University and Research, the latter having the most collaboration links, which suggests its global research collaborations. Also, the contributions of Universities like Universiti Putra Malaysia and the University of Alberta appear to be focused on developed or developing areas (Table 5). The pattern of productive organisations would suggest that aquaponics research is conducted at universities with strong agricultural, environmental and water management programmes. The link strength values are high, indicating that the institutions tend to work internationally and promote the transfer of knowledge and innovation.

Table 5
Performance analysis by organisations (Threshold 46)

Rank	Organisations	Documents	Citations	Total Link Strength
1	Sultan Qaboos University	4	139	4
2	Central Institute of Fisheries Education	2	97	2
3	Texas A&M University	3	93	2
4	University of Bologna	2	86	4

Table 5 (*continued*)

Rank	Organisations	Documents	Citations	Total Link Strength
5	Wageningen University & Research	5	84	15
6	National Water Research Center	2	67	8
7	Universiti Putra Malaysia	2	61	5
8	University of Alberta	3	58	6
9	University of the West of England	3	55	3
10	United Arab Emirates University	3	47	7

Countries

At the country level, the distribution and participation of aquaponics studies in the global context are shown. The number of citations and total number of links were significantly higher for Italy (454 and 30, respectively), with a very active and well-connected research base in sustainable agriculture and recirculating aquaculture technologies in Europe. Germany and the United States also demonstrate high output and strong collaboration due to their developed research and food-system innovation funding systems. Interestingly, India has the maximum number of documents (20), which in this context signifies the growing interest in low-cost, resource-efficient farming solutions in addressing food security issues, although the number of citations and link strength is not as high as that of Italy. Singapore and Pakistan had a few small but prominent studies that focused on urban density and climatic constraints. The closest one is Malaysia, which shows a high level of international cooperation. In the meantime, Oman and the United Kingdom are steadily contributing to the knowledge base. The distribution shows that research on aquaponics is scattered worldwide; both developed and developing countries recognise the potential of this practice to enhance sustainable food production. This international involvement enables knowledge exchange across cultures and offers the possibility of scaling up aquaponics globally (Table 6).

Table 6
Performance Analysis by Countries (Threshold 36)

Rank	Countries	Citations	Documents	Total Link Strength
1	Italy	454	12	30
2	Germany	232	11	32
3	India	217	20	29
4	United States	193	18	33
5	Canada	184	5	20
6	Singapore	173	3	4
7	Pakistan	172	2	19
8	Malaysia	143	6	41

Table 6 (*continued*)

Rank	Countries	Citations	Documents	Total Link Strength
9	Oman	139	4	10
10	United Kingdom	118	7	32

Bibliographic Coupling

Bibliographic coupling analysis describes the degree of relatedness of documents, using the number of shared references between them. When used in the context of aquaponic farming and food security, this approach can show which studies are based on similar theoretical foundations, and thus, they pertain to similar streams of knowledge. Food First: COVID-19 Outbreak and Cities Lockdown a Booster on Urban Agriculture (Pulighe & Lupia, 2020) is one of the most impactful papers in terms of citations, but with lower link strength, indicating that it is highly cited; however, it relies on a broader or more general reference base, as opposed to the same specialised aquaponics literature. In comparison, Aquaponics: A Sustainable Path to Food Sovereignty and Enhanced Water Use Efficiency (Ibrahim et al., 2023) has the highest link strength (297), which means that there is a great similarity with other core studies, and it is acting as the central node in the aquaponics knowledge network.

Likewise, Towards Sustainable Food Production Systems in Qatar: Assessment of the Viability of Aquaponics (Abusin & Mandikiana, 2020), Aquaponics for Improved Food Security in Africa: A Review (Obirikorang et al., 2021), and The Complex Microbiome in Aquaponics: Significance of the Bacterial Ecosystem (Kasozi et al., 2021), have high total link strengths, which indicate strong similarity between themes and methodological backgrounds. These articles focus on system performance, sustainability, and the application of the systems to food security at the regional level. The coupling network proposes that aquaponics research is organised around highly integrated technical and sustainability-oriented research, with review and feasibility articles serving as intellectual bridges. This interrelationship underscores the existence of a unified and fast-solidifying research field in which researchers extend shared evidence bases (Table 7).

Table 7
Bibliographic coupling most productive document (Threshold 52)

Rank	Authors	Title	Citations	Total Link Strength
1	Pulighe and Lupia (2020)	Food First: COVID-19 Outbreak and Cities Lockdown a Booster for a Wider Vision on Urban Agriculture	214	7
2	Mok et al. (2020)	Technology innovations for food security in Singapore: A case study of future food systems for an increasingly natural resource-scarce world	141	71

Table 7 (*continued*)

Rank	Authors	Title	Citations	Total Link Strength
3	Khan et al. (2020)	Urban Horticulture for Food Secure Cities through and beyond COVID-19	126	25
4	Abisha et al. (2022)	Sustainable development of climate-resilient aquaculture and culture-based fisheries through adaptation of abiotic stresses: a review	88	2
5	Kasozi et al. (2021)	The complex microbiome in aquaponics: significance of the bacterial ecosystem	85	81
6	Abusin and Mandikiana (2020)	Towards sustainable food production systems in Qatar: Assessment of the viability of aquaponics	70	113
7	Calone et al. (2019)	Improving water management in European catfish recirculating aquaculture systems through catfish-lettuce aquaponics	69	35
8	Okomoda et al. (2022)	Aquaponics production system: A review of historical perspective, opportunities, and challenges of its adoption	66	84
9	Ibrahim et al. (2023)	Aquaponics: A Sustainable Path to Food Sovereignty and Enhanced Water Use Efficiency	63	297
10	Obirikorang et al. (2021)	Aquaponics for Improved Food Security in Africa: A Review	53	108

Bibliographic Coupling by Clusters

Bibliographic coupling at the cluster level shows clear thematic groupings in the literature, showing how the field structures itself into specialised research subdomains (Figure 3). Table 8 presents the cluster analysis of Aquaponics as a Sustainable Food Security Solution, and this pattern is applied to indicate specific areas of the research focus. The largest group (Cluster 1 Red), comprising 16 articles, focuses on technological innovation and intelligent agricultural solutions. Examples of representative works include Urban Horticulture for Food Secure Cities through and beyond COVID-19 and Technology Innovations for Food Security in Singapore: a Case Study of Future Food Systems in an Increasingly Natural Resource-Scarce World, as well as works on artificial intelligence, nutrient regulation, and automated management systems. The cluster is indicative of a progressive attitude towards adopting digital solutions like IoT and machine learning to further enhance productivity and resilience in aquaponics.

Cluster 2 (Green) is less focused on performance, sustainability, economic viability and regional adoption, with 9 articles. The articles, such as Towards Sustainable Food

Table 8
Bibliographic coupling cluster on aquaponic farming and food security (Threshold 52)

Cluster No.	Cluster Labels	No. of Articles	Representative Publications
Cluster 1 (Red)	Smart/AI-Enabled Aquaponics and Urban Innovation	16	Abbasi et al. (2023); Ali et al. (2024); Dhal et al. (2022); Dhal and Kar (2024); Dutta et al. (2025); Khan et al. (2020); Kok et al. (2024); Mešić et al. (2024); Mok et al. (2020)
Cluster 2 (Green)	Sustainable Food Production and Regional Adoption	9	Abusin and Mandikiana (2020); Baganz et al. (2020); Channa et al. (2024); Gillani et al. (2022); Ibrahim et al. (2023); Karimanzira and Rauschenbach (2021); Obirikorang et al. (2021); Pinho et al. (2021)
Cluster 3 (Blue)	Techno-Economic Feasibility and Market Acceptance	7	Asciuto et al. (2019); Babatunde et al. (2023); Baiyin et al. (2020); Cifuentes-Torres et al. (2021); Eichhorn and Meixner (2020); Greenfeld et al. (2020); Okomoda et al. (2022)

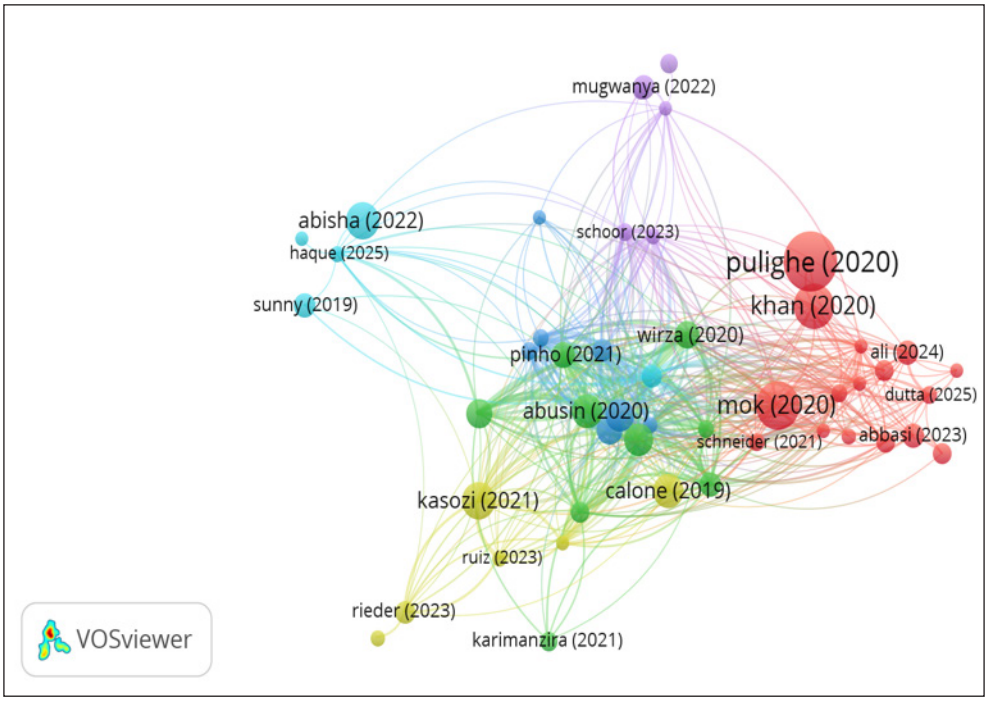

Figure 3. Bibliographic coupling analysis (VOSviewer Visualisation)

Production Systems in Qatar: Assessment of the Viability of Aquaponics, Aquaponics: A Sustainable Path to Food Sovereignty and Enhanced Water Use Efficiency and Aquaponics for Improved Food Security in Africa: A Review, are more on the practical side and the issue of food sovereignty. This cluster emphasises practice/policy implications.

In Cluster 3 (blue), there are 7 articles covering the following topics: economic feasibility, consumer acceptance and environmental sustainability evaluation. This research includes market demand, cost-benefit analysis, and urban production models. The clusters reveal the multidisciplinary nature of aquaponics research and innovation, the sustainability of aquaponics systems, and the assessment of socio-economic outcomes. This framework proposes a parallel shift of technical designs towards broader approaches to food security and adoption.

Co-Occurrence Analysis

The co-occurrence analysis of keywords provides insight into the conceptual framework and prevailing research themes in the aquaponic farming and food security literature. This process can be used to determine the most central issues and the correlation among the technological, environmental, and socio-economic aspects of the subject by analysing how often the keywords co-occur. The keywords used in the co-occurrence analysis provide an insight into the conceptual structure and predominant research trends of the aquaponic farming and food security literature. By analysing the co-occurrence of keywords, the process identifies the central issues and correlations among technological, environmental, and socio-economic aspects of the subject. The frequency of the term food security (221) indicates the major focus of the dataset on making food more available, accessible, and resilient.

Interestingly, water has one of the highest relevance scores, indicating that efficient water management and recirculation are an important research focus. Similarly, keywords such as efficiency, sustainability, and sustainable food production reflect the high level of environmental sustainability on which the literature focuses. These words demonstrate the increasing attention to resource conservation, climate adaptation, and ecological performance. Social and implementation-oriented words like the community, implementation, and activity show the growing interest in real-life adoption and local involvement. The relevance scores reported for "Community" (2.21) and "Activity" (3.12) in Table 9 are far outside the range of every other keyword (0.14 -0.74).

The co-occurrence network indicates a balanced knowledge system whereby technical production systems are well intertwined with sustainability and societal results. This convergence implies that research in aquaponics has ceased to focus on experimental design and started to engage in global food system issues. The introduction of scientific and community-oriented terminology reflects the existence of a multidisciplinary area that integrates engineering solutions with development-oriented approaches.

Table 9
The 13 most frequent keywords in the co-occurrence analysis (Threshold 56)

Rank	Keywords	Occurrences	Relevance
1	Food Security	221	0.26
2	Fish	141	0.25
3	Plant	102	0.14
4	Water	101	0.36
5	Hydroponic	99	0.30
6	Community	87	2.21
7	Efficiency	84	0.51
8	Sustainability	84	0.23
9	Research	82	0.22
10	Activity	79	3.12
11	Land	73	0.57
12	Sustainable Food Production	68	0.74
13	Implementation	62	0.25

Co-Occurrence Analysis by Clusters

Co-occurrence analysis also provides insights into how the research themes are grouped into various conceptual areas. Two large clusters are created, each of which is indicative of a different orientation of the literature. Cluster 1 (Red), with 22 keywords, may be considered a cluster related to technology and production. The keywords mentioned in the publication are horticulture, efficiency, integration, nutrient, innovations, IoT, crop, and climate change, which reflect the high priority on optimising the system and technological improvement. This cluster aims to leverage engineering solutions and smart technologies for farming to boost productivity, resource-use efficiency, and environmental resilience. The text has been incorporated into what is called the concept of innovation, which suggests that scientists are still in the process of developing an interest in automation and digital monitoring to enhance aquaponics performance under changing climatic conditions (Figure 4)

Cluster 2 (Green) (12 keywords) is on the socio-economic issues and community. The words that are associated with outputs of adoption, education and local development are associated with food security, community, implementation, program, knowledge, land and fish farming. This group highlights the use of aquaponics at grassroots and regional scales for improving livelihoods and food security. In this instance, the emphasis of the research is not primarily on technical efficiency, but on how the technology was implemented, who was involved, and what policy implications it had. Together, these clusters provide evidence of the twofold nature of the aquaponics studies: one technological innovation

and the other social application and food system benefits. All themes overlap, representing an integrated research environment where the objectives of food security in terms of engineering advancement and community development go hand in hand (Table 10).

Table 10
Co-word analysis on aquaponic farming and food security (Threshold 56)

Cluster No.	Cluster Labels	No. of Keywords	Representative Keywords
Cluster 1 (Red)	Technology-Driven Aquaponics, Efficiency, and Climate-Resilient Production	22	"Climate Change" "crop" "demand" "efficiency" "food production" "hydroponic" "innovation" "integration" "IoT" "nutrient" "paper"
Cluster 2 (Green)	Community-Based Aquaponics Adoption and Food Security Development	12	"Activity" "community" "fish" "fish farming" "food security" "implementation" "knowledge" "land" "person" "program"

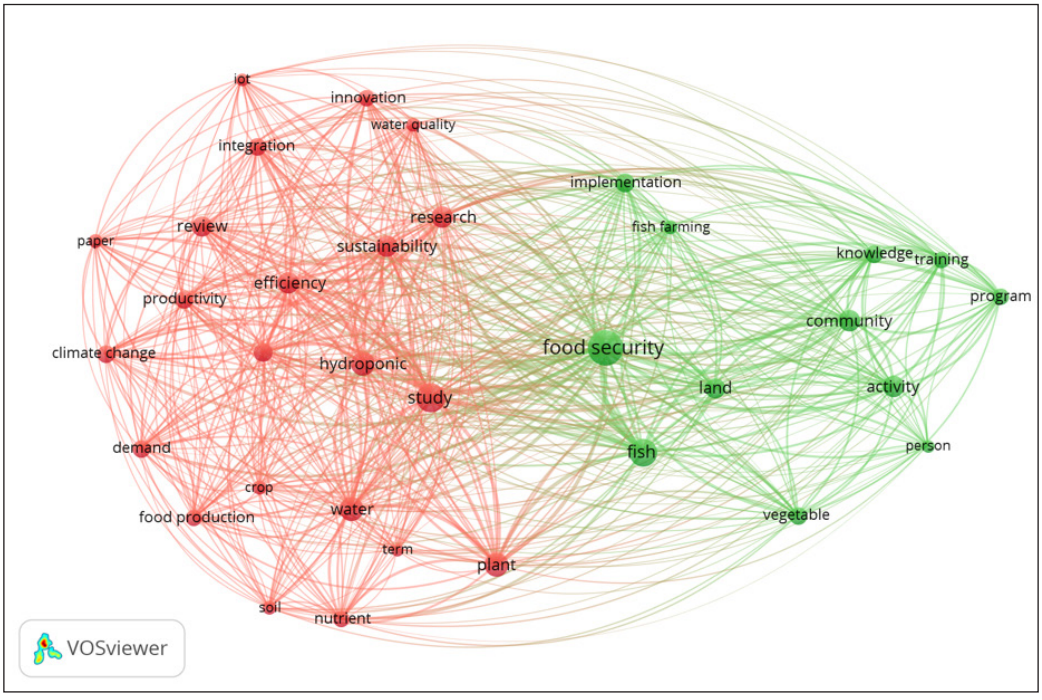

Figure 4. Co-word analysis on aquaponic farming and food security

DISCUSSION

The results of this bibliometric review demonstrate the growing multidimensional interest in aquaponics research, particularly in economic viability, technology optimisation, and

food sovereignty. Some works cited in this section (e.g., Dhal et al., 2022; Dutta et al., 2025; Mešić et al., 2024) provide contextual background and do not appear among the performance, coupling, or co-occurrence tables in Section 3; they are cited for interpretive context rather than as members of the analysed 328-document corpus. One of the major concerns about the scalability of the aquaponic systems is economic viability. It has been empirically estimated that profitability is determined by the scale of production, system design, and integration in the market (Baganz et al., 2020). The Mediterranean and African cases of financial feasibility studies also indicate that under suitable cost structure and local demand, aquaponics may make economic sense (Asciuto et al., 2019; Babatunde et al., 2023). Equally, techno-economic calculations that include renewable energy options, including photovoltaic integration, show the potential to lower operational spending and increase sustainability in arid regions (Baiyin et al., 2020). These results support the need to match technological innovation with economic performance in order to guarantee its long-term adoption.

Outside the economic aspect, technological development is now playing a bigger role in the development of aquaponics. Smart management and optimisation devices, using AI, enhance the accuracy of monitoring and control of nutrient levels and productivity (Channa et al., 2024; Karimanzira & Rauschenbach, 2021). Artificial light that is energy-efficient is also a factor in the consumption of resources and better performance of the system (Gillani et al., 2022). In addition, species selection is also vital in the success of the system, and fish species adapted to the region improve the biological compatibility and productivity (Pinho et al., 2021). Notably, aquaponics is set as a road to food sovereignty and water utilisation efficiency, especially in susceptible areas (Ibrahim et al., 2023; Obirikorang et al., 2021).

The three bibliographic-coupling clusters and two co-occurrence clusters describe an organised field. The larger, technology-oriented coupling cluster (Cluster 1, 16 articles) and the technology-driven co-occurrence cluster together indicate that a majority of the shared-reference and shared-keyword structure of the literature still centers on system optimisation, automation, nutrient regulation, and digital monitoring, rather than on food-security outcomes directly. The smaller regional-adoption coupling cluster (Cluster 2, 9 articles) and the community-based co-occurrence cluster indicate a distinct but less densely linked stream concerned with implementation, food sovereignty, and local livelihoods; its comparatively lower total link strength suggests this stream draws on a more heterogeneous and less mutually-citing set of sources than the technology cluster. The techno-economic coupling cluster (Cluster 3, 7 articles) connects these two approaches by considering the economic and social feasibility of implementing technically optimised systems. In this regard, it is important to note that in this field, the intellectual core is still maturing more quickly than the accumulation of citations, as is the case in the unusually high coupling strength of Ibrahim et al. (2023) relative to its number of citations, which indicates that,

despite not having a particularly high number of citations yet, the article serves as a kind of "nuclear point" in the shared literature evidence base.

The co-occurrence and coupling structure does reveal technological and socio-economic orientations, existing together as separate and related clusters; however, this echoes a field that has progressed beyond simple small-scale experimentation. However, the analysis does not provide a breakdown of the clusters by year, so it is not possible to conclude from it whether the field is increasingly becoming more scalable and digital in its applications over time or whether these are increasingly becoming more prevalent. The shift claim could be supported directly with a temporal decomposition of cluster membership (e.g., comparing the composition of each cluster between 2019 - 2021 and 2023 - 2025).

This bibliometric approach also carries limitations that should be considered when interpreting these findings. The corpus was drawn from a single database (Dimensions AI); although this improved metadata consistency, it also means coverage may diverge from Scopus- or Web of Science-indexed corpora, which is the choice made by the two closely related prior reviews of aquaponics bibliometrics discussed above (Basumatary et al., 2023; Kushwaha et al., 2025). No cross-database sensitivity check was performed, so the extent of this divergence in the present corpus is unknown.

CONCLUSION

This bibliometric work attests that aquaponic farming has taken a multidisciplinary and innovative form with high potential for sustainable food security. The literature has proven that aquaponics is not just a method of production but a holistic system that incorporates environmental care, technological development, and socio-economic factors. Urban aquaponics is widely recognised as a promising solution for resilient urban food systems (Wirza & Nazir, 2021), and broader reviews focus on its historical context, opportunities, and barriers to adoption (Okomoda et al., 2023). Notably, sustainability remains a focus of water research, and the use of reclaimed water under controlled conditions is supported (Cifuentes-Torres et al., 2021). Improvements in the study of microbiomes also indicate the ecological complexity and positive bacterial interactions in the aquaponic ecosystem (Ruiz et al., 2023), which supports the stability of the biological system and productivity.

In addition to environmental performance, market acceptance and consumer perception are decisive to long-term success. Research indicates that the sustainability awareness and perceived quality of aquaponic products influence willingness to pay (Eichhorn & Meixner, 2020; Greenfeld et al., 2020). Studies also suggest that aquaponic crops have similar sensory and safety qualities as traditional systems (Kralik et al., 2023). Efficiency and profitability improve through technological integration, such as IoT-based monitoring and smart nutrient management (Zamnuri et al., 2024), and through solutions like advanced foliar fertilisers, which can enhance crop performance (Frassine et al., 2025). Also, fish-plant interactions

will continue to play a vital role in the productivity and balance of water quality in a system (Loaiza et al., 2025). Taken together, these results indicate that aquaponics provides a potentially scalable, climate-sensitive, and technologically versatile avenue for enhancing the security of sustainable and resilient food systems across the globe.

ACKNOWLEDGEMENT

This research was supported by the High Community Engagement Grant (HICEG 04/2025), Albukhary International University. The authors would like to thank Albukhary International University for the institutional support and resources provided during this study. The authors declare no conflict of interest.

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