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A TCCM -BASED SYSTEMATIC REVIEW ON FARMERS' TECHNOLOGY ADOPTION THROUGH DIGITAL EXTENSION

A. Awentia [1], M. Senthilkumar[2*], C. Karthikeyan [3], M. Prahadeeswaran [4], B. Vinoth Kumar[5]

[1] Department of Agricultural Extension and Rural Sociology, Tamil Nadu Agricultural University, Coimbatore-641 003, India
[2] Training Division, Directorate of Extension Education, Tamil Nadu Agricultural University, Coimbatore-641 003, India
[3]Department of Agricultural Extension and Rural Sociology, Tamil Nadu Agricultural University, Coimbatore-641 003, India
[4] Department of Agricultural Economics, Tamil Nadu Agricultural University, Coimbatore-641003, India
[5] Department of Agricultural Entomology, Tamil Nadu Agricultural University, Coimbatore- 641003, India
*Corresponding Author Email -senthilmsk@tnau.ac.in

ABSTRACT
The rapid advancement of Information and Communication Technologies (ICTs) has transformed agricultural extension systems and improved farmers' access to agricultural information. Among digital communication platforms, YouTube has emerged as an important medium for disseminating agricultural knowledge through video-based learning and interactive communication. This study systematically reviews the literature on farmers' technology adoption through agricultural YouTube channels and digital extension platforms using bibliometric analysis and the TCCM (Theory–Context–Characteristics–Methodology) framework. The review followed the PRISMA methodology and utilized the Scopus database for literature retrieval. A total of 345 publications were initially identified, of which 96 studies were selected for final analysis after applying predefined inclusion and exclusion criteria. The findings reveal increasing publication trends, growing international collaboration, and strong intellectual connectivity within digital agricultural extension research. Existing studies primarily focus on e-extension, ICT applications, mobile-based advisory services, and digital communication technologies, while YouTube-specific agricultural extension research remains comparatively limited. The review further identified perceived usefulness, digital literacy, internet accessibility, content credibility, social influence, and ICT infrastructure as major factors influencing farmers' adoption of agricultural technologies through YouTube-based platforms. The study also highlights the dominance of quantitative and cross-sectional approaches, indicating the need for more qualitative, longitudinal, and user-centred research. Overall, the findings emphasize the growing role of YouTube-based agricultural communication in enhancing agricultural knowledge dissemination, farmer learning, and sustainable technology adoption.

KEYWORDS: agricultural extension; digital agriculture; e-extension; farmers' technology adoption; information and communication technology; youtube-based extension

INTRODUCTION

The agricultural sector still plays an important role in providing sustenance, ensuring food security, and fostering economic growth in numerous developing nations, including India, in which a significant percentage of its population is engaged in agriculture either directly or indirectly. In today's agricultural world, the availability of accurate and pertinent information has assumed a high level of significance in terms of increasing productivity, generating income for farms, and achieving agricultural growth through sustainability. Agricultural innovations relating to crop cultivation, pest control, irrigation, mechanization, post-harvest operations, and climate-based agriculture are emerging at a fast pace, necessitating effective means of agricultural communication and extension (1).

In general, the traditional agricultural extension system has been used as the principal means of spreading agricultural innovations among farm communities. Public extension organizations, agricultural universities, Krishi Vigyan Kendras (KVKs), agricultural research centers, demonstrations in the fields, radio shows, TV shows, and training sessions for farmers have traditionally played a role in transferring agricultural knowledge. Nonetheless, there exist several problems inherent to conventional agricultural extension systems such as the lack of extension workers, unfavorable ratio of farmers to extension workers, insufficient funding, poor infrastructure development, and restricted outreach in rural areas far from the main centers (2). The development of ICTs at breakneck speed has greatly changed the field of agriculture through communication and extension in many parts of the world. Modern technologies like smartphones, internet connectivity, mobile apps, social networking sites, and online video websites have provided innovative ways to transmit agricultural information to rural farmers more effectively and interactively (3). ICT-based agricultural extension systems have become famous for helping to achieve real-time communication, overcoming physical distance, improving farmer involvement, and providing information about science, technology, and the market place.

There are several ways of digital communication that can be adopted for agricultural information sharing. In this context, YouTube has been found to be an effective method due to its role in agricultural information exchange and education. YouTube is a popular video sharing site that allows users to upload, view, share, and comment on video files. Due to the

video nature of YouTube, this form of digital communication becomes more appropriate for agricultural extension work due to the practical nature of agricultural practices. By using videos, farmers can watch agricultural operations such as seed bed preparations, grafting, fertilizing, pest and disease control, irrigation systems, machine use, and harvesting procedures (4). Rising smartphone usage and availability of cost-effective internet services have increased the use of YouTube among the rural population. Digital India, BharatNet, and other rural internet services in India have significantly enhanced digital connectivity among rural people (5). Therefore, YouTube channels dedicated to agriculture created by forward-thinking farmers, agricultural institutions, agritech firms, extension workers, NGOs, and independent content providers are increasingly becoming sources for agricultural information and guidance.

Agricultural YouTube channels offer a lot of information on topics such as crop farming, organic farming, weather forecast, market price, livestock farming, government initiatives, success stories, and innovations in agricultural technology. While conventional extension mechanisms have been more of one-way methods, the use of YouTube for extending information creates opportunities for collaborative and self-directed learning platforms. Farmers can watch video anytime that suits them, communicate by commenting, resolve any misunderstandings, share experiences, and compare farming techniques across various places and nations. Interactive communication is essential for experiential learning and agriculture education (6). The existing empirical literature has emphasized the role played by digital media and social networks in the dissemination and adoption process of agricultural technologies. It has been found that farmers have been increasingly using video-based agricultural information due to its availability, clear presentation, practicality, and relevance to the current context (7). In addition, video-based extension has proved successful in enhancing awareness, attitude, skill, and behavioral intention among farmers related to new technologies in agriculture. Moreover, previous research studies have identified that educational background, age, farm size, digital literacy, access to internet, social influence, and perceptions about usefulness and ease-of-use play a critical role in shaping farmers' adoption behavior (8). In this regard, the integration of YouTube in agricultural extension systems is further influenced by the increasing adoption of digital agriculture or smart farming systems. Digital agriculture utilizes cutting-edge technology including artificial intelligence, big data analytics, remote sensing, precision farming, and digital communication systems to increase agricultural efficiency and sustainable practices (9). As part of the larger ecosystem of modern technologies, YouTube serves as not just a means of communication, but also an innovative platform for sharing information and knowledge between experts in the field of agriculture and farm communities.

Although there has been a rise in the number of agricultural YouTube channels and their real-life applications, the existing academic literature on this topic is not well-integrated. There have been different research papers on the subject matter in multiple fields such as agricultural extension, rural sociology, communications, information systems, digital media, and innovations studies. Furthermore, all past studies have generally emphasized the adoption of ICTs, social media, and digital agricultural extension but paid little attention to farmers' technology adoption on agricultural communication channels on YouTube.

Systematic literature reviews and bibliometric analyses have become increasingly significant for synthesis and identification of new research agendas in fragmented disciplines in recent times. Bibliometric analysis involves the quantification of the state of affairs, such as publication patterns, citation patterns, influential researchers, journals, networking and themes in the area under study (10). Systematic literature reviews on the other hand help conduct critical appraisals of researches already conducted. The most efficient strategy among all those presented above is TCCM (theory–context–characteristics-methodology), which was suggested by Paul and Rosado-Serrano (11). The TCCM framework divides the body of existing literature into categories depending on theories applied, context analyzed, characteristics studied, and methodology used. This strategy allows identifying some of the possible gaps in theory, contexts that should be considered, as well as potential avenues for future research.

Given the rapid growth of agricultural digital communications and the growing impact of YouTube-based agricultural extension systems, there is an urgent need for a thorough review of the extant literature on the subject matter. An analysis of previous research studies would enable us to better understand the major trends and themes within the literature, as well as the theoretical foundations and methodological approach behind it. Therefore, the present study aims to conduct a systematic literature review and bibliometric analysis on farmers' technology adoption through agricultural YouTube channels. Specifically, the study seeks to:

(1) Examine recent publication trends through bibliometric analysis;

(2) evaluate the existing literature on agricultural YouTube-based extension using the TCCM framework; and

(3) Identify the major factors influencing farmers' adoption of agricultural technologies through YouTube-based digital extension platforms.

METHODOLOGY

The current study adopted a systematic literature review (SLR) and bibliometric analysis approach in investigating the extant literature on the uptake of technology by farmers using agricultural YouTube channels. The review was conducted following the PRISMA framework to guide the selection of the relevant literature (12). Selection of the Scopus database as a source of literature search was due to its wide range of articles that were peer-reviewed and covered agricultural extension, communication sciences, digital agriculture, information systems, and rural development. The inclusion/exclusion criteria that guided the process are presented in Table 1 below. The time frame used in conducting this review was from 2015 to 2026 since this era experienced tremendous growth in digital agricultural communication as well as the availability of smartphones and internet connectivity. The era was marked by many studies on ICT-enabled agricultural extension services and farmers' technology behavior.

Table 1. Inclusion and exclusion criteria

Databases	Inclusion	Exclusion
Time span	2015 – 2026	<2015
Document type	Articles, Review	Conference papers, Book chapters, Books, Editorials, Conference reviews
Languages	English	Non- English And others all
Source type	Journal	Trade journal Book series Book Conference proceeding
Publication stage	Final	Article in press
Open access	All open access	Others

A systematic search strategy was developed using keywords such as “Agricultural YouTube Channels,” “YouTube-based Extension,” “YouTube in Agriculture,” “Agricultural Video Platforms,” “Digital Agricultural Communication,” “Social Media Extension,” “E-Extension,” “Digital Extension Services,” and “ICT-based Agricultural Extension.” Boolean operators such as AND and OR were applied to improve the relevance and comprehensiveness of the search process. The detailed search keywords are presented in Table 2.

Table 2. The list of keywords employed during the database literature searches

DATABASES	KEYWORDS	TOTAL NUMBER OF ARTICLE
Scopus	"Agricultural YouTube Channels" OR "YouTube-based Extension" OR "YouTube in Agriculture" OR "Agricultural Video Platforms" OR "Digital Agricultural Communication" OR "Social Media Extension" OR "E-Extension" OR "Digital Extension Services" OR "ICT-based Agricultural Extension"	345

The initial search in the Scopus database identified 345 publications related to the research topic. After applying the inclusion and exclusion criteria, duplicate and irrelevant studies were removed during the screening stage. Only English-language journal articles, review papers, and conference papers were included, while editorials, books, book chapters, conference reviews, trade journals, conference proceedings, book series, and articles in press were excluded from the analysis.

The remaining studies were further evaluated based on titles, abstracts, and keywords to ensure their relevance to agricultural YouTube channels, digital agricultural communication, ICT-enabled extension systems, and farmers’ technology adoption through digital platforms. The quality assessment process focused on scientific relevance, methodological clarity, and thematic consistency. After the final screening process, 96 articles were selected for detailed review and bibliometric analysis. The overall selection process is illustrated in the PRISMA flow diagram presented in Figure 1.

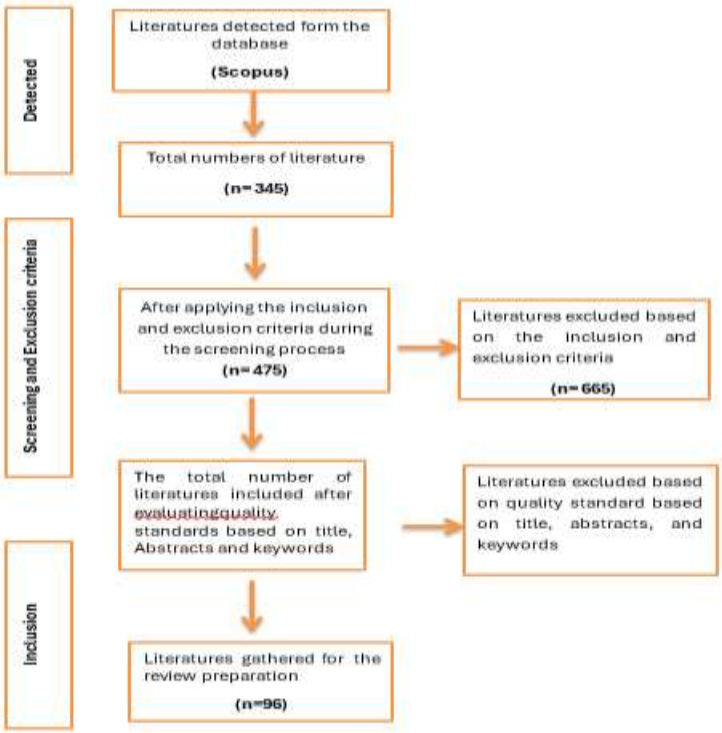

Fig. 1. The PRISMA flowchart.

Bibliometric analysis has been performed to analyze the publication pattern, prominent researchers, leading journals, citation pattern, and most frequent keywords among the studied literature. Also, TCCM (Theory-Context-Characteristics-Metho dology) model, suggested by Paul and Rosado-Serrano, has been followed to categorize the selected literature into various groups (11). TCCM model has helped in finding out the prevailing theories, context, variables, methodology, as well as future research directions for agricultural YouTube-based digital extension.

RESULT AND DISCUSSION

Co-authorship Network of Authors

Co-authorship network among authors who conduct research in agriculture-focused YouTube channels, digital agricultural extension, and farmers' adoption of technologies is illustrated in Figure 2. VOSviewer software was used to create the network, with nodes representing authors while connections between them signify collaborative research activities. Linkage density in the network measures the extent of cooperation among scholars conducting research in the area.

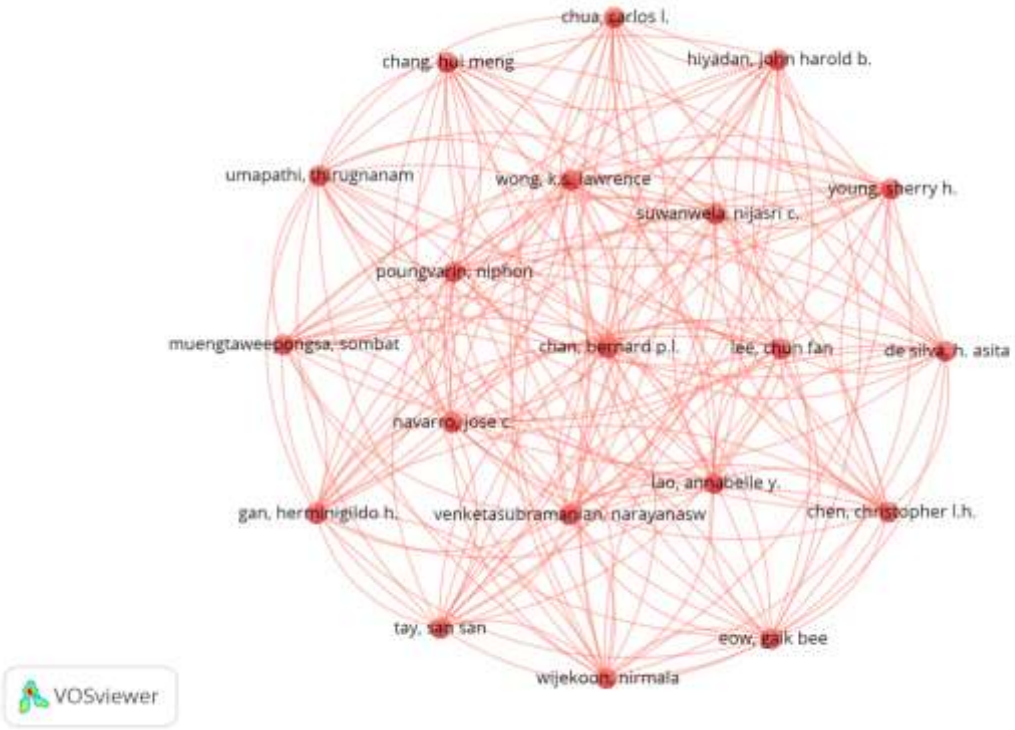

Fig. 2. Co-authorship Network of Authors in Agricultural YouTube-Based Digital Extension Research

It can be observed from the figure that the research community is very well interconnected, signifying the high degree of collaboration and interdisciplinary nature of research being conducted. Key nodes in the network include authors like Chan Bernard P.L., Wong K.S. Lawrence, Suwanwela Nijasri C., and Poungvarin Niphon, implying a higher level of collaboration and academic influence. The high levels of author collaboration suggest that the current research involves knowledge transfer and similar research areas concerning digital agriculture, social media extension, and technology adoption behavior. The use of different author collaboration paths also shows that the development of this area happens due to joint efforts of scientists rather than individual studies.

Some authors, such as Wijekoon Nirmala, Young Sherry H., and De Silva H. Asita, find themselves in the outer part of the network and have less collaboration links compared to other authors, showing low degrees of interaction. However, the inclusion of these researchers shows that the range of research in the sphere of digital agricultural extension expands. In summary, the co-authorship network reveals the increased interdisciplinary and collaboration trends in agricultural YouTube channels and digital extension studies. High levels of connectivity show that researchers' interest in digital agricultural communication and its application to increase technology adoption is constantly rising.

Co-authorship Network of Countries

Figure 3 illustrates the co-authorship network of countries contributing to research on agricultural YouTube channels, digital agricultural extension, and farmers' technology adoption. The network was generated using VOSviewer software, where nodes represent countries and connecting lines indicate collaborative research relationships. Node size reflects publication strength, while link thickness represents the intensity of international collaboration.

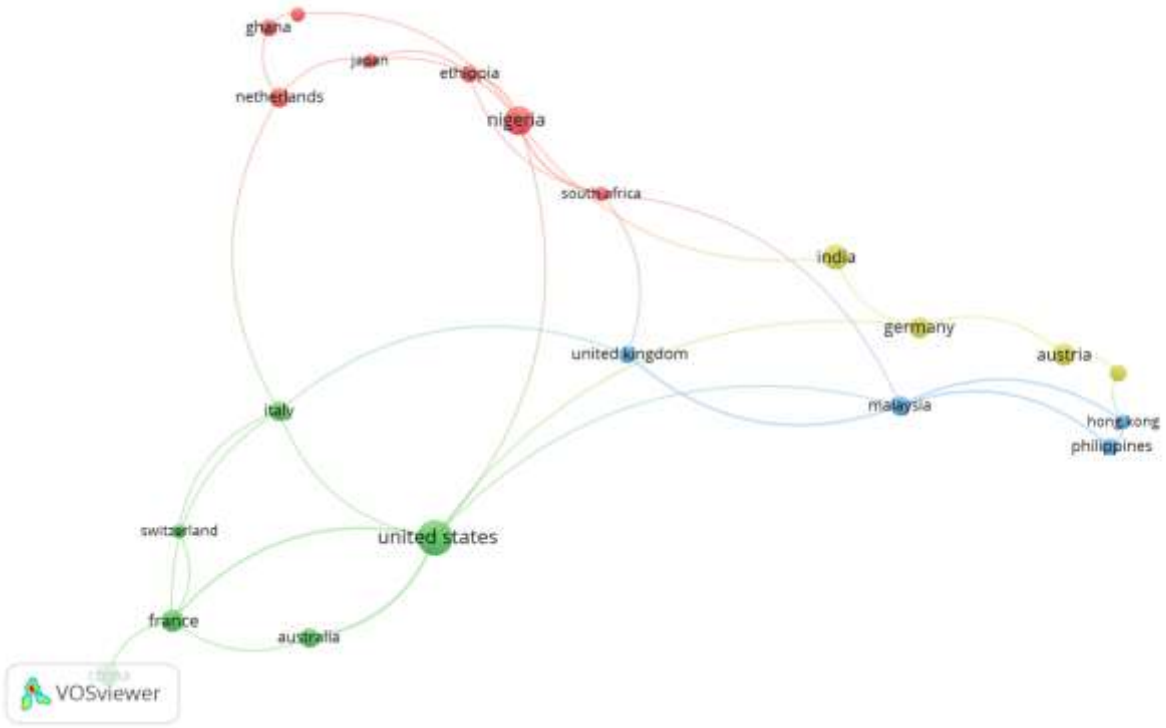

Fig. 3. Co-authorship Network of Countries in Agricultural YouTube-Based Digital Extension Research.

In this network, it becomes apparent that there is rising international collaboration in digital agricultural extension research. It should be noted that the United States holds a very central place, suggesting highly productive research activities and extensive collaboration with nations like the United Kingdom, Australia, France, and Malaysia. This suggests the dominant role played by developed nations in forming the intellectual structure of this research area. Also, Nigeria is seen as a significant contributor to this topic owing to the significance of ICT-based agricultural extension in Africa, where ICTs have gained ground as potential solutions to deficiencies in conventional extension methods. In addition, nations like India, Malaysia, and the Philippines have gained research momentum due to increasing digitization and phone penetration in rural areas. The clustering pattern suggests that international collaboration is largely influenced by shared research interests, regional priorities, and technological development levels. Overall, the network reflects the increasingly global and interdisciplinary nature of research related to digital agricultural communication and online extension platforms.

Co-occurrence Network of Author Keywords

The co-occurrence network of author keywords related to agricultural YouTube channels, digital agricultural extension, and farmers' technology adoption is presented in Figure 4. The network was generated using VOSviewer software, where nodes represent author keywords and connecting lines indicate the frequency of co-occurrence within the selected literature. Node size reflects keyword frequency, while clustering patterns represent thematic relationships across the research domain.

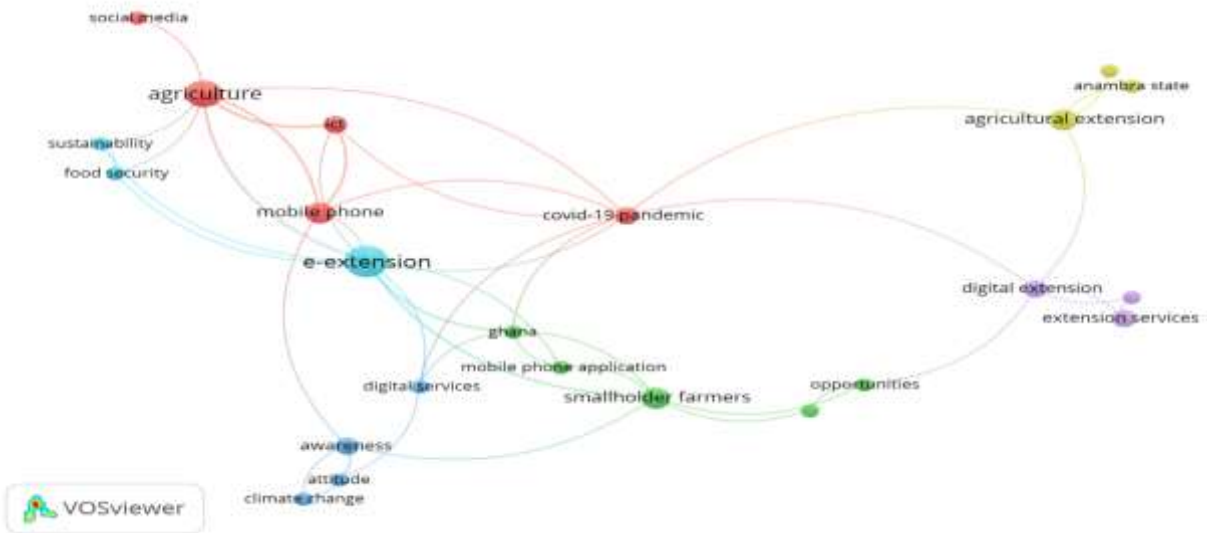

Fig. 4. Co-occurrence Network of Author Keywords in Agricultural YouTube-Based Digital Extension Research.

The network identifies “e-extension” and “agriculture” as the most dominant keywords, indicating that existing research is primarily centered on ICT-enabled agricultural communication and digital extension systems. Strong associations among keywords such as “ICT,” “mobile phone,” and “digital extension” further demonstrate the increasing reliance on mobile-based advisory services and digital communication technologies in agricultural extension practices. A major thematic cluster is associated with “smallholder farmers,” reflecting the growing research emphasis on digital inclusion and technology dissemination among small-scale farming communities, particularly in developing countries. The presence of country-specific keywords such as “Ghana” further suggests that much of the literature is context-driven and focused on addressing region-specific agricultural extension challenges.

The keyword “COVID-19 pandemic” appears as an important connecting node within the network, highlighting the significant shift toward remote extension services and digital advisory platforms during the pandemic period. This indicates that the pandemic accelerated the adoption and research focus on online agricultural communication systems due to limitations in conventional face-to-face extension activities.

Furthermore, the use of terms likes “food security,” “sustainability,” and “social media” suggests that the scope of study has moved beyond adoption of new technologies and is now concerned with other developmental aspects of sustainable agriculture, climate adaptation, and availability of information. Nevertheless, although there are increasing interests in video-based learning tools, the amount of literature on YouTube’s role in agricultural extension appears relatively scarce. Generally, the co-occurrence network highlights the fact that existing studies focus mainly on e-extension, ICTs, digital communication technologies, smallholders’ farming, and sustainability-focused agricultural extension programs.

Bibliographic Coupling Network of Countries

The bibliographic coupling network of countries contributing to research on agricultural YouTube channels, digital agricultural extension, and farmers’ technology adoption is presented in Figure 5. The network was generated using VOSviewer software, where nodes represent countries and connecting lines indicate bibliographic coupling relationships based on shared references cited in scientific publications. Node size reflects publication strength, while link thickness represents the intensity of bibliographic similarity among countries. The network demonstrates that the United States occupies the most dominant and central position, indicating its strong intellectual influence and substantial contribution to research related to digital agricultural communication, ICT-enabled extension systems, and technology adoption. Strong bibliographic linkages between the United States and countries such as Nigeria, China, France, and the United Kingdom suggest that these countries frequently rely on similar theoretical foundations and reference sources.

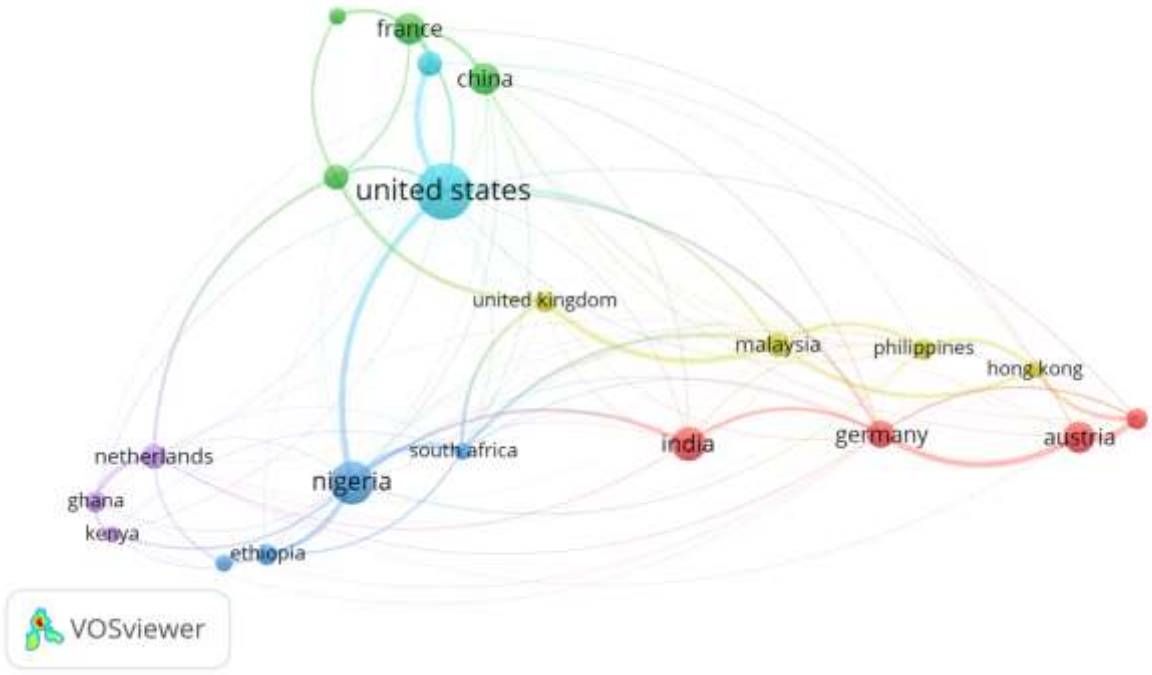

Fig. 5. Bibliographic Coupling Network of Countries in Agricultural YouTube-Based Digital Extension Research.

Nigeria also emerges as a major contributor, particularly among developing countries, reflecting the increasing research emphasis on digital agricultural extension and ICT adoption within African agricultural systems. Its strong connections with countries such as South Africa, Ethiopia, and India indicate shared research interests related to smallholder farming, rural development, and technology dissemination. The network further reveals several regional and thematic clusters. Countries such as India, Germany, Austria, and Hong Kong demonstrate strong bibliographic similarity, suggesting common conceptual and methodological approaches in studies related to digital agriculture and online extension systems.

Similarly, the cluster involving Malaysia, the Philippines, and the United Kingdom highlights the growing research focus on digital extension services and mobile-based agricultural communication within emerging economies.
The extensive coupling relationships among both developed and developing countries indicate that the field is becoming increasingly globalized and intellectually interconnected. Researchers across regions appear to rely on similar theoretical perspectives and research themes while addressing challenges related to digital agricultural communication and farmers' technology adoption. Overall, the bibliographic coupling network highlights the strong intellectual connectivity and increasing internationalization of research on digital agricultural extension and YouTube-based communication platforms.

Co-citation Network of Cited References

The co-citation network of cited references related to agricultural YouTube channels, digital agricultural extension, and technology adoption studies is presented in Figure 6. The network was generated using VOSviewer software, where nodes represent cited references and connecting lines indicate the frequency with which two references are cited together within the selected literature. Node size reflects citation influence, while link thickness represents the strength of co-citation relationships among references. The network demonstrates a highly interconnected intellectual structure, indicating that existing studies rely heavily on shared theoretical foundations, methodological approaches, and conceptual frameworks. The dense linkage patterns among references suggest strong intellectual cohesion within the research domain and highlight the interdisciplinary nature of research related to digital communication, ICT-enabled extension, and agricultural technology adoption.

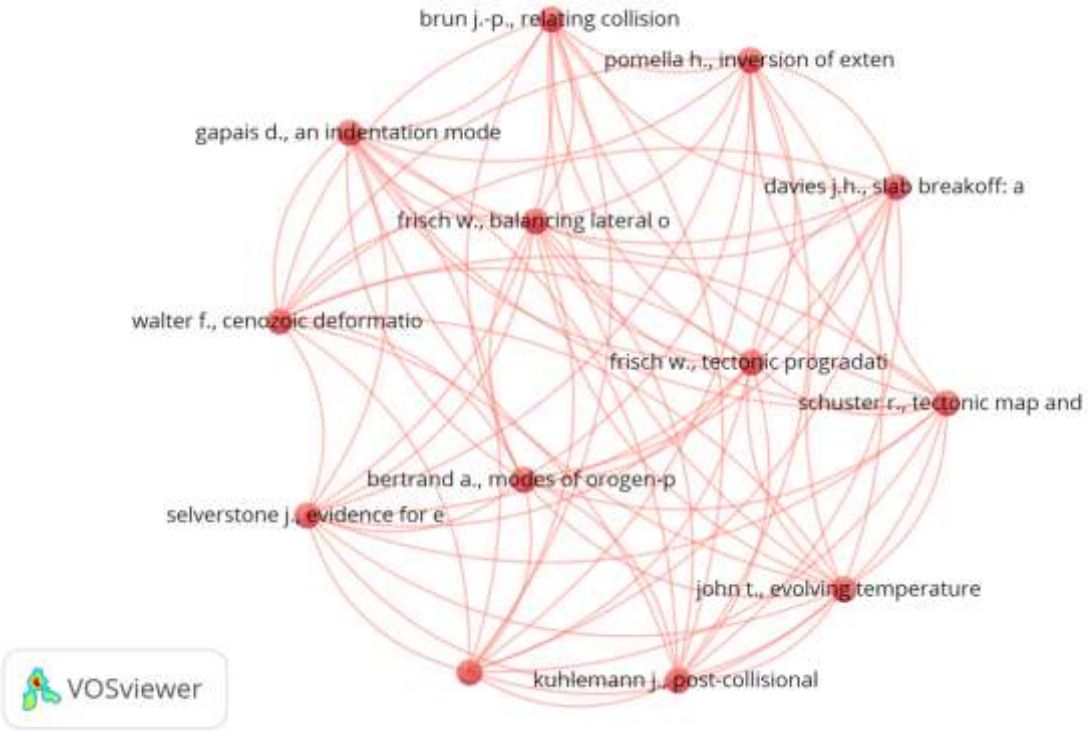

Fig. 6. Co-citation Network of Cited References in Agricultural YouTube-Based Digital Extension Research.

Several references, including works by Frisch W., Bertrand A., Pomella H., and Schuster R., occupy central positions within the network, indicating their significant scholarly influence and frequent co-citation in the literature. The prominence of these references suggests that they have contributed substantially to shaping the conceptual and methodological foundations of digital agricultural extension research. The strong co-citation relationships further indicate that researchers frequently draw upon similar bodies of literature while examining digital agricultural communication and online extension systems. The absence of isolated reference clusters suggests that the research field is relatively integrated rather than fragmented, reflecting increasing theoretical and methodological convergence within the domain.
Furthermore, the frequent citation of pioneering studies underscores the slow build-up of the research area. The commonly cited works usually include groundbreaking theoretical models and empirical findings that shape future research and facilitate the construction of a solid scholarly base for the study of digital agricultural extension. In general, it can be said that the co-citation pattern reveals the existence of a well-knit intellectual infrastructure underpinning research on YouTube-based agricultural extension services.

TCCM framework

Theory

Most of the studies in this review primarily focused on theories, as only a few less than half of the studies employed structured theoretical frameworks. Among those, the most widely used theories were the Technology Acceptance Model (TAM) and the Theory of Planned Behaviour (TPB), with some other theories also incorporated, including Diffusion of Innovations (DoI), welfare economics, and innovation studies frameworks. Many studies employed TAM as their theoretical framework, like (13), which employed this theory to explore Tasmanian dairy farmer's attitude towards e-

extension programmes and identified that age, education, herd size; and perceived usefulness and ease of use influenced their adoption level of e-extension programmes. Also applied TAM to assess the functionality of e-extension programmes among the extension workers in Nigeria and they found that gender, age, education, work experience and organisational support influenced the perceived ease of use (14). Applied the Theory of Planned Behaviour (TPB) and demonstrated that subjective norms, perceived behavioural control and perceived usefulness had a significant positive influence on the adoption of digital extension by smallholder farmers (15). The research indicated that the fundamental concepts of the TPB are applicable in all contexts, but their impact may vary depending on the socio-cultural and socio-economic factors. The diffusion of innovations theory has resulted in numerous studies and the Diffusion of Innovations (DoI) theory on compatibility and complexity had been incorporated to demonstrate mobile phone adoption in eastern Ghana (16). They observed that voice calls were still prevalent; the diffusion process was still in its beginning satge. They believed that adoption would increase with the development of digital literacy. The use of ICT-based extension tools demands behavioural changes that are in accordance with the features of innovation. Analysed ICT-based extension literacy among rice farmers employing the diffusion of innovation theory (17). Studies of willingness to pay and incentives to adopt were often anchored in welfare economics and rational choice models. Examined the willingness of Ethiopian farmers to pay for mobile-based extension services based on the Contingent Valuation Method (CVM) and Tobit regression (18). The authors considered farmers as players who optimised their well-being by acquiring valuable and timely information. Employed a similar approach in Ghana to analyse farmer's digital adoption during the COVID-19 outbreak using a multivariate probity model (19). They stated that relevancy, efficiency and sustainability are factors which determine the adoption level.

Some studies explored innovation systems and platform economics. Emphasised digital extension by integrating Web Science and social machines theory to establish block chain-based extension platforms as socio-technical ecosystems and used DoI theory to assess adaptability compared with traditional services (20). Developed a user readiness (UR) framework based on capabilities, opportunities and motivations to evaluate banana farmer's willingness for adopting the mobile-based extension services (21). This framework offers a methodological approach for measuring willingness before adoption, beyond post hoc TAM-based assessments.

Context

The reviewed papers predominantly focused on Sub-Saharan Africa and South Asia, while Southeast Asia, East Asia, the Middle East and developed countries were less represented. Across these regions, variations in digital infrastructure, organizational capacity, socioeconomic conditions and extension system development strongly influenced digital extension outcomes. Sub-Saharan Africa was prominently featured with Nigeria and Ghana standing out. Nigerian studies consistently identified unreliable internet access, limited smartphone usage, inadequate policy support, aged extension staff and rural insecurity as primary obstacles to digital extension services (14, 22-27). In Ghana, information gaps, uneven digital infrastructure and post-pandemic difficulties in adoption were documented (16, 19, 28). Additionally, African studies highlighted persistent gaps in extension service access, low digital literacy and insufficient institutional support, despite increased demand for e-extension systems (18, 29-34).

South and Southeast Asian studies indicated the relevance of contextual and infrastructural elements in addressing digital extension outcomes. For instance, in India, personalized digital advisory services enhanced productivity and agricultural income while traditional extension systems remained limited in rural regions (35, 36). Similarly, in Nepal, combining farmer training programs with digital extension significantly improved rice production (37). In Indonesia, studies found that ICT literacy, age and accessibility to information were key adoption indicators (17). Across Cambodia, Philippines and Vietnam, evidence showed that cultural norms, socioeconomic conditions, infrastructure quality and gender disparities strongly influenced adoption, limiting the effectiveness of uniform strategies (15). Comparatively, research from China described more sophisticated digital ecosystems with WeChat-based advisory systems effectively promoting precision fertilization among small-scale farmers by leveraging high smartphone penetration and robust infrastructure (38).

Research from the Middle East and North Africa revealed both possibilities and persistent disparities in digital access. In Tunisia, gender-responsive digital initiatives have facilitated womens access to agricultural knowledge and social networks (39). In Saudi Arabia, extension personnel indicated positive attitude towards e-extension technology (40). Even though studies from developed nations are very limited, they provide comparative insights into modern extension systems. For example, research in Australia revealed that hybrid approaches which incorporated digital and face-to-face in-person extension services, achieved greater adoption rates than completely digital models (13, 41). Comparative studies in Kenya and India also demonstrated that the complex nature of digital tools must correspond to the users technical and financial abilities (42). The COVID-19 pandemic had emerged as a major contextual factor promoting the adoption of digital extension while exposing pitfalls in traditional in-person procedures across Africa and other regions (26, 28, 31, 39, 43). Collectively, it revealed that digital agricultural extension outcomes were extremely context-dependent and influenced by infrastructural, institutional, socioeconomic and cultural factors.

Characteristics

The reviewed literature pointed out high variation in digital extension platforms, customer demographics and reported outcomes. Despite this variation, mobile-based communication remains the prominent delivery system. Most research addressed mobile calls, SMS, interactive voice response (IVR) systems, social media platforms, mobile applications and upcoming artificial intelligence (AI)-enabled technologies. In Nigeria and Ethiopia, simple mobile communication technologies including calls, SMS, radio and IVR continued to dominate primarily due to infrastructure limitations and limited smartphone adoption (22, 29, 44). Social media platforms like WhatsApp, Facebook and WeChat are extensively

recognized as informal extension channels that enhance engagement, information dissemination and technology adoption among farmers and rural younger generations (30, 38). A recent study also underlined the rapid development of AI-powered and smart digital technologies in agricultural extension. For example, explained the benefits of the PlantVillage Nuru application for cassava disease diagnostics (45), whereas identified digital livestock tools as informative, smart or value-chain-integrated systems (42). Collectively, these results demonstrated a progressive transformation from basic information exchange to more participatory and data-driven extension strategies. Farmer characteristics act as significant predictors of digital extension adoption. Younger, more educated, higher-income and larger-scale farmers are more likely to adopt digital technologies and generate revenue from their usage (16-19, 25, 35, 38). Gender disparities remains as a notable one, particularly associated with smartphone ownership, digital literacy and active engagement with digital platforms (15, 32, 34, 39). Additionally, previous mobile phone experience and proactive information-seeking activity favourably affected adoption intentions (18, 44).

Many research works underlined the necessity of extension agent willingness. Evidence from Nigeria and Saudi Arabia revealed that regardless of generally being positive opinions about e-extension, digital competence and actual utilization of e-resources remain low, notably among senior extension workers (23, 24, 40). These results implied that extension workers competency is essential for the efficient adoption of digital advisory systems. The examined studies primarily reflected beneficial impacts connected with digital extension. Notable improvements have been observed in agricultural yield, technology adoption, input usage efficiency and farmers willingness to communicate with digital advisory services (18, 35, 37, 38). Nevertheless, persisting constraints such as poor infrastructure, low digital skills, lack of engagement and structural disparities continued to impede equitable adoption and overall efficiency (21, 32, 46). A key gap in the research is the lack of focus on video-based and YouTube-specific agricultural extension. Even though educational videos are regarded as an alternative extension medium, empirical investigations remain limited (43). Furthermore, bibliometric analyses disclosed that YouTube-based agricultural extension has not yet emerged into a substantial research cluster within ICT-enabled extension studies emphasizing a critical domain for future research (47).

METHODOLOGY

Most existing research in this study is quantitative relied on cross-sectional surveys and econometric analysis. Research studies from Nigeria, Ghana, Ethiopia, India and other developing countries frequently used structured questionnaires given out to farmers and extension workers (14,16-18, 22-24,36,40,44). Sample sizes were fluctuated greatly and multi-stage sampling was commonly implemented to mitigate geographical variances. Econometric modelling is commonly used to analyse adoption drivers and behavioural effects. Tobit, probity and logit models are often evaluated for willingness to pay, mobile application usage patterns and adoption preferences (18, 19, 39, 44). Descriptive statistics remains essential in many extension studies particularly in Sub-Saharan Africa (22- 24, 27). Advanced approaches such as Structural Equation Modelling (SEM) for behavioural analysis (46) and mixed logit choice tests for evaluating farmer's preferences for digital extension applications (25) were utilized. Applied IPWRA (37), instrumental variable estimation and apparently unrelated regression to investigate the impact of combined training and digital extension on rice production. Employed Propensity Score Matching (PSM) to quantify the benefits of digital advisory services on small-scale farmer performance in India (35). Similarly, (38) employed household choice models to examine the causal effects of WeChat-based extension services in China.

Systematic reviews and bibliometric analyses are more prevalent. synthesised studies on digital extension and agricultural technology using systematic and scoping reviews (28, 34, 46). Employed bibliometric analysis using VOS viewer and R software to map publication patterns and research clusters in ICT-based agricultural extension (47). Qualitative and mixed-methods studies are less prevalent but still provided essential contextual information. Research that employs interviewing techniques, case studies, field assessments and mixed-methods approaches strengthened the understanding of user willingness, digital disparities, technology failure and implementation challenges (21, 26, 32, 42, 45, 48). Further extended the approach by developing and validating a psychometric scale to evaluate farmer's knowledge of e-extension services in India (49). Overall, the methodological setting is largely dominated by quantitative, cross-sectional research. Longitudinal, experimental, participatory and qualitative techniques are marginalised, which restricted the knowledge of long-term behavioural change and farmers experiences with digital extension platforms. This gap is particularly noticeable for video-based and YouTube-mediated agricultural extension, where more user-centred and mixed-methods research is required.

Major Factors Influencing Farmers' Adoption of Agricultural Technologies Through YouTube-Based Digital Extension Platforms

The recent literature from the year 2020 to 2026 suggests that the use of agricultural technologies by farmers via YouTube digital extension services is affected by various technological, socio-economic, behavioral, and communication-based variables. Out of these, perceived usefulness has been found to be one of the major predictors of adoption behavior. Noted that farmers tend to adopt agricultural technologies if YouTube videos help them to enhance their productivity while reducing the costs involved in cultivation activities (50). Likewise, found that video-based agriculture extension facilitates farmers to understand difficult agricultural technologies (51). Furthermore, it is also true that education levels and digital literacy contribute greatly towards the participation of farmers in YouTube agricultural learning programs. According to , education plays a positive role in enhancing the adoption of technology among farmers on YouTube (50). In addition, also stressed on the significance of digital literacy and awareness of ICTs among farmers (5).

Access to the internet, availability of smartphones, and ICT infrastructure were commonly regarded as crucial variables that influenced adoption behavior. Emphasized the lack of adequate internet connectivity and weak ICT infrastructure as

significant challenges in the use of digital agricultural extension services by rural farmers (52). This result underscores the presence of a digital divide that is prevalent in underdeveloped areas.

The quality and credibility of agricultural video content also significantly influence farmers' adoption decisions. reported that farmers prefer agricultural videos that are scientifically accurate, practically oriented, and locally relevant (53). Similarly, noted that practical field demonstrations and region-specific recommendations increase farmers' confidence in adopting agricultural innovations promoted through YouTube channels (50). Social influence and peer learning emerged as another important factor affecting adoption behaviour. According to YouTube-based agricultural extension supports collaborative learning by enabling farmers to observe successful farming practices, exchange experiences, and interact through online communities. Such participatory communication strengthens trust in digital advisory systems and reduces uncertainty associated with new agricultural technologies (52).

Economic and farm-related characteristics were also found to influence farmers' adoption behaviour. identified annual family income, farm size, farming experience, and extension media exposure as factors positively associated with YouTube usage among farmers(50). Farmers with better economic capacity and greater extension exposure were generally more willing to adopt innovative agricultural technologies introduced through digital platforms. An additional aspect found in the literature is the efficacy of visual demonstrations and self-paced learning. It has been highlighted that video-based communication aids understanding of technology since farmers can repeatedly view agricultural demonstrations at their own convenience (51). It has also been pointed out that audiovisual communication makes it easier for illiterate farmers to understand and communicate (53).

Moreover, institutional support and extension programs also have a major role to play in the adoption of digital agriculture technology. In particular, government policies such as rural digitalization policies, farmer training programs, and digital literacy programs are helpful in enhancing farmers' engagement in online agricultural learning systems (5). It can be seen from the literature review that there are certain factors affecting farmers' adoption of agricultural technologies using YouTube based digital extension programs. These include usefulness, digital literacy, ICT infrastructure, credibility of information, social interactions, economic capabilities, and visual efficacy of learning materials. The findings also show that it is important to enhance digital infrastructures in rural areas and provide good agricultural videos.

CONCLUSION

The study analyzed the current state of literature on farmers' technology adoption via agricultural YouTube channels and digital extension applications by conducting a bibliometric analysis of publications in combination with the use of the TCCM model. The results of the research show that scientific papers in the area have increased significantly in recent years because of the increased role played by ICTs, social networking sites, and digital communication technologies in agricultural extension programs. Specifically, it was shown that current research on the topic mostly concentrates on e-extension, mobile advisory, and agricultural communication facilitated by ICTs, whereas there is a lack of YouTube-specific agricultural extension studies. Furthermore, the results indicated that perceived usefulness, digital literacy, internet access, credibility of information sources, social influence, and ICT infrastructure are significant determinants of farmers' technology adoption via YouTube-based digital platforms. However, there is a clear bias towards quantitative and cross-sectional studies, which suggests that qualitative and longitudinal research should receive greater attention. On balance, YouTube-based agricultural extension has considerable potential to facilitate agricultural information dissemination, learning, and technology diffusion. It is imperative to improve rural internet connectivity, ensure credible localized video content, and enhance the digital literacy of farmers in order to maximize the effectiveness of digital agricultural extension systems.

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