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Bibliometric Exploration of Aeroponics and Sustainability Literature: Trends, Patterns, and Future Directions (1986-2023)

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Abstract

This work aims to provide a bibliometric and systematic overview of the progress of aeroponics research over the past thirty years. The study examined the publication pattern, productive authors, journals, and significant research topics throughout this period. The analysis reveals a consistent upward trajectory in the publishing trend of aeroponics in recent years. Recent years have seen a significant surge in academic publications on aeroponics in emerging nations like India, due to a range of contributing factors. The United States and China are in the forefront of citations, indicating their significant academic influence and substantial impact on the worldwide research environment. Primary areas of study include hydroponics, aeroponics, and potato growing, predominantly conducted in India, China, and the United States of America. Analysis of the systematic review revealed that Aeroponics can make a substantial contribution to sustainability. The application of aeroponics in sustainable agriculture holds promise, but there exist notable scientific shortcomings that must be addressed to optimise its implementation. These include assessments of long-term sustainability, analyses of energy use, investigations on scalability, evaluations of impacts on biodiversity, and studies on customer acceptance. Therefore, by giving priority to these areas, researchers can provide significant contributions to the progress of aeroponic systems that demonstrate not only exceptional efficiency and productivity, but also outstanding environmental sustainability and broad social acceptance. It is imperative to address the research gap in the area of sustainable food production among global challenges; it is inevitable to tackle the potential of aeroponics in agriculture.

Keywords: Aeroponics, Bibliometric Analysis, Sustainability, Systematic Literature Review

Introduction

As a consequence of the continuously growing global population, there exists a pressing need to enhance food production (1, 2). The escalating demand for resources such as energy, water, and soil, which grows in tandem with the expansion of food production, poses a significant threat to the sustainability of the planet. Likewise, the overutilization of land and the implementation of intensive agricultural methods can lead to the erosion of soil, depletion of nutrients, and a decline in soil fertility (3). These factors collectively contribute to a systematic reduction in land productivity over an extended period. As a means to address this matter, the Food and Agriculture Organization proposed the use of sustainable agricultural practices, including aquaponics, hydroponics, and aeroponics (4). The aforementioned tactics are employed to optimise food production efficiency without relying on land and instead leverage technological advancements, hence mitigating possible risks to global sustainability. The term "aquaponics" refers to the cultivation of fish and plants using water tanks and integrated hydroponic systems (5-7). In contrast to hydroponics, which involves the growing of plants using a water-based nutrient solution instead of soil, aeroponics pertains to the development of plants using air or a mist environment. The predominant technique employed for the cultivation of both plants and fish is aquaponics. In the absence of interest in fish cultivation, hydroponics emerges as a prevalent cultivation method, contingent upon the availability of ample water resources. Lastly, aeroponics is the recommended approach to employ when there is a lack of interest in fish cultivation and the existing water resources are inadequate (8). Aeroponics is a sophisticated

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agriculture technique that enables the plant cultivation process to be conducted without the utilization of traditional soil. This methodology entails the suspension of plants in air, accompanied by periodic application of a nutrient-rich solution to their roots, so establishing an ideal microenvironment conducive to growth (9). Through the removal of dirt, plants are able to attain enhanced oxygenation, hence facilitating accelerated growth and increased agricultural productivity in comparison to conventional approaches. An aeroponic system involves the utilization of lightweight media to secure roots in position, while the nutrient solution is administered directly to the roots via a timed misting system (10). The unrestricted suspension of roots facilitates the acquisition of vital nutrients and moisture, leading to improved nutrient assimilation and subsequent growth dynamics. This approach not only facilitates water conservation but also mitigates the associated risks of diseases commonly linked to soil agriculture. The exact alteration of environmental parameters, efficient water utilization, optimal spatial allocation, and effective pest and disease control are all facilitated by technological advancements, which play a pivotal role in the achievement of aeroponics (11). The aforementioned variables collectively contribute to the enhancement of food production. Aerial cultivation, facilitated by technological advancements, possesses the capacity to produce crops of exceptional quality and nutrient density, while concurrently exhibiting a reduced ecological footprint when compared to traditional agricultural methods. Prior studies suggest that technology-mediated aeroponic systems integrate at least one of the following technology categories: sensors, Industry 4.0 technologies, dispenser technologies, and renewable energy technologies (12-14). Within the realm of aeroponics, a significant use of technology involves the systematic utilization of sensors to effectively monitor and assess environmental conditions (15). Sensors provide the capability to monitor environmental variables, including temperature, humidity, and nutrient levels, in real-time. This functionality empowers farmers to make informed decisions on the adjustment of circumstances, with the ultimate goal of optimizing plant development. Optimizing nutrient levels, regulating temperature and humidity, and monitoring plant health are all illustrative instances of this strategic approach (16). Moreover, the integration of sensors into automated control systems enables the incorporation of modifications to ambient circumstances; hence accommodating potential variations in those conditions is inevitable. As a result, this reduces the probability of human errors and ensures the ongoing optimization of climatic conditions for ideal plant growth. Furthermore, sensors possess the capability to detect issues like as nutrient deficiencies, pest infestations, and diseases prior to their conspicuous manifestation. The implementation of this early detection technology can effectively mitigate crop loss and promote the overall health and productivity of crop plants.The study primarily focused in the field of bibliometric analysis pertaining to aeroponics involves the assessment of the present level of technology adoption within this agricultural methodology, as well as the identification of any emerging patterns or trends. In order to facilitate this evaluation, it is imperative to undertake a thorough examination of the digital technologies integration into aeroponics systems. Also, the study extended to the diverse range of services offered within this framework, the extent to which technology is equipped to meet the needs of practitioners, and the numerous farming techniques currently employed in aeroponic environments. Accurate identification and comprehensive addressing of any deficiencies in the current body of literature pertaining to aeroponics are of paramount significance. The presence of these gaps may provide challenges in the successful implementation of aeroponic techniques, hence impeding the attainment of sustainable agriculture and the implementation of programs aimed at enhancing food security. Within the realm of aeroponic research, conducting a comprehensive bibliometric analysis has the promise of uncovering hitherto unknown domains, namely pertaining to advancements in technology and the challenges encountered during their applied application. The present study holds promise as a fundamental basis for future research endeavors aimed at augmenting comprehension of aeroponic systems and

optimizing their functionality. Engaging in a bibliometric analysis of aeroponics holds significant value due to its potential to unveil crucial insights into the myriad advancements and breakthroughs within this agricultural technique, which have significantly enhanced efficiency and sustainability. By closely monitoring the advancement of aeroponic technology and practices through published research, scholars can enhance their comprehension of the evolution of this field and evaluate its present status. This research facilitates a comprehensive comprehension of the extent to which technology enhances the accuracy and effectiveness of aeroponic systems, leading to heightened crop yields and reduced resource utilisation. Moreover, bibliometric analysis possesses the capacity to provide insights into the intellectual contributions made by various authors, organisations, and nations within the realm of aeroponics research (17, 18). The facilitation of collaborative networks can be achieved by identifying key actors within the research environment, leading to the transmission of knowledge that enables the advancement of innovations and the adoption of best practices. A network of this nature is particularly crucial given that aeroponics is a multifaceted domain that intersects with engineering, agricultural research, environmental policy, and technological advancement. Moreover, due to its provision of a complete overview of the aeroponics industry, this paper serves as a crucial reference for those occupying policymaking roles. The ability of policymakers to make informed judgements on the promotion of aeroponic farming as a viable alternative to conventional farming methods is contingent upon their comprehensive understanding of the breakthroughs in aeroponic technology and its implications for sustainable agricultural practices. Sustainable agriculture is increasingly recognized as a vital approach to address the growing pressures of food production while safeguarding the environment and enabling social equity (19). This concept encompasses a range of practices aimed at achieving long-term agricultural viability, focusing not only on high yields but also on methods that promote biodiversity, enrich soil health, and minimize the use of nonrenewable resources. As global food demands continue to rise, particularly in the context of a burgeoning population, sustainable agriculture strives to ensure that farmers can meet these needs without compromising future generations' ability to produce food (20). The principles of sustainable agriculture are particularly pertinent as they aim to create a systemic resilience against challenges like climate change, resource depletion, and the pollution of water and land. Among the innovative practices emerging within sustainable agriculture, aeroponics stands out as a groundbreaking method that significantly enhances the farming efficiency and sustainability (21). Aeroponics is a soil-less cultivation technique where plants are grown in a mist environment, allowing for direct access to nutrient-rich solutions. Furthermore, aeroponics eliminates soil, thus removing concerns related to pests and diseases, resulting in a healthier crop yield and a more efficient use of space, especially in urban environments. By harnessing advanced monitoring technologies, aeroponics can not only maximize growth conditions but also respond dynamically to environmental changes, making it a sustainable solution capable of contributing significantly to food security in an era of climate unpredictability.The primary objective of these frameworks and strategies is to promote the growth of aeroponic systems and streamline their integration into agricultural policies at the national level. Given the increasing gravity of global issues such as the diminished availability of food resources and the degradation of the natural environment, the examination of aeroponics using bibliometric analysis emerges as a potentially productive method for addressing these pressing concerns. The implementation of aeroponics cultivation techniques yields crops of enhanced quality while necessitating reduced resource utilization (22). The generation of tailored information has the potential to facilitate targeted interventions aimed at enhancing food security measures. The generation of this information can be achieved by the implementation of a methodical analysis pertaining to the individuals involved in aeroponic research and invention. The imperative to meet the increasing demand for ecologically sustainable agriculture solutions necessitates the establishment of technological preparedness and the implementation of successful service types (23). The present study is aiming for bibliometric investigation to examine

the direction of scientific publication, to identify the top nations, important publications, and authors, to evaluate the global collaboration and to identify the most contributed paper. The study also employs a detailed systematic review for the examination of research gaps regard to aeroponics. The utilization of bibliometric analysis has promise in facilitating future study on aeroponics by establishing a foundation for investigations that are informed by empirical evidence. The findings derived from extensive bibliometric evaluations possess the capacity to furnish researchers with valuable information pertaining to prevailing trends, upcoming study domains, and possible prospects within the aerial cultivation industry. The aforementioned field is expected to undergo further advancements, hence facilitating the proliferation of prospects for conducting comprehensive technology integration study. This will enhance the design and implementation of aeroponic systems to achieve greater ecological sustainability and economic viability.The burgeoning global population and the consequent need for sustenance have prompted the investigation of novel agricultural methodologies that can augment food production while mitigating ecological repercussions (24). A critical evaluation of the existing literature on bibliometric analysis in the context of aeroponics and sustainable development reveals significant insights and knowledge gaps. The synthesis of findings from various studies highlights the potential of bibliometric methods to identify trends and research opportunities, particularly in the rapidly evolving field of aeroponics. Studies indicate that aeroponics can enhance resource efficiency and crop quality, addressing challenges like land scarcity and water shortages (25). Bibliometric analysis serves as a crucial tool for mapping the state of research, revealing trends and gaps in aeroponics and sustainable practices (26).The cultivation technique known as aeroponics, which entails growing plants in a mist environment without the need of soil, has garnered attention as a potentially effective option owing to its capability to optimize resource utilization and promote sustainability. Nevertheless, the extensive and diverse body of research pertaining to aeroponics calls for a thorough bibliometric analysis and systematic evaluation in order to evaluate its development and influence on sustainable agriculture. The present evaluation will additionally examine the socio-economic ramifications of aeroponics, encompassing its contribution to the improvement of food security, specifically in metropolitan environments characterised by spatial constraints. Through the synthesis of findings derived from a range of studies, this research aims to uncover deficiencies within the existing body of literature. Specifically, it seeks to highlight the necessity for conducting long-term investigations pertaining to the sustainability of aeroponic systems and their capacity to adapt to varying climatic circumstances. Also, this evaluation will elucidate the various challenges encountered by aeroponic systems, encompassing technological impediments, economic viability, and the imperative for proficient workforce. This thorough methodology will not only offer valuable perspectives on the present status of aeroponics research but also educate policymakers, practitioners, and researchers regarding the potential of aeroponics as a sustainable agricultural technique. Through a rigorous analysis of the existing literature and the identification of significant trends and gaps, this study will establish a foundation for future research endeavors focused on enhancing aeroponic systems and incorporating them into sustainable agricultural frameworks. The results of this study could therefore be seen as a significant asset for various stakeholders within the agricultural industry, such as farmers, agronomists, and environmentalists, who face the challenge of implementing novel approaches that are in line with sustainability objectives. In summary, the research problem identified in this study involves a comprehensive evaluation of aeroponics using bibliometric analysis and systematic review.

Methodology

Both bibliometric and systematic review methodologies are widely employed throughout the scientific investigation. When considering the mitigation of potential bias that may occur from qualitative analysis conducted by researchers with diverse backgrounds, bibliometric and systematic review approaches present notable benefits. In order to achieve this purpose, it is necessary to employ quantitative data analysis techniques and focus on a wide-ranging research

domain. The present study used a multidimensional methodology to examine the constructs and their respective aspects. Topics such as trend analysis, knowledge gaps, methodological evolutions, interdisciplinary connections, historical context, and future directions are all seen as potential subjects for scholarly investigations. Figure 1 depicts the architectural framework employed in bibliometric research to facilitate the retrieval of relevant literature. To gather the relevant academic papers on the subject, the search query "Aeroponics" was utilized. This search initially yielded a total of 447 articles. To refine the results and ensure their relevance, the articles were systematically filtered using criteria such as publication year, subject area, document type, and language. After applying these eligibility filters, the final selection consisted of 293 articles deemed appropriate for further analysis.

Results

This study utilizes the Scopus database to conduct a bibliometric analysis as part of its research investigation. The search query incorporates the keyword "Aeroponics," and the associated results encompass a cumulative count of 447 documents. After the removal of duplicate entries, the study yielded a final search outcome comprising 293 documents. Concerning the sample size of the investigation, this is duly considered. The Scopus database is widely recognised for its extensive coverage of peer-reviewed research in the field of finance, its rapid update cycle, and its ability to effectively review and assess data (27). In light of this, the Scopus database was employed. The time period considered for this study spans from 1986 to 2023, as it encompasses a substantial body of literature pertaining to the relevant topic. The present investigation will be capable of examining the overarching pattern in the spillover effect by utilising the provided data. To access the relevant papers pertaining to the subject matter, the search query "Aeroponics" was employed.

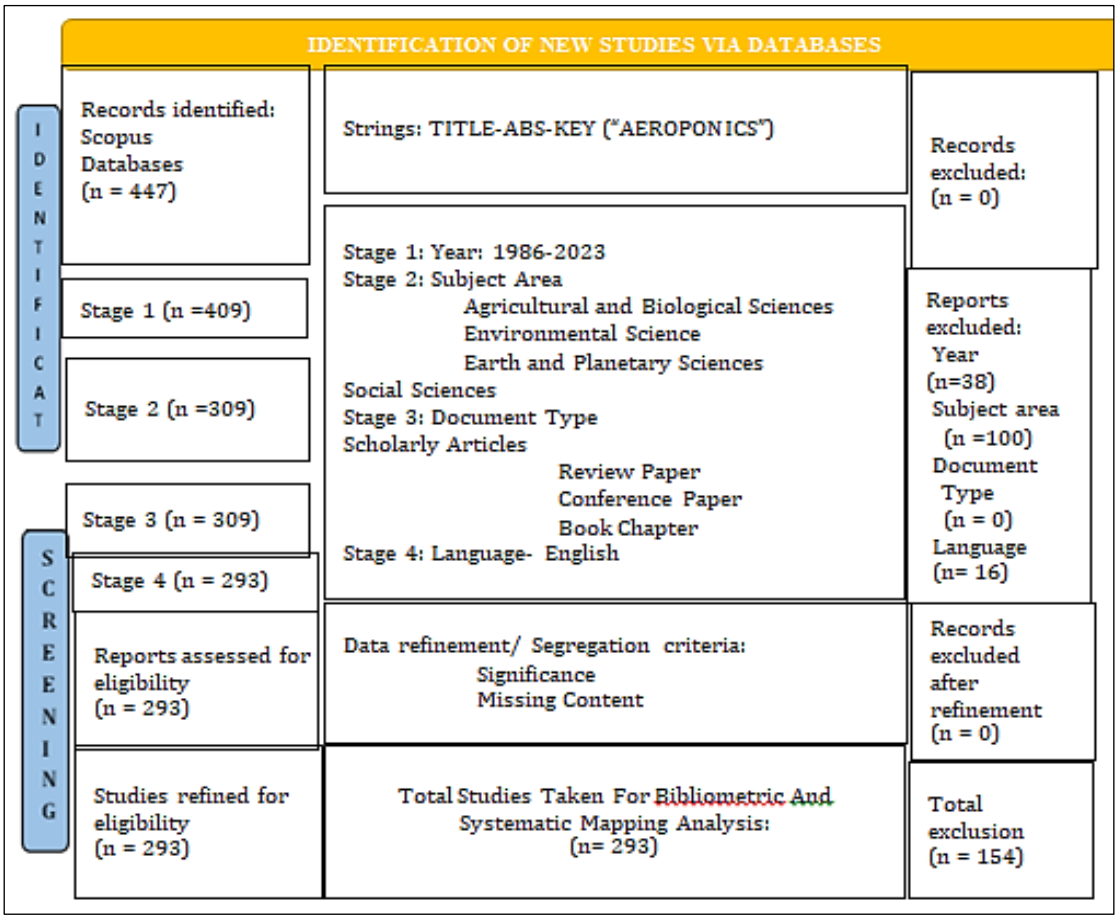

Figure 1: PRISMA Protocol 2020

In order to conduct the bibliometric analysis, the R programming language was employed due to its exceptional skills in visualising secondary data. Biblioshiny, a package employing a graphical user interface, provides academics with the capability to visually represent their findings through tabular and graphical representations. The descriptive statistics of the study is shown in Table 1, which provides a detailed summary of publication patterns and specifics spanning the years 1986 to 2023. The presented data demonstrate a research environment that is both dynamic and collaborative, exhibiting a notable annual growth rate of 10.17%. This growth rate serves as an indication of a flourishing field of study. A comprehensive compilation of 293 scholarly documents has been obtained from 147 authoritative publications and several other sources, thereby demonstrating a wide array of academic contributions. These materials exhibit an average age of 8.51 years, indicating the enduring significance of the research. Furthermore, these publications exhibit a notable academic influence within the scientific community, as evidenced by an average of 17.83 citations per publication. Significantly, within the cohort of 964 writers, a mere 19 authors are accountable for co-authored materials, hence emphasizing the collaborative character of the research domain. An estimated 20.48% of the documents exhibit international co-authorships, so underscoring the global nature of these research collaborations and underscoring the interdependence among scientists from diverse geographical areas. The predominant mode of publication for the majority of scholarly work is through journal articles, which continue to serve as the primary means of dissemination. In addition, a significant number of scholarly contributions can be found in the form of conference papers and book chapters, which serve to enhance the existing body of literature and provide various opportunities for the dissemination of information in this ever-evolving field.

Table 1: Descriptive Statistics

Description	**Results**
Timespan	1986:2023
Sources (Journals, Books, etc)	147
Documents	293
Annual Growth Rate %	10.17
Document Average Age	8.51
Average citations per doc	17.83
References	11783
Document Contents	
Keywords Plus (ID)	958
Author's Keywords (DE)	971
AUTHORS	
Authors	964
Authors of single-authored docs	19
AUTHORS COLLABORATION	
Single-authored docs	21
Co-Authors per Doc	4.2
International co-authorships %	20.48
Document Types	
Article	194
Book	2
book chapter	28
conference paper	48
Review	21

Bibliometric Analysis

Annual Production Trend: The annual scientific production of research articles offers a detailed overview of aeroponics research's history, advancements, and current trends. Figure 2 displays the number of publications from 1986 to 2023. Initially, there were just a few periodicals published from 1986 to 1999, which resulted in a minimal number of papers. During this period of low activity, there may have been several factors contributing to it, such as a restricted research emphasis or a lack of resources. However, since 2000, there has been a discernible rise in the quantity of publications, which is indicative of an increase in the amount of research activity. This expansion became more noticeable beginning in 2010, with an important milestone occurring around the year 2012, which may indicate a possible shift in research goals, an increase in financing, or an increased interest in the subject, respectively. The last decade has seen the most significant increases, particularly from 2020 to 2023, when the number of articles increased dramatically, reaching a record high of 36 in 2023. Global food security concerns, technological advancements, the rise of urban agriculture, increased research funding, and the disruptions caused by the COVID-19 pandemic have primarily driven the increased interest in aeroponics since 2020. As a result, there has been a surge in publications on this innovative agricultural method, which offers potential solutions for efficient and sustainable food production in various environments. This is the decade that has seen the most dramatic increases. There are a number of factors that could be responsible for this recent growth, including breakthroughs in research technology, an expanded range of study topics, or more research collaboration.

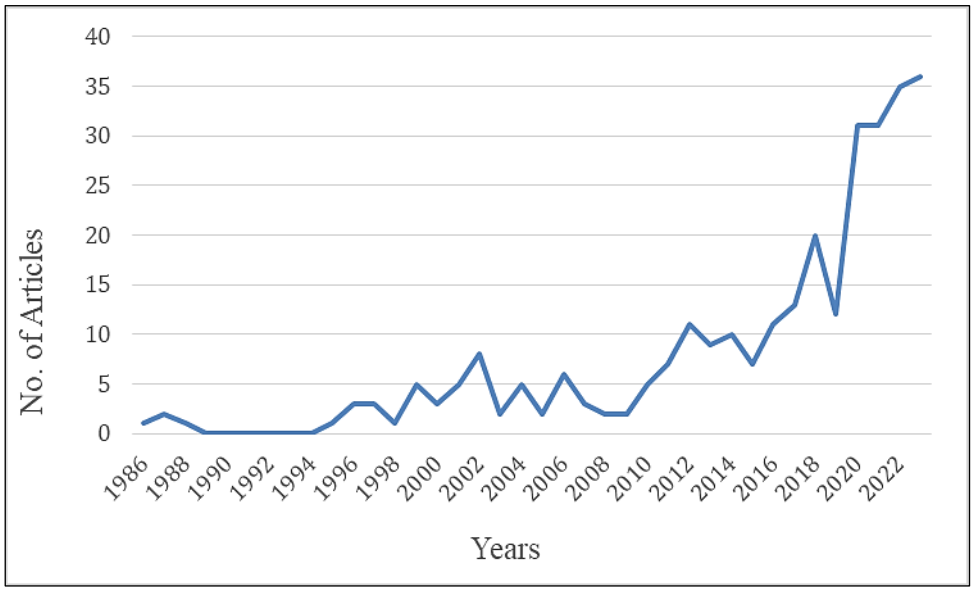

Figure 2: Annual Production Trend

Leading Countries in the scientific production of articles: The data presented in the study reveals a pronounced global dispersion of research output, characterised by noteworthy contributions from a wide range of countries. India, as the world leader with 212 publications, demonstrates a strong and expanding research infrastructure, which may be bolstered by its extensive network of academic institutions and several research financings projects. Emerging economies such as India have experienced a notable increase in scholarly papers pertaining to aeroponics, owing to various contributing factors. First and foremost, these nations frequently encounter difficulties pertaining to the issues of food security, agricultural land scarcity, and climate change. Aeroponics presents a potentially viable alternative by enabling efficient food production inside confined areas, irrespective of prevailing climatic conditions. Furthermore, the rising urban population in developing nations has resulted in a heightened need for domestically cultivated, readily available agricultural products. The United States of America demonstrates its pronounced prominence in worldwide research through its 114 publications. China, boasting a

total of 99 papers, moreover serves as a noteworthy contributor within this particular sector. Indonesia, Singapore, South Korea, and Germany have achieved publication counts of 52, 43, 43, and 42 respectively, thereby underscoring their significant contributions to the relevant subject. The United Kingdom, with 39 articles, and Australia, with 38 publications, both have a robust research output. Poland, with 30 publications, completes the list of prominent countries. Figure 3 illustrates the leading nations that have made significant contributions to the field of aeroponics.

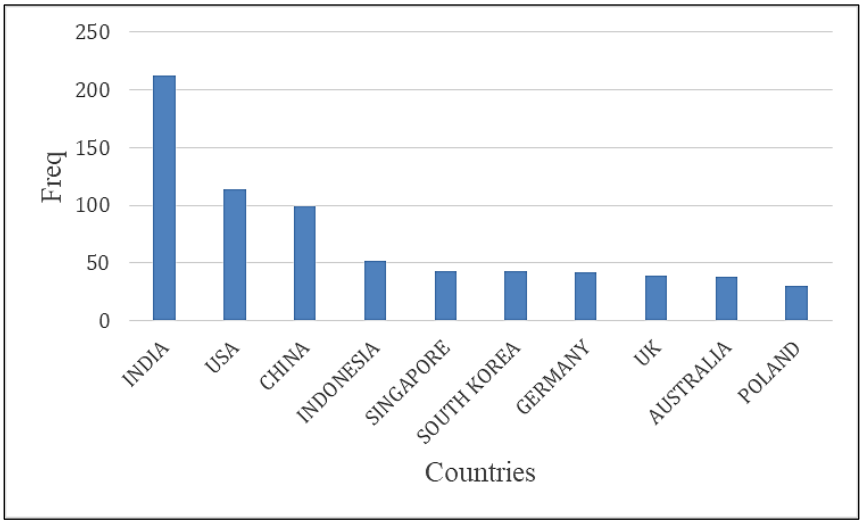

Figure 3: Leading Countries in the Scientific Production of Articles

Leading countries in citation of articles: By utilizing the citation information, the researcher can ascertain the frequency of citations for publications from different countries, thereby reflecting the impact and influence of their research outputs. With 635 citations, the United States of America is in the lead, which is indicative of its vast academic influence and strong impact on the landscape of global research. China comes in second with 348 citations, which demonstrates the country's significant and expanding influence on the scientific community around the world. With 321 citations, Belgium demonstrates a significant impact on the field of research. The fact that India has received 307 citations is evidence of the country's growing involvement in international research. The growing number of citations is evidence that Indian research is becoming more important and appreciated, which is in line with the increased investment that the government is making in research and higher education. Greece, Australia, and France each have 256, 251, and 205 citations, respectively, which indicates that their research findings have a significant impact, but on a little smaller scale. Figure 4 displays the countries with the highest number of cited papers.

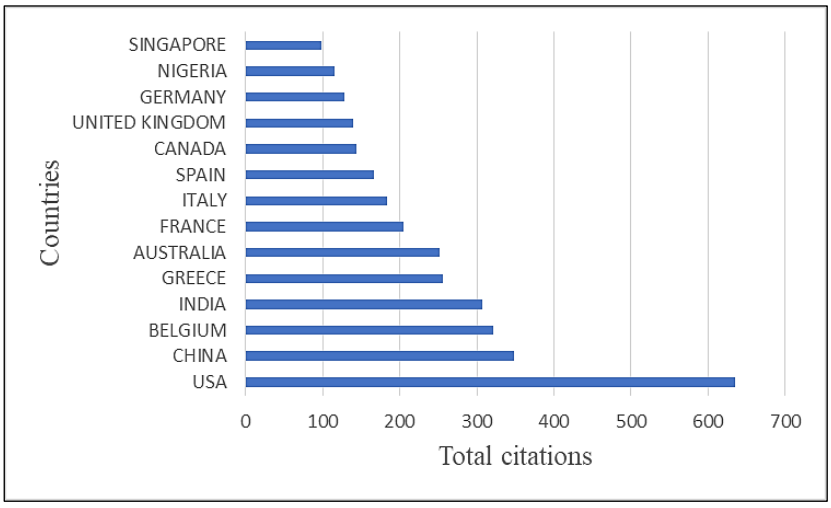

Figure 4: Leading Countries in the Citation of Articles

Three-field plot analysis: For the purpose of expanding the scope of bibliometric analysis, we take into consideration the primary areas of research, countries, and publications that are relevant. An illustration of the linkages between countries, topics of research, and publications that is based on a Sankey diagram and consists of three fields. The threefold study of aeroponics is depicted in Figure 5, with the names of the research publication presented on the left side, the countries represented on the right side, and the keywords presented in the middle. There is a clear correlation between the frequency of presence of the rectangular nodes and the height of the nodes themselves. It can be seen from the graph that the most important fields of research are hydroponics, aeroponics, and potato cultivation, with the majority of the research coming from India, China, and the United States of America.

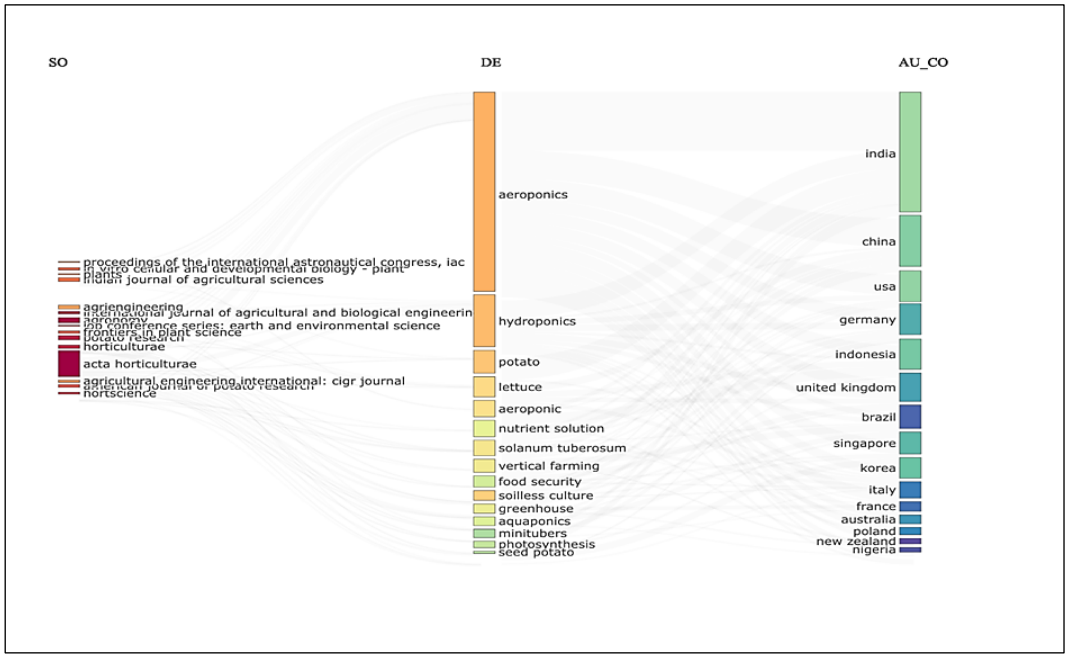

Figure 5: Three-Field Plot Analysis

Leading publications: The promotion and exchange of fresh ideas is made possible for academics and researchers through the publication of new discoveries and ideas in scholarly journals. Through the process of selecting the most significant articles that are associated with a specific study topic, scientists are able to select the papers that possess the highest level of relevance and excellence for publish their findings. Acta Horticulture is the most prominent publication in this area of research, as evidenced by the fact that it contains 44 articles, further demonstrating its widespread acceptability. The most prestigious research journals, ranked according to the impact of their sources, are presented in Table 2. In addition, Figure 6 illustrates the classification of the most prestigious research journals according to Bradford Law.

Table 2: Top Journals According to Source Impact

Element	h_index	g_index	m_index	TC	NP	PY_Start
Acta Horticulturae	10	16	0.385	325	44	1999
Agronomy	6	9	0.545	97	10	2014
Horticulturae	6	6	0.857	161	6	2018
American Journal Of Potato Research	5	5	0.263	245	5	2006
Hortscience	5	6	0.238	129	6	2004
In Vitro Cellular And Developmental Biology - Plant	5	5	0.172	290	5	1996
Frontiers in Plant Science	4	5	0.444	104	5	2016

Potato Research	4	7	0.167	191	7	2001
Agri Engineering	3	3	0.75	44	3	2021
Chilean Journal of Agricultural Research	3	3	0.273	92	3	2014

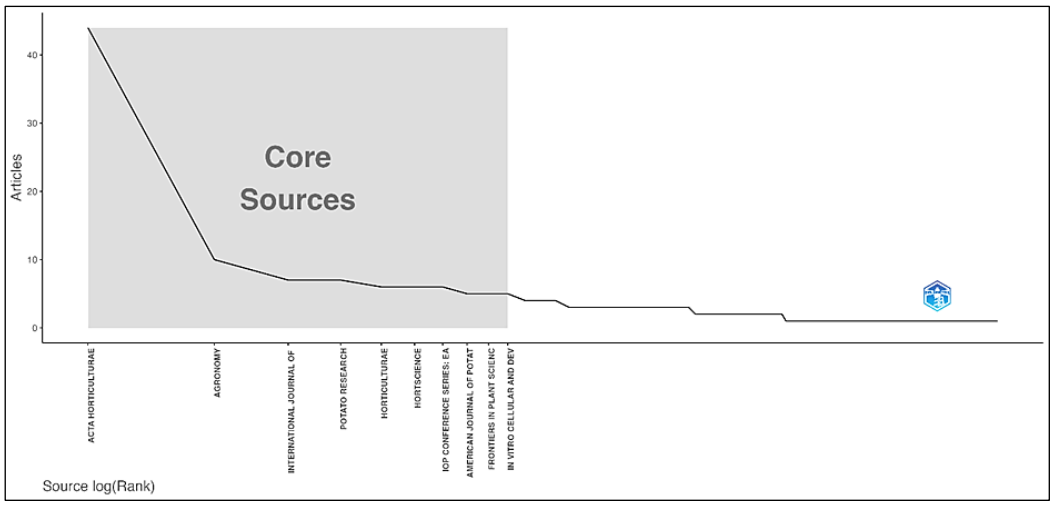

Figure 6: Top Research Journals According to Bradford Law

Collaboration network analysis: Figure 7 shows a network map of international academic collaboration that emphasizes the key countries. The map showcases a relatively sparse network of connections between countries, suggesting that research and development in this field are still developing. While there are some notable connections, such as the link between the United States and India, the overall pattern indicates a limited level of international collaboration. This could be attributed to various factors, including geographical distance, language barriers, differing research priorities, or the novelty of aeroponics as a field of study. However, the existing connections suggest a growing interest in aeroponics and the potential for future collaborations. As research progresses and the benefits of aeroponics become more widely recognized, we can expect the network to expand and become more interconnected. This increased collaboration could lead to advancements in technology, knowledge sharing, and the adoption of sustainable agricultural practices. Strengthening existing connections between countries, establishing new collaborations, expanding the geographical reach of research, developing innovative technologies, investigating environmental benefits, and analyzing economic viability are all promising avenues for advancing this field. By addressing these areas, future research can contribute to the development of sustainable and efficient aeroponics systems.

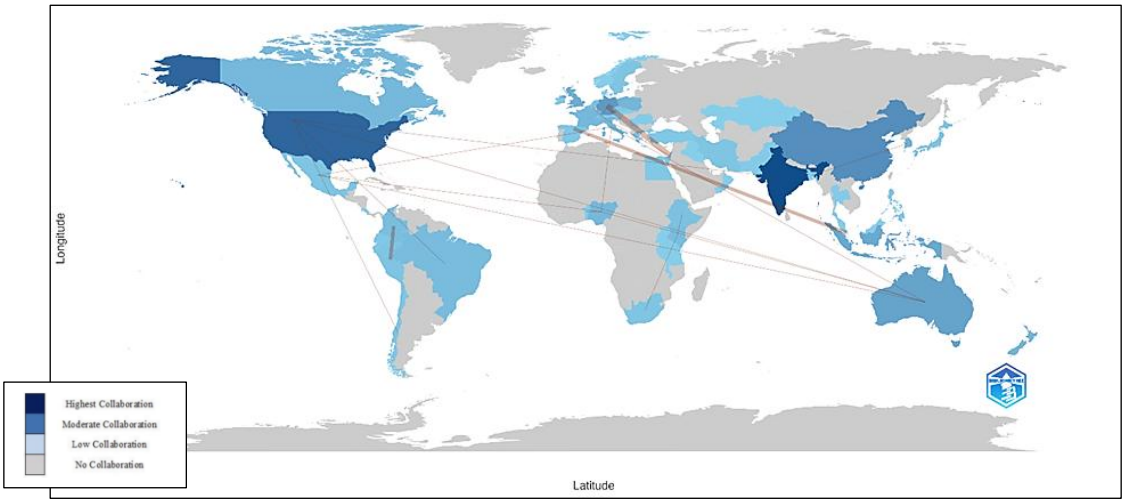

Figure 7: Collaboration Network Analysis

Co-occurrence network analysis: When it comes to finding the most important study areas in this field, keyword co-occurrence analysis is also an extremely important tool. As a result of this analysis, relevant issues, developing trends, and the links between various concepts linked to aeroponics will be identified, which will eventually guide future research and development activities in this cutting-edge agricultural technology. This is indicated by the thickness of the node, which indicates the total frequency with which each keyword appeared in the aeroponics research. Stronger associations between keywords are indicated by nodes that have a greater number of connections. As an illustration, the keywords "aeroponics," "cultivation," "hydroponics," and "Plant root" have significantly larger nodes and stronger link strengths in comparison to other keywords. There appears to be a strong connection or association between these themes in the study literature or conversations that are associated with aeroponics, as indicated by this phenomenon. Figure 8 showcases the results for the analysis of the co-occurrence network.

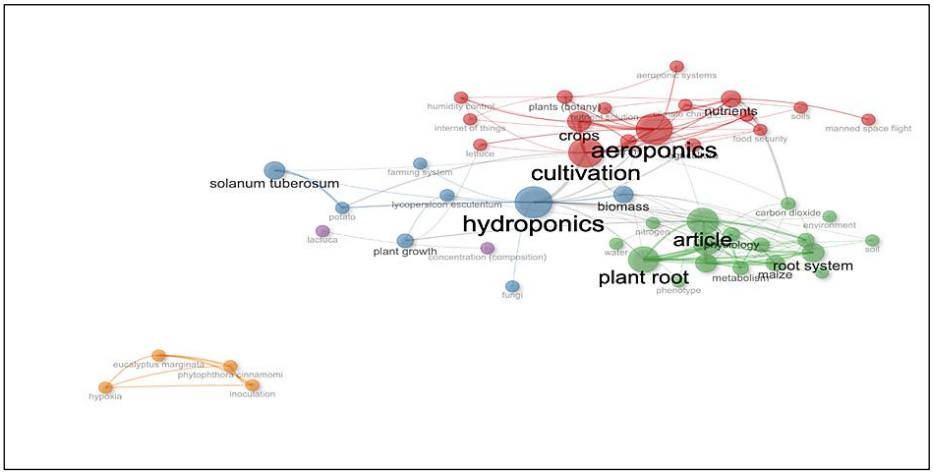

Figure 8: Co-occurrence Network Analysis

Centrality analysis: Based on the figure 9, aeroponics appears to be positioned within the "motor themes" quadrant. This suggests that it's a moderately relevant topic within the broader field of agriculture or plant science. However, its specific position within the "motor themes" quadrant might indicate that it's either a rapidly emerging or a declining topic. The potential future directions for aeroponics include technological advancements in controlled environment systems, nutrient delivery, and plant lighting; its integration into urban farming initiatives for sustainable food production; commercialization for large-scale crop production; and further research into plant physiology, nutrient requirements, and disease management to optimize yields and sustainability.

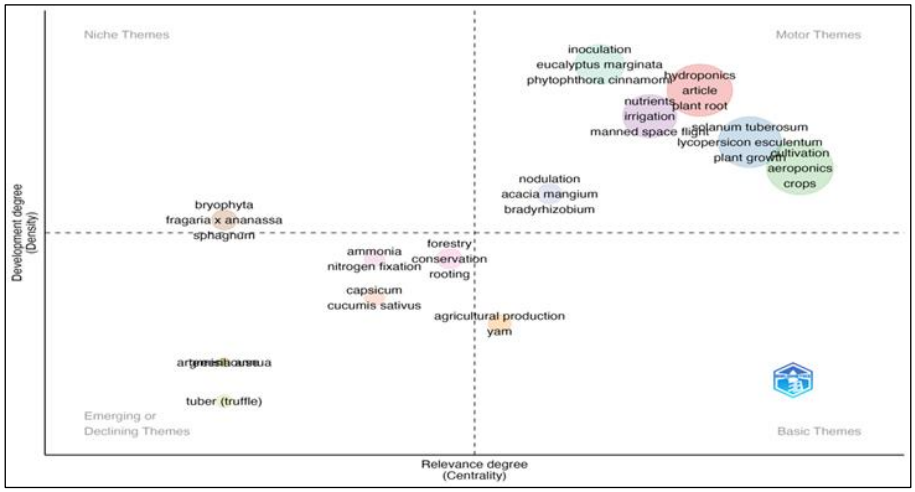

Figure 9: Centrality

Table 3: Systematic Literature Review

Authors	Title	Year	Source	Total Citation
Garzón J, Montes L, Garzón J, Lampropoulos G. (28)	Systematic Review of Technology in Aeroponics: Introducing the Technology Adoption and Integration in Sustainable Agriculture Model	2023	Agronomy	3
Suresh M, Singh R, Gehlot A. (29)	Automated Aeroponics System Using IoT for Smart Agriculture	2022	Internet of Things for Agriculture 4.0: Impact and Challenges	1
Lucero L, Lucero D, Ormeno-Mejia E, Collaguazo G. (30)	Automated aeroponics vegetable growing system. case study lettuce	2020	2020 IEEE ANDESCON, ANDESCON 2020	14
He J, Qin L, Alahakoon PKDT, Chua BLJ, Choong TW, Lee SK. (31)	LED-integrated vertical aeroponic farming system for vegetable production in Singapore	2018	Acta Horticulturae	7
Savvas D, Gruda N. (32)	Application of soilless culture technologies in the modern greenhouse industry - A review	2018	European Journal of Horticultural Science	234
Schmidt Rivera X, Rodgers B, Odanye T, Jalil-Vega F, Farmer J. (33)	The role of aeroponic container farms in sustainable food systems – The environmental credentials	2023	Science of the Total Environment	6
Tunio MH, Gao J, Shaikh SA, Lakhiar IA, Qureshi WA, Solangi KA, Chandio FA. (34)	Potato production in aeroponics: An emerging food growing system in sustainable agriculture for food security	2020	Chilean Journal of Agricultural Research	48
Mytton-Mills H. (35)	Reimagining resources to build smart futures: An agritech case study of aeroponics	2018	Smart Futures, Challenges of Urbanisation, and Social Sustainability	1
Subramaniam R, Kong L S. (36)	Aeroponics: Experiences from Singapore on a green technology for urban farming	2012	Environmental Leadership: A Reference Handbook	2
Ampim P A Y, Obeng E, Olvera-Gonzalez E. (37)	Indoor Vegetable Production: An Alternative Approach to Increasing Cultivation	2022	Plants	14
Eldridge B M, Manzoni LR, Graham CA,Rodgers	Getting to the roots of aeroponic indoor farming	2020	New Phytologist	55

B, Farmer JR, Dodd AN. (38)				
Wimmerova L, Keken Z, Solcova O, Bartos L, Spacilova M. (39)	A Comparative LCA of Aeroponic, Hydroponic, and Soil Cultivations of Bioactive Substance Producing Plants	2022	Sustainability (Switzerland)	21
Ragaveena S, Shirly Edward A, Surendran U. (40)	Smart controlled environment agriculture methods: a holistic review	2021	Reviews in Environmental Science and Biotechnology	54
Lakhiar IA, Gao J, Syed TN, Chandio FA, Buttar NA. (41)	Modern plant cultivation technologies in agriculture under controlled environment: A review on aeroponics	2018	Journal of Plant Interactions	159
Adepoju A O, Olaseni OC. (42)	Are Yam Farmers Aware and Willing to Adopt the Aeroponics Farming System in Oyo State, Nigeria?	2021	Agris On-line Papers in Economics and Informatics	1
Broćić Z, Momčilović I, Poštić D, Oljača J, Veljković B. (43)	Production of High-Quality Seed Potato By Aeroponics	2021	The Potato Crop: Management, Production, and Food Security	5
Barla S A, Salachas G, Abeliotis K. (44)	Assessment of the greenhouse gas emissions from aeroponic lettuce cultivation in Greece	2020	Euro-Mediterranean Journal for Environmental Integration	5
Çalışkan ME, Yavuz C, Yağız A K,Demirel U, Çalışkan S. (45)	Comparison of Aeroponics and Conventional Potato Mini Tuber Production Systems at Different Plant Densities	2021	Potato Research	14
Despommier D. (46)	Vertical farming using hydroponics and aeroponics	2017	Urban Soils	6
Giurgiu RM, Morar G, Dumitraş A, Vlăsceanu G, Dune A, Schroeder FG. (47)	A study of the cultivation of medicinal plants in hydroponic and aeroponic technologies in a protected environment	2017	Acta Horticulturae	9
He J, Lee SK. (48)	Impact of climate change on food security and proposed solutions for the modern city	2013	Acta Horticulturae	6
Reyes JL, Montoya R, Ledesma C, Ramírez R.	Development of an aeroponic system for	2012	Acta Horticulturae	12

(49)	vegetable production			
Christie CB, Nichols MA. (50)	Aeroponics - A production system and research tool	2004	Acta Horticulturae	33
Nichols M.A, Christie CB. (51)	Continuous production of greenhouse crops using aeroponics	2002	Acta Horticulturae	6
Johnstone PR, Nichols MA, Fisher KJ, Reid J. (52)	Nutritional studies with processing tomato grown in aeroponics	2001	Acta Horticulturae	10

Table 3 is showing the studies selected for the systematic literature review. A comprehensive analysis of 25 papers based on relevance and significance for aeroponics and its potential contribution to sustainability was selected for the systematic literature review. The study's thorough literature evaluation revealed that aeroponics exerts a substantial role in the preservation of sustainable agriculture. A study conducted a comprehensive examination of 47 research studies to ascertain the present condition and patterns in the use of technology in aeroponics, as well as the main opportunities and challenges (28). Analysis revealed that Industry 4.0 and sensor technology are the predominant technologies employed in aeroponics. These technologies have yielded several benefits, such as improved time efficiency and increased sustainability. Furthermore, it emphasised that power reliance and technical intricacy are the main challenges in technology-assisted aeroponics. Additionally, they also introduced the Technology Adoption and Integration in Sustainable Agriculture (TAISA) concept. Ultimately, they reached the determination that aeroponics has extensively adopted technology and that its usage should be promoted to advance sustainable agriculture. Also, separate research investigated the use of an Internet of Things (IoT) optimised automated aeroponics system to improve and simplify agricultural activities (29). Through the integration of sensors, data analytics, and automation, the system seeks to enhance efficiency, accuracy, and regulation of growing conditions in aeroponics. Furthermore, the research demonstrated how the integration of IoT can enhance agricultural productivity and resource efficiency by providing immediate monitoring and control of environmental variables, nutrient levels, and plant health, thereby promoting sustainability. A separate research endeavor aimed to propose the implementation of an automated aeroponic farming system for cultivating green leaf lettuce (30). This system would regulate variables such as temperature, humidity, and irrigation time by applying nutrients at the plant roots. The authors of the study expressed their belief that the method offers an appropriate management approach for the aeroponic environment, which has been demonstrated to be more efficient than traditional farming. By contrast to a traditional culture, the green leaf lettuce crop demonstrates a growth of over 40% in leaf production and diameter. Furthermore, it achieves a performance that is almost 40% greater in terms of root length and cultivable area density. An investigation was conducted to examine the significance of LED-integrated vertical aeroponic farming system for vegetable production in Singapore (31). In their perspective, the optimal combinations of LED spectra are contingent upon the species and possess the capacity to enhance agricultural productivity and photosynthesis. Nevertheless, there was no significant link between productivity and photosynthesis under different LED lighting spectra. The extensive use of vertical aeroponic farming systems with LED integration will decrease Singapore's reliance on vegetable imports, therefore enhancing the nation's food security and sustainability. Therefore, soilless culture is currently considered the safest and most efficient substitute for soil disinfection using methyl bromide (32). Therefore, Systematic Control Systems (SCS) are gaining significance in protected horticulture, encompassing both contemporary, fully equipped glasshouses and basic greenhouse structures designed to make use of favourable environmental circumstances. Another study aims to assess the environmental impacts of aeroponic container farm food production systems in the United Kingdom and compare them with other vertical farming techniques, including hydroponic and

conventional food production methodologies (33). Furthermore, the objective is to assess the possible role of aeroponic container farms in mitigating the environmental effects of food production and delivery in metropolitan regions of the United Kingdom. The study findings indicated that food cultivated in aeroponic farm containers may have a lower environmental footprint compared to similar food imported into the UK. Furthermore, it has the potential to enhance food security by improving the availability, stability, and accessibility. A comprehensive examination of the literature on aeroponic potato production was undertaken, focussing on the key challenges that must be addressed prior to establishing an aeroponic system for potato crops (34). Research findings indicate that, especially in areas with critical soil and water quality, the aeroponics system appears to be the most efficient approach for cultivating potatoes, a burgeoning food growing technique in sustainable agriculture aimed at ensuring food security. Furthermore, the approach not only provides protection against pests and soil-borne diseases but also significantly increases potato yield in comparison to existing techniques. Given its potential advantages, the aeroponics method has the capacity to drastically transform the potato-growing industry. Furthermore, a separate study aimed to investigate the potential of aeroponics, a soilless cultivation technique that utilises nutrient-rich mist for plant growth, to transform agricultural industries (35). Furthermore, it emphasises the technology's capacity to improve resource efficiency, namely in the use of water and nutrients, while also tackling spatial constraints and environmental issues. Utilising real-world case studies, the paper illustrates the economic and environmental advantages of aeroponics. It also explores its incorporation with emerging technologies and future potential, offering valuable insights into how this innovative approach can enhance the sustainability and efficiency of food production systems. The study contended that the aeroponics method of agriculture should secure broader adoption, particularly in urban areas, due to its superior sustainability compared to conventional agriculture or hydroponics (36). In addition, they exchange the experiences of Singapore, a city-state, in the field of aeroponic vegetable cultivation. Moreover, they emphasised the entrepreneurial ramifications of aeroponics agriculture. An interesting study on hydroponics, aeroponics, aquaponics, soilless mixes, and other alternative vegetable production methods has highlighted the need of future exploration to optimise crop results (37). Furthermore, their examination encompassed the facilities employed, components of plant development, current challenges such as energy expenses, and future potential. The research findings indicate that these alternative agricultural methods provide opportunities to achieve resource efficiency by reducing the use of water, pesticides, and land. Furthermore, the study facilitates the extension of the growth season and the control of production parameters such as temperature, relative humidity, and carbon dioxide. Moreover, in order to enhance crop growth and productivity, certain production systems enable the more efficient and consistent provision and dispersion of nutrients to crops. A study investigated the impact of aeroponic culture on various measures of plant physiology, growth, and production (38). They discover that aeroponics entails the deliberate application of a nutrient aerosol to the roots, resulting in higher plant productivity compared to hydroponic farming. The utilisation of aeroponics is believed to address certain physiological limitations faced by plants in hydroponic systems. The comparative assessment of aeroponic, hydroponic, and soil cultivations and provided information on major environmental impacts of operations of these cultivation systems (39). It also highlighted important factors of the soil-less systems' sustainability and economic feasibility. The results of the compared soil and soil-less systems showed that the consumption of fertilizers, diesel, and water in soil systems and of conventional electricity in aeroponics and hydroponics contributed mostly to their environmental burden. The major environmental impact categories are terrestrial ecotoxicity, human non-carcinogenic toxicity, and global warming. Therefore, in order to make the soil-less cultivation systems sustainable, these environmental aspects need to be considered deeply. An analysis examined literature in the field of controlled environment agriculture, including soilless hydroponics, aquaponics, nutrient film method, and aeroponics, published

between 1999 and 2020 (40). Based on their analysis, they proposed that "smart farming" is a developing phenomenon in the field of agriculture, whereby every person engages in farming and cultivates vegetables and fruits independently in their own homes without the need for organic soil. Another study presents a new method of cultivating plants in a soil-less environment and offers a concise literature review on the aeroponics system (41). Its analysis determines that the aeroponics system is regarded as the most effective plant cultivation technique for ensuring food security and promoting sustainable development. The technology has demonstrated considerable potential in several nations and is highly recommendable as the most efficient, practical, meaningful, cost-effective, and convenient plant cultivation system compared to soil and other soilless techniques. In another study, the awareness and factors influencing the willingness of yam farmers to use the aeroponics farming system were evaluated using a Likert scale and a logit regression model (42). The study findings revealed that over 60% of the farmers were unfamiliar with the aeroponics farming system. However, they expressed a willingness to adopt it for cultivating yam and seed yam. The main obstacle to adoption was the high cost of capital. The researchers identified several key determinants of farmers' awareness of the aeroponics system, including gender, age, education, membership in cooperative society, monthly income, and access to extension agent. The main factors influencing the adoption of the aeroponics system were marital status, age, credit access, membership in cooperative society, farm size, and income. A research study examined the application of aeroponics, a sophisticated soilless culture method, to generate seed potatoes of superior quality with enhanced growth performance and resistance to diseases (43). By utilising aeroponics, the researchers showcase the efficacy of this technique in maximising circumstances for the growth of potato tubers. In comparison to conventional soil-based techniques, the study emphasised the benefits of aeroponics in improving seed potato quality, such as higher yield, uniformity, and health of the seed stock. Furthermore, the authors explored the capacity of aeroponics to tackle prevalent challenges in seed potato production, including soil-borne illnesses and variability. This offers a beneficial alternative for seed potato growers aiming to enhance the quality and uniformity of their crops. The objective of a study was to investigate the greenhouse gas emissions associated with aeroponic lettuce growing in an automated greenhouse in Greece using the life cycle assessment approach (44). The findings suggested that the emissions produced by aeroponics were equivalent to or even lower than those from growing techniques that necessitate the recirculation of water and/or nutrients using electrically powered equipment. Energy appears to be the primary cost that humanity must bear in order to substitute soil as a crucial natural resource for food production. The study conducted a comparison of the productivity between conventional and aeroponics small tuber production systems. Additionally, it aimed to select the optimal planting densities for both production methods (45). As the planting density in both aeroponics and conventional systems grew, the tuber yield per plant declined. However, overall, the tuber yield per plant was greater in aeroponics compared to the conventional system. Subsequent research proposed the implementation of controlled environment agriculture (CEA) techniques to urban communities, therefore ensuring a fresh, secure, and environmentally-friendly food provision (46). Once CEA gains widespread acceptance and becomes deeply ingrained in the urban landscape of all cities globally, it is possible that some of the urgent issues related to urban sprawl will be significantly mitigated. This will be achieved through the generation of additional job prospects, the provision of healthier food options with year-round access to fresh produce, and consequently a reduction in malnutrition among the most impoverished individuals in the global urban population. The impediments to the rapid development of vertical farming include the absence of commercial manufacturers specialising in hydroponic and aeroponic equipment tailored for tall buildings, effective LED grow lights, and financial backing for the establishment of small-scale demonstration vertical farms. In an investigation, three medicinal plants grown in commercial hydroponic and aeroponic systems were examined (47). The study analysed the

growth characteristics and time to reach the peak of harvest, in comparison to conventional soil cultivation, all under identical environmental conditions and stress inducers. The research findings indicate that medicinal plants can be grown in various hydroponic and aeroponic systems, resulting in much greater yields and earlier harvest compared to plants grown in soil under identical environmental circumstances. Hydroponics and aeroponics are valuable research tools due to their ability to provide fine control over fertigation and the potential for environmental control in protected horticulture. This makes them ideal for further research in the discipline of medicinal plants. An investigation was undertaken to assess the influence of climate change on food security and to suggest a sustainable solution for contemporary urban areas (48). A proposed integrated vertical aeroponic farming (VAF) system aims to improve vegetable production in Singapore, a country with limited land for traditional large-scale crop cultivation. The implementation of an integrated VAF system, coupled with low energy input LED lighting, has the potential to enhance both cropping density per unit land area and productivity in a cost-efficient manner. Furthermore, they reached the conclusion that enhancing the use of existing land through the VAF system and implementing plant physiological solutions will provide an effective framework for massive vegetable cultivation in the contemporary urban area. Another investigation sought to devise and suggest adaptable systems for monitoring, watering, and plant care that may be used with various crop varieties, therefore reducing the country's reliance on technology imported from elsewhere (49). The researchers reached the determination that aeroponics offers the greatest benefits in comparison to other planting methods routinely employed in Mexico. Aeroponics allows for precise regulation of humidity, temperature, pH, and water conductivity within a greenhouse. Due to the suspension of roots in the air, aeroponics allows for planting in virtually any location and the utilisation of cubic space. Consequently, aeroponics can be implemented in various applications. The only limitations are the farmer's infrastructure to operationalise the system and the specific requirements of each crop. Authors used aeroponics for both plant research and for crop production, and have developed systems for growing vegetable crops eg. tomatoes, cucumbers, potatoes and herbs, and flower crops Lisianthus and Zantedeschia (50). Aeroponic techniques have also been used by them as a research tool to examine gas levels in the root zone, crop nutrition and root growth. In another study conducted by the same authors in 2002 they opined that aeroponic production systems offer improved control of the root environment, and the potential to crop many plants, including tomato, cucumber, capsicum, eggplant, watermelon, honeydew, and cantaloupe melon continually, without the need to replant on a regular basis (51). Study examined the nutritional uptake and dry matter accumulation of processing tomatoes grown aeroponically (52). Their study reported that aeroponic technology offers the potential then to study plant nutrition in an optimal root environment, where neither water nor oxygen are limited or influenced by intrinsic soil properties. They also opined that using this technology it should be possible to define potential uptake of nutrients to the plant and the resultant ability to accumulate and utilize assimilates for optimal productivity and quality. Such information could then provide the basis for a sustainable approach to crop nutrition using drip fertigation. Drip fertigation allows for improved control in timeliness and quantity of nutrients and water supplied. Aeroponics, a hydroponic technique for cultivating plants in an air or mist environment without soil, has garnered recognition as an environmentally friendly agricultural alternative. Nevertheless, despite its remarkable potential, there exist various areas of research that require attention in order to comprehensively comprehend and enhance its use in sustainable agriculture. A notable disparity exists in the long-term viability of aeroponic systems in comparison to conventional agricultural practices. Although aeroponics can decrease water consumption and obviate the requirement for pesticides, there is a scarcity of studies on the enduring impacts of nutrient allocation and system upkeep on plant well-being and productivity. Gaining insight into the impact of various fertiliser solutions on plant growth over long periods is essential for formulating optimal strategies that guarantee both productivity and sustainability. An additional

issue that necessitates deeper inquiry is the energy consumption linked to aeroponic systems. Although aeroponics may be more resource-efficient in terms of water consumption, the energy needed to maintain ideal environmental criteria, such as temperature and humidity, can be significant. Further investigation is required to assess the energy efficiency of different aeroponic configurations and to investigate the potential integration of renewable energy sources into these systems to maximise their sustainability. Furthermore, the scaleability of aeroponic devices is an area of research that lacks attention. Historically, most research has concentrated on small-scale or laboratory environments, resulting in a dearth of data regarding the performance of these systems in larger, commercial operations. A comprehensive grasp of the economic feasibility and operational obstacles associated with the expansion of aeroponic systems is crucial for their integration into conventional agriculture. The investigation encompasses the examination of expenses related to infrastructure, maintenance, and labour, together with the prospective market demand for aeroponically cultivated crops. Moreover, the influence of aeroponics on biodiversity and the whole health of ecosystems remains a relatively uncharted domain. Although aeroponic systems have the potential to decrease land requirements and mitigate soil degradation, it is necessary to evaluate the compatibility of these systems with local ecosystems. Research should prioritise investigating the possible impacts of aeroponic farming on pollinators, soil health, and the ecological systems in the surrounding area, together with the consequences for food security and local economy. Furthermore, there is a significant study gap in understanding consumer perception and adoption of aeroponically cultured product. Gaining insight into consumer perspectives on aeroponics, including their perceived advantages and risks, is crucial for the promotion of these systems. Research investigating marketing tactics, educational outreach, and the impact of certification on consumer decision-making can facilitate the process of connecting innovative agricultural techniques with market acceptability. To summarise, although aeroponics has potential for sustainable agriculture, there are significant research deficiencies that need to be resolved in order to enhance its application. These encompass evaluations of long-term sustainability, examinations of energy usage, studies on scalability, assessments of implications on biodiversity, and research on consumer acceptance. By prioritising these domains, scholars can make valuable contributions to the advancement of aeroponic systems that exhibit not only high efficiency and productivity, but also excellent environmental sustainability and widespread social acceptance. In order to fully exploit the promise of aeroponics in the pursuit of sustainable food production in the presence of global issues like climate change and population expansion, it will be essential to address these gaps.

Discussion

In recent years, there has been a significant increase in the amount of research conducted on aeroponics all over the world. This increase has been driven by a number of causes, including the growing worries regarding food security, the developments in technology, and the rise of urban agriculture. The bibliometric analysis that is offered in this paper offers useful insights into the trends, geographical distribution, and key research areas that are associated with this developing discipline. In the early 2000s, there has been a large increase in the number of research articles that are produced annually on aeroponics. This development has been exponential, with a particularly notable increase being noticed beginning in 2010. The increased interest and investment in aeroponics as a viable solution for sustainable and efficient food production is reflected in this trend, which is indicative of the expanding interest in aeroponics. India has emerged as a prominent contributor, which is a reflection of the country's strong research infrastructure and focus on tackling local food security concerns. The geographical distribution of research output is diversified, with India emerging as a leading provider. Additionally, the United States of America, China, and a number of European countries have made a significant contribution, which highlights the fact that aeroponics research is conducted on a global scale. Through the use of citation analysis, the impact and influence of research conducted in various countries can be revealed. The USA and China lead the pack in terms of the number of

citations, which is indicative of their robust research communities and significant contributions to the area. The involvement of countries like Belgium, India, and Greece highlights the global importance of aeroponics research and the growing significance of international collaboration. It is possible to identify major study areas and developing trends within the discipline through the use of keyword co-occurrence analysis. The terms "aeroponics," "cultivation," "hydroponics," and "plant root" emerge as major themes, indicating that a great attention is placed on the fundamental ideas and procedures of aeroponics. Because of this analysis, valuable insights have been provided for the future paths of research. According to the findings of the analysis of the collaboration network, there is a very small network of linkages between nations, which indicates that there is limited international collaboration in the field of aeroponics research. It is possible that this is due to a number of factors, including geographical distance, linguistic obstacles, or different study interests. Nevertheless, the linkages that are already in place indicate that there is a rising interest in the sector, as well as the possibility of future cooperation. In the context of the more general field of agriculture or plant science, the centrality analysis places aeroponics in the category of a topic that is only moderately relevant. It is possible that the exact position it holds within the "motor themes" quadrant indicates that it is either a topic that is fast emerging or one that is waning. For the purpose of determining its precise trajectory, additional study is required. Aeroponics offers transformative potential for addressing socioeconomic challenges, particularly in regions facing food insecurity, limited arable land, and rapid urbanization. By enabling high-yield food production in non-traditional environments, such as urban centers, aeroponics contributes to local food systems, reducing dependency on imported produce and enhancing food sovereignty. This can lead to lower food prices and improved access to fresh, nutrient-rich crops, particularly for underserved communities. Additionally, the technology's low water and land requirements make it an attractive solution for regions with scarce natural resources, such as arid or densely populated areas. The adoption of aeroponics also creates new economic opportunities. It fosters innovation and entrepreneurship by encouraging the development of localized systems and support industries, such as nutrient solutions, plant lighting, and automation technologies. Furthermore, aeroponics has the potential to create jobs across the supply chain, from system design and manufacturing to farming and distribution. However, socioeconomic challenges remain. The high initial investment and operational costs may limit accessibility for smallholder farmers and marginalized communities. Governments, NGOs, and private sectors need to collaborate to address these barriers through subsidies, training programs, and technology transfer. Overall, the socioeconomic implications of aeroponics extend beyond agriculture, influencing public health, employment, and resource sustainability on a global scale. According to this bibliometric analysis, future aeroponics research should focus on technological advances in controlled environment systems, nutrient delivery, and plant lighting; the incorporation of aeroponics into urban farming initiatives to produce food sustainably; the commercialisation of aeroponics for large-scale crop production; and plant physiology. Research in the future can help to the creation of aeroponics systems that are both sustainable and efficient by focusing on these areas. This will allow for the fulfilment of the ever-increasing need for food as well as the resolution of global issues such as climate change and food insecurity. The findings of the bibliometric analysis highlight the growing prominence of aeroponics as a research field, driven by pressing global concerns such as food security, sustainability, and urban agriculture. While the exponential growth in publications since the early 2000s reflects the increasing interest in this innovative agricultural technique, a deeper exploration reveals both opportunities and challenges that merit attention. Research should prioritize advancements in automation, nutrient delivery systems, and energy-efficient plant lighting. Such innovations are critical for making aeroponics systems cost-effective and scalable. Greater focus on integrating aeroponics into urban farming initiatives could address challenges related to food security and urbanization. Pilot projects in densely populated

cities could serve as models for larger-scale adoption. While this bibliometric analysis provides valuable insights, it is not without limitations. First, the study relies on data from specific bibliographic databases, which may not capture all relevant publications, especially those in regional or non-English journals. Second, the analysis primarily focuses on citation and co-occurrence metrics, which may not fully represent the quality or practical applicability of the research. Additionally, the limited scope of international collaboration highlighted in the study may overlook smaller-scale but impactful efforts. Finally, the emerging trends and themes identified require further validation through experimental studies and field trials to confirm their significance and applicability.

Conclusion

The primary goal of this research is to identify the publication trend, important authors, leading publications, Leading countries in the publication of articles, significant study areas, and Leading countries in the citation of articles and trend topics in the area of aeroponics. To deliver a clear and comprehensive overview of aeroponics, a thorough systematic review of 25 papers was conducted. First, we studied the publication trend to identify the trend in the publication of articles. The trend shows that the number of articles produced was minimal in the initial period. However, from 2000 onward, there is a marked increase in the number of publications, indicating a surge in research activity. The most dramatic increases are observed between 2020 and 2023 when the number of articles jumps dramatically to a new high of 36 in 2023. The publication trend in leading countries shows that India, the USA, and China are the top nations in the scientific production of articles related to aeroponics. Second, we identified important publications about aeroponics. Acta Horticulture is the leading journal in the field of aeroponics. Third, we examined the key areas of research in this field they are: aeroponics, hydroponics, and potato with most of the research being contributed from India, China, and the USA**.** Fourth, we identified the most significant study areas in this field. According to co-occurrence network research, it is very clear that the keywords with more time occurrences are “aeroponics”, “cultivation,” “hydroponics,” and “Plant root’’. Finally, we performed a thorough systematic review of the recent and relevant papers to understand the current research trend in the area of aeroponics. We identified that various aspects of aeroponics have been brought into study by different authors. Several studies have highlighted the benefits of aeroponics, its impact, its efficiency in the production of various crops, determinants of the adoption of aeroponics, etc. Similarly, the role of aeroponics in the achievement of sustainable agriculture was discussed by various authors. Additionally, the role of technology in aeroponics was also studied. this review underscores the multidisciplinary nature of aeroponics research, spanning agricultural efficiency, sustainability, and technological advancements. Key takeaways include its potential to revolutionize crop production, its alignment with sustainable agriculture goals, and the need for further exploration into adoption barriers and technological integration. By synthesizing these diverse perspectives, this study highlights both the progress achieved and the critical gaps that remain, paving the way for more targeted and impactful future research. Aeroponics is becoming more and more popular in India since it offers several benefits, such as higher agricultural yields, less water consumption, and the ability to produce crops in spaces that aren't very big. Even though various studies have emphasized the significance of aeroponics, a study covering the comprehensive assessment of aeroponic systems is still lacking. Therefore, in future research, it is important to consider the requirements of having more efficient, productive, and resilient aeroponic cultivation system. While significant progress has been made in exploring the benefits, technological advancements, and sustainability potential of aeroponics, there remains a need for holistic assessments that integrate these aspects into comprehensive system evaluations. Future research should prioritize addressing existing gaps by developing standardized methodologies, fostering interdisciplinary collaboration, and scaling innovations for widespread adoption. This approach will be crucial in unlocking the full potential of aeroponics as a transformative tool for achieving global food security and sustainable agriculture. Policymakers should prioritize funding and subsidies for aeroponics research and implementation, particularly in resource-scarce

regions. Financial support can lower barriers to entry for smallholder farmers and entrepreneurs, fostering inclusive agricultural innovation. Developing standardized protocols for aeroponics systems, including nutrient delivery, water use, and energy efficiency, is essential. These standards will ensure consistency, reliability, and scalability while facilitating international collaboration. Governments and institutions should invest in education and training programs for farmers, technicians, and researchers to build local expertise. Such programs can enhance the operational efficiency and widespread adoption of aeroponic systems. International partnerships should be fostered to share best practices, resources, and research outcomes. This can help address the limited collaboration networks identified in the study and drive collective progress in aeroponics. By acting on these recommendations, stakeholders can bridge the gaps identified in the study, paving the way for aeroponics to contribute significantly to global food security and sustainable agriculture.

Abbreviation

Nil.

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Author Contributions

Sreejith B: Conceptualization, Methodology, Writing; Yedhu Harikumar: Analysis, Writing, Original draft preparation; Muthumeenakshi.M: Supervision, Writing, Literature review, Data collection; Maneesh B: Supervision, Writing, Original draft preparation.

Conflict of Interest

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