

Original Research Paper

Vertical Farming as Remedy to Boost Food Security: A Bibliometric Viewpoint

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Article history

Received: 19-09-2024

Revised: 28-10-2024

Accepted: 21-11-2024

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Abstract: The current study presents bibliometric investigations on research findings on vertical farming as related to food security from 1992-2023. The results obtained from findings includes key authors, leading nations in the number of citations and publications, leading affiliations, relevant journal outlets and trending topics among authors in the research domain. An aggregate of 484 research documents were gotten from the Web of Science (WoS) database with an average citations per doc and co-authors per document ratio of 25.3 and 4.11, respectively. Publications on vertical farming research was correlated in line the number of years ($R^2 = 0.5196$; $y = 2.0264x - 4052.9$) which is indicative of more increase in the number of articles as the years grows. The USA was the leading nation in terms of article numbers ($N = 60$) and citations ($N = 2120$). While China was second ($N = 42$) in number of publications, but sixth ($N = 636$) in terms of citations. The nations of USA ($N = 19$), China ($N = 14$) and Italy ($N = 11$) had multiply country collaborations (MCP) with other nations globally. Leading authors keywords trending topics include Vertical farming ($N = 100$), Hydroponic, Agriculture, Urban Agriculture, Sustainability, Farming among others. Economically stable as well as scientifically advanced nations had higher research outputs when compared to developing countries. The author keywords of the subject matters from the trending topics suggests the direction of future research for policy makers, governments and other stakeholders in promoting vertical farming in with food security and sustainability.

Keywords: Smart Farming, Scientometric, Research Trends, Limited Land, Water Restriction

Introduction

One of the serious challenging situation of the current 21st century is that of food insecurity at the global stage. As human population continues to rise especially in large cities, more arable lands are diminishing rapidly across the world because of the increase in residential and infrastructural buildings on the lands (Tooy *et al.*, 2023). From the report of the Food and Agriculture Organization of the United Nations, the global human population is predicted to be above 9 billion people by 2050, which in turn will increase pressure on the global agricultural sector for increase in the production of food for human sustenance (Paudel *et al.*, 2023). This calls for a fundamental shift that will increase food production to carter for the growing human population. Likewise, food production is at the moment a foremost concern due to

the severe threats it poses to conventional soil-based agricultural system of production. An alternative approach of food farming system that will help tackle the problem of increase in food demands as human population increases (despite the diminishing land resource) is of essence. The system of little or no soil farming could offer a solution to these existing problems. Vertical farming systems can be employed along side the soil-based farming systems as a complementary approach to help tackle the present scarcity of fertile arable lands and water. Vertical farming combines both engineering as well as natural science disciplines to improve food production in an environmentally friendly manner (Maurya *et al.*, 2023). This suggests that vertical farming can produce food without being affected by external conditions such as weather and other natural phenomena.

Vertical farming is a smart system of farming that is presently a game-changing approach of innovation which has come to stay in the agricultural sector. Likewise, vertical farming is an environmentally friendly type of farming that can thrive virtually in most communities of the world. According to Barui *et al.* (2022), vertical farming is a smart method of farming that has the capacity to contribute significantly to food security and sustainability in the twenty-first century. It is expected that in the next two and half decade, vertical farming will be a modern instrument that will be used to feed the fast growing human population globally (Barui *et al.*, 2022). This is because vertical farming can be utilized in areas where land and water are limited (Van Gerrewey *et al.*, 2022; Vaishnavi *et al.*, 2024).

This new farming approach has brought together several experts including public health workers, agronomists, architects, as well as environmentalists among others in a bid to figure out how to thrive with regards to food production in an increasingly urbanized and food scarce future. The idea of vertical farming has also brought together a collection of expertise from various fields in aquaponics, hydroponics, aeroponics as well as robotics to form a united front in increasing food production and availability (Beacham *et al.*, 2019; Lau and Mattson, 2021; Maurya *et al.*, 2023; Tooy *et al.*, 2023). Non-profit organizations are in support of the idea of vertical farming to boost their local economy and cleaner environment/ society (Jaeger *et al.*, 2023). In addition, profit-oriented organizations are also striving to key into the prospect of boosting food production and market from local food produce by utilizing the avenue of vertical farming (Van Gerrewey *et al.*, 2022). Several governments of the world are also searching for efficient methods to increase domestic food production and security by providing financial supports for vertical farming initiatives (Van Gerrewey *et al.*, 2022). Similarly, various nations globally are partnering together on the possibility of adopting vertical farming for the purpose of increasing food production and availability for their citizens which have made them to consistently support the idea of this system of farming (Tooy *et al.*, 2023).

Of importance to note is that vertical farming is also able to create new employment opportunities for a variety of people including regular crop farmers, maintenance workers, technologists, project managers and marketing staff and support local agro-industries (Benke and Tomkins, 2017; Al-Kodmany, 2018). However, the increase of health and environmental consciousness by food consumers have heightened the demand for healthy food produced with a low impact on the immediate environment. In addition, vertical farming can improve food safety by fully utilizing the traceability of crops and plummeting the need for herbicides as well as pesticides (Benke and Tomkins, 2017; Maurya *et al.*, 2023). More

importantly, food security can be enhanced by increasing food self-sufficiency in large cities or regions with scarce resources or punitive climates (Al-Kodmany, 2018; Tooy *et al.*, 2023). Unarguably, vertical farming has a positive prospect to contribute to a large range of future crop production, thereby offering a technologically innovative farming system to promote food security in most regions of the world (Barui *et al.*, 2022; Jaeger *et al.*, 2023).

Although, several articles are in the public domain on vertical farming and its potential roles in the global ecosystem (Van Gerrewey *et al.*, 2022; Maurya *et al.*, 2023; Jaeger, 2024; Singh *et al.*, 2024). It is however rare to find literatures that have employed the approach of bibliometrics to present and describe the trending global status on vertical farming with respect to food security. The current paper wish to firstly reveal the knowledge bank of studies done on vertical farming as relates to food security. The study also aimed to describe the trends on social network among scientists, the leading countries, institutions with respect to authors, nations, literature outputs, keywords, citations and trending themes in this research domain (vertical farming and food security). Likewise, the study hope to discuss the global future directions in the topic of vertical farming as relates to food security from a scholarly viewpoint by employing different bibliometric indices. It is perhaps safe to state that, the present bibliometric approach of literature presentations is a distinct tool that allows the use of mathematical and statistical permutations to review research results and how they impact various global nations, organizations and academic scholars on the world stage in a particular field of study (Zou *et al.*, 2019).

Materials and Methods

Data Collection from Scholarly Database

This study used scholarly publications covering the aspects of vertical farming as related to food security research from Web of Science (WoS) databank. The WoS databank is reputable for generating quality scholarly research documents for research use (Zhu and Liu, 2020). In addition, the WoS data source is known to have a range of reliable as well as quality academic papers when compared to other data sources including Scopus and PubMed (Qin *et al.*, 2020; Mejia *et al.*, 2021). The WoS data source was specifically chosen for this study because of its reputable collections of biological sciences, agricultural sciences, physical sciences as well as information and technology research contributions in the global body of knowledge (Balstad and Berg, 2020; Tarragona *et al.*, 2020), which is well suited for this study. While the present study rightly acknowledges other data

sources such as Scopus, PubMed, google scholar, etc. as good databases for document retrieval of this nature, the WoS database is often considered superior for bibliometric analysis due to the fact that it has advanced citation analysis, all-inclusive coverage, great pool of quality data, good analytical tool and user-friendly for extracting articles from its resource (Singh *et al.*, 2021; Zhang *et al.*, 2023). Again, WoS database is reported to be one of the most dependable and extensive intellectual storehouse for bibliometric literatures that accommodates a range of high-caliber as well as prominent academic articles with over 12 million research literatures in over 12,000 reputable journals (Wang *et al.*, 2023).

Advanced search technique was employed in WoS to gather the suitable articles for this study as it allows a build up of long as well as all-inclusive search queries. Furthermore, the general consensus for the use of one database for bibliometric evaluation is widely supported due to the complexities encountered in doing bibliometric assessments with multiple databases which may cause the loss of some relevant articles that should be included in the study (Sweileh, 2020).

Search Stratagem for Data Recovery

A search query that cuts across the related research subject matter with slightest false-positive out-come was carried by searching several literatures on vertical farming (especially the ones related to research studies as well as systematic reviews) in order to acquaint with the right keywords in line with the search topic. This strategy has also been previously used for keyword search in bibliometric analysis (Fesseha *et al.*, 2020). For a wider search the study used the topic search method for closely related keywords on “vertical farming” and “food security” and “vertical agriculture” studies to collect all the necessary data for this investigation. As a result of the fact that, assembling related data of literatures from WoS entails a search query, the research query included both searching for closely related keywords as well as Boolean metrics. Conversely, this study focused on vertical farming/agriculture in relation to food security and sustainability research. The operator function “AND” was used to separate the afore-mentioned keywords. The operator function “OR” was employed to separate the selected keywords within each categories of keywords used for the study. The study search was done using the search keyword string “vertical farming* AND (food* OR securit* OR vertical agricultur* OR safety* OR sustainabilit*)” in all fields source covered by WOS from 1992-2023.

Both the Boolean permutations “AND” as well as “OR” were utilized to limit the scope of the resulting topic for this study. From the initial search query, all retrieved

article types were collected including research articles, review manuscripts, book chapters, technical notes and conference proceedings among others from 1992-2023 from the WoS. Conversely, the present study consciously excluded every other literatures, apart from research and review articles so as to reduce any form of ambiguity that may surface from other publication types which results/findings may not be properly and well indexed for the purpose of this study. The aggregate article collections that was used for analysis in this study comprises of 484 literature documents.

Inclusion and Filtering of Unwanted Documents

After the general collections of all kinds of literature documents were retrieved from WoS, they were further cleaned-up by removing any publication that do not correctly align to the purpose of the current study before validation. Literatures that do not to directly address the subject matter of discourse were excluded and removed. This filtering, inclusion and exclusion of data for the present study was done with the help of exhaustive literature review search of keywords as aligned to the subject that is in consideration. Earlier studies have also employed this type of inclusion and exclusion stratagem to remove undesirable articles in bibliometric evaluations (King *et al.*, 2018; Fesseha *et al.*, 2020). Figure (1) gave a detailed explanation about the inclusion and exclusion method used for this study.

Analysis of Data in R-Studio

All the selected research data gotten from WoS were evaluated with R-Studio (version 4.3.0. 2023-04-21 UCRT) software with bibliometrix R-package for bibliometric analysis (Aria and Cuccurullo, 2017). Before analysis, all data were first inputted into R-Studio software and evaluation and visualization of outcomes (Idamokoro, 2023).

Summary of articles on vertical farming as relates to food security used for analysis in R-studio

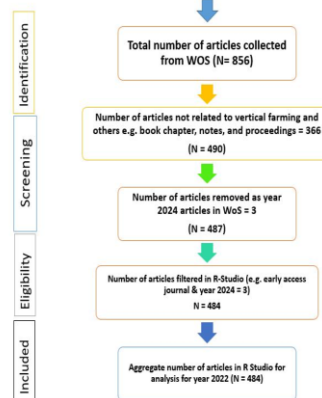


Fig. 1: Diagram showing the criteria for inclusion and exclusion of articles from WoS

The bibliometrix R-package was also employed (R-project web interface in Biblioshiny) to describe the outcomes which include citation analysis, individual authors' performance, countries performance, leading keywords and scholarly networking by leading nations and authors in the research subject matter. For a further explanation, the statistical illustration of a typical bibliometric networking and collaboration is as given below:

$$Network(N) = O \times T^P$$

where, the letter “N” represents Network; “O” depicts a bipartite composite matrix of research publications × attributes (e.g., keywords, affiliations, keywords plus, nations and citation of articles). The letter “N” further denotes symmetrical matrix of $N = T^P$.

Results

An aggregate of 484 research articles were gotten for the study within the year 1992-2023. The information of the evaluated documents are well explained in Table (1). The total sum of authors that worked on the focused study research niche (vertical farming) was 1786, meanwhile the total number of single authors of the subject matter is 34. There were 4.11% co-authors per document and 30.58% international co-authorships. The total number of references is 27001, the average citations per document is 27.54%, while the yearly growth rate for this research discourse is 13.73%.

The result from Fig. (2) showed data that were analysed with a polynomial metric fitting curve. This polynomial fitting function described by the yearly increase growth of the present study depicts a positive correlation ($R^2 = 0.5196$; $y = 2.0264x - 4052.9$) between the cumulative numbers of articles and the years of research publications. From Fig. (2), the result further showed a trend in research publications with some years not having a single output (including 1994, 1996, 1997, 1998 and 2000). However, there was appreciable rise in research articles on vertical farming and food security studies from 2013 (N = 10) to date (2023; N = 108). The annual growth rate of publications is 13.73%. The highest number of research outputs on the subject matter was recorded in 2023.

Table 1: Summary on vertical farming and food security research from WoS data bank

Description	Results
Main information about data	
Timespan	1992:2023
Sources (Journals, Books, etc)	245
Documents	484
Annual growth rate %	13.73
Document average age	5.08
Average citations per doc	25.3

References	27001
Document contents	
Keywords plus (ID)	1554
Author's keywords (DE)	1968
Authors	
Authors	1786
Authors of single-authored docs	34
Authors collaboration	
Single-authored docs	36
Co-Authors per Doc	4.11
International co-authorships %	30.58
Document types	
Article	406
Review	78

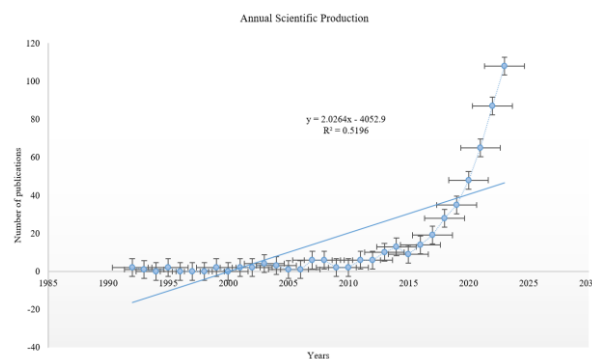


Fig. 2: Yearly number of publications on vertical farming from 1992-2023

Table (2) showed outputs on vertical farming and food security for the top leading and productive countries with regards to the number of research outputs and citations. The United States of America was rated first in publication and citation numbers in the research domain (N = 60; N = 2120). The other leading nations in terms of publication numbers and citations include; China (N = 42; N = 636), Germany (N = 31; N = 919), Italy (N = 25; N = 621) and UK (N = 22; N = 900) among others. The frequency of outputs varied among the 25 top leading nations from 0.012 to 0.124. The top 25 globally ranked nations with multiple country publications (MCP), include USA (N = 18), China (N = 14), Italy (N = 11), Netherlands (N = 9) and Denmark (N = 7), respectively. The countries ranked in top place for single country publications (SCP) of research studies include USA (N = 42), China (N = 28), Germany (N = 26), UK and India (N = 16), respectively (Table 2).

In the same vein, the top ranked 25 keywords (author's keywords) by scientists in the studied field of vertical farming and food security, it was revealed that vertical farming (N = 110) was ranked in the first position, next was sustainability (N = 35), followed by urban agriculture (N = 34), hydroponics (N = 28), farming (N = 26), agriculture (N = 21) and food security (N = 20) among other author keywords (Table 3).

Table 2: 20 most productive nations on vertical farming and food security studies based on number of articles and citation numbers

Ranking based on publication numbers							Ranking based on citation numbers			
S/N	Country	Articles	SCP	MCP	Freq	MCP_Ratio	Country	TC	AAC	
1	USA	60	42	18	0.124	0.3	USA	2120	35.30	
2	China	42	28	14	0.087	0.333	Germany	919	29.60	
3	Germany	31	26	5	0.064	0.161	United Kingdom	900	40.90	
4	Italy	25	14	11	0.052	0.44	Netherlands	875	67.30	
5	United Kingdom	22	16	6	0.045	0.273	Belgium	685	52.70	
6	France	17	12	5	0.035	0.294	China	636	15.10	
7	India	17	16	1	0.035	0.059	Italy	621	24.80	
8	Canada	16	14	2	0.033	0.125	Denmark	563	46.90	
9	Spain	15	10	5	0.031	0.333	France	450	26.50	
10	Sweden	15	10	5	0.031	0.333	Malaysia	381	38.10	
11	Belgium	13	13	0	0.027	0	Canada	359	22.40	
12	Netherlands	13	4	9	0.027	0.692	Sweden	357	23.80	
13	Denmark	12	5	7	0.025	0.583	Singapore	319	26.60	
14	Singapore	12	9	3	0.025	0.25	Spain	294	19.60	
15	Australia	11	9	2	0.023	0.182	Greece	281	93.70	
16	Malaysia	10	5	5	0.021	0.5	Australia	268	24.40	
17	New Zealand	10	4	6	0.021	0.6	Egypt	201	67.00	
18	Korea	9	6	3	0.019	0.333	Norway	182	30.30	
19	Turkey	9	9	0	0.019	0	India	169	9.90	
20	Brazil	8	6	2	0.017	0.25	New Zealand	157	15.70	
21	Iran	8	4	4	0.017	0.5	Switzerland	109	36.30	
22	Japan	8	7	1	0.017	0.125	Japan	105	13.10	
23	Mexico	6	4	2	0.012	0.333	Mexico	105	17.50	
24	Norway	6	3	3	0.012	0.5	Iran	102	12.80	
25	Russia	6	6	0	0.012	0	Turkey	102	11.30	

SCA: Single Country Articles; MCA: Multiple Country Articles; TC: Total Citations; AAC: Average Article Citations

Table 3: 25 most relevant words used by authors in vertical farming as relates to food security research

S/N	Author Keywords (DE)	Occurrences	Keywords Plus	Occurrences
1	Vertical Farming	110	Agriculture	58
2	Sustainability	35	Growth	54
3	Urban Agriculture	34	Quality	35
4	Hydroponics	28	Water	33
5	Farming	26	System	30
6	Agriculture	21	Food	29
7	Food Security	20	Yield	29
8	Contract Farming	18	Performance	27
9	Vertical	17	Systems	27
10	Controlled Environment Agriculture	14	Impact	26
11	Plant Factory	14	Management	26
12	Urban Farming	11	Lettuce	22
13	Vertical Farm	11	Sustainability	20
14	Greenhouse	10	Photosynthesis	18
15	Indoor Farming	10	Temperature	16
16	Precision Farming	10	Climate-Change	15
17	Sustainable Agriculture	10	Energy	15
18	Horticulture	9	Efficiency	14
19	IOT	9	Soil	13
20	Smart Farming	9	Blue-Light	12
21	Soil	8	City	12
22	Yield	8	Dynamics	12
23	Efficiency	7	Future	12
24	Energy	7	Plant Factories	12
25	Lettuce	7	Design	11

TC: Total Citation; NP: Number of Publications; PY_Start: Publication Start Year

The top leading 25 relevant journals with the highest published publications in the field of vertical farming and food security are tabulated in Table (4). The names of these journals include Sustainability (N = 36; h_index = 15); Journal of Cleaner Production (N = 16; h_index = 12); Agronomy-Basel (N = 16; h_index = 8); Science of the Total Environment (N = 11; h_index = 8); Soil & Tillage Research (N = 7; h_index = 7); Horticulturae (N =

10; h_index = 6); Agricultural Water Management (N = 5; h_index = 5) and Food Policy (N = 5; h_index = 5), respectively. Meanwhile, the 25th ranked journal source is Food and Energy Security (N = 4; h_index = 3). The top leading research institutions with at least eight (8) research outputs on the subject matter are shown in Table (5). Natl Univ Singapore in Singapore (N = 16), Aarhus Univ in Denmark (N = 15), Michigan State Univ in the United

States of America (N= 15), Univ Putra Malaysia in Malaysia (N = 15), New Zealand INST Plant And Food Res Ltd (N = 13) and Wageningen Univ in Netherlands (N = 13), were the top six institutions in the research field of vertical farming, accordingly.

Table (6) showed the top 20 ranked globally cited documents in the research domain in vertical farming and food security research based on aggregate number of citations from 1992-2023. The publication authored by Aanen (2002) in The Proceedings of the National

Academy of Sciences USA was ranked first with a combined total of 339 citations. The second place publication was written by Klerkx and Rose (2020) in the Global Food Security-Agriculture Policy with an aggregate of 272 citations. The third (N = 256) and fourth (N = 240) position for highly cited journals were written by Ramin Shamshiri *et al.* (2018) and Bantis (2018) in the International Journal of Agricultural and Biological Engineering and Scientia Horticulturae, accordingly (Table 6).

Table 5: The 25 leading institutions on vertical farming and food security research with 8 publications and above

S/N	Affiliation	Nations	Articles
1	Natl Univ Singapore	Singapore	16
2	Aarhus Univ	Denmark	15
3	Michigan State Univ	USA	15
4	Univ Putra Malaysia	Malaysia	15
5	New Zealand Inst Plant and Food Res Ltd	New Zealand	13
6	Wageningen Univ	Netherlands	13
7	Ohio State Univ	USA	12
8	Ivl Swedish Environm Res Inst	Sweden	11
9	Univ Autonoma Barcelona	Spain	11
10	China Agr Univ	China	10
11	Swedish Univ Agr Sci	Sweden	10
12	Univ Florida	USA	10
13	Univ Montpellier	France	10
14	Chungnam Natl Univ	South Korea	9
15	Galatasaray Univ	Turkey	9
16	Nanyang Technol Univ	Singapore	9
17	Northwest Aandf Univ	China	9
18	Univ Almeria	Spain	9
19	Univ Arizona	USA	9
20	Univ Hohenheim	Germany	9
21	Delft Univ Technol	Netherlands	8
22	Ege Univ	Turkey	8
23	Katholieke Univ Leuven	Belgium	8
24	Kth Royal Inst Technol	Sweden	8
25	Univ Calif Davis	USA	8

Table 6: Top 20 leading cited journal sources on vertical farming as related to food security research

S/N	Author first name, year of publication & journal	DOI	Total Citations	TC per Year	Normalized TC
1	Aanen DK, 2002, Proc Natl Acad Sci USA	10.1073/pnas.222313099	339	14.74	1.45
2	Klerkx L, 2020, Glob Food Secur-Agricpolicy	10.1016/j.gfs.2019.100347	272	54.40	7.06
3	Shamshiri RR, 2018, Int J Agric Biol Eng	10.25165/j.ijabe.20181101.3210	256	36.57	3.84
4	Bantis F, 2018, Sci Hort	10.1016/j.scienta.2018.02.058	240	34.29	3.60
5	Pigford AAE, 2018, Agric SYST	10.1016/j.agry.2018.04.007	240	34.29	3.60
6	Eigenbrod C, 2015, Agron Sustain Dev	10.1007/s13593-014-0273-y	228	22.80	2.57
7	Smith Led, 2015, Agric Ecosyst Environ	10.1016/j.agee.2015.02.016	225	22.50	2.54
8	Lal R, 2020, Food Secur	10.1007/s12571-020-01058-3	218	43.60	5.66
9	Al-Kodmany K, 2018, Buildings-Basel	10.3390/buildings8020024	192	27.43	2.88
10	Ouedraogo MM, 2014, Geomorphology	10.1016/j.geomorph.2014.02.016	173	15.73	5.90
11	Van Delden SH, 2021, Nat Food	10.1038/s43016-021-00402-w	171	42.75	7.08
12	Pulighe G, 2020, Sustainability	10.3390/su12125012	136	27.20	3.53
13	Trommsdorff M, 2021, Renew Sust Energy Rev	10.1016/j.rser.2020.110694	132	33.00	5.46
14	El-Sayed AFM, 2021, Rev Aquac	10.1111/raq.12494	131	32.75	5.42
15	André HM, 2002, Oikos	10.1034/j.1600-0706.2002.11216.x	130	5.65	0.55
16	Shah F, 2019, Sustainability	10.3390/su11051485	126	21.00	4.14
17	Basile-Doelsch I, 2020, Biogeosciences	10.5194/bg-17-5223-2020	119	23.80	3.09
18	Beacham AM, 2019, J Horticult Sci Biotechnol	10.1080/14620316.2019.1574214	116	19.33	3.81
19	Al-Chalabi M, 2015, Sust Cities Soc	10.1016/j.scs.2015.06.003	112	11.20	1.26
20	Touliatos D, 2016, Food Energy Secur	10.1002/fes3.83	111	12.33	4.03

In Fig. (3), the network visualization map of nations' co-operation was depicted. The single node is an individual nation and the radius of the node relates to the number of articles by the individual nation. The strokes depicts the direction of networking among the different nations and the thickness of strokes is indicative of the degree of collaboration among nations globally. The varied colours represents the collaboration alignments of the nations. Networking links stretched from 0-18. The United States of America (USA) had highest amount of networking (N=18); followed by China (N= 14), Italy (N = 11) and Netherlands (N = 9), respectively.

Figure (4), showed the co-occurrence network as well as interrelationship of the top ranked keywords on vertical farming as used by authors. Each circle with varied colour depicts a class of terms and the strokes represent the rate of connection as associated with the keywords. Further, the nearness of one keyword to another shows the more probable their closeness in the research literatures during the study period of 1992-2023. The network visualisation in Fig. (4) primarily depicts the regularly utilized words in vertical farming as related to food security research, which makes it more easier to distinguish the interest of the niche area from other fields.

Figure (5) reflects the authors' keywords via the thematic evaluation diagram. This result show four (4) main quadrants in line with the authors' keywords and networking as well as their grouping including the emerging theme, niche theme, basic theme and the motor theme. From these thematic illustration, the motor themes had keywords grouped into words such as urban agriculture, sustainability, vertical farming, energy, efficiency, controlled environment agriculture, smart farming, precision farming, indoor farming, soil, assessment, yield, lettuce, innovation. The basic themes had keywords such as contract farming, vertical coordination, Vietnam, rice, integration, governance. The emerging themes had keywords such as nitrogen, management, aquaculture, irrigation, soil moisture. The niche themes family farming, vertical integration, biomass, energy demand.

Furthermore, Fig. (6) showed the conceptual framework of the research niches explaining the k- means clustering with two groups reflecting the concepts of vertical farming (aeroponics, urban farming, vertical farm, smart farming, efficiency, hydroponics, micro greens etc.) as relates to boosting food security and food production (rice, contract farming, Africa, Vietnam). Likewise, the result from Fig. (7) explained the contents of the author keywords giving scholars a good view and current understanding of the publication trends of vertical farming and food security. This result extracted the topic trends of literatures by promoting better keywords for evaluating the means of the subject matter in R studio.

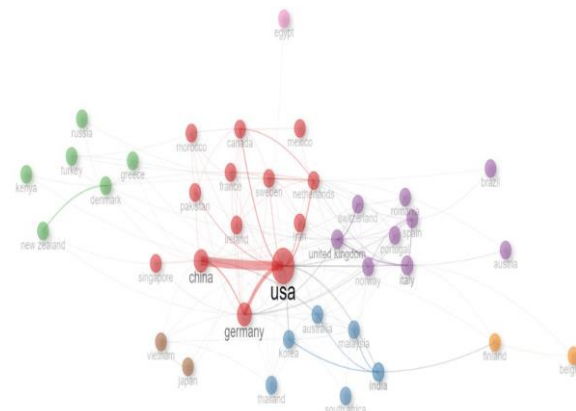


Fig. 3: Collaborative mappings of networking among nations doing research on vertical farming as relates to food security

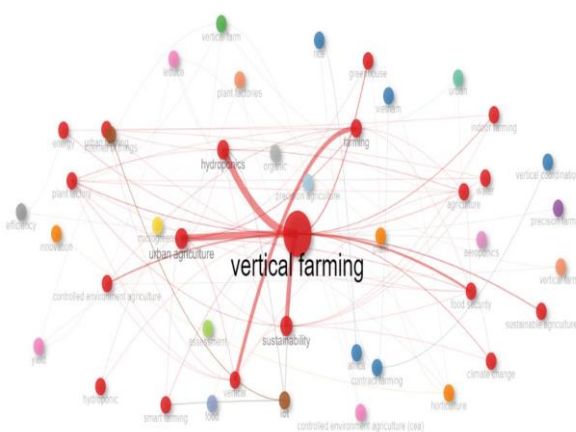


Fig. 4: Collaboration strength of keywords of global research on vertical farming as relates to food security from 1992-2023

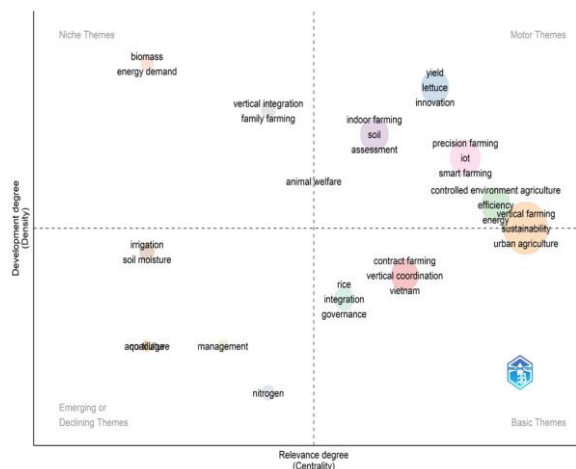


Fig. 5: Thematic map (author-keywords) in the research niche of vertical farming as relates to food security

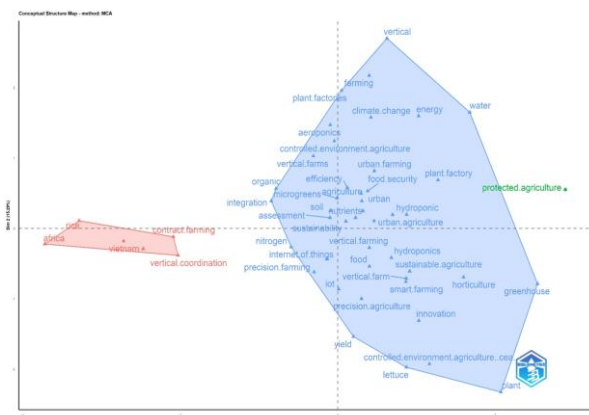


Fig. 6: Basic conceptual frames related to vertical farming and food security research. The retrieved articles exhibited K-means clustering with two (2) clusters showing models of vertical farming (aeronomics, urban farming, vertical farm, smart farming, efficiency, hydroponics, micro greens etc.,) for boosting food security and food production (rice, contract farming, Africa, Vietnam)

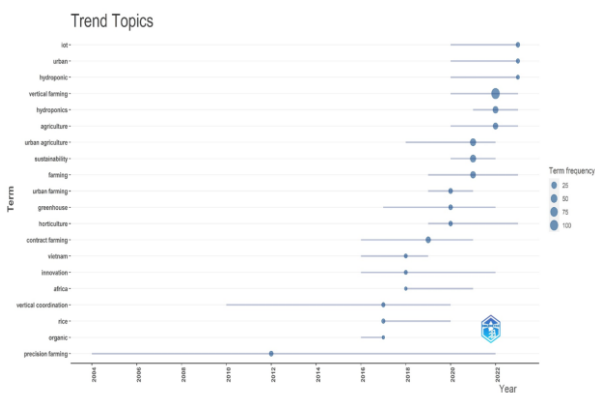


Fig. 7: Top trending topics of author keywords on vertical farming and food security research studies with high frequency terms over 25-100

Discussion

The present manuscript evaluated several research publications on vertical farming as related to food security between 1992 and 2023 based on data that were retrieved from WoS data resource. The number of articles on vertical farming research from the study start year of 1992 had a fluctuating trend and pattern with some years not having a single publication. However, from the year 2012, there was a steady rise in publications with the highest number of research articles in 2023 (N = 108). The increase in research publications in vertical farming is indicative of a huge growing interest in the subject matter. The current result is inline with the findings of Nájera *et al.* (2023) who also reported an increase in research publications on vertical farming with increase in years.

This observation further agrees with the report by Barui *et al.* (2022) who stated that, vertical farming is the current innovative approach of farming that has gain more attention of late and that it is a system of agriculture that is well poised to help combat the challenge of food insecurity as the rate of global population keeps growing on a yearly basis. Again, vertical farming is a system of farming that could be adopted in place of soil-based farming, thereby acting as a supplementary method to assist tackle the present scarcity of both fertile arable lands as well as water (Maurya *et al.*, 2023). One interesting fact why vertical farming is attracting global interest is because this type of farming approach can be used to produce a wide collection of crops primarily inside highly populated urban settlements (Maurya *et al.*, 2023). Another possible reason for increase in research in this type of farming may be due to the fact that vertical farming system is agreed to be in synchrony with present sustainable production stratagems and global development treaties to increase production efficiency, as well as sustainability as promoted by the Food and Agriculture Organization of the United Nations (Nájera *et al.*, 2023).

A relative large number of research activities and articles written with regards to the subject matter were mostly done in developed nations such as USA, China, Germany, Italy and UK among others. In a related study, the present observation was similar to the findings in another study who reported that developed nations mostly from USA, Canada, European countries, China and Japan are among the leading countries in vertical farming for promoting food production and security (Nejara *et al.*, 2023; Singh *et al.*, 2024). The reason for the increase in research from the afore-mentioned nations may be as a result of insufficient natural solar radiation for crop utilization (Nájera *et al.*, 2023). Another reason cited for increase vertical farming was the fact that it will help reduce possible environmental pollution of crops during transportation to long distance market places which is a common situation in these regions (Nájera *et al.*, 2023). Other bibliometric studies in varied fields have also reported rise in research work from economically stable nations (Cañas-Guerrero *et al.*, 2013; Olisah *et al.*, 2019). The quest by scientists, researchers and even government agencies in economically stably countries to continuously explore innovative and technological ways (in various research domains) for the purpose of combating possible food shortage both in their nations and in the global society is the reason why they are involved in several research adventures. Of interest is the fact that, several institutions and scientists from advance nations are often heavily funded by global agencies and their governments to carry out researches that will solve the multi-facet human challenges including food insecurity (Peng *et al.*, 2015; Idamokoro and Hosu, 2022; Idamokoro, 2023).

The present study further observed that there was no single African nation (out of the 25 leading nations in vertical farming research-Table 2) among the global nations doing active research as relates to the present subject matter. This observation should be a reflection as well as a wake up call to the continent of Africa to explore this novel field of farming for improving food production and reducing the challenge of food shortage. Most essentially, more attention is required in this field of research, more so that this aspect of research plays important role in global food production (Urrestarazu *et al.*, 2016; Natsuraha *et al.*, 2020; Olvera-Gonzalez *et al.*, 2021). It is assumed that more developing nations especially African nations can as well tap into the prospect of collaborating with economically stable and scientifically advanced nations to invest in this area of research, especially due to the positive economic significance of this field to boost their nations and promote food security. According to literatures, vertical farming as related to food security is environmentally friendly and in terms of land and water utilization, it is highly efficient (Benke and Tomkins, 2017; Singh *et al.*, 2024); which makes this kind of farming system highly practicable in any part of the world and especially in areas of limited water resource.

USA, China, Germany, Italy and UK were placed in the top spots of countries contributing to studies on vertical farming inline with food security research with respect to the numbers of citations and articles (Table 2). One main reason for the afore-mentioned nations to be ranked as a relevant nation topping the charts with high number of publications as well as article citations in any particular research field has been ascribed to the funding supports that they receive from several organizations including government institutions (Peng *et al.*, 2015; Ekundayo and Okoh, 2018). In addition, the rise in participation by the previously-mentioned economically stable nations in this type of research is credited to a possible high level of their involvement in regional as well as international collaboration with other research organizations and nations (Ekundayo and Okoh, 2020). This is a vital booster that enhance research impact and frequency of their article citations (Altarturi *et al.*, 2023). Another reason why these nations including USA, China, Germany and others are ranked in the leading nations that do research in vertical farming is that they have advanced technologies in artificial intelligence, robotic farming, as well as precision agriculture, which are very important for increasing automation agriculture (Csordás and Füzesi, 2023). In addition, institutions (universities) and research organizations located in these countries possesses highly equipped facilities to do complex research and tests in controlled farming conditions (Ekundayo and Okoh, 2018; 2020).

Conversely, the moderately low number of research on vertical farming with regards to food security as noticed in the present study (developing nations) may not be unconnected with the fact that some scientific research work done in these nations are in some cases carried out as self-funded by institutions as well as other internal agencies (Orimoloye and Ololade, 2021; Idamokoro, 2023). Another probable reason could be that researches from these developing nations are not indexes in recognized data sources such as Scopus, WoS, Google scholar, PubMed etc.

The 25 top leading nations having multiple collaboration publications (MCP) in vertical farming studies indicates their partnerships are with researchers from economically stable nations that are based in countries of financially stable economy such as USA, China, Germany and Italy (Table 2). This observation is inline to the result of other bibliometric studies who also reported partnerships among nations of financially stable economy (Smith *et al.*, 2022; Idamokoro and Hosu, 2022). Meanwhile, it is often observed in bibliometric studies that collaborations between financially established nations and developing ones is scare (Ekundayo and Okoh, 2018; Orimoloye and Ololade, 2021). The current study also noticed that countries such as Belgium, Turkey and Russia had result of single country publications (SCP; N = 13; N = 9; N = 6), but with zero (0) Multiple Country Publications (MCP), respectively. Collaborations among scientists from different nations is important because it allows for successful executions of innovative ideas for development in science (Lloyd *et al.*, 2023). The absence of international partnership among nations may further affect citations of research publications from developing nations. Global collaboration in scholarly investigations is essential because it allows for exchange of intellectual knowledge, resources and findings from the partnering nations (Ekundayo and Okoh, 2018; Smith *et al.*, 2021).

Keywords in research publications are used to address areas of important topics of a scientific field and to help other intellectuals to comprehend key concepts of a paper (Olisah *et al.*, 2019; Chen *et al.*, 2021). Keywords are further used to help researchers to project cutting hedge explanation of a paper (Synnestvedt *et al.*, 2005). Journals commonly request author keywords during paper submission prior to the review of the paper. This approach of author keywords assessment is an indication of its essential role in the use of keywords before a manuscript is accepted for review before possible publication in a given journal (Okaiyeto and Oguntibeju, 2021). The current study utilized both the singular and the plural method of the subject keywords to depict the most occurring research trend on vertical farming as relates to food security research. This kind of approach has previously been used by researchers understand the scope

of research emergence trends of a subject matter (Cañas-Guerrero *et al.*, 2013). The result of the present study gives both the author keywords and keyword plus from the searched documents that was used for visualization. This is highly essential in this kind of study because, author keywords are a collection of terminologies that tells the actual story of a publication; whereas keyword-plus indicates the references of titles of papers apart from the titles of the main paper (Zhang *et al.*, 2016).

The frequently used author keywords of a particular research area expresses the most trending topics as well as subject discourse over a given time span. Between the year 1992 and 2023, an aggregate of 1968 author keywords and 1554 keyword-plus were collected from WoS database on vertical farming and food security (Table 1). These author keywords and keyword plus including Vertical Farming, Sustainability, Urban Agriculture, Hydroponics, Farming, Agriculture, Food Security, Contract Farming, Controlled Environment Agriculture, Urban Farming, Water, System, Food, Precision Farming, Horticulture, IOT, Lettuce, Smart Farming among others are relevant to the research field related to vertical farming as related to food security (Table 3). In a related previous bibliometric study on “Role of Spectrum-Light on Productivity and Plant Quality over Vertical Farming Systems”, the most frequently used keywords were similar to the present study (Nájera *et al.*, 2023). This further buttresses the importance of these keywords in explaining the coverage and importance of the field of vertical farming as related to food security.

With respect to journal source where articles are published, journal sources are recognized as an essential aspect of bibliometric evaluation because they are used to source for similar or related research work in a particular field (Leydesdorff and Rafols, 2009). The 25 most relevant journal sources for the present topic in Table (4) indicate that they are reliable journal outlets dedicated to publishing intellectual findings as relates to vertical farming and food security. These leading article outlets (journal) include the following; Sustainability (N = 36; h_index = 15); Journal of Cleaner Production (N = 16; h_index = 12); Agronomy-Basel (N = 16; h_index = 8); Science of the Total Environment (N = 11; h_index = 8); Soil & Tillage Research (N = 7; h_index = 7); Horticulturae (N = 10; h_index = 6); Agricultural Water Management (N = 5; h_index = 5) and Food Policy (N = 5; h_index = 5), respectively. With the calibre of the leading journal sources and their h_indexes, it is clear that these journal sources has what it takes to publish research findings in the field of vertical farming and its derivative fields.

The information shown in Table (5) for the top leading institutions that have produced more research findings in vertical farming as related to food security indicated that Singapore led the chart with institutions doing research in

this niche area even though the table showed that the United States of America had more research organizations featuring in this ranking and had the highest pooled number of publications compared to other nations. Several other earlier bibliometric studies have also observed similar results showing that institutions based in the USA makes relevant contributions to academic knowledge in several areas of research ranging from computer science, medicine, , microbiology, geography, technology and agriculture, among others (Ekundayo and Okoh, 2018; 2020; Orimoloye and Ololade, 2021; Okaiyeto and Oguntibeju, 2021; Idamokoro, 2023).

Conversely, with respect to the number of citation of articles and its relevance on the global stage, the common world indices to rate the impact of an article is through their citation numbers that they attract over a period and the number of downloads that they accumulate through the years. The citation numbers of an article also depend on the academic impact of the citing paper compared to the number of citations. A paper cited by a high influential/impact factor attracts the attention of other research and scientists in the field, while the citation number of that article attracts to itself indicates the level of influence it has on the global society. According to Tahim *et al.* (2016), the relevance of an article on the global stage is often based on how regularly it gained citation from scholarly peers. Howbeit, the impact of a well-written and impactful paper increases in its significance as citation increases.

The top 20 leading publications analysed based on total citations per year (TC/Year) and total citations (TCs) on vertical farming as relates to food security research from 1992 – 2023 are given in Table (6). These papers were written by researchers including; Aanen, D.K (TC/Year: N = 14.74; TC: N = 339), Klerkx, L (TC/Year: N = 54.40; TC: N = 272), Shamshiri, R.R (TC/ Year: N = 36.57; TC: N = 256) and Bantis, F (TC/Year: N = 34.29; TC: N = 240), among others. The findings from these top cited documents covers different research topics on the importance of vertical farming and possible threats that may hinder its implementation in some parts of the world especially with regards to financial resources and expertise in the field. Meanwhile, there is a possibility that some articles may be listed as one of the highly cited papers in a particular research domain, yet, they may attract negative criticisms because of the presentation, result and content of the study (Cheek *et al.*, 2006).

From one of the top ranked cited research articles (Table 6), the authors explained how vertical farming is one of the innovative farming systems that is now a game-changer in improving the future of agriculture and food systems (Klerkx and Rose, 2020). In this article, vertical farming is described as one of the potential game-changing technologies that is capable of shifting the way food is being produced for the purpose of meeting the

needs of the growing population. This system of farming has a transformative potential to boost the economic and social impacts on food and nutrition security and on the ways in which agricultural production systems are designed and operated for improved food produced (Klerkx and Rose, 2020).

Furthermore, another top ranked cited article reported the advancement in controlled environment agriculture and its derivatives including vertical farming as a positive emerging sector that have developed as a response-system of farming capable of tackling the surging population, environmental degradation, as well as urbanization that are currently threatening food security in most nations (Ramin Shamshiri *et al.*, 2018). The article further explain how vertical farming as a concept is a promising direction along the right path for the agricultural sector for the revolutionary resource-based economic movement (Ramin Shamshiri *et al.*, 2018).

As seen in Table (7), the present result shows the outline of the leading researchers in the field of vertical farming as related to food security studies. The leading authors including Zhang Y, Martin M, Avgoustaki DD, Pennisi G and Wang G (N = 8; N = 6; N = 5; N = 6; N = 9) are ranked in their order of inputs in the field of study, respectively. Looking at these leading authors academic profile, they had h-index of 7, 6, 5, 5 and 4 (with citation number; 319, 173, 179, 211 and 55), accordingly. H-index is commonly used to analysed how relevant articles perform on the world stage (Huang *et al.*, 2019). Again, h- index is used to assess how productive and active scientists within a given research domain is based on the number of articles they have produced and the citations of their published articles (Hirsch, 2005). The calculation of h-index is done through the h algorithm (of articles) on the minimum number of h times an article was cited by other authors within the field (Hirsch, 2005). It is essential to note that the h-index criteria for evaluation of author's

performance on the global stage is a vital tool in bibliometric analysis because of its accuracy to reproduces the number of impact a given researcher have had toward the knowledge pool of a given field over the years (Guilak and Jacobs, 2011).

In bibliometric studies, collaboration among researchers, nations and institutions is very important because it is a benchmark that is used to know how to advance scholarly findings in any research field; more so, it will help to increase partnership among scholars or nations with common interest in a related research niche globally. Networking further gives room for inter-disciplinary exchange of useful ideas from different cadres among intellectuals with common interest to achieve greater research goals (Wu *et al.*, 2019). Networking in research also boost the quality of research findings. Other significant benefits of research networking includes ground-breaking innovative findings, publishing findings in impactful journals, exchange of intellectual human potentials, funds accessibility and facility sharing among others (Bozeman *et al.*, 2013). The result of nation's networking is presented in Fig. (3) with different colours depicting its different classifications in line with their collaboration with other nations. The node in the diagram represents a nation. The strokes connecting the different nations together have different magnitudes of thickness. These links are indicative of the strength in ties among these nations. The USA had the most global networking with other nations due to the thickness of its lines and the size of its node. The central placing of USA is also indicative of its rankings as the leading nation in networking. This result is in line with reports from other studies who reported that USA as a nation had significant impact in terms of networking with most nations of the world (Zyoud, *et al.*, 2017; Aparicio-Martinez *et al.*, 2019; Baier-Fuentes *et al.*, 2020; Idamokoro, 2023).

Table 7: 25 top leading authors on vertical farming as relates to food security research

S/N	Authors	h_index	g_index	m_index	TC	NP	PY_start
1	Zhang Y	7	8	0.636	319	8	2014
2	Martin M	6	6	1	173	6	2019
3	Avgoustaki DD	5	5	0.833	179	5	2019
4	Pennisi G	5	6	1	211	6	2020
5	Wang Y	5	7	0.833	55	9	2019
6	Ares G	4	7	1	80	7	2021
7	Gupta D	4	4	1	42	4	2021
8	Jaeger SR	4	8	1	84	8	2021
9	Maertens M	4	4	0.333	237	4	2013
10	Orsini F	4	5	0.8	165	5	2020
11	Xydis G	4	5	0.8	160	5	2020
12	Bantis F	3	3	0.429	281	3	2018
13	Chen Y	3	4	0.273	54	4	2014
14	Chheang SL	3	5	1	35	5	2022
15	Dsouza A	3	3	1	26	3	2022
16	Dutta M	3	3	1.5	24	3	2023
17	Gianquinto G	3	3	0.6	90	3	2020

18	Kalantari F	3	3	0.429	269	3	2018
19	Klerkx L	3	3	0.429	683	3	2018
20	Liu X	3	3	0.75	41	3	2021
21	Paucek I	3	3	0.6	87	3	2020
22	Quaini S	3	3	0.6	87	3	2020
23	Rieradevall J	3	3	0.375	191	3	2017
24	Weidner T	3	3	0.75	96	3	2021
25	Zhou Z	3	4	1	18	4	2022

NB = PY_start: Publication year start; TC: Total citation; NP: Number of publication

The keyword co-occurrence analysis was also developed in the present study. This evaluation serves to explain the different areas of research that is associated to the research topic of the present study. Figure (4) presents a visualization of the main author keywords in the research domain using a threshold of co-occurrences and the fifty most-frequent coincidences. This approach gives a cue of the most recent concepts as related to the research subject matter. There were several keywords used in this research topic. The chief keyword used in this research topic is “vertical farming.” Interesting to note is the fact that other related concepts that appeared to be derivatives to the concept of vertical farming are those of sustainable agriculture, hydroponics, farming, greenhouse, food security, urban agriculture, sustainability, controlled environment agriculture and climate change, among several other concepts. It is also of interest to state that several other concepts have been linked to vertical farming quite often in recent years. This can be seen from other colours in Fig. (4) (such as microgreen, rice, plant factories, assessment, yield, Africa, precision farming among others). All these keywords indicate the different conceptual frameworks utilized to explain the intersection of the present topic (vertical farming as relates to food security). In line with the present result, similar keyword co-occurrence analysis of networking was also observed in a related study (Nájera *et al.*, 2023).

The result in Fig. (5) further presented the authors’ keywords using the thematic evaluation map to explain the significance of the author’s keywords that have been utilized over the study span (1992-2023). This kind of bibliometric analysis has earlier been used for present the progression of keywords (Cobo *et al.*, 2011). This study showed the four key themes formed on the authors’ keywords network clustering namely:

a. The motor theme (the top-right quadrant) which demonstrates high centrality and the concentration keywords of vertical farming as it relates to food security. From this thematic map, there were several authors keywords such as urban agriculture, sustainability, vertical farming, energy, efficiency, controlled environment agriculture, smart farming, precision farming, indoor farming, soil, assessment, yield and lettuce, innovation. This aspect of vertical farming deals with areas of farming that combines

both engineering and natural science disciplines to improve food production in an environmentally friendly manner (Maurya *et al.*, 2023). In addition, this aspect of vertical farming is a modern tool that could be used to feed the fast growing global human population (Barui *et al.*, 2022). This is because vertical farming is a farming system that is appropriate in areas where land and water are limited (Van Gerrewey *et al.*, 2022; Vaishnavi *et al.*, 2024)

- b. The niche theme (the top-left quadrant), it has some themes such as family farming, vertical integration, biomass and energy demand. This theme is still evolving and not properly develop, but it has little significant links with the other keywords on the subject topic. This aspect of vertical farming possibly covers the area of farming that helps to boost food production and market from local food produce by individual families and small scale farmers (Van Gerrewey *et al.*, 2022)
- c. The basic theme (bottom-right quadrant), it has keywords such as contract farming, vertical coordination, Vietnam, rice, integration and governance. This aspect of vertical farming likely covers areas that are able to create new employment opportunities for a variety of people including regular crop farmers, maintenance workers, technologists, project managers and marketing staff and support local agro-industries (Benke and Tomkins, 2017; Al-Kodmany, 2018)
- d. The emerging themes (the bottom-left quadrant) had keywords such as nitrogen, management, aquaculture, soil moisture and irrigation. This aspect of vertical farming is the area that requires more research and diversity such as developing cutting-edge water recycling, multi-nutrient distribution and management techniques including closed-loop hydroponic systems that is capable of reducing nutrient and water inputs for more efficient food production

In another bibliometric study with a different subject matter, Altarturi *et al.* (2023) made use of the thematic evolution map to describe the emergence of innovative technology in advertising the importance of e-commerce on food production as an emerging and educative field in agricultural science. This type of analysis gives the

centrality (i.e., the degree of relevance) of the different keywords to the main theme of the subject matter.

In like manner, the trending topics (from 1992-2023) for the present subject matter is given in Fig. (7). The line depicts timeframe of topics over the studied years, while the diameter of the circle is proportional to article numbers of the trending topic. The darker the circle, the higher the number of citations that topic trend gets. For words to feature in this graph (Fig. 7), the topic frequency must be more than 25 times. The trend topics started in 2012 with only one keyword which is the “precision farming”. The trend of topics then evolves to represent related studies in vertical farming as relates to food security over the years. Top trending topics of author keywords on vertical farming and food security research with high frequency terminologies over the years include precision farming, organic, rice, vertical coordination, Africa, innovation, contract farming, horticulture, greenhouse, urban farming, sustainability, urban agriculture, hydroponics, vertical farming, urban among others. These earlier-mentioned author keyword’s top the ranks with high term frequencies (between 25-100) from 2012-2023.

In recent years, there has been a significant interest in vertical farming and this system of farming is increasingly becoming a necessity for the agricultural sector, due to increase in global population, limited agricultural land as well as reduction of natural resources (van Delden *et al.*, 2021). Vertical farming has also demonstrated over the years that it may be able to increase yields of food crops (Johkan *et al.*, 2012; Urrestarazu *et al.*, 2016) and secure an all year-round food production and sustainability for any nation globally (Nájera *et al.*, 2023). The utilization of vertical farms could significantly enhance food sustainability and security differs environment and especially in urban areas. Conversely, vertical farming has shown to have several advantages over traditional farming system in terms of sustainability on the social, economic, as well as environmental perspectives. According to Maurya *et al.* (2023), vertical farming can support crops such as vegetables, maize and potatoes to be grown annually on an incredibly limited land space with minimal labour which can be of immense benefits to financially limited people and those with limited access to land and water.

The implication of vertical farming as relates to food security for developing nations with limited research in this discipline presents an innovative answer to strengthen food security by plummeting dependence on the conventional system of using arable land and old-style of growing food crops at certain seasons. However, with supportive and effective policies as well as investment in workable technologies for local conditions/environments, vertical farming could play a transformative part in building sustainable, accessible food sources in both

urban and rural environments of developing nations alike. In summary, vertical farming will enhance the efficient use of land, increase food crop production all year round, create possible employment opportunities for people and provision of more nutritional foods (cabbages, veggies, fruits etc.) in developing nations that may adopt this innovative farming system.

Considering some future research directions on vertical farming as relates to food security, several other aspects of research such as:

- Developing low-cost infrastructural systems and energy-efficient solutions that is practicable for doing vertical farming so as to reduce operational expenditures and increase production and profits for individual farmers, government institutions and private industries
- Another area of focus is by developing cutting-edge water recycling, multi-nutrient distribution and management techniques including closed-loop hydroponic systems that is capable of reducing nutrient and water inputs for effective and practical vertical farming approach
- The use of Artificial Intelligence (AI) and robotics to monitor as well as manage environmental situations and crop health is another research focus and direction in vertical farming that can enhance productivity and reduce labour costs making this kind of farming system a more practicable choice for food availability and security in high-populated urban areas
- Furthermore, an aspect of research area on how vertical farming can be adopted to protect food crops from harsh weather conditions by researching on integrated disease and pest management in controlled environments will help to prevent disease outbreaks and extreme harsh-weather conditions which will ensure all-year round food supplies, especially in regions that are easily and highly affected by uncertain climate change

Study Possible Limitations

The retrieved data used for analysis for the present study was exclusively from the WoS data archive, thus may not have fully captured all publications on vertical farming research. Although, as previously asserted in the methodology section, WoS is an original knowledge base and it is a widely used data source among researchers/scientists. It is also greatly suggested that other possible alternative data bases such as Google Scholar, Scopus or PubMed should be used in future research of the study of this kind for a comprehensive analysis on this subject matter. Despite the aforementioned limitation, the present study still provides insights on research trends and directions in the field of vertical farming as it relates to food security.

Conclusion

Research studies on vertical farming as relates to food security research is presently gaining attention as observed from the annual scientific production from 1992-2023. This trend is encouraging as a result of the importance of the subject matter especially as it relates to helping in tackling food shortage in the face of the growing global population and assisting to meeting the high need of food demands in the world. Economically stable and scientifically developed countries showed higher involvements in research on the subject matter when compared to developing nations. It was observed from the trending topic that keywords such as “urban”, “hydroponics”, “greenhouse”, “innovation”, “precision farming” among others were vital to scientists carrying out research in vertical farming, thus signifying the direction for future research. Likewise, since it was observed that some economically stable and scientifically advance countries are actively involved in vertical farming projects, it is imperative that scientists and government institutions from less productive countries should make deliberate effort to network with them to increase food production in their countries. The aspect of the economic evaluation of the impact of vertical farming as relates to food security on post-industrial urban settlements needs further investigation.

Acknowledgment

The author will like to sincerely appreciate and commend the research office of the Walter Sisulu University, South Africa for their all round support in making this manuscript a reality.

Funding Information

The authors have not received any financial support or funding to report.

Ethics

No ethical issues are applicable for the present study.

Reference

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