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Mapping the Landscape of ICTs in Agriculture Research: A Bibliometric Analysis of Influential Publications and Authors

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Abstract. This study aims to identify influential publications and authors in the field of ICTs in agriculture research through a bibliometric analysis. A search on the SCOPUS database yielded 1,104 documents published between 2010 and 2023, from which the 100 most-cited articles were determined. VOSviewer was employed for bibliometric analyses, including keyword occurrences, co-authorship networks, and bibliometric coupling networks. The analysis revealed that India, the UK, and the USA had the highest number of publications, while contributions from Africa were limited. Key recurring keywords included ICT, agriculture, information and communication, information management, and sustainable development. High-ranked journals with significant impact were identified, emphasizing the importance of journal metrics. The study highlighted the potential of ICT in enhancing agricultural performance, productivity, food security, farmer livelihoods, and stakeholder awareness. Despite limitations such as relying on a single database (SCOPUS) and focusing on highly cited publications, this bibliometric analysis provides valuable insights into ICTs in agriculture research. To enrich future research, it is recommended to incorporate multiple databases and consider a broader range of publications. Furthermore, given the limited number of existing bibliometric studies in ICT in agriculture, further research is warranted to advance knowledge in this area.

Keywords: Bibliometric analysis, ICT, Agriculture, Science mapping,

1. Introduction

Recently studies on ICT in agriculture have significantly improved the agricultural aspects, including access to information, decision support, and enhanced the productivity of farm products. It also improved the livelihood of farmers and other stakeholders such as extension officers, owners, producers, and managers (Abdullahi et al., 2021; Eitzinger et al., 2019; W. Liu et al., 2021; Rao, 2007).

ICTs in agriculture offer the potential for improving productivity, sustainability, and effectiveness through sharing information and resources. The sustainability of food production has considerably enhanced in recent years because of agriculture's usage of ICT tools and smart farming systems (Awuor et al., 2013). For instance, integrating wireless sensor networks in farming to monitor irrigation valve and switch operation and remote area control can significantly increase the production of high-quality agricultural goods (Wu et al., 2018). Furthermore, ICTs can help farmers and other stakeholders in the food system make better decisions about resource management, crop selection, and distribution. For example, satellite imagery can provide information about soil health and moisture levels, while mobile apps can help farmers track weather patterns and predict pest outbreaks (Serbulova et al., 2019).

Moreover, a study highlights the benefits of integrating Internet of Things (IoT) technology into precision agriculture's irrigation management systems. By leveraging IoT, water requirements can be effectively met, and crop productivity can be increased. The study presents a validated mathematical model in MATLAB and illustrates the advantages of the proposed system architecture, including energy efficiency, cost-effectiveness, forecasting capabilities, and scalability (Suciu et al., 2019).

Several bibliometric studies have been undertaken in various disciplines, including medicine (Bayram et al., 2016; Kolkailah et al., 2019; B. Liu et al., 2019), environment (Zhang et al., 2019), education (Hallinger & Kovačević, 2019), business (Fellnhofer, 2019), and management (Zupic & Čater, 2015).

On the other hand, A study also discussed the bibliometric analysis of ICT in agriculture between 2010 and 2020 and indicated thematic clusters in the use of ICT in agriculture. Based on a bibliometric analysis of 91 peer-reviewed publications from the Scopus database, two thematic areas were identified: one focused on knowledge acquisition and sustainable practices, and the other on integrating ICT into agriculture (M. I. B. Ribeiro et al., 2021).

Another study examined the application of ICT in Agri-farming systems. It also highlights the importance of ICT in enhancing decision-making in agricultural aspects. The study also acknowledges the digital divide in the sector and emphasizes the need for comprehensive solutions to bridge this gap and promote inclusive and sustainable growth (Brintha et al., 2022). Meanwhile, a few bibliometric analyses have been conducted on ICT in agriculture (Dayahna et al., 2020; M. I. Ribeiro et al., 2020; M. I. B. Ribeiro et al., 2021).

In general, a few bibliometric studies based on SCOPUS searches summarize the scholarly efforts on ICT in agriculture. Nevertheless, it is still necessary to conduct the present bibliometric analysis to fill the identified literature gap with the following objectives:

- To study the publications and citations patterns of the 100 most-cited articles on ICT in agriculture
- To identify and analyze the publication trends and growth of research in ICT in agriculture from 2010 to 2023.
- To determine the most influential publications and authors in ICT in agriculture based on citation counts and other bibliometric indicators.
- To discover the top journals that have published the 100 articles on ICT in agriculture that have received the most citations and to examine these publications' characteristics.
- To map the collaboration networks among authors and institutions in ICT in agriculture research, examining co-authorship and research collaboration patterns.
- To analyze the keyword occurrence and co-occurrence patterns, identifying the main

research themes and areas of focus within ICT in agriculture.

2. Research Methodology

The paper employs science mapping to provide an overview of the existing knowledge base on ICT in agriculture. Research mapping analyses literature and scholarly articles based on their bibliometric data (Morris & Van der Veer Martens, 2008). Bibliometric analysis, or scientometric analysis, is commonly employed to examine and visualize the connections between evolving scientific ideas throughout time (Small, 1997; van Eck, 2010). These connections can be explored using various units of analysis, such as keywords, authors, publications, journals, institutions, and countries (Cobo et al., 2011).

According to the findings of (Cobo et al., 2012), a science mapping analysis can be divided into seven steps: data acquisition, preprocessing, network extraction, normalization, mapping, research, and visualization. However, it is worth noting that some of these steps may not be distinct as the software used in the analysis often performs them simultaneously with a few simple actions. An example is the VOSviewer software, which quickly executes the steps of network extraction, normalization, mapping, analysis, and visualization once the required parameters are configured. Some researchers argue that these steps can be condensed into three main stages: data identification, acquisition, and analysis (Narong & Hallinger, 2023). The following outlines the steps the researcher takes to collect and analyze the data for this study.

2.1. Criteria for searching data.

Researchers can find data for bibliometric analysis in various online databases, known as bibliographic sources. There are several important sources, such as Google Scholar, SCOPUS, and the Institute for Scientific Information (ISI) Web of Science (WoS) (Cobo et al., 2011). The researcher used the SCOPUS database to conduct this literature review because it provides more extensive coverage of publications and journals related to technology in agriculture than the Wos database (Narong & Hallinger, 2023). Since Google Scholar has fewer strict indexing rules than SCOPUS and ISI (World of Science), it was not chosen as the database of choice due to its difficulty in obtaining bibliometric data.

The initial step of this study involved defining the relevant terms or keywords to gather information specifically related to ICT in Agriculture. It was important to select keywords that conveyed meaningful information, considering word derivatives and equations. The Scopus database (www.scopus.com) was identified as the most comprehensive indexer globally for accessing high-quality reference articles.

The most relevant articles were identified from the initial search results and stored for further analysis during this stage. The search was conducted in 2023, yielding 1104 documents published between 2010 and 2023. Only journal articles and conference papers written in English were included in the search results. CSV files were exported for all the initial search results, including author names, citation names, document titles, publication years, source titles, volume numbers, publication details, page numbers, citation counts, source types, DOIs, abstracts, keywords, and conference information.

2.2. Getting and cleaning data.

The researcher obtained data from the database and exported it as Comma-Separated Values (.csv) files. Due to limitations on the SCOPUS website, only the bibliometric data for the first 2,000 entries could be exported. Since the analysis for this study focused on the 100 most-cited articles, the researcher chose to export only the initial 2,000 entries and excluded the remaining data. The researcher conducted An extensive cleaning process to identify and correct any inaccurate or missing entries. It was achieved by correctly completing all relevant fields (columns) and ensuring that each field's data corresponded to its designated title (e.g., the author field did not contain the publication name). During the data cleansing phase, any erroneous or incomplete entries were eliminated. The remaining entries were subsequently transferred to a separate Microsoft Excel (.xls) file after the completion of the data-cleaning process. The new file was saved as a Text (tab-delimited) file to be conveniently imported into

VOSviewer for analysis.

2.3. Bibliometric analysis.

According to van Eck (2010), keyword maps, co-author networks, citation networks, and bibliographic link networks are frequently employed in scientific mapping to explore bibliographic relationships. This study utilized keyword maps, co-author networks involving multiple countries, and a bibliographic link network. The analysis also included publications, citations, and prominent journals associated with the 100 most cited papers in agricultural information and communication technologies.

A variety of software options are available for scientific mapping purposes. These include INSPIRE (Small, 1999), HistCite (Garfield et al., 2003), VantagePoint (Porter & Cunningham, 2004), CoPalRed (Porter & Cunningham, 2004), CiteSpace II (Chen, 2006), Gephi (Bastian et al., 2009; van Eck, 2010). For the present study, VOSviewer, accessible at www.vosviewer.com, was employed by the researcher to visualize bibliometric maps and networks. Additionally, the data generated by VOSviewer was utilized to create graphs using Microsoft Excel.

In science mapping, various approaches exist for visualizing research outcomes. These methods commonly involve distance-based, graphical, or temporal representations (van Eck, 2010). Irrespective of the chosen visualization method, maps consist of two fundamental components: "nodes" represented as circles and "edges" depicted as lines connecting the nodes. The visual appearance of nodes and edges in these three approaches conveys distinct interpretations of the maps. In the distance-based method, the proximity of nodes reflects the strength of the connection between them.

In the distance-based method, closer proximity of nodes indicates a stronger relationship between the corresponding entities (Fabrikant et al., 2010). Conversely, in the graph-based approach, the distance between nodes does not provide information about their relationship; instead, the edges represent the connections. If there is no edge connecting two entities, it implies no relationship between them (van Eck, 2010). Furthermore, the timeline-based or temporal analysis arranges the nodes vertically based on specific periods, and their horizontal distance indicates their level of connection (Cobo et al., 2011; van Eck, 2010). The VOSviewer software employs a distance-based method to visualize bibliometric networks, but it also provides the option to display edges for a more comprehensive representation (van Eck, 2010). In the present analysis, the decision was made to include the edges in the visualization. Consequently, there are three key considerations when interpreting the bibliometric maps in this study:1) Node size indicates the frequency of an entity's occurrence. 2) When nodes are close to each other, the connections between the entities are stronger. 3)The thickness of the lines connecting two nodes indicates the presence of both frequency and strong connections.

3. Results and Discussions:

3.1. The publications and citation pattern:

As shown in Figure 1, the distribution of the 100 most-cited articles over time, along with the total number of publications in each year. Furthermore, it provides the average number of citations for the highly cited articles after normalizing for potential publication year differences. The graphs indicate the number of publications on ICT in agriculture and their citation count for a specific group of authors from 2010 to 2023. The number of publications has steadily increased over time, with a peak of 129 publications in 2022. Additionally, the number of publications for 2020 and 2019 was the second highest, 124 and 122, respectively. Interestingly, this suggests that the authors have been active in producing new research, with a particular increase in output in recent years. The total citation count also generally shows an upward trend, peaking in 2020 at 1570 citations. This indicates that the authors' research has been impactful and well-received by their peers. However, in 2023, the citation count appears to be significantly lower than in previous years, with only 22 citations recorded so far. But it's crucial to note that the data for the current year is not yet complete. According to the graph, the authors have been actively publishing and producing research with increasing impact over the years.

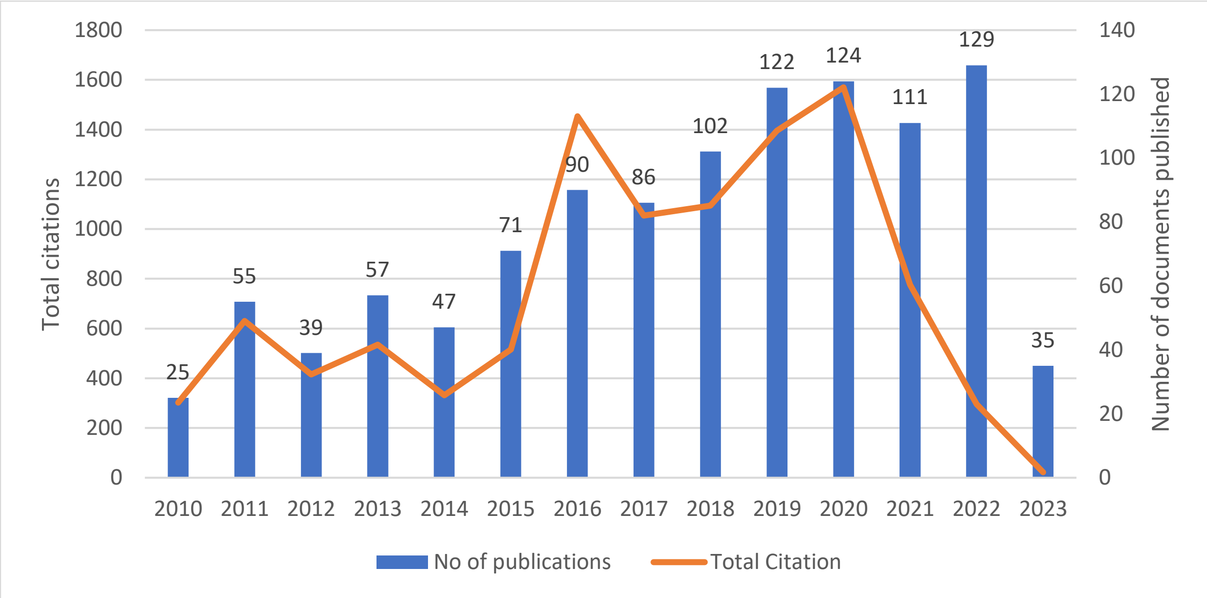

Fig.1: The total number of publications and the number of articles

3.2. International Contribution and Collaboration

This graph shows the number of publications by country, ranking the top 15 nations by quantity of publications. As indicated in the results, India has the highest number of publications, with 225 highly cited literature on ICT in agriculture, followed by Japan and the United States with 72 each. Moreover, China, Italy, and Nigeria are the next three countries with 59, 53, and 47 publications, respectively. The result also reveals that India is a leading contributor to academic publications among the listed countries. At the same time, Japan and the United States follow closely, likely reflecting their advanced research capabilities. Additionally, Italy and Nigeria also have a substantial presence in academic research, though with a lower number of publications. In addition to these nations, Greeks, Australians, Koreans, Indonesians, Germans, the United Kingdom, Kenyans, South Africans, and the Netherlands were also represented, showing various research abilities and interests worldwide.

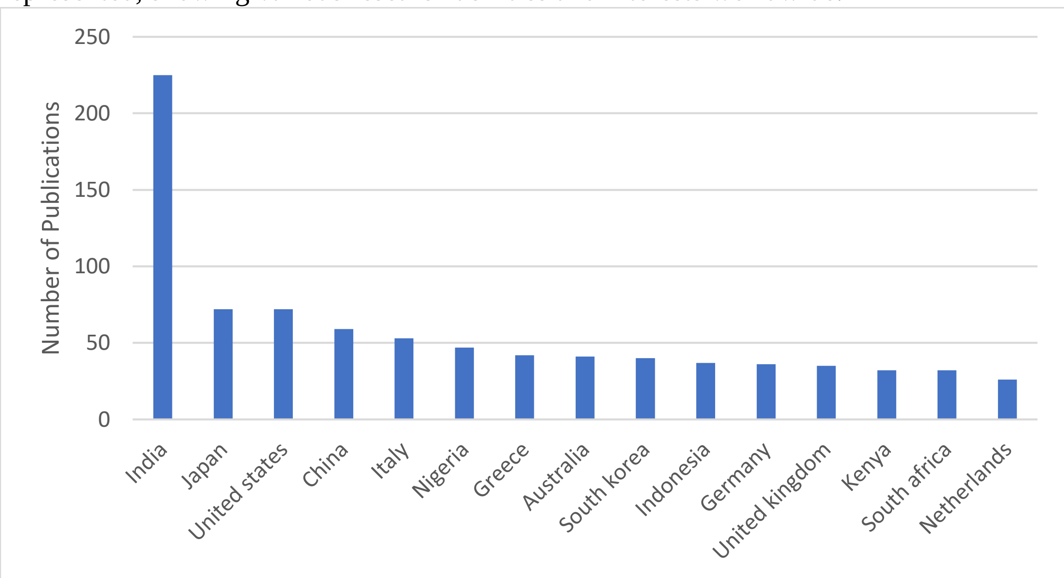

Fig.2: The distribution of the number of publications by country

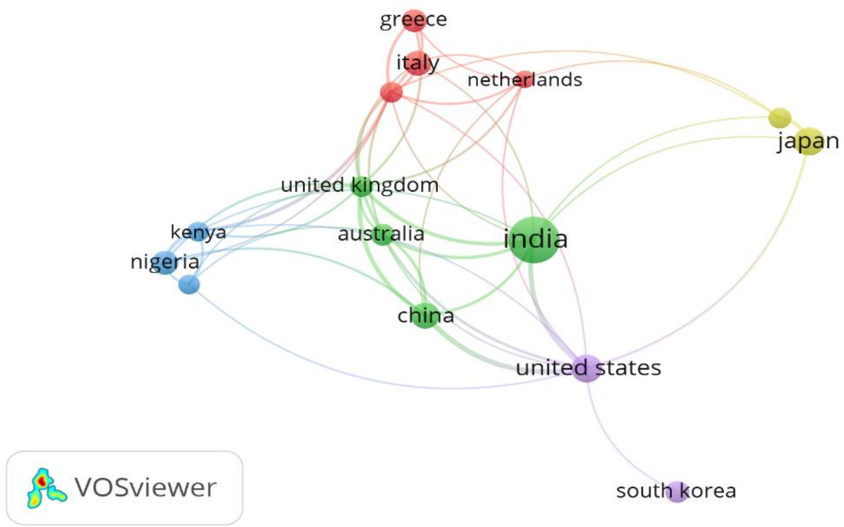

Fig.3: A network of cooperation among the countries

The total number of publications explored in this study is greater than 100, indicating that there has been some cooperation among the contributing nations. Therefore, VOSviewer was employed to create a network of collaboration between these countries, as shown in Figure 3. The results denote that the UK and USA collaborate with a similar number of countries, with ten and eleven links, respectively. However, when the strength of the collaborations is considered, the USA becomes the top-one (link strength = 29), whereas the UK occupies the number two position (link strength = 27). Furthermore, India and Germany come to third place based on the number of links which is 9 per each. As a result of considering link strength, India is ranked third (link strength = 24), while Germany occupies the number four position (link strength = 19). While the Netherlands comes in fifth in terms of the number of links (7), China, Kenya, Australia, and Italy have the same links (6); however, they beat the Netherlands in terms of the strength of collaboration, as their strength of collaboration is 24, 14, 13, 10, while the Netherlands' is only 9. Each of these nations has primarily cooperated with several other countries. These findings highlight the significance of international collaboration for producing highly influential publications on the subject.

3.3. Key Journal

The scope of this study was expanded to encompass the top 100 influential journals that disseminate research on ICT in agriculture. The findings revealed a dispersed distribution of articles across a diverse range of periodicals. Specifically, among the 100 most cited papers, 33 journals were identified as publishers. However, only 17 of these journals published two or more highly cited articles. To maintain brevity, Table I presents the details of these 17 journals. The ordering of the journals in Table I is based on the cumulative journal citations of the included publications, given that the quantity of publications is consistent across different journals.

The data in this table pertains to several scholarly publications in Information communication technology and agriculture. The table covers journal names as well as Information about their Publishers, Total Publications (TP), Total Citations (TC), Citations Per Publication (CPP), Citescore, SNIP, and SJR. Subsequently, our attention was directed towards the values presented in the third last column of Table I, denoting the source normalized impact per publication (SNIP). SNIP serves as a metric for assessing the average citation count per paper within a particular journal relative to the citation potential of that journal within its specific subject field (Waltman et al., 2013). Consequently, SNIP scores exceeding one indicate that the average citation count per article in the journal surpasses the citation potential of that journal within its subject field. The table shows that the ACM International Conference Proceeding Series is the most prolific journal, with 30 total publications and 92 total citations.

No	Journal name	TP	TC	CPP	Citescore	SNIP	SJR	Publisher
1	acm international conference proceeding series	30	92	3	1.00	0.31	0.23	Association for computing machinery (ACM)
2	computers and electronics in agriculture	20	708	35	11.80	2.38	1.60	Elsevier
3	iop conference series: earth and environmental science	20	79	4	0.60	0.41	0.20	IOP Publishing Ltd.
4	communications in computer and information science	16	46	3	0.90	0.29	0.21	Springer Nature
5	agris online papers in economics and informatics	14	62	4	2.00	0.62	0.27	Faculty of Economics and Management CULS Prague
6	electronic journal of information systems in developing countries	12	197	16	3.90	1.12	0.53	Wiley-Blackwell
7	ifip advances in information and communication technology	11	39	4	1.20	0.36	0.25	Springer Nature
8	information technology for development	10	122	12	6.70	1.63	1.01	Taylor & Francis
10	sustainability (Switzerland)	10	93	9	5.00	1.31	0.66	Multidisciplinary Digital Publishing Institute (MDPI)
11	journal of cleaner production	9	266	30	15.80	2.44	1.92	Elsevier
12	information development	7	72	10	4.00	1.53	0.47	SAGE

13	development in practice	6	26	4	2.10	0.96	0.47	Taylor & Francis
14	agricultural systems	5	119	24	9.70	2.20	1.55	Elsevier
15	information processing in agriculture	5	301	60	12.00	2.68	1.01	Elsevier
16	International Journal of agricultural sustainability	5	76	15	5.00	1.53	0.82	Taylor & Francis
17	journal of Agricultural and food information	5	71	14	2.20	0.45	0.24	Taylor & Francis

Computers and Electronics in Agriculture have the highest Citescore of 11.80 and the highest SNIP of 2.38. Journal of Cleaner Production has the highest SJR of 1.92.

The table also highlights the publishers of the journals. Elsevier appears to be the most prominent publisher, with four journals listed, followed by Taylor & Francis with three. Meanwhile, Springer Nature also appears as the third publisher and has only two journals, while others ranked lowest publishers in the table, and they received only one journal per each. The data presented in this table can be useful for researchers and academics interested in information and communication technology and agriculture to identify prominent journals in their field of interest. The Citations Per Publication metric indicates the impact of the journals, and the Citescore, SNIP, and SJR metrics provide a relative measure of the influence and quality of the journals in their respective fields.

3.4. ICT in agriculture: Mapping the key concepts:

In addition, we examined the key concepts explored by researchers in the 100 most-cited articles. As shown in Figure 4, co-occurrences of keywords (author, journal, and journal keywords assigned by journals) were analyzed using VOSviewer. Based on the results, five major clusters can be mapped onto the knowledge embedded in these publications. According to the cluster size, the most significant keywords are "Information and Communications", "ICT", "Agriculture", "Sustainable development", and "Information Management".

Likewise, "Agriculture" is the keyword that appears the most repeatedly (frequency = 525) in Cluster 3 (keywords = 21). However, it is the general keyword that is used the most frequently. This term is closely related to ICT concepts (link strengths = 114) found in Cluster 3 and Cluster 2. Furthermore, it has strong relationships with some keywords in Cluster 1. For instance, its link strength with agriculture robots, the internet of things, big data, artificial intelligence, and smart farming are 67, 41, 20, 19, and 14, respectively. Its link strength with agriculture robots, the internet of things, big data, artificial intelligence, and smart farming has 67, 41, 20, 19, and 14, respectively.

The most frequent keyword in Cluster 2 (keywords = 16) is "ICT" (frequency = 208). This keyword is also the third most frequent keyword overall. As indicated in the results, ICT has strong links with agricultural technology, agricultural extensions, Innovations, sustainability, and information technology (link strength ranging from 16 to 7), all belonging to cluster 2. Furthermore, ICT also indicates strong associations with several keywords from the third cluster. In this regard, it portrays strong links with agriculture, farmers, rural areas, economics and information systems, with link strengths ranging from 16 to 7, respectively.

Regarding cluster 1 (keywords = 15) is "Information and communication" (frequency = 215). As indicated in figure2, Information and Communications have strong links with agricultural robots, IOT, precision agriculture, and decision Marking (link strength ranging from 42, 29, 20 and 18, respectively. Moreover, information and communication also show strong associations with several keywords from the fourth and fifth clusters. In this regard, it portrays strong links with food supply (18), supply chain (8), knowledge management (11) and e-agriculture (5). Meanwhile, the last two clusters, which are very similar in links, are 4 and 5. Cluster 4 has 33 links with other groups, while Cluster 5 has 35 connections. In a nutshell, those clusters have the smallest links compared with other clusters.

As seen from Figure 4, the second and third clusters are positioned very close to each other in the visualization network – while at the same time, other clusters are also placed nearby each other. This shows the close relationship between the keywords in all clusters, which means the ICT and agricultural aspects positively impact the productivity and sustainability of farm products and services.

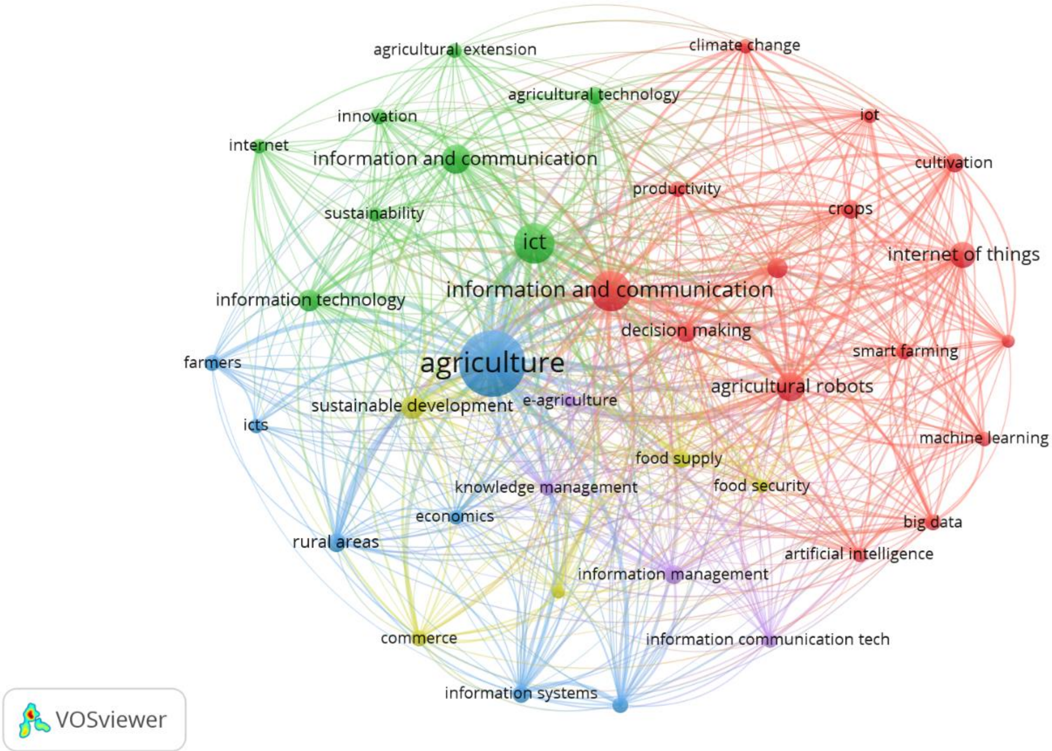

Fig.4: Co-occurrence network of the most frequent keyword

3.5. Citation network

We also examined the references cited in the 100 most-cited publications on the topic of ICT in agriculture to discover commonalities among those cited by authors in these publications. An analysis of bibliometric couplings was conducted using VOSviewer. The outcomes of the software generated on this subject are displayed in Figure 5.

According to findings, the 100 most-cited publications can be categorized into five clusters based on the works cited in these publications. For example, the cluster in blue (on the bottom left) represents those which investigated agriculture. Likewise, the cluster at the upper left of the map (in purple) denotes those exploring Information Management.

Furthermore, the green cluster at the top-centre of the map represents publications focused on exploring ICT. The yellow cluster at the map's centre corresponds to publications related to sustainable development. In contrast, the red cluster positioned on the right side of the map signifies publications associated with information and communication.

The disparity in distance between the blue and red clusters and the limited connections between them suggests that the cited works within these groups of publications are not particularly similar. In contrast, the other clusters are closely positioned to each other and exhibit numerous links, indicating a higher degree of similarity among the cited works in these publication groups.

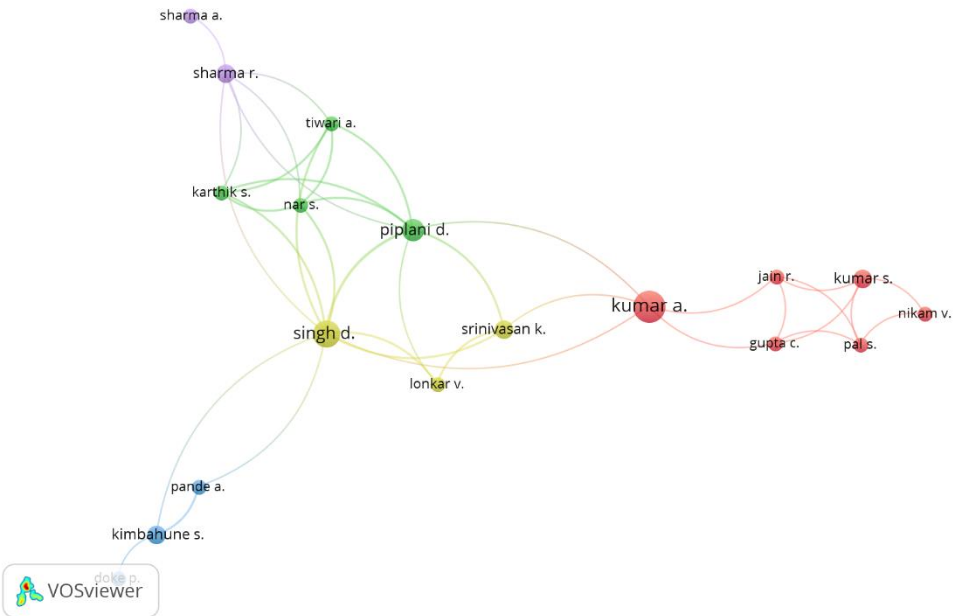

Fig.5: Bibliometric coupling network of articles cited in the top 100 most-cited publications.

4. Limitations

This bibliometric analysis has certain limitations that need to be addressed. The study relied on a single database, although the credibility of other databases was acknowledged. The SCOPUS database was deemed sufficient due to its extensive coverage, but it is acknowledged that using different databases or a combination of them could lead to slightly different results. Apart from the time frame, there are other factors that may have influenced citation rates, such as journal and author self-citations, as well as the availability of research materials to other scholars, which we were unable to consider in our analysis. Additionally, the study was limited to the 100 most cited publications, and using a broader range of publications could have yielded different results. Considering these limitations, it is recommended that future studies incorporate expanded time scales and utilize more data from diverse databases or sources to enhance the comprehensiveness of the research.

5. Conclusion

This paper presents a bibliometric analysis of publications on ICT in agriculture. Scholarly work has been cited and published since 2010 to our search date (May 2023). Further analysis of the 100 most-cited articles on the topic was conducted to determine the countries' contribution and collaboration and the key journals that published these works. In addition, we analyze cited references and keywords in these publications to represent the map of knowledge on this topic.

It has been found that the number of publications on ICT in agriculture has been on the rise over the past few years, as well as the number of citations. Furthermore, it was observed that most of the publications are from India, while it also noted the second-ranking countries are UK and USA. Interestingly, those from Africa are very limited. The keywords most used were ICT, agriculture, information and communication, information management, and sustainable development. Regarding the key journals in which these publications appear, we found that almost all are high-ranked journals. Furthermore, we found that each of these publications significantly influences the field. We also notice that these journals are members of reputable publishers. Therefore, researchers should look at both quartile ranking and SNIP metrics when selecting a journal.

This research holds great significance for the agricultural field and has the potential to make valuable contributions. It is not only important for researchers but also for farming industries worldwide. The study addresses essential aspects of information technology and agriculture to enhance agricultural productivity and contribute to national efforts to ensure food security. By tackling the challenges of food insecurity, it also promotes using agricultural technology to improve farmers' livelihoods and increase agricultural production. As a result, this study significantly contributes to the academic and industrial sectors.

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