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Review Article

A Bibliometric Study of Machine Learning in Precision Agriculture

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Abstract *- Machine Learning (ML) has revolutionized precision agriculture, offering solutions to contemporary challenges in farming practices. This paper presents a comprehensive bibliometric analysis of ML applications in precision agriculture, leveraging the Scopus database and advanced visualization tools. Through quantitative and qualitative techniques, the study interprets key trends, influential publications, and emerging research areas within this interdisciplinary field. The analysis encompasses publication and citation trends, contributing countries, influential sources, authors, collaboration networks, thematic evolution, and trending topics. The findings highlight the growing significance of ML techniques in optimizing agricultural processes, enhancing sustainability, and fostering innovation. By providing a detailed understanding of the research landscape, this study enables stakeholders to identify emerging trends, foster collaborations, and advance the application of ML in agricultural practices.*

Keywords *- Precision agriculture, Machine learning, Bibliometric analysis, Agricultural innovation, Collaborative networks, Thematic evolution.*

1. Introduction

Precision agriculture, a transformative solution for contemporary agricultural challenges, integrates new technologies and data-driven methodologies [1]. At its core, the incorporation of ML methods enables the analysis of extensive datasets to optimize agricultural processes, boost productivity, and minimize resource consumption [2]. As the agricultural sector grapples with increasing global demands and environmental concerns, understanding the current state of ML research in precision agriculture becomes crucial. This bibliometric study, a significant endeavor, comprehensively examines the academic literature on ML in precision agriculture, focusing on key trends, influential publications, and emerging research areas. Through rigorous bibliometric methods, the authors aim to dissect the evolution of this interdisciplinary field and elucidate the impact of ML techniques on agricultural production, sustainability, and innovation.

While previous studies have provided valuable insights through bibliometric analysis within ML and agriculture, our research aims to fill a gap, offering a more recent understanding of ML applications in agriculture. For instance, Coulibaly et al. conducted a bibliometric analysis on deep learning research in agriculture, utilizing the WoS database to identify 1406 English-language documents up to 2022. Their study mapped the scientific structure of deep learning research, shedding light on relationships between authors and papers to provide insights into underlying issues [3]. Similarly, Bhagat et al. conducted a comprehensive bibliometric analysis focusing on sustainable agriculture and AI, refining their search to 465 articles from 2000 to 2021. Their analysis included citation network analysis, geographic network analysis, and visualization techniques to chart the development of literature in the field [4]. Additionally, Zhang et al. conducted a bibliometric analysis from 2006 to 2020, utilizing bibliographic coupling to identify research similarities across authors, organizations, and journals. Our study, however, brings a fresh perspective, highlighting top contributors to big data analytics and ML research and offering intriguing insights for potential stakeholders [5].

While previous studies have made significant contributions, our research aims to bridge a crucial gap by offering a more comprehensive analysis. Leveraging the Scopus database and employing methodologies such as VOSViewer, R package Biblioshiny, and Microsoft Excel, our study provides insights into publication and citation trends, contributing countries, influential sources, authors, collaboration networks, thematic evolution, and trended topics within the intersection of ML and agriculture. By utilizing these tools and techniques, the authors aim to offer a detailed and up-to-date understanding of the current state of research in this field, filling a gap left by previous studies that focused on specific methodologies or limited timeframes. This broader perspective will enable stakeholders to identify emerging trends, potential collaborations, and areas for further exploration, ultimately advancing the application of ML in agricultural practices.

2. Literature Review

ML has become an increasingly popular tool in agriculture due to its ability to analyze large amounts of data and make predictions based on that data [6], [7]. In recent years, there has been a growing interest in applying ML in agriculture, with researchers exploring its potential to improve crop yields, reduce waste, and increase efficiency [8]. This literature review aims to provide an overview of the current state of research on using ML in agriculture, focusing on bibliometric analysis.

The adoption of ML in agriculture has seen remarkable growth over the past decade [9]. The agricultural industry has undergone a profound transformation driven by technological advancements, particularly ML [10]. As the global population rises and climate change poses new challenges to traditional farming practices, there is an increasing demand for innovative solutions to optimize agricultural processes and ensure food security [11]. With their ability to analyze vast amounts of data and extract valuable insights, ML algorithms have emerged as powerful tools for addressing these complex issues [12].

A study by Condran et al. highlights a substantial growth in research interest at the intersection of ML and agriculture over the past two decades. According to the study, the number of publications related to ML in agriculture has dramatically increased, with a 100-fold rise compared to earlier times [13]. Another study by Haval and F. Rahman indicates that ML in agriculture is experiencing significant growth, with a focus on smart and sustainable practices. Integrating IoT and AI technologies in agriculture is becoming more prevalent, leading to the development of innovative systems like the Remote Sensing Aided Framework for Smart Sustainable Agriculture (RSAF-SSA). These technologies are revolutionizing traditional farming practices by optimizing irrigation methods, increasing agricultural productivity, and promoting sustainable agricultural growth [14].

Another research by Araújo et al. mentioned that the growth of ML in agriculture has been significant, with advancements in technologies such as the Internet of Things, sensors, robotics, artificial intelligence, big data, and cloud computing propelling the sector toward the transformative agriculture 4.0 paradigm. Integrating ML with advanced technologies enhances sustainability, productivity, and efficiency in agriculture. Future research directions in ML integration in agriculture focus on harnessing diverse data sources, creating affordable solutions for regions with limited resources, and assessing the socio-economic impacts of widespread ML adoption in agriculture. These trends highlight the significant impact of ML on improving agricultural practices and driving innovation in the sector [15].

This growth is attributed to advancements in sensor technologies, big data availability, and the development of sophisticated ML algorithms. ML in agriculture represents a pivotal moment in the evolution of farming practices worldwide. With its capacity to harness data-driven insights and optimize resource allocation, ML offers unprecedented opportunities to address modern agriculture's complex challenges [16]. By enabling precision farming, proactive pest and disease management, and sustainable land use practices, these technological advancements are enhancing productivity and profitability for farmers and contributing to global food security and environmental sustainability [17]. As the authors continue to explore and implement innovative applications of ML in agriculture, it is evident that this synergy between technology and tradition will play a crucial role in shaping the future of food production and ensuring a resilient and prosperous agricultural sector for generations to come [18].

3. Methods

Bibliometric studies are crucial in evaluating and understanding research publications' significance, impact, and trends in specific fields like ML in precision agriculture. Using quantitative and qualitative techniques to analyze journals, articles, and their associated citations over time, these studies provide a comprehensive understanding of the current state of research [19]. Bibliometric analysis aids researchers in identifying research topics, refining their focus, and predicting future trends [20]. This statistical analysis enables the estimation of publication numbers and trends within specific fields, facilitating a quantitative literature review by establishing connections between relevant keywords [21]. The standardized method of bibliometric analysis evaluates written communication among authors [22], quantifies research trends and characteristics [23], and examines parameters such as research titles, keywords, affiliations, authors, and publication details [24]. It also extends to network analysis, including countries, co-authorship links, co-citation links, and bibliographic coupling links, which can be used to visualize thematic clusters or trends through citation mapping [25]. This study uses Scopus databases due to their extensive coverage and comprehensive search capabilities [26]. They are suitable for covering diverse research areas and providing accurate results [27], especially within broad research domains like ML in precision agriculture.

Furthermore, thematic evolution, an emerging research methodology, is currently the most widely accepted approach for measuring a particular research area's growth, evolution, and flows over time across multiple disciplines. It assists scholars in gaining a more methodical comprehension of the growth of a particular research area. In this study, the authors utilized Biblioshiny, a shiny application for the Bibliometrix R program, to conduct theme evaluation mapping [28], [29]. This tool is instrumental in analyzing the evaluation theme, as it shows the proportion of all authors' keywords by plotting the range of the subject direction on the coordinate axis. The study selected the online Scopus database from 2012 to 2023 for ML in precision agriculture research. Scopus offers a broader range of articles than other databases such as Web of Science (WoS), Google Scholar (GS), and PubMed. It has a 20% greater coverage than WoS in citation analysis; Google Scholar yields inconsistent results, while PubMed is a frequently used resource in scientific research [30].

3.1. Search Strategy

This study utilizes the comprehensive and carefully organized Scopus database to create a strong foundation for analysis. Targeted search terms were used to find publications relevant to precision agriculture and its ML or deep learning components. The queries combined important terms like "ML," "deep learning," "agriculture," and "precision agriculture" in names to match the study's focus. The search was narrowed to include articles, conference papers, book chapters, reviews, and editorials published in english between 2012 and 2024. The date was selected to encompass the most recent progress in the subject, offering a thorough summary of advancements in recent years. The search aims to gather various scholarly contributions using several document forms, allowing for a detailed investigation of the subject matter. Including only papers in English made the study's analysis more accessible and comprehensible. After all the work, a significant set of 530 papers was gathered, free of duplicates, discrepancies, or missing information. The documents are fundamental for a detailed bibliometric analysis of ML in precision agriculture, providing significant insights into the research landscape and trends.

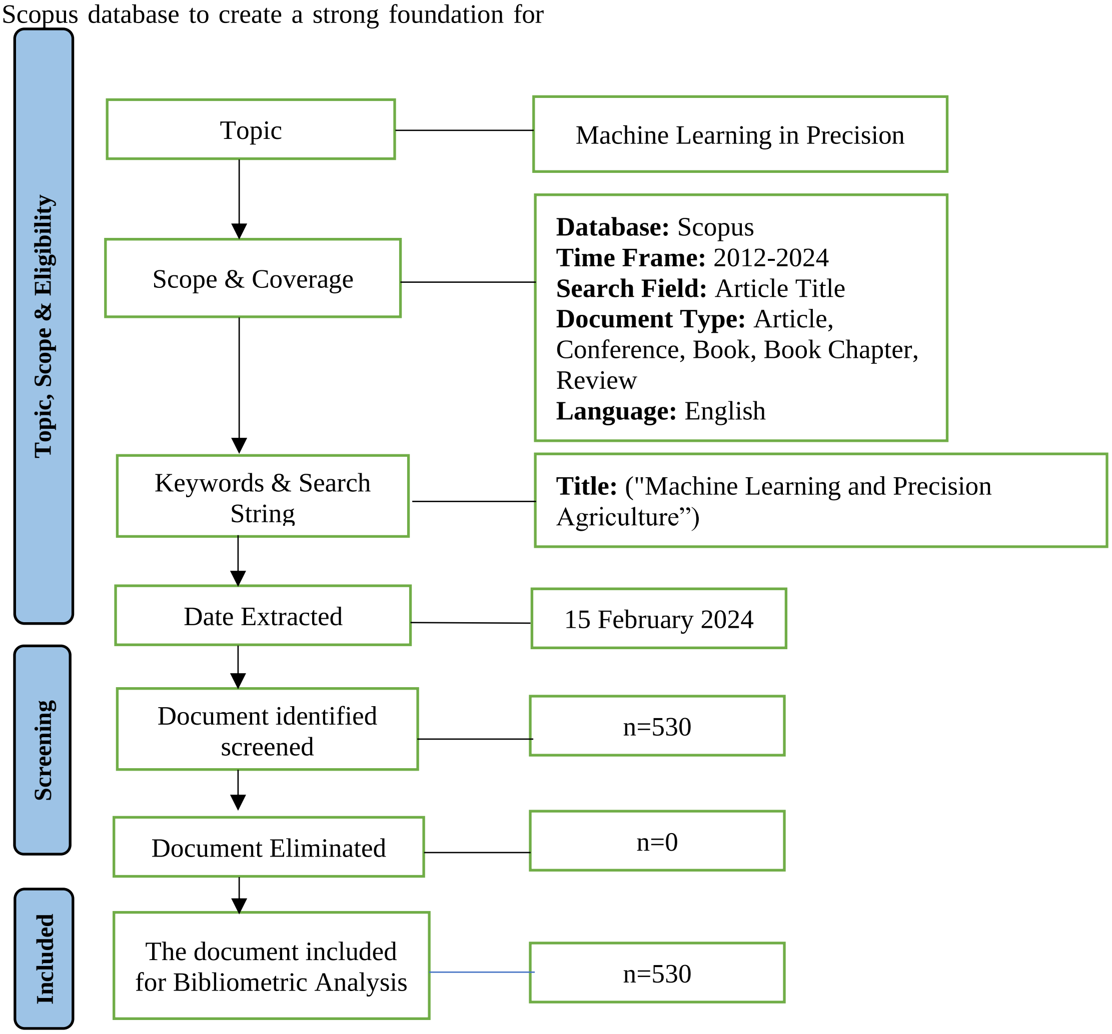

Fig. 1 Search strategy

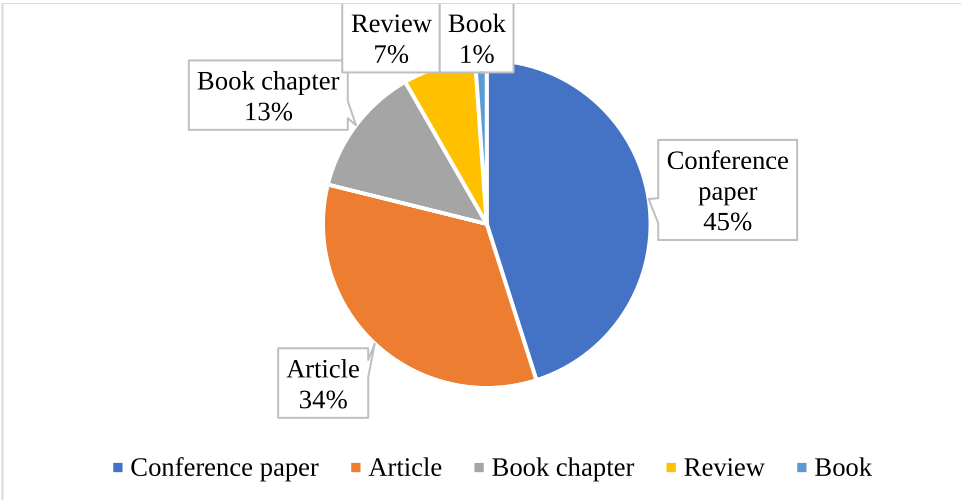

Fig. 2 Types of documents

4. Results and Discussion

4.1. Document Types

Figure 2 displays a detailed analysis of the various categories of documents found in the research corpus. A comprehensive analysis was conducted on 530 documents, classified into five primary categories: conference papers, articles, book chapters, reviews, and books. Conference papers were the most common of all the documents, making up 239. This shows how vital academic conferences are for sharing and spreading research discoveries in ML in precision agriculture. After conference papers, articles were the second most prevalent document type, comprising 179 publications. This emphasizes the significance of peer-reviewed journal articles in exchanging intellectual information and disseminating knowledge in this field. In addition, the research landscape was enriched by 68 book chapters, 38 reviews, and 6 books. Although fewer books and book chapters were available, they will likely provide more thorough and detailed explanations of certain areas of ML in precision agriculture. In summary, this thorough analysis offers valuable insights into the wide range of academic outputs that contribute to the progress of knowledge and innovation in precision agriculture, namely, using ML techniques.

4.2. Publication and Citation Trends

Figure 3 displays a bibliometric study of research papers on ML in precision agriculture from 2012 to 2024. The data indicates a conspicuous pattern in expanding research output and citations within this domain. The inaugural paper was released in 2014 and garnered 62 citations, signifying an early interest in the subject matter. Following that, there was a period until 2016 when another document was released, receiving 52 citations. Nevertheless, the upsurge in research endeavors began in 2017, as evidenced by the consistent annual growth in publications and citations. Significantly, there was a notable increase in articles and citations in 2018. Specifically, 13 documents resulted in 4928 citations, indicating major progress and acknowledgment of ML applications in precision agriculture. The increasing trend persisted in the following years, reaching its highest point in 2021 with 93 documents and 2228 citations. As of the initial two months of 2024, the bibliometric analysis of research documents about ML in precision agriculture continues to exhibit a significant rising trajectory. Since the commencement of the study in 2014, there has been a consistent rise in the number of published documents and their related citations. In 2024, the upward trend in growth has continued, as evidenced by the registration of 20 papers during the initial two months. This suggests a positive and encouraging beginning to the year. Although there have been only 4 citations so far, it is crucial to acknowledge that this data only covers a portion of the year. As more research becomes accessible and gains recognition among the academic community, the total number of citations is anticipated to rise. The continuous increase in research output demonstrates ML techniques' persistent interest and importance in precision agriculture. This highlights its crucial role in enhancing agricultural practices and promoting sustainability efforts.

4.3. Contributing Countries

The diagram below presents an overview of the research endeavors in ML for precision agriculture in the top 10 countries that have made the most significant contributions. It uncovers many significant findings. India has established itself as a frontrunner in the field, with the most links, eight (8), and the most overall citations, 2782. This signifies India's substantial contributions and extensive recognition within the research community. The United States has fewer links of five (5) but has the highest link weight strength, 33. This implies that the relationships between the United States and other nations have a greater influence, possibly because of variables such as significant financial support for research or prestigious research establishments. China closely trails

India with six (6) connections and a weight link strength of 19, consolidating its status as another significant participant. Although Australia, Canada, Italy, Pakistan, Saudi Arabia, Spain, and the United Kingdom have a relatively lesser representation regarding connections and citations, they nonetheless significantly contribute to the subject.

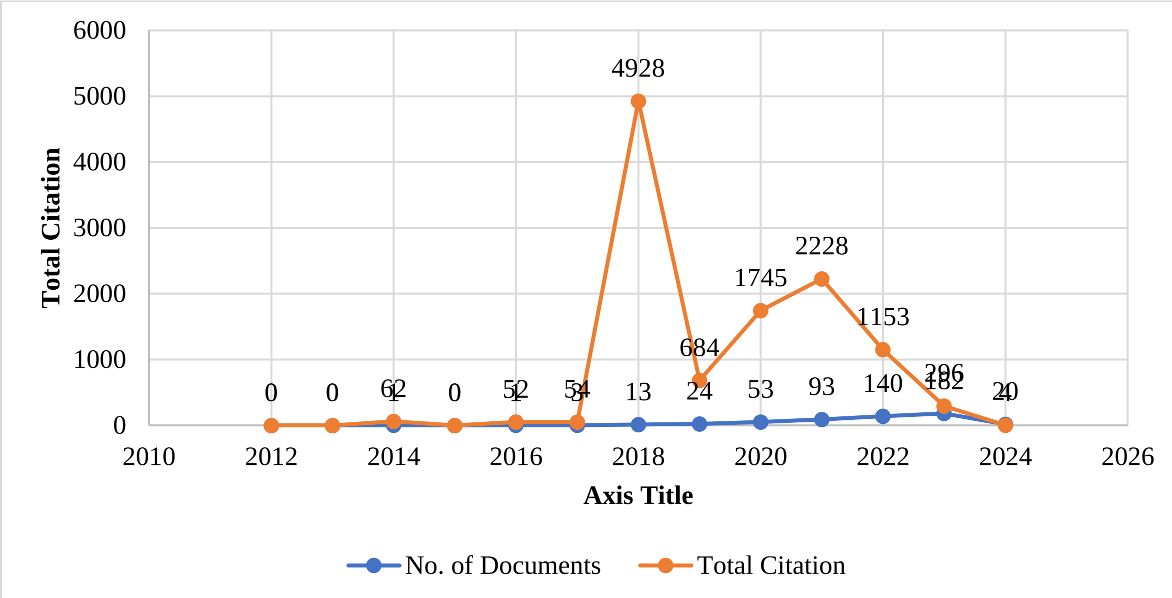

Fig. 3 Publication and citation trends

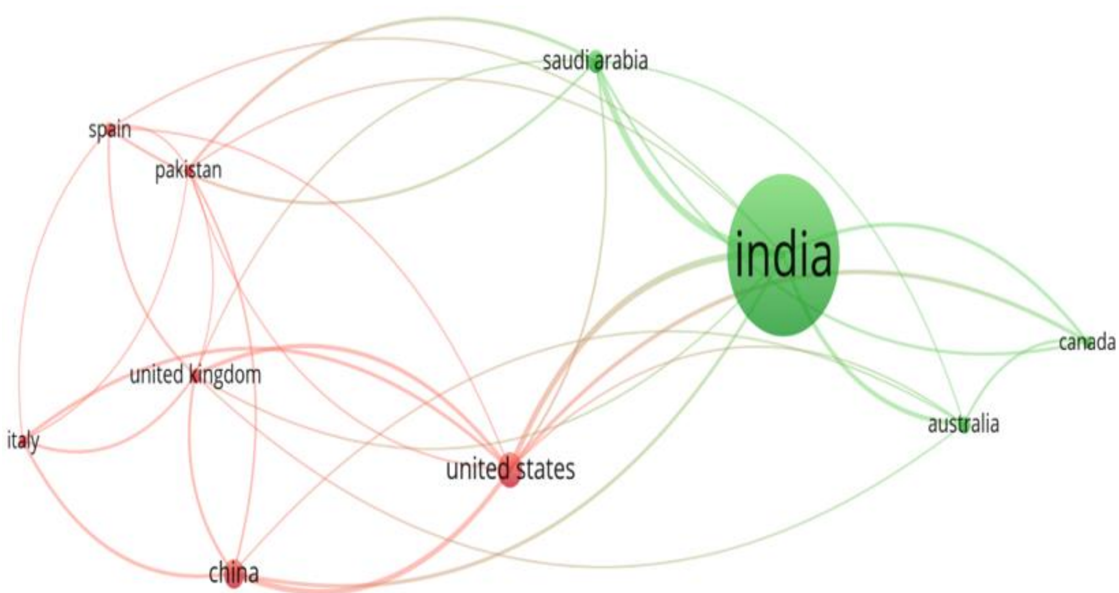

Fig. 4 Contributing countries

4.4. Influential Sources

Table 1 presents information on the primary sources that have the greatest impact on scholarly papers in precision agriculture that utilize ML techniques. This information is determined using several bibliometric indicators. The sources are presented with their respective h-index, g-index, m-index, Total Citations (TC), Number of Publications (NP), and the initial year of publication (PY_start). "Computers and Electronics in Agriculture" is a very influential source with an h-index of 7 and a total citation count of 3135. This signifies the notable impact and extensive dissemination of its writings. Similarly, the publication "Sensors (Switzerland)" has been significantly influenced by its h-index of 5 and a substantial total citation count of 1889. This is noteworthy, considering that it began publishing very recently in 2018.

The journals "Advances in Intelligent Systems and Computing" and "Applied Sciences (Switzerland)" have a moderate level of influence, as indicated by their h-indices of 5 and 107 and total citations of 95, respectively. These sources began their publications in 2018 and 2020, suggesting a relatively new yet significant presence in the field. Furthermore, "IEEE Access" is notable for its impressive g-index of 9, indicating many works that have received many citations. Despite having a somewhat lower overall number of citations compared to other sources, its influence on the academic discussion in precision agriculture is significant. Additional scholarly sources, including "Computers and Electrical Engineering," "Materials Today: Proceedings," and "Agronomy," make contributions to the academic field with differing levels of impact, as seen by their h-indices and total citation counts. This offers significant insights into the main sources fueling research and scholarly discussions in precision agriculture that utilize ML techniques. It highlights the wide variety of publications shaping the progress and innovation in this sector.

4.5. Most Influential Authors

Table 2 result shows that Kumar S is a highly influential author on the subject, with an h-index of 5 and a TC of 190, demonstrating significant effect and acknowledgment in the academic community. Jin X-B is a notable contributor with an h-index of 3 and a TC of 417, indicating extensive engagement with their research. Authors Kumar A and Phasinam K have shown significant involvement and influence in expanding ML applications in precision agriculture, with h-indices of 3 and TCs of 367 and 44, respectively.

Authors like Garg S, Kassanuk T, and Singh P, each with unique contributions and impact metrics, enhance the community of authors dedicated to advancing ML in precision agriculture. The outcome emphasized the authors' varied and significant contributions to the study field, showcasing their influence in molding the development of ML applications in precision agriculture.

Table 1. Influential sources

Sources	h_index	g_index	m_index	TC	P	PY_start
COMPUTERS AND ELECTRONICS IN AGRICULTURE	7	10	1	3135	10	2018
ADVANCES IN INTELLIGENT SYSTEMS AND COMPUTING	5	7	0.714	107	7	2018
APPLIED SCIENCES (SWITZERLAND)	5	5	1	95	5	2020
SENSORS (SWITZERLAND)	5	5	0.714	1889	5	2018
COMPUTERS AND ELECTRICAL ENGINEERING	4	6	1.333	70	6	2022
IEEE ACCESS	4	9	1	360	9	2021
MATERIALS TODAY: PROCEEDINGS	4	6	1	85	6	2021
AGRONOMY	3	6	0.5	103	6	2019
ECS TRANSACTIONS	3	3	1	17	3	2022
LECTURE NOTES IN NETWORKS AND SYSTEMS	3	6	0.75	45	20	2021

Table 2. Influential authors

Authors	h_index	g_index	m_index	TC	NP	PY_start
KUMAR S	5	7	0.833	190	7	2019
GARG S	3	4	0.75	40	4	2021
GENOUD D	3	3	0.429	60	3	2018
JIN X-B	3	3	0.5	417	3	2019
KASSANUK T	3	5	0.75	31	5	2021
KONG J-L	3	3	0.5	417	3	2019
KUMAR A	3	6	0.6	367	6	2020
PHASINAM K	3	6	0.75	44	6	2021
SINGH P	3	4	0.6	19	5	2020
SU T-L	3	3	0.5	417	3	2019

4.6. Collaboration Network

Figure 5 shows collaborative relationships between ML and precision agriculture authors. Authors are categorized into clusters according to their collaborative connections, where each cluster signifies a unique group of authors who work closely together. Cluster 1 (Red) has significant authors such as Kumar A, Sharma A, Singh P, Singh A, Singh S, Singh G, Jain A, and Alkhayyat A. The authors display distinct betweenness and closeness centrality, highlighting their significance in linking various sections of the collaboration network and their nearness to other authors. Singh S exhibits a high PageRank, indicating a substantial impact in this cluster.

Cluster 2 (Blue), on the other hand, includes authors Garg S, Kumar H, Kumar R, Singh M, and Ahmed MA. Although these authors do not show considerable betweenness or closeness centrality individually, their combined participation enhances the overall cohesion of the network. Singh M has a high PageRank, suggesting a significant impact in this cluster. Authors Phasinam K, Kassanuk T, and Ghosh T are part of Cluster 3 (Green), known for their significant closeness centrality and PageRank scores. These authors play a key role in the network and substantially impact their collaborative group. Cluster 4 (Dark Blue), led by authors Sharma R, Kukreja V, and Yadav P, creates a unique collaborative group within the larger ML network and precision agricultural research. Although these authors have lesser betweenness and closeness centrality than authors in other clusters, they exhibit a cohesive collaboration centered upon specific research themes or approaches. Sharma R, possessing a moderate PageRank and betweenness centrality, is probably a key figure in this cluster, aiding in connecting and exchanging knowledge among its members.

Clusters 5 to 13 comprise authors with little or no collaboration within the network, as shown by their lack of betweenness and closeness centrality. Nevertheless, they remain significant in their specific clusters, enriching the variety and scope of ML and precision agriculture research. Therefore, the result thoroughly summarizes the collaborative connections between authors in the field, emphasizing significant contributions and their roles in influencing research and information sharing in ML and precision agriculture.

4.7. Most Frequent Words

The Word Cloud created from the data displays the frequency of ML terms about agriculture and related areas. The magnitude of each phrase in Word Cloud reflects its frequency in the dataset, facilitating the rapid recognition of significant themes and concepts.

"Deep learning" is the most prominent term displayed in Word Cloud. This shows a strong focus on deep learning methods in research, underscoring the significance of advanced neural network structures in tackling intricate agricultural issues. The terms "crops," "ML," and "precision agriculture" are highly included in the Word Cloud. The phrases highlight fundamental concepts in the subject, focusing on using ML methods to better agricultural practices, increase crop yield, and improve precision in farming operations.

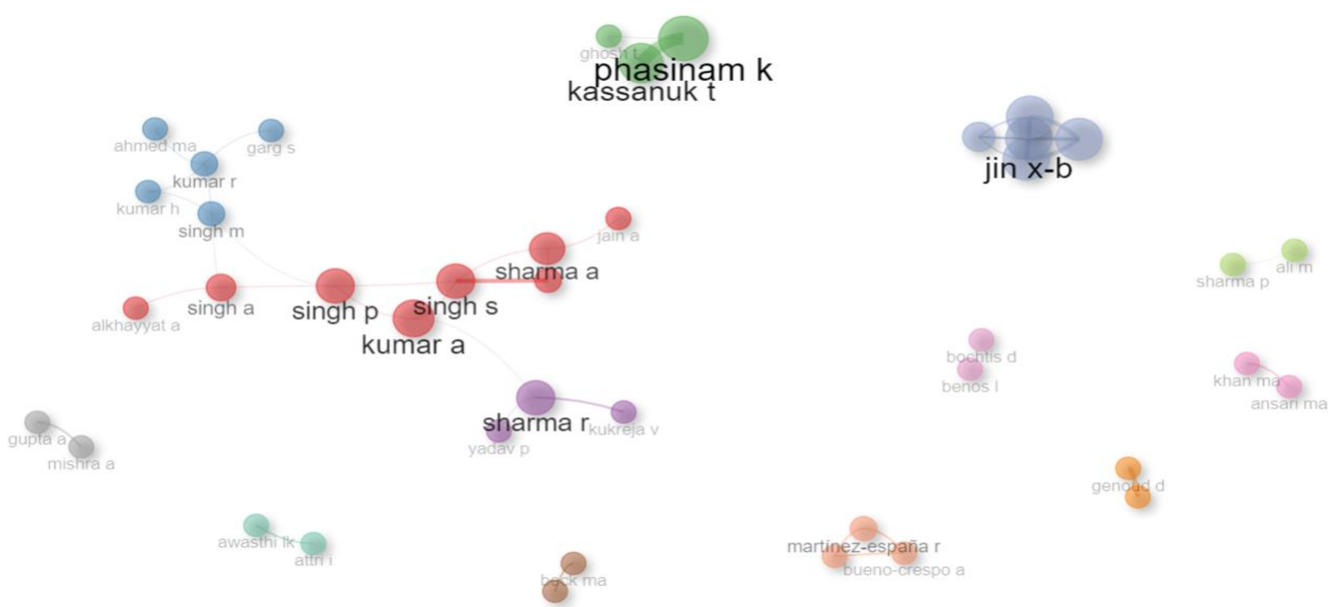

Fig. 5 Collaboration network

Fig. 6 Word cloud

Additional significant phrases include "ML," "learning systems," and "internet of things," highlighting the combination of ML with developing technologies such as IoT in agricultural environments. The terms indicate an increasing shift towards utilizing linked sensor networks and data-driven decision-making to improve agricultural output and sustainability. The terms "learning algorithms" and "agricultural robots" emphasize using sophisticated algorithms and robotics in agricultural research and automation. This suggests a move towards cutting-edge technologies designed to enhance efficiency and decrease labor-intensive activities in agricultural operations. The Word Cloud analysis offers significant insights into the main topics and concepts present in the overlap of ML and agriculture. The visualization showcases a variety of study subjects in the sector, including deep learning methods, precision agriculture techniques, and the incorporation of new technology such as IoT and robotics.

4.8. Thematic Evolution

Figure 7 illustrates a thematic evolution analysis showing shifts in research focus and issues in ML applied to agriculture and associated areas between 2014-2018 and 2019-2021. The methodology relies on the weighted inclusion index, inclusion index, occurrences, and stability index of different thematic transitions.

The observed thematic trend shows a progression towards more sophisticated and specialized subjects in ML and its use in agriculture. There has been a significant rise in the use of deep learning methods, demonstrated by the shift from the broad word "agriculture" to "deep learning" between 2019 and 2021. This shift is marked by a notable rise in the weighted inclusion index and instances, emphasizing the increasing significance of deep learning techniques like convolutional neural networks and deep neural networks in agricultural research, especially in fields such as image processing and object detection.

The thematic evolution shows a growing focus on precision agriculture and smart farming methods, demonstrated by the shift in terminology towards terms such as "precision agriculture," "smart agriculture," and "wireless sensor networks." This change indicates an increasing focus on utilizing ML and data-driven methods to improve agricultural processes, decision-making, and resource management in agricultural environments.

The thematic analysis shows that certain motifs, including "ML" and "data mining," endure over both periods. These subjects remain significant across the investigated time, with subtle changes in focus observed, such as the shift from "ML techniques" to "climate models" and from "data mining" to "decision trees." Therefore, figure 8 illustrates the changing themes in ML research applied to agriculture, emphasizing a shift towards specialized and advanced methods, a focus on precision agriculture and smart farming technologies, and the ongoing importance of core topics like ML and data mining. This development highlights the continuous use of technical developments in ML to tackle intricate difficulties in agricultural sustainability, productivity, and decision-making processes.

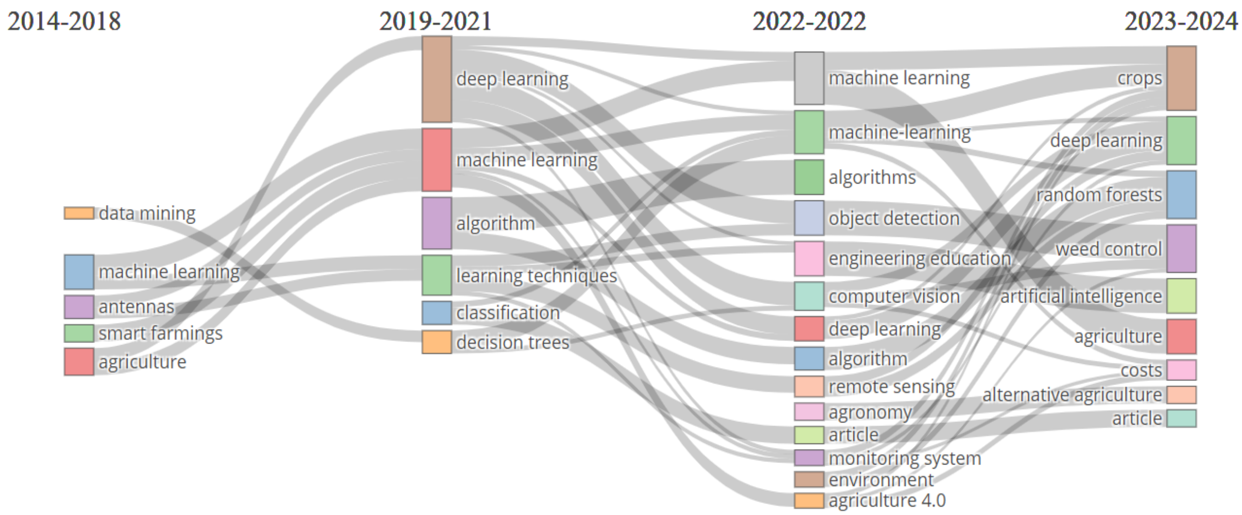

Fig. 7 Thematic evolution

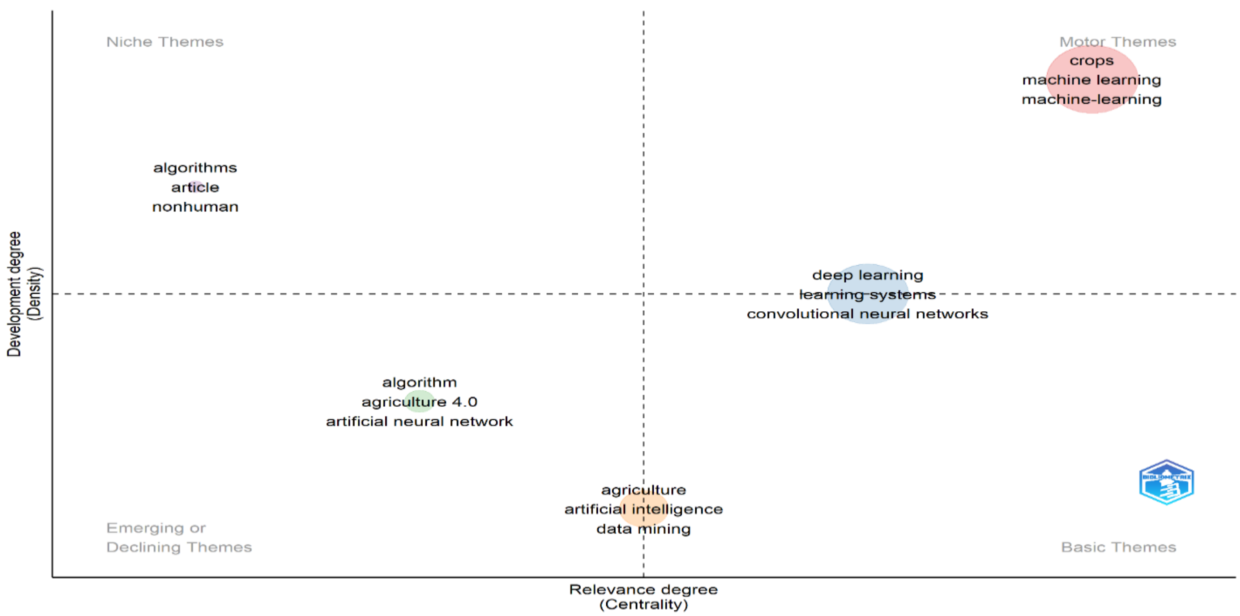

Fig. 8 Thematic map

4.9. Thematic Map

The thematic map reveals a cluster named "crops," containing several terms associated with agricultural techniques and technologies. The terms "crops," "precision agriculture," "machine learning," and "internet of things" are key nodes in this cluster, showing strong betweenness centrality. This indicates their important function in linking other phrases and aiding the transmission of information within the theme group. The presence of words such as "machine learning," "learning algorithms," and "agricultural robots" highlights the significant influence of technology, specifically machine learning and automation, in the field of precision agriculture. Terms such as "cultivation" and "farms" emphasize agricultural procedures and processes designed to enhance crop yield and efficiency. Furthermore, "smart agricultures" emphasizes incorporating smart technologies and digital solutions into contemporary agricultural systems. This highlights the connections and significance of many concepts in precision agriculture, focusing on the crucial role of technology-driven methods, especially machine learning, in improving agricultural productivity and sustainability.

4.10. Trend Topics

Table 3 presents an analysis of trending topics in ML applied to agriculture, revealing insights into the evolving research landscape and focus areas over time. One notable trend is the sustained interest in Artificial Intelligence (AI), a significant research focus from 2018 to 2022, with 16 occurrences recorded across these years. Another area of focus is maize research, with moderate frequency observed from 2014 to 2021, indicating ongoing interest in studying maize-related applications in ML and agriculture.

Additionally, topics such as agricultural fields, state-of-the-art methods, and wireless sensor networks have emerged as significant research areas, particularly in the years spanning from 2019 to 2022. These topics reflect a growing interest in exploring the latest advancements and technologies for enhancing agricultural practices and monitoring systems. Moreover, the central importance of agriculture is highlighted by the highest frequency observed for this topic, with 108 occurrences spanning from 2020 to 2022, signifying sustained interest and ongoing research efforts in various aspects of agricultural optimization and integration with ML techniques.

Furthermore, agricultural robotics and ML techniques have garnered substantial attention in recent years, particularly in 2020 and 2021, indicating a surge in interest and advancements in utilizing robotics technology and diverse ML methodologies for agricultural tasks. Deep learning, with the highest frequency of 219 occurrences, has emerged as a dominant and highly researched topic in later years, from 2021 to 2023, underscoring the recent surge in interest and exploration of deep learning techniques in agricultural applications.

The analysis of trending topics highlights a diverse range of research areas within the intersection of ML and agriculture, reflecting the multidisciplinary nature of research in this domain. The temporal distribution of these topics indicates ongoing interest and evolving research priorities over the years, with certain topics experiencing surges in attention during specific periods.

5. Limitation of the Study

While this study provides valuable insights into the landscape of ML in precision agriculture, several limitations should be acknowledged. Firstly, the analysis primarily relies on bibliometric data, which might not capture the entirety of research activities in this domain. Some relevant research may not be indexed or included in the database analyzed, potentially leading to gaps in the findings. Furthermore, the study's scope is limited to a specific timeframe and a single database, potentially excluding relevant research published outside the defined period or in alternative venues. This temporal and database restriction may result in a biased representation of the research landscape, overlooking emerging trends or contributions from niche journals or conferences. Additionally, the analysis of collaboration networks and influential authors may overlook informal collaborations or contributions from researchers not captured in the dataset.

Table 3. Trend topics

Topics	Freq	year_q1	year_med	year_q3
Artificial Intelligence	16	2018	2018	2022
Maize	5	2014	2018	2021
Agricultural Fields	12	2020	2020	2022
State Of The Art	10	2019	2020	2022
Wireless Sensor Networks	10	2019	2020	2022
Agriculture	108	2020	2021	2022
Agricultural Robots	74	2020	2021	2021
ML Techniques	37	2020	2021	2022
Deep Learning	219	2021	2022	2023
Crops	165	2021	2022	2023

6. Conclusion

The study sheds light on the dynamic landscape of ML applications in precision agriculture, providing valuable insights into key trends, influential sources, collaborative networks, thematic evolution, and trending topics within this interdisciplinary field. The analysis of document types revealed that conference papers and peer-reviewed articles are predominant, underlining the pivotal role of academic conferences and journals in disseminating research findings and fostering knowledge exchange among scholars. Furthermore, the steady increase in publication and citation trends over the years underscores the growing significance and recognition of ML techniques in addressing agricultural challenges and enhancing farming practices. Notably, the surge in research output and citations since 2017 highlights the accelerating pace of innovation and interest in this domain.

The collaborative network analysis elucidated the interconnectedness among authors and clusters within the research community, showcasing the diverse contributions and collaborative dynamics shaping the advancement of ML in precision agriculture. Noteworthy authors and clusters were identified, highlighting their significant impact and influence in driving research progress and knowledge dissemination. Additionally, the analysis of influential sources revealed key publications and journals contributing to scholarly discourse and shaping research directions in the field. These findings underscore the importance of scholarly publications in advancing knowledge and facilitating interdisciplinary collaboration.

Thematic evolution analysis demonstrated a shift towards specialized topics such as deep learning, precision agriculture, and smart farming techniques, reflecting the evolving research landscape and emerging areas of interest within ML applied to agriculture. Moreover, the identification of trending topics highlighted key research areas such as artificial intelligence, agricultural fields, wireless sensor networks, and deep learning, indicating ongoing research priorities and emerging trends in the field. This study provides valuable insights into the multifaceted nature of ML applications in precision agriculture, emphasizing interdisciplinary collaboration, evolving research themes, and emerging trends shaping the future of agricultural innovation and sustainability. By understanding these dynamics, researchers, policymakers, and industry stakeholders can make informed decisions and foster further advancements in leveraging ML for precision agriculture.

7. Recommendation and Future Direction

To address the limitations identified in this study and further enhance the understanding of ML in precision agriculture, several recommendations and future directions can be pursued. Firstly, future studies should consider utilizing a broader range of databases and repositories to capture a more comprehensive view of research activities in the field. This could involve incorporating additional databases, such as disciplinary repositories or regional databases, to ensure a more inclusive representation of research outputs. Furthermore, efforts should be made to include non-English language publications and grey literature sources to capture diverse perspectives and contributions from around the world.

Additionally, researchers should explore alternative methodologies beyond bibliometric analysis to complement the findings and provide a more nuanced understanding of the research landscape. Qualitative methods, such as interviews, surveys, or case studies, can offer insights into the practical implications of research findings and the perspectives of key stakeholders, including practitioners, policymakers, and industry professionals. Moreover, future studies could adopt a longitudinal approach to track the evolution of research themes and trends over time. This would involve conducting periodic analyses at regular intervals to capture emerging topics, shifts in research focus, and evolving collaboration networks within the field. Longitudinal studies would provide valuable insights into the dynamics of knowledge production and dissemination in ML applied to precision agriculture.

Furthermore, efforts should be made to enhance the accessibility and visibility of research outputs in the field. This could involve promoting open access publishing practices, sharing datasets and code repositories, and fostering collaborative networks to facilitate knowledge exchange and dissemination. Additionally, initiatives aimed at bridging the gap between academia and industry could facilitate the translation of research findings into practical applications and solutions for real-world agricultural challenges. By adopting a more inclusive and interdisciplinary approach, leveraging alternative methodologies, and promoting open access and collaboration, future research in ML and precision agriculture can overcome the limitations of existing studies and contribute to addressing pressing challenges in agricultural sustainability and food security.

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References

[1] Showkat Ahmad Bhat, and Nen-Fu Huang, "Big Data and AI Revolution in Precision Agriculture: Survey and Challenges," *IEEE Access*, vol. 9, pp. 110209–110222, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[2] Ravesa Akhter, and Shabir Ahmad Sofi, "Precision Agriculture Using IoT Data Analytics and Machine Learning," *Journal of King Saud University - Computer and Information Sciences*, vol. 34, no. 8, pp. 5602–5618, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[3] Solemane Coulibaly et al., "Deep Learning for Precision Agriculture: A Bibliometric Analysis," *Intelligent Systems with Applications*, vol. 16, pp. 1-18, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[4] Priya Rani Bhagat, Farheen Naz, and Robert Magda, "Artificial Intelligence Solutions Enabling Sustainable Agriculture: A Bibliometric Analysis," *PLoS One*, vol. 17, no. 6, pp. 1-19, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[5] Justin Zuopeng Zhang et al., "Big Data Analytics and Machine Learning: A Retrospective Overview and Bibliometric Analysis," *Expert Systems with Applications*, vol. 184, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[6] Lefteris Benos et al., "Machine Learning in Agriculture: A Comprehensive Updated Review," *Sensors*, vol. 21, no. 11, pp. 1-55, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[7] Abhinav Sharma et al., "Machine Learning Applications for Precision Agriculture: A Comprehensive Review," *IEEE Access*, vol. 9, pp. 4843–4873, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[8] Rambod Abiri et al., "Application of Digital Technologies for Ensuring Agricultural Productivity," *Heliyon*, vol. 9, no. 12, pp. 1-21, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[9] Anna Chlingaryan, Salah Sukkarieh, and Brett Whelan, "Machine Learning Approaches for Crop Yield Prediction and Nitrogen Status Estimation in Precision Agriculture: A Review," *Computers and Electronics in Agriculture*, vol. 151, pp. 61-69, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[10] Sharvari Patil, Nikhil Aklade, and Ashish Ashok Uikey, "Revolutionizing Vegetable Value Chains: A Comprehensive Review of Digital Technologies and their Impact on Agricultural Transformation," *Current Journal of Applied Science and Technology*, vol. 42, no. 47, pp. 54–65, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[11] Abdukadir Dahir, Mohamed Omar, and Yahye Abukar, "Internet of things based agricultural drought detection system: case study Southern Somalia," *Bulletin of Electrical Engineering and Informatics*, vol. 12, no. 1, pp. 69–74, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[12] Yonghong Tian, Bing Zheng, and Zeyu Li, "Agricultural Greenhouse Environment Monitoring System Based on Internet of Things," *3rd IEEE International Conference on Computer and Communications*, Chengdu, China, pp. 2981-2985, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[13] Sarah Condran et al., "Machine Learning in Precision Agriculture: A Survey on Trends, Applications and Evaluations over Two Decades," *IEEE Access*, vol. 10, pp. 73786–73803, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[14] Abhijeet Madhukar Haval, and F. Rahman, "Application of Machine Learning Techniques and the Internet of Things for Smart, Sustainable Agriculture," *BIO Web of Conferences*, EDP Sciences, vol. 82, pp. 1-11, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[15] Sara Oleiro Araújo et al., "Machine Learning Applications in Agriculture: Current Trends, Challenges, and Future Perspectives," *Agronomy*, vol. 13, no. 12, pp. 1-27, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[16] Mohd Javaid et al., "Understanding the Potential Applications of Artificial Intelligence in Agriculture Sector," *Advanced Agrochem*, vol. 2, no. 1, pp. 15–30, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[17] Sakshi Balyan et al., "Seeding a Sustainable Future: Navigating the Digital Horizon of Smart Agriculture," *Sustainability (Switzerland)*, vol. 16, no. 2, pp. 1-21, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[18] Kavery Ganguly, Ashok Gulati, and Joachim von Braun, "Innovations Spearheading the Next Transformations in India's Agriculture," 2017. [CrossRef] [Google Scholar] [Publisher Link]

[19] Massimo Aria, and Corrado Cuccurullo, "Bibliometrix: An R-Tool for Comprehensive Science Mapping Analysis," *Journal of Informetrics*, vol. 11, no. 4, pp. 959–975, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[20] Guozhu Mao et al., "Research on Biomass Energy and Environment from the Past to the Future: A Bibliometric Analysis," *Science of the Total Environment*, vol. 635, pp. 1081–1090, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[21] Marcelo Werneck Barbosa, "Uncovering Research Streams on Agri-Food Supply Chain Management: A Bibliometric Study," *Global Food Security*, vol. 28, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[22] Bipul Kumar et al., "Digital Mediation in Business-To-Business Marketing: A Bibliometric Analysis," *Industrial Marketing Management*, vol. 85, pp. 126–140, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[23] B.M. Gupta, and S. Bhattacharya, "Bibliometric Approach towards Mapping the Dynamics of Science and Technology," *DESIDOC Bulletin of Information Technology*, vol. 24, no. 1, pp. 3–8, 2004. [CrossRef] [Google Scholar]

[24] Claudio A. Bonilla, José M. Merigó, and Carolina Torres-Abad, "Economics in Latin America: A Bibliometric Analysis," *Scientometrics*, vol. 105, no. 2, pp. 1239–1252, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[25] Nees van Eck, and Ludo Waltman, "Software Survey: VOSviewer, A Computer Program for Bibliometric Mapping," *Scientometrics*, vol. 84, no. 2, pp. 523–538, 2010. [CrossRef] [Google Scholar] [Publisher Link]

[26] Hans W. Ittmann, "A Bibliometric Analysis of the Journal of Transport and Supply Chain Management," *Journal of Transport and Supply Chain Management*, vol. 15, pp. 1-15, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[27] Jasman Tuyon et al., "Sustainable Financial Services: Reflection and Future Perspectives," *Journal of Financial Services Marketing*, vol. 28, no. 4, pp. 664–690, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[28] Massimo Aria, Michelangelo Misuraca, and Maria Spano, "Mapping the Evolution of Social Research and Data Science on 30 Years of Social Indicators Research," *Social Indicators Research*, vol. 149, no. 3, pp. 803–831, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[29] Judit Bar-Ilan, "Informetrics at the Beginning of the 21st Century - A Review," *Journal of Informetrics*, vol. 2, no. 1. pp. 1–52, 2008. [CrossRef] [Google Scholar] [Publisher Link]

[30] Matthew E. Falagas et al., "Comparison of PubMed, Scopus, Web of Science, and Google Scholar: Strengths and Weaknesses," *The FASEB Journal*, vol. 22, no. 2, pp. 338–342, 2008. [CrossRef] [Google Scholar] [Publisher Link]