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Digital Innovations in Agricultural Extension: Exploring the Role of ICT and Social Media in Information Dissemination

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***Abstract*:** The study explores the role of information and communication technologies (ICT) and social media on agricultural extension. Through digital tools, these innovations have greatly improved information dissemination and knowledge exchange among farmers and agricultural households. The study presents an extensive bibliometric analysis based on 166 articles from Scopus, from 2000 to 2023. Bibliometric tools like VOSviewer and R-Biblioshiny are used to answer five major research questions, mainly identifying influential authors, leading journals, key organizations, seven thematic clusters, etc. The findings indicate increased publications after 2017, reflecting a growing interest in this field. Significant contributions come from the United States, India, and China, indicating the global relevance of digital innovations in agricultural extension. This study expands beyond previous research by covering a broader array of countries, themes, and a more extensive timeframe. The study concludes by detailing six identified themes(Digital agricultural extension, adoption of ICT in agricultural extension, Impact of ICT in agricultural extension, barriers to adoption of ICT in agricultural extension, use of social media in agricultural extension, and digital agricultural extension in developing regions) providing information into each theme's main topics, relevant articles, authors, publication years, sources, total citations, and total link citations, that gives a comprehensive overview of this research area.

Keywords: Information and communication technologies (ICT), social media, agricultural extension, information dissemination

1. INTRODUCTION

The arrival of digital innovations has transformed the agricultural extension landscape, introducing new ways for information dissemination and knowledge exchange among farmers and agricultural households. Information and Communication Technologies (ICT) and social media are at the forefront of this transformation, and they have emerged as essential tools in bridging the information gap, making access to agricultural knowledge easy, and creating community-based information systems.

ICT, having a broad spectrum of technologies such as mobile phones, the internet, and radio broadcasts, has provided farmers with direct access to vital information on crop management, weather forecasts, market prices, pest control, and other vital information. The fast penetration of mobile technology in rural areas has further increased the impact of ICT, enabling real-time communication and information exchange that was previously unattainable (Aker, 2011). These technologies offer cost-effective solutions for information dissemination and empower farmers to make informed decisions, hence improving their productivity.

Social media are emerging as an essential platform for disseminating agricultural information. In India, for instance, platforms like Facebook, Twitter, YouTube, and WhatsApp are being increasingly used by Agricultural Extension and Advisory services to share farming-related information with farmers, showcasing the power of social media in reaching out to and engaging with farming communities (Devi & Tripathi, 2020). These digital platforms facilitate peer-to-peer learning and create a sense of solidarity and mutual support necessary for addressing the challenges of modern agriculture. The synergy between ICT and social media, can transform agricultural extension by easing access to information, enhancing the quality and relevance of advisory services, and creating collaborative networks among stakeholders. However, challenges such as digital literacy, infrastructure deficits, and the digital divide need to be addressed fully harness the benefits of these innovations (World Bank Group, 2017).

According to (G P et al., 2023), there is an indication of a strong foundation for advancing digitalization in agriculture. A study conducted across all three agro-climatic zones within Telangana revealed a favorable attitude towards digital agricultural communication and services among more than half of the stakeholders, including farmers, extension personnel, and scientists. Also, the use of personalized digital extension services has been associated with positive and major impacts on input intensity, production diversity, crop productivity, and income for farmers in India, stressing the potential of digital technologies to tailor information to farmers' individual needs and conditions (Rajkhowa & Qaim, 2021).

Moreover, adopting a user-centered approach to designing digital extension services can address the communication challenges faced by potential users, ensuring that digital technologies meet the specific needs of the agricultural community and lead to more effective extension services (Steinke et al., 2020).
Despite the promising developments, the potential of digital technologies to transform agriculture in developing countries has yet to be fully realized. Challenges such as digital divide, lack of ICT infrastructure, and low access to technology create challenges for the effective implementation of digital extensions. However, the increasing penetration of mobile phones and the internet presents major opportunities for overcoming these barriers and leveraging digital innovations for sustainable agricultural development (Deichmann et al., 2016).
We have come up with the following five key research questions for this bibliometric analysis:
RQ 1: What are the prevailing trends in publishing about digital innovations in agricultural extension from 2000 to 2023?
RQ 2: Who are the key authors, publications, and institutions that have significantly contributed to the research on the use of ICT and social media in agricultural extension?
RQ 3: Which articles have been most influential in shaping the understanding and implementation of digital technologies in agricultural extension?
RQ 4: What is the current landscape of international collaborations among researchers in this field, and how do these collaborations influence the research output and impact?
RQ 5: What are the dominant themes and emerging trends in the literature on digital innovations within the agricultural extension sector based on bibliometric coupling analysis?

1.1. Importance of the Study
Given the limited research in the domain of agricultural extension, especially when it comes to complete bibliometric analysis, the study seeks to expand upon the existing literature. Prior studies, such as "Mapping Research Contributions on Agricultural Extension in India: A Bibliometric Analysis" (Sinha & Nag, 2023), which offers an insightful exploration focused primarily within the geographical confines of India, and "Bibliometric Analysis of Information Communication Technology Research in Agricultural Extension" (Mansingh et al., 2020), narrows its lens to the connection between information communication technology (ICT) and agricultural extension. While these studies provide valuable perspectives and understandings, our bibliographic analysis study goes beyond these thematic and geographical limitations by having a broader spectrum of research contributions across multiple countries, covering wider themes within agricultural extension and extensive timeframe. This approach shows the existing research paths and also identifies less explored areas and emerging trends, as a result offering a more global and inclusive view of the agricultural extension research.

1.2. Significance of the Study
The significance of the study lies in its ability to provide a comprehensive understanding of the role of information and communication technologies (ICT) and social media in agricultural extension. By analyzing 166 articles from Scopus, the study provides a wide range of findings, which enhance the reliability of the analysis. The inclusion of different regions in the study allows for a better understanding of how ICT and social media are utilized in different agricultural contexts worldwide, this helps in finding region-specific challenges and opportunities. Also, the analysis of articles from different years provides information on the evolution of these technologies, which offers a path for future research in this area.
Moreover, the nature of the selected articles coming from different disciplines, ranging from agriculture, communication studies, information technology, and social sciences, improves the analysis by bringing more viewpoints and methods. This approach leads to a better understanding of the topic and helps discover research gaps and opportunities for future studies. The bibliometric analysis aids as a benchmark for future research, which helps guide scholars in building upon existing knowledge in this area.

2. DATA AND METHODOLOGY
The study uses a bibliometric analysis approach to examine the role of Information and Communication Technologies (ICT) and social media on agricultural extension. The data source is the Scopus database, from which a total of 166 articles published from 2000 to 2023 were selected. The articles focus on the role of ICT and social media in information dissemination.

2.1. Bibliometric Database Selection

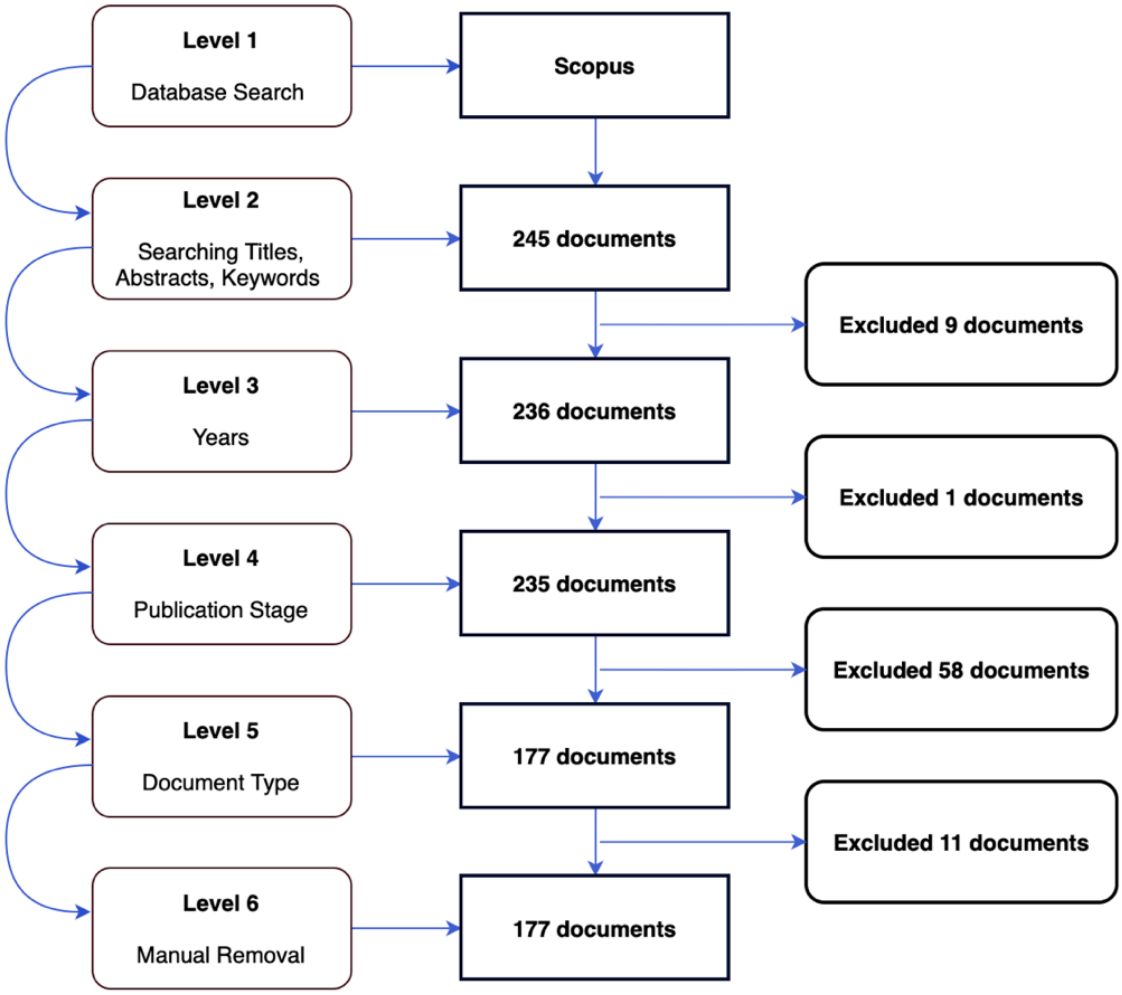

Fig. 1. Document selection

Level 1 - Database Search: The initial step involves performing a complete search query in the Scopus database.
Level 2 - Searching Titles, Abstracts, Keywords: The search criteria are refined to look for specific terms within the titles, abstracts, and keywords of documents, which narrows down the results to 245 documents.
Level 3 - Years: The search is then further narrowed by focusing on documents published within a specific year or range of years. This step resulted in the exclusion of 9 documents, leaving 236 documents. The years were set from 2000 to 2003.
Level 4 - Publication Stage: At this stage, documents are filtered based on their publication stage and only final stage publications were selected. This leads to the exclusion of 1 more document, yielding 235 documents.
Level 5 - Document Type: The remaining documents are then screened based on the document type (journal articles). This step excludes 58 documents, bringing the count down to 177 documents.
Level 6 - Manual Removal: Finally, a manual review of the documents is performed to remove any remaining irrelevant documents, resulting in the exclusion of 11 documents and a final count of 166 documents that are suitable for inclusion in the analysis.

2.2. Search Strings of Keywords

The documents were retrieved on Scopus through a keyword search string: (("Digital Sources" OR "Digital Media" OR "ICT" OR "Social Media" OR "Information Sharing" OR "Information Dissemination" OR "Agricultural information dissemination") AND ("Agricultural Extension")). This search result yielded 245 documents. After a detailed review and exclusion process, the total number of documents finalized for analysis was reduced to 166.

2.3. Bibliometric Tool Selection

Microsoft Excel is used to create tables within the study. The findings and analysis were conducted using R's Biblioshiny, a tool for bibliometric analysis that allows for the exploration of complex datasets through descriptive statistics, trend analysis, and thematic investigations. The bibliometric data are visualized using VOSviewer.
Biblioshiny, being part of Bibliometrix, provides an extensive set of techniques suitable for a wide range of bibliometric studies. Its capabilities include data acquisition from multiple sources, performance analysis, and visualization tools, making it a wide-ranging choice for bibliometric researchers (Moral-Munoz et al., 2020).

VOSviewer is a tool designed to construct and visualize bibliometric maps. The software allows for the loading and exporting information from many sources, facilitating the analysis of bibliometric data. Its visualization features are especially highlighted which gives detailed representations of data that can help find trends, hotspots, and collaborations within the scientific community (van Eck & Waltman, 2010).

3. ANALYSIS AND FINDINGS

Overview of Data: Descriptive analysis of the collected bibliometric data.

RQ 1: What are the prevailing trends in publishing about digital innovations in agricultural extension from 2000 to 2023?

To answer this question, we will examine the descriptive analysis of bibliometric data collected from 2000 to 2023. This includes analyzing the annual growth rate, the number of documents and sources, authorship, and collaboration trends. We will also review the citation count to assess the impact and relevance of these studies over time. The keyword analysis and temporal trends in publication volumes will be critical for identifying the prevailing trends in publishing about digital innovations in agricultural extension.

Fig. 2. Descriptive statistics

Figure 2 shows the data collected from 2000 to 2023 reveals a steadily increasing engagement with this research area. The analysis encompasses 166 documents from 106 sources, indicating an annual growth rate of 13.66% and a rising interest in adopting digital sources for agricultural extension. The collaborative nature of the research is evident, with 551 authors and 3.35 co-authors per document, and a big portion of these studies involving international partnerships indicates the global effort to innovate in agricultural extensions through digital means. As suggested by the average citation count of 13.39 per document, the body of literature is broad and impactful, showing the reference value of these studies within the academic community. With an average age of 6 years for the documents in the dataset, it is clear that the findings continue to be relevant over time. In short, the bibliometric indicators reflect a rich field characterized by growth in research, sustained interest over the years, and extensive collaboration across nations.

3.1. Trends in Publication Volumes Over the Years

Figure 3 indicates an overall increasing trend in the number of articles published each year from 2000 to 2023. This suggests a growing volume of scientific research output over time. As shown by the graph, there is a sharp increase in publication increase starting from 2017. This could be due to various reasons, including increased interest and awareness, the rise in internet penetration, and other contributing factors.

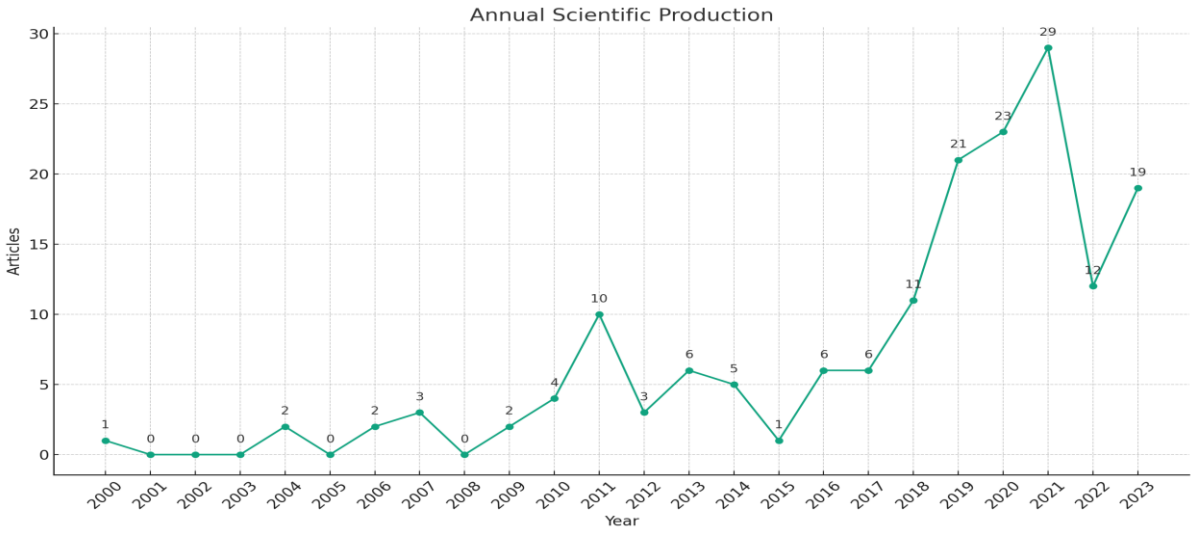

Fig. 3. Annual scientific production over the years (2000 to 2023)

3.2. Analysis of Research Contributions by Country:

RQ 2: Who are the key authors, publications, and institutions that have significantly contributed to the research on the use of ICT and social media in agricultural extension?

For this RQ, we will focus on the sections detailing key publishing outlets, publications by authors and organizations, and research contributions by countries. We will show the most prolific authors, the most influential publications, and the leading institutions based on their academic output and impact, measured by the total number of publications and the total number of citations received.

Table 1. Analysis of research contributions by countries

Rank	Countries	Articles	Rank	Countries	Total Citations
1	INDIA	63	1	GHANA	216
2	NIGERIA	54	2	USA	179
3	KENYA	39	3	INDIA	130
4	USA	38	4	CHINA	122
5	CHINA	35	5	NETHERLANDS	120
6	GHANA	29	6	BELGIUM	93
7	NETHERLANDS	27	7	CANADA	85
8	INDONESIA	25	8	COSTA RICA	80
9	ETHIOPIA	18	9	SOUTH AFRICA	72
10	SOUTH AFRICA	16	10	NIGERIA	71

In table 1. the countries are ranked based on their scientific output and impact, with the number of articles indicating productivity and the citations indicating influence or impact in the scientific community. The presence of countries like Ghana in the citations list suggests that while their production volume may be lower, the research coming out of there has a great impact. There is some overlap between the two lists, indicating that countries like the USA, China, and India not only produce a lot of research but also that their research is frequently cited.

3.3. Key Publishing Outlets

The table 2. analysis showcases a great portion of scholarly work in a few key journals, with the Journal of Agricultural Extension at the forefront, contributing the greatest number of articles.

Table 2. Key publishing outlets

Sources	Publisher	Articles
Journal of Agricultural Extension	Agricultural Extension Society of Nigeria	12
Information Development	SAGE Publications Ltd	8
Journal of Agricultural Education and Extension	Taylor and Francis Ltd	8
Sustainability (Switzerland)	MDPI	7
Journal of Agricultural and food Information	Taylor and Francis Group	6
International Journal of Agricultural Sustainability	Taylor & Francis	4
Library Philosophy and Practice	University of Idaho Library	4
Computers and Electronics in Agriculture	Elsevier	3
South African Journal of Agricultural Extension	Agricultural Extension Association of Africa	3
World Development	Elsevier	3

The table further illustrates that, alongside the Journal of Agricultural Extension, Information Development and the Journal of Agricultural Education and Extension stand out as the top three journals in terms of volume, prominently driving research publication in their domains.

3.4. Publication by Author and Organization

The table 3. shows a ranking of authors and organizations based on the number of published articles and the total citations (TC) received. The left column lists ten authors, with Leeuwis C at the top, who has authored four articles and has accumulated 122 citations, which indicates a great impact within the academic community. Lie R and Mcnamara Pe, each with four articles and 91 and 92 citations, respectively. The other authors listed, such as Oladele Oi, with three articles and 15 citations, and Steinkie J, with three articles but a higher citation count of 100, indicate varying levels of impact among their peers. On the right side, the table ranks ten organizations by the number of articles published under their name and the citations those articles have received. Wageningen University and Research Centre leads with 21 articles and 73 citations, showing highest research output. The University of Agriculture and Agricultural Information Institute are the following, with 8 and 7 articles, respectively. The University of Agriculture has a citation count of 110, and the Agricultural Information Institute has only 14 citations. Other institutions, such as King Saud University, with six articles and 48 citations, and Texas AANDM University with six articles yet no citations.

Table 3. Total publication & total citation by author and organization

Rank	Authors	Articles	TC	Organizations	Articles	TC
1	LEEUWIS C	4	122	WAGENINGEN UNIVERSITY AND RESEARCH CENTRE	21	73
2	LIE R	4	91	UNIVERSITY OF AGRICULTURE	8	110
3	MCNAMARA PE	4	92	AGRICULTURAL INFORMATION INSTITUTE	7	14
4	OLADELE OI	3	15	KING SAUD UNIVERSITY	6	48
5	STEINKE J	3	100	TEXAS AANDM UNIVERSITY	6	0
6	VAN DE GEVEL J	3	100	UNIVERSITY FOR DEVELOPMENT STUDIES	6	84
7	VAN ETTEN J	3	100	UNIVERSITY OF GHANA	6	46
8	AGUILAR-GALLEGOS N	2	31	UNIVERSITY OF THE WEST INDIES	6	25
9	AZUMAH SB	2	84	UNIVERSITY OF ZIMBABWE	6	27
10	CHAMBERLIN J	2	54	CENTRAL AGRICULTURAL UNIVERSITY	5	24

3.5. Citation Network Analysis

RQ 3: Which Articles have been most influential in shaping the understanding and implementation of digital technologies in agricultural extension?

To address RQ 3, we will use citation network analysis and data on the top 10 globally cited articles to identify the most influential works in digital technologies for agricultural extension. We'll also consider local and global citation counts for their impact and relevance.

Citation network analysis helps as a great method for finding the relationship of scholarly communications, which gives insights into how research influences and builds upon itself. (G P et al., 2023) emphasize that citation analysis enables the examination of knowledge flows and the visualization of research impact across disciplines, fueled by digital advancements that enable extensive large-scale studies. It's a tool that aside from tracing the lineage of ideas, it also helps in understanding the social construct of knowledge as articulated by McLaren and Bruner, who argue that citation practices within texts embody the foundational structure upon which current research stands, requiring citation network analysis as a method to capture these significant, yet often overlooked, metrics (McLaren & Bruner, 2022). Additionally, Meho discusses the transformation brought about by the digital era, where citation analysis has become an integral part of measuring scholarly impact, leveraging the Web to provide more accurate assessments of research and its reach (Meho, 2007). Together, these perspectives give a view on the dynamic nature of citation networks as evolving structures.

The table 4 in the previous page presents data from 166 articles was extracted using R's Biblioshiny. This analysis shows the top 10 articles with the highest number of global citations, representing how often each article has been cited by other works worldwide. Global citations help as an indicator of an article's impact and relevance. Also, the table includes local citations, referring to the number of times the articles have been cited within a more limited scope, such as a specific journal or geographic region. From this data, these articles hold more influence in the global academic community than in local or specialized contexts.

The top three articles originate from sources such as the Annual Review of Resource Economics, the Wageningen Journal of Life Sciences, and the American Journal of Agricultural Economics, with global citations of 134, 58, and 51, respectively. While local citations are generally low, the articles from the American Journal of Agricultural Economics and The Wageningen Journal of Life Sciences stand out with the highest local citation count of 8.

Table 4. Top contributing authors and organizations

Articles	Authors	Source	Pub. Years	GC	LC
The Power of Information: The ICT Revolution in Agricultural Development	Nakasone E.; Torero M.; Minten B.	Annual Review of Resource Economics	2014	134	8
Innovation intermediation in a digital age: Comparing public and private new-ICT platforms for agricultural extension in Ghana	Munthali N.; Leeuwis C.; van Paassen A.; Lie R.; Asare R, et al.	Wageningen Journal of Life Sciences	2018	58	8
Information and Communication Technologies to Provide Agricultural Advice to Smallholder Farmers: Experimental Evidence from Uganda	Bjorn Van Campenhout, Michael Joseph Puma	American Journal of Agricultural Economics	2021	51	5
Social Factors that Influence Use of ICT in Agricultural Extension in Southern Africa	Justice Stanley Tata, Ephraim Nkonya, Tahirou Abdoulaye	Agriculture (Switzerland)	2018	50	5
Changes in Agricultural Extension and Implications for Farmer Adoption of New Practices	George W. Norton, Jeffrey Alwang	Applied Economic Perspectives and Policy	2020	110	4
The determinants of mobile-phone usage among small-scale poultry farmers in Ghana	Folitse B.Y.; Manteaw S.A.; Dzandu L.P.; Obeng-Koranteng G.; Bekoe S.	Information Development	2019	24	3
How mobile phones contribute to growth of small farmers? evidence from India	Mittal S.; Mehar M.	Quarterly Journal of International Agriculture	2012	71	3
Factors Influencing Access to Integrated Soil Fertility Management Information and Knowledge and its Uptake among Smallholder Farmers in Zimbabwe	Gwandu T.; Mtambanengwe F.; Mapfumo P, et al.	Journal of Agricultural Education and Extension	2014	27	3
Household-Specific Targeting of Agricultural Advice via Mobile Phones: Feasibility of a Minimum Data Approach for Smallholder Context	Jonathan Steinke, Jerusha Achieng Onyango, James Hammond, et al.	Computers and Electronics in Agriculture	2019	8	2
User-Centered Design of a Digital Advisory Service: Enhancing Public Agricultural Extension for Sustainable Intensification in Tanzania	Berta Ortiz-Crespo, Jonathan Steinke, Carlos F. Quirós, et al.	International Journal of Agricultural Sustainability	2021	38	2

3.6. Keyword Analysis and co-occurrence Analysis

Keyword analysis in the bibliometrics context is a crucial method for understanding scientific knowledge's evolution and structure, as it plays an important role in bibliometric analysis giving us insights into various dimensions of research trends, technologies, and the connection of literature across disciplines.

Kawahara and Kawano emphasize that keyword analysis is crucial for getting more insightful rules in bibliographic databases. By exploring relationships between categorized attributes, keyword

analysis enhances bibliographic tools, shown by developing a bibliographic navigator. This approach enables a deeper understanding of literature and improves navigation through complex bibliographic information (Kawahara & Kawano, 2000).

Meanwhile, through analysis of keywords, researchers can discover emerging trends and shifts in research focus. (Zhang et al., 2010) showed how keyword analysis could reveal the evolving research trends in nanotechnology, pinpointing the shift from fundamental research to applications in energy and biomedicine. Keyword analysis can also be used to forecast future research directions. (Small, 2006) introduced a method for predicting the emergence of new scientific paradigms by analyzing the co-evolution of keywords in scientific literature, giving a tool for policymakers and researchers to anticipate future developments.

On the other hand, Keyword co-occurrence analysis can help assess the impact of research topics and the nature of scientific collaborations. (Leydesdorff & Milojevic, 2012) applied co-occurrence analysis to understand the interdisciplinary interactions within the field of bibliometrics itself, identifying the key areas where bibliometrics has made great contributions to other fields.

The keywords in table 5 are extracted using R Biblioshiny reflect the ten highest-frequency terms across 161 articles.

The terms 'agricultural extension,' 'Information and Communication Technology,' and 'agriculture' are the three most frequently occurring keywords. The most frequent keyword is "agricultural extension," appearing 38 times, suggesting that the concept of providing services to improve agricultural practices, productivity, and offer training to farmers is an important area of focus or concern within the scope of the articles sampled. "Information and Communication Technology," ranking second with 19 mentions, shows that there is considerable interest in how new technologies are being taken up by the agricultural sector, potentially focusing on innovation diffusion among farmers.

Table 5. Top keywords

Rank	Keywords	Frequency
1	agricultural extension	38
2	information and communication technology	19
3	agriculture	17
4	smallholder	14
5	agricultural technology	13
6	information dissemination	10
7	agricultural worker	9
8	china	8
9	farmers attitude	8
10	human	8

Keyword co-occurrence analysis is a key tool in bibliometric research, that enables scholars to map out the intellectual structure of various disciplines and discover emerging trend within the scientific literature. According to Wang and Chai, keyword co-occurrence is helpful in unveiling patterns and relationships within the literature, thereby facilitating the creation of new bibliometric indicators and methodologies. This indicates the method's use in deepening our understanding of research landscapes (Wang & Chai, 2018).

Fig. 4. Top keywords

The figure 5 displays a keyword co-occurrence network generated by VOSviewer. In these networks, the nodes represent keywords, and the connections (edges) between them represent the frequency with which two keywords appear together in the same set of documents (in this case, articles). The minimum number of occurrences of keywords for this network was set at seven keywords.

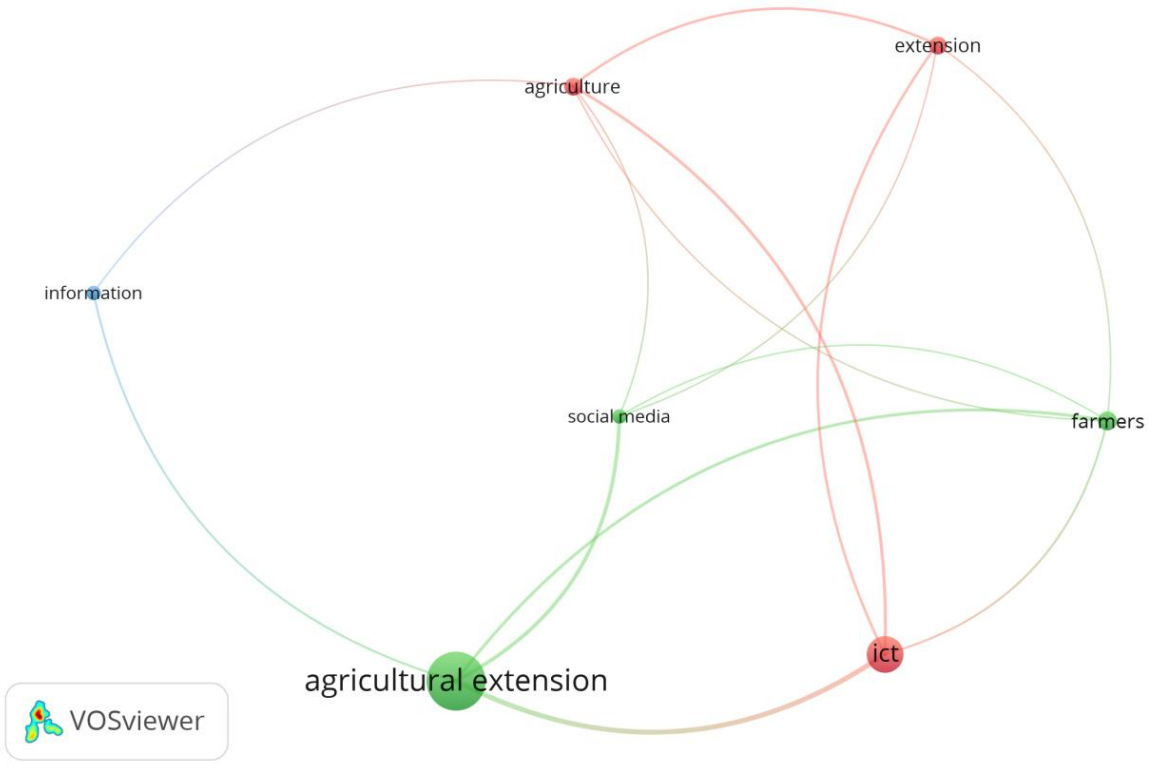

Fig. 5. Keyword co-occurrence network map

In this network, "Agricultural extension" appears as a larger node with many connections, showing it is a hub topic that is frequently discussed in conjunction with other subjects. The node's size indicates it is a predominant keyword within the data set. The network is color-coded, representing different clusters or themes within the data set.

3.7. International Collaboration Patterns

RQ 4: What is the current landscape of international collaborations among researchers in the field of digital innovations in agricultural extension, and how do these collaborations influence the research output and impact?

We will go into the international collaboration patterns found in 166 articles, mainly focusing on visualizing co-authorship connections between countries. Doing this allows us to understand the current landscape of international collaborations among researchers and how these collaborations influence the research output and impact. The analysis will examine the importance of collaborative research activity between countries regarding digital innovations in agricultural extension.

International co-authorship in research papers means a collaborative effort beyond national borders, creating a global research community. (Katz & Martin, 1997) showed the importance of internal collaboration in increasing the quality and impact of research outputs. They argued that collaboration enables sharing skills, and expertise among researchers, leading to higher-quality publications and innovative research findings.

The figure 6 taken from VOSviewer represents international co-authorship connections between various countries, with each node representing a country and the lines indicating the collaboration linkages between them. The connections among countries like India, Nigeria, and the United States are particularly prominent, suggesting substantial collaborative research activity between these countries in this research domain. The minimum number of documents of a country was set to 7, which resulted in 12 countries meeting the threshold out of the 56 countries available in the data set.

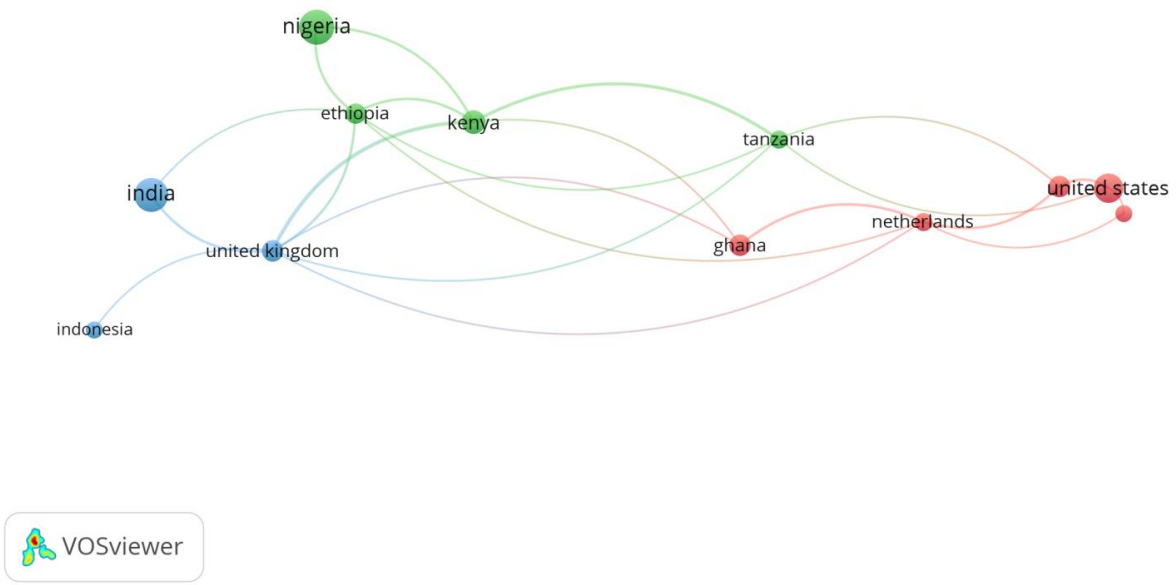

Fig 6. International collaboration network map

3.8. Bibliometric coupling and research themes

RQ 5: What are the dominant themes and emerging trends in the literature on digital innovations within the agricultural extension sector based on bibliometric coupling analysis?

Finally, for RQ 5, we will explore the identified themes and emerging trends through bibliometric coupling and research themes. This includes reviewing the bibliometric mapping to visualize the scientific research landscape and list the most influential studies, journals, authors, and emerging trends in literature.

Bibliometric mapping is a method used to visualize the landscape of scientific research. It has various techniques and tools to analyze and map bibliographic data that offers information into the development, structure, and relationships within specific research areas.

According to (Cobo et al., 2011) bibliometric mapping enables researchers to identify the most influential studies, journals, and authors, as well as emerging trends and patterns in literature. This method not only enables a complete understanding of a field's intellectual structure but also helps in the discovery of new research directions.

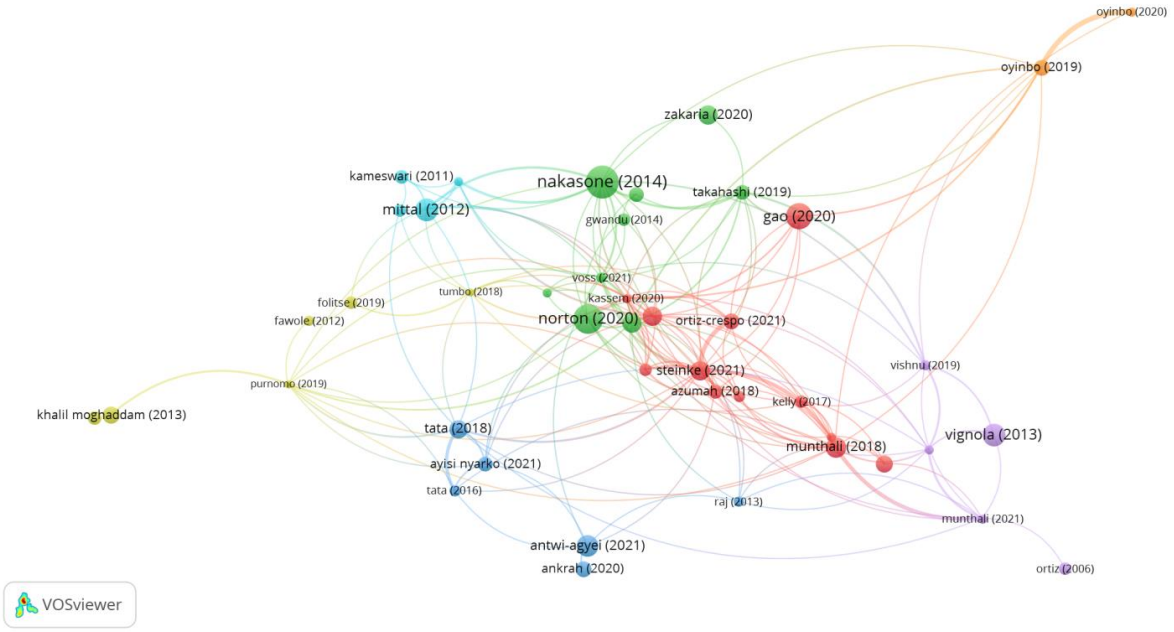

Fig 7. Bibliometric coupling theme map

Figure 7 shows network diagram, the articles are shown with nodes and the network shows the link between the articles. The bibliographic coupling of documents provides various clusters of documents. The citation has been taken 12. Out of 166 documents, 44 met the threshold. In our study, seven clusters are formed comprising 44 articles.

The table 6 shows the distribution of the number of publications over time from the year 2000 to 2023 across different thematic clusters. This can be useful for understanding trends, the evolution of research interests, and the impact of different research areas (indicated by citations). The number of links is related to how much the cluster themes are built upon previous publications or are interconnected with other research areas.

Table 6. Clusters Year-Wise

Year	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6	Cluster 7	Grand Total
2006					1			1
2011		1				1		2
2012				1		1		2
2013	1		1	1	1			4
2014	1	2				1		4
2016			1	1				2
2017	2							2
2018	3		1	1		1		6
2019		1		2	1		1	5
2020	3	2	1				1	7
2021	2	2	2		1			7
2022		1			1			2
Total Article	**12**	**9**	**6**	**6**	**5**	**4**	**2**	**44**
Total Citations	**465**	**476**	**222**	**143**	**144**	**139**	**54**	**1643**
Total Link Strength	**227**	**118**	**60**	**40**	**59**	**41**	**47**	**592**

In this section, we explore six identified themes. Cluster 7 has been excluded because only two publications supported it. For each theme, we present a list of all relevant articles, including details on their authors, publication years, sources, total citations, and link strength for each title. This set of tables aims to assist researchers in identifying current gaps and guiding future research in this domain.

Theme 1 discusses digital agricultural extension. Digital agricultural extensions are transforming the agricultural sector with the use of digital technologies to improve efficiency and accessibility of extension services. Also, integrating digital technologies into agricultural extension practices ensures real-time communication, proper decision-making, and access to extensive agricultural information, empowering farmers.

Table 7. Research themes (Cluster 1)

Cluster	Title of the Article	Authors	Year	Source	Total Citations	Total Link Strength	Themes
1	influence of a new agricultural technology extension mode on farmers' technology adoption behavior in china	gao, yang; zhao, duanyang; yu, lili; yang, haoran	2020	journal of rural studies, 76, 173-183	87	10	Digital Agricultural Extension
	tapping the full potential of the digital revolution for agricultural extension: an emerging innovation agenda	steinke, jonathan; van etten, jacob; müller, anna;	2021	international journal of agricultural sustainability, 19(6-may), 549-565	54	49	
	farmers' perception of the quality of mobile-based extension services in egypt: a comparison between public and private provision	kassem, hazem s; shabana, rasha m;	2020	information development, 36(2), 161-180	14	22	
	user-centred design of a digital advisory service: enhancing public agricultural extension for sustainable intensification in tanzania	ortiz-crespo, berta; steinke, jonathan; quirós, carlos f.; van de	2021	international journal of agricultural sustainability, 19(6-may), 566-582	38	21	
	agricultural technology transfer preferences of smallholder farmers in tunisia's arid regions	boubaker; rudiger, udo;	2020	sustainability (switzerland), 12(1)	24	15	
	networked learning for agricultural extension: a framework for analysis and two cases	kelly, nick; bennett, john mclean; starasts, ann	2017	journal of agricultural education and extension, 23(5), 399-414	25	9	
	design and development of a digital farmer field school. experiences with a digital learning environment for cocoa production and certification in sierra leone	witteveen, loes; lie, rico; goris, margriet; ingram, verina	2017	telematics and informatics, 34(8), 1673-1684	14	9	
	the perceived effectiveness of agricultural technology transfer methods: evidence from rice farmers in northern ghana	azumah, shaibu baanni; donkoh, samuel a.;	2018	cogent food and agriculture, 4(1)	31	15	
	transforming the roles of a public extension agency to strengthen innovation: lessons from the national agricultural extension project in bangladesh	chowdhury, ataharul huq; hambly odame,	2014	journal of agricultural education and extension, 20(1), 7-25	45	5	
	can mobile phone-based animated videos induce learning and technology adoption among low-literate farmers? a field experiment in burkina faso	maredia, mywish k.; reyes, byron; ba, malick n.;	2018	information technology for development, 24(3), 429-460	52	23	
	agricultural extension in asia: constraints and options for improvement	baig, m.b.; aldosari, f.	2013	journal of animal and plant sciences, 23(2), 619-632	23	10	
	innovation intermediation in a digital age: comparing public and private new-ict platforms for agricultural extension in ghana	munthali, nyamwaya; leeuwis, cees;	2018	njas - wageningen journal of life sciences, 86-87, 64-76	58	39	

The digitization of agricultural extension is enhancing the delivery of information, knowledge, and advisory services to farmers more efficiently, timely, and targeted. Key elements include infrastructure and connectivity, farmer-centric approaches, tailored and context-specific content, interactive platforms, and public-private partnerships (Awad, 2021).

(Ortiz-Crespo et al., 2021) detail the user-centered design of a digital advisory service called Ushauri in Tanzania, which aimed to increase public agricultural extension for sustainable intensification. The service allows farmers to access pre-recorded messages and interact with extension agents through an automated hotline, showing the capability of digital platforms to deliver tailored agricultural advice efficiently

(Steinke et al., 2020) emphasize the untapped potential of the digital revolution in agricultural extension, advocating for an emerging innovation agenda that responds to the specific communication challenges of potential users. The study sheds light on the need for user-centered design and problem orientation in developing new services, suggesting that digital media can address common deficiencies of agricultural extension by enhancing user engagement, tailoring advice to individual needs, and facilitating direct farmer-to-farmer communication.

The second theme discusses the adoption of ICT in agricultural extension. Adoption of information and communication technologies in agricultural extension services is changing how information is disseminated among farmers which increases agricultural productivity and sustainability. ICT in agricultural extension involves using digital tools, including mobile phones, internet platforms, and specialized software, to provide farmers with relevant information on agricultural practices, farming trends, and weather forecasts. A major shift towards digital agricultural extension has been observed over the past four decades, driven by various factors, including structural changes in agriculture, the development of new agricultural technologies and information, advancements in ICT, and the changing dynamics of funding support and government decentralization. These changes have led to the emergence of pluralistic extension systems that combine public and private mechanisms for financing and implementing extension activities (Norton & Alwang, 2020).

ICTs, including mobile phones and internet platforms, have the potential to enhance the efficiency of agricultural extension services by providing a platform for rapid dissemination of information. However, the adoption and impact of ICTs vary, with huge benefits in enhancing market performance at the macro level, while impacts at the micro level are mixed (Spielman et al., 2021).

Table 8. Research themes (Cluster 2)

Cluster	Title of the Article	Authors	Year	Source	Total Citations	Total Link Strength	Themes
2	analyzing ict-enabled agricultural advisory services in pakistan: evidence from a marginalized region of punjab province	khan, nasir abbas; gao, qijie; ali, shoukat; shahbaz, babar; khan, palwasha; abid, muhammad	2022	electronic commerce research, 22(4), 1107-1129	15	5	Adoption of ICT in Agricultural Extension
	encouraging technology adoption using icts and farm trials in senegal: lessons for gender equity and scaled impact	voss, rachel c.; jansen, tony; mané, bacary; shennan, carol	2021	world development, 146	19	21	
	adoption of climate-smart agricultural practices among farm households in ghana: the role of farmer participation in training	zakaria, abraham; azumah, shaibu baanni; appiah-twumasi, mark; dagunga, gilbert	2020	technology in society, 63	53	2	
	and implications for farmer adoption of new practices	norton, george w.; alwang, jeffrey	2020	perspectives and policy, 42(1), 8-20	110	14	
	information and communication technologies to provide agricultural advice to smallholder farmers:	van campenhout, bjorn; spielman, david j.; lecoutere, els	2021	american journal of agricultural economics, 103(1), 317-337	51	19	
	farmers about rice production: experimental evidence from cote	takahashi, kazushi; mano, yukichi; otsuka, keijiro	2019	world development, 122, 157-169	33	19	
	revolution in agricultural development	nakasone, eduardo; torero, maximo; minten, bart	2014	annual review of resource economics, 6(1), 533-550	134	30	
	factors influencing access to integrated soil fertility management information and knowledge and its	gwandu, t.; mtambanengwe, f.; mapfumo, p.; mashavave,	2014	journal of agricultural education and extension, 20(1), 79-93	27	4	
	coupled information diffusion-pest dynamics models predict delayed benefits of farmer cooperation in	rebaudo, françois; dangles, olivier	2011	plos computational biology, 7(10)	34	4	

Theme 3 addresses the impact of ICT on agricultural extension. ICT boosts extension services by using tools like mobile phones, SMS, and call centers. Research findings indicate that farmers using ICT in farming activities have increased their farm productivity by approximately 2.01% compared to those without exposure to ICT (Chhetri, 2016). ICT in agricultural extension offers new ways to communicate, disseminate information, and interact with farmers, increasing agricultural productivity, market access, and farmer livelihoods.

While ICT has the potential to impact agricultural extension in a big way, several challenges hinder its practical use. These challenges include insufficient training for extension workers in ICT, lack

Table 9. Research themes (Cluster 3)

Cluster	Title of the Article	Authors	Year	Source	Total Citations	Total Link Strength	
3	gendered access to productive resources – evidence from small holder farmers in awutu senya west district of ghana	ankrah, daniel adu; freeman, comfort y.; afful, albert	2020	scientific african, 10	39	2	Impact of ICT in Agricultural Extension
	improving the effectiveness of agricultural extension services in supporting farmers to adapt to climate change: insights from northeastern ghana	antwi-agyei, philip; stringer, lindsay c.	2021	climate risk management, 32	62	7	
	information and communication technologies (icts) usage among agricultural extension officers and its impact on extension delivery in ghana	ayisi nyarko, daniel; kozári, józsef	2021	journal of the saudi society of agricultural sciences, 20(3), 164-172	32	9	
	e-agriculture prototype for knowledge facilitation among tribal farmers of north-east india: innovations, impact and lessons	raj, saravanan	2013	journal of agricultural education and extension, 19(2), 113-131	17	7	
	social factors that influence use of ict in agricultural extension in southern africa	tata, joyous s.; mcnamara, paul e.	2016	agriculture (switzerland), 6(2)	22	14	
	impact of ict on agricultural extension services delivery: evidence from the catholic relief services smart skills and farmbook project in kenya*	tata, joyous s.; mcnamara, paul e.	2018	journal of agricultural education and extension, 24(1), 89-110	50	21	

of infrastructure, and inadequate localization and contextualization of content, which can limit the actionable value of information disseminated through ICT (Bhavesh, 2015).

The e-Agriculture prototype implemented among tribal farmers in North-East India showed the capacity of ICT to streamline the extension service delivery process, substantially saving costs and time for farmers and extension agents. However, it also emphasized that ICT solutions alone may not suffice in less developed areas without the support of field demonstrations, forward and backward linkages, and appropriate public-private partnerships to facilitate complete agricultural development (Raj, 2013).

Theme 4 explores the barriers to adopting ICT in agricultural extension. Several barriers hinder ICT widespread adoption, impacting the reach of extension services. Understanding these barriers is crucial for fully leveraging ICT's potential in agricultural extension.

In many rural areas, particularly in developing countries, access to reliable internet is a major barrier. The need for connectivity limits the use of online ICT tools and platforms necessary for modern agricultural extension (Purnomo & Kusnandar, 2018).

In some communities, there is resistance to adopting new technologies due to cultural preferences for traditional farming practices and skepticism towards digital solutions.

Overcoming this barrier requires demonstrating the tangible benefits of ICT to farmers and building trust in technology-based interventions (Cynthia & Nwabugwu, 2016).

Table 10. Research themes (Cluster 4)

Cluster	Title of the Article	Authors	Year	Source	Total Citations	Total Link Strength	Themes
4	the determinants of mobile-phone usage among small-scale poultry farmers in ghana	folitse, benjamin yao; manteaw, seth awuku; dzandu, lucy payne; obeng-koranteng, grace; bekoe, stephen	2019	information development, 35(4), 564-574	24	5	Barriers in adoption of ICT in Agricultural Extension
	barriers to acceptance of information and communication technology in agricultural extension in indonesia	purnomo, sutrisno hadi; kusnandar	2019	information development, 35(4), 512-523	13	16	
	factors affecting ict adoption among rural users: a case study of ict center in iran	khalil moghaddam, b.; khatoon-abadi, a.	2013	telecommunications policy, 37(11), 1083-1094	45	4	
	awareness and use of information communication technologies by farmers in oyo state, nigeria	fawole, o.p.; olajide, b.r.	2012	journal of agricultural and food information, 13(4), 326-337	18	2	
	exploring information seeking behavior of farmers' in information related to climate change adaptation through ict (chai)	tumbo, siza d.; mwalukasa, nicholaus; fue, kadeghe g.; mlozi, malongo r.s.; haug, ruth; sanga, camilius a.	2018	international review of research in open and distance learning, 19(3), 299-319	13	12	
	farmer perceptions of wetlands and waterbodies: using social metrics as an alternative to ecosystem service valuation	greenland-smith, simon; brazner, john; sherren, kate	2016	ecological economics, 126, 58-69	30	1	

In Nigeria, despite farmers' widespread awareness of older ICTs such as radio and television, modern ICTs like mobile phones and the Internet are less prevalent. This discrepancy is attributed to several constraints, including the prohibitive cost of ICT tools and services, service failures, and the need for a robust support system for ICT usage in agricultural practices. These challenges are exacerbated by broader infrastructural issues, such as unreliable electricity supply and the general low socioeconomic status of rural and smallholder farmers, which limit their ability to afford and effectively use ICTs (Fawole & Olajide, 2012).

Theme 5 shows the use of social media in agricultural extension. The use of social media in agricultural extension shows a modern approach to enhancing the dissemination of information and knowledge among farmers.

Social media provide a powerful platform for the diffusion of agricultural knowledge, enabling faster adoption of new technologies among farmers. Effective communication within these networks, facilitated by extension officers and other actors, can greatly impact the agricultural knowledge transfer process which offers an alternative to traditional extension practices (Nadeeshani Silva, 2023).

Table 11. Research themes (Cluster 5)

Cluster	Title of the Article	Authors	Year	Source	Total Citations	Total Link Strength	Themes
5	social media platforms, open communication and problem solving in the back-office of ghanaian extension: a substantive, structural and relational analysis	munthali, nyamwaya; van paassen, annemarie; leeuwis, cees; lie, rico; van lammeren, ron; aguilar-gallegos, norman; oppong-mensah, birgitta	2021	agricultural systems, 190	15	23	Use of Social Network in Agricultural Extension
	social network analysis of spreading and exchanging information on twitter: the case of an agricultural research and education centre in mexico	aguilar-gallegos, norman; klerkx, laurens; romero-garcía, leticia elizabeth; martínez-gonzález, enrique genaro; aguilar-ávila, jorge	2022	journal of agricultural education and extension, 28(1),	16	16	
	social network structures among the livestock farmers vis a vis calcium supplement technology	vishnu, sreeram; gupta, jancy; subash, s.p.	2019	processing in agriculture, 6(1),	17	14	
	governance structures for ecosystem-based adaptation: using policy-network analysis to identify key organizations for bridging information across scales and policy areas	vignola, raffaele; mcdaniels, timothy l.; scholz, roland w.	2013	environmental science and policy, 31, 71-84	72	5	
	evolution of agricultural extension and information dissemination in peru: an historical perspective focusing on potato-related pest control	ortiz, oscar	2006	agriculture and human values, 23(4), 477-489	24	1	

In the Article "Social network analysis of spreading and exchanging information on Twitter: the case of an agricultural research and education centre in Mexico" (Aguilar-Gallegos et al., 2022), the study provides an analysis of how a Mexican agricultural research and education center used Twitter to foster a virtual community, which indicates the roles various accounts play within the network. The findings emphasize the importance of strong and weak ties for spreading information and engaging in a community on social media which gives information into optimizing online networks for agricultural extension.

The final theme focuses on digital agricultural extension in developing regions. Rajkhowa and Qaim provide evidence from India on the positive connection between the use of personalized digital extension services and smallholder agricultural performance. Personalized information on crop choices, input types, and cultivation methods has been linked with increased input intensity, production diversity, crop productivity, and income, underscoring the potential of digital technologies to tailor extension services to individual needs and conditions for better agricultural outcomes (Rajkhowa & Qaim, 2021).

Table 12. Research themes (Cluster 6)

Cluster	Title of the Article	Authors	Year	Source	Total Citations	Total Link Strength	Themes
6	addressing the challenges of extension and advisory services in uganda: the grameen foundation's community knowledge worker program	mccole, daniel; culbertson, michael j.; suvedi, murari; mcnamara, paul e.	2014	journal of international agricultural and extension education, 21(1), 6-18	15	14	Digital Agricultural Extension in Developing Regions
	how mobile phones contribute to growth of small farmers? evidence from india	mittal, surabhi; mehar, mamta	2012	quarterly journal of international agriculture, 51(3), 227-244	71	17	
	icts for agricultural extension: a study in the indian himalayan region	kameswari, v.l.v.; kishore, devash; gupta, vinita	2011	electronic journal of information systems in developing countries, 48(1), 1-12	29	5	
	sources of agricultural information for women farmers in tanzania	isaya, elizabeth l.; agunga, robert; sanga, camilius a.	2018	information development, 34(1), 77-89	24	5	

4. CONCLUSIONS

The study "Digital Innovations in Agricultural Extension: Exploring the Role of ICT and Social Media in Information Dissemination" explores the role of Information and Communication Technologies (ICT) and social media in agricultural extension. The study outlines how ICT, encompassing mobile technology, the internet, and radio broadcasts, has provided farmers direct access to critical information on crop management, pest control, market prices, and weather forecasts.

Moreover, the study explores how social media platforms like Facebook, Twitter, YouTube, and WhatsApp have become as vital channels for disseminating agricultural information. The synergy between ICT and social media can change the landscape of agricultural extension, easing information access, enhancing advisory services quality, and creating collaborative networks among stakeholders.

Furthermore, using data from the Scopus database, a robust bibliometric analysis is done to examine the role of ICT and social media on agricultural extension. The process—from initial database searching to manual review—ensures the selection of relevant articles, giving a final set of 166 relevant documents. Tools like R's Biblioshiny and VOSviewer provides thorough data analysis and enhance the understanding of complex datasets through graphical representations, making it easier to find trends, relationships, and thematic structures.

The findings of this bibliometric analysis study provide a bigger view of digital innovations in agricultural extension from 2000 to 2023. The data shows a huge and growing interest in this research area, shown by an annual growth rate of 13.66% in published documents. This uptrend in publication volumes, particularly noticeable from 2017 onwards, indicates high interest in this field. Further findings reveal that key countries like the USA, China, and India are active in their research output and their impact, as shown by high citation counts.

The study's citation network analysis and keyword co-occurrence act as essential methods for understanding the relevance and impact within this research area. The top cited articles, identified through their global and local citations, show the impact and relevance of the research within the global academic community.

Also, the keyword analysis and co-occurrence provide deep insights into the field's thematic clusters and intellectual structure. The prominence of "agricultural extension" and "ICT" and their frequent connections with other keywords indicate a strong focus on integrating technology into agricultural extension. Additionally, the visualization of international collaboration patterns shows a strong network of partnerships across countries, with notable interactions between researchers in India, Nigeria, and the United States.

The final section of the study, focusing on bibliometric coupling and research themes, offers an exploration of the major themes. The analysis reveals that digital agricultural extension, the adoption of ICT, the impact of these technologies on extension services, and the barriers to their full utilization represent core themes in the literature.

To conclude, the study underlines the important role of digital innovations in agricultural extension, showing the potential of ICT and social media in enhancing information dissemination and knowledge exchange among agricultural households. The findings stress the necessity for addressing challenges to fully use digital innovations' benefits, further research to explore bigger factors affecting ICT integration in agricultural extension and impacts of social media platforms on the agricultural households.

4.2. Scope for Further Research

Even though this study provides overall bibliometric analysis of the field, there still remain several areas that can be explored further. While some studies have explored barriers to the integration of ICT in agricultural extension, there is a need for more comprehensive research that looks at a broader range of factors, including individual, cultural, governmental policy, support, and technological barriers and their combined effect on the acceptance of ICT (Purnomo & Kusnandar, 2018).

Based on (Samadder et al., 2023), research is needed to assess how social media platforms specifically cater to and impact the agricultural community beyond the generalized use of ICT. This includes analyzing the effectiveness of these platforms in improving agricultural outcomes, community engagement, and knowledge sharing among farmers.

The further research focus can be on a deeper analysis of barriers to ICT integration with research beyond in field of individual, cultural, governmen, the impact of social media on agricultural communities and user-centered design of digital extension services. Also, exploring emerging trends and technologies such as artificial intelligence, machine learning, and blockchain can provide further details into the future directions of digital agricultural extension.

Thus, the following areas can be explored deeply for further research:

- In-depth analysis of barriers to ICT integration
- Social media impact on agricultural households
- New trends and technologies in agricultural extensions
- Government policies in adoption of agricultural extensions

By exploring these areas, future research can provide useful insights and suggestions to make ICT and social media more effective and widely used in agricultural extension. This will help improve agricultural productivity and sustainability.

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