

Towards Inclusive Agricultural Digitalization: A Bibliometric and Systematic Review on Technology Adoption in Indonesia

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ABSTRACT

Adoption of technology in agriculture is an important step in improving agricultural efficiency and productivity. However, although various studies have been conducted, there is no specific picture regarding the extent of the development of technology implementation in agriculture in Indonesia. Therefore, this study aims to identify the characteristics of studies related to the adoption of agricultural technology in Indonesia which include 1) bibliometric analysis of publication trends, 2) classification of types of agricultural technology that have been adopted by farmers, and 3) identification of challenges and limitations of agricultural technology in Indonesia. This study used a qualitative approach combining a systematic literature review (SLR) with bibliometric analysis to explore trends, technology types, and challenges in the adoption of agricultural digitalization in Indonesia. The PRISMA framework guided the literature selection process, while bibliometric analysis using VOSviewer facilitated the visualization of keyword linkages and publication trends. The study reveals growing scholarly attention toward digital agriculture in Indonesia, with ICT and smart farming technologies at the forefront. Despite the increasing interest, various systemic barriers hinder equitable adoption, underscoring the need for inclusive policies and infrastructure development.

KEYWORDS: agricultural technology; digital farming; inclusive agriculture; systematic literature review; technology adoption

INTRODUCTION

The agricultural sector not only has a strategic role in the national economy as a provider of food and employment, but also plays a role in maintaining social and environmental stability. Increasing global challenges such as climate change, population growth, limited land and the development of information technology demand a transformation of the agricultural sector towards a more adaptive, efficient and sustainable system. One of them is through the adoption of agricultural technology that can increase agricultural efficiency and productivity. This is also expected to lead to increased farmer welfare.

Various forms of technology have been widely developed in Indonesia, including superior seed production techniques, modern irrigation systems, biofertilizers, agricultural machinery, and digital technology based on the Internet of Things (IoT) and artificial intelligence (AI). For example, superior seed production techniques can now be carried out using various methods such as pollination and castration (Sujadmiko et al., 2021), LEISA (Low External Input Sustainable Agriculture) technology (Sutariati et al., 2025), in vitro culture (Husen et al., 2018), and many others. Several studies related to the use of agricultural machinery have also been conducted, including the application of corn seed planting technology (D. Santoso et al., 2021), rice planting line making tools (Sugandi, 2018), grass cutting machines and oil palm fruit harvesting cutters (Marpaung et al., 2018), and rice harvesters (Putra et al., 2022), as well as various other agricultural machinery. In line with the development of more modern technology, IoT-based digital technology has also been widely used to control temperature, humidity, and acidity levels of planting media in limited areas such as greenhouses

(Nasution et al., 2020; Ridwan & Sari, 2021). Likewise, the use of AI in agriculture allows farmers to make decisions faster and more accurately while still optimizing increased productivity and resource efficiency (Nurani et al., 2025).

In contrast to these conditions, the development and application of agricultural technology in Indonesia is still uneven due to various problems. The results of the study indicate that social, economic, and institutional factors need more attention to increase the impact of agricultural technology dissemination in efforts to improve the welfare of farmers in rural areas (Kuntariningsih & Mariyono, 2014). In addition, the results of other studies concluded that the implementation of innovative technology in agriculture is also hampered by access to technology, lack of formal education, and limited infrastructure, which is also supported by market accessibility for millennial farmers and policy regulations that are not yet systematic to ensure the sustainability of modern agricultural practices (Faried et al., 2024). This means that there are various factors that need attention in the adoption of agricultural technology, both at the local and national levels.

Various studies related to the adoption of agricultural technology in Indonesia have been conducted. However, there has been no study that specifically identifies the form of existing technology until now, as well as the challenges and opportunities in its application. Based on this description, a systematic study is needed to identify the characteristics of research related to the adoption of agricultural technology in Indonesia in terms of publication trends, commonly used methods, and the focus of the study. In addition, an understanding is also needed regarding the types of technology that have been developed, adoption patterns at the farmer level, challenges and limitations faced in its application in Indonesia. Therefore, this study aims to identify the characteristics of studies related to the adoption of agricultural technology in Indonesia which include 1) bibliometric analysis of publication trends, 2) classification of types of agricultural technology that have been adopted by farmers, and 3) identification of challenges and limitations of agricultural technology in Indonesia. The results of this study are expected to provide a comprehensive picture of the development of studies on the adoption of agricultural technology in Indonesia and become a consideration in further research related to the development and application of technology in the agricultural sector, as well as being the basis for formulating more appropriate policies in encouraging sustainable agricultural technology transformation in Indonesia.

METHODOLOGY

Research Design. This study employed a qualitative research design by integrating a systematic literature review (SLR) with bibliometric analysis. This combined approach was adopted to address three core objectives: (1) identifying publication trends related to agricultural digitalization adoption in Indonesia, (2) classifying the types of digital agricultural technologies that have been implemented, and (3) examining the key challenges and barriers associated with their adoption.

Data Collection Techniques

1. Systematic Search Strategy

The systematic review process was conducted using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework, which includes three main phases: identification, screening, and eligibility assessment. In the identification phase, literature was retrieved from the Google Scholar database using the Publish or Perish software. The search covered the publication period from 2015 to 2025 and employed Boolean operators with search terms such as “digital agriculture” adoption Indonesia, “digital agriculture” AND “adoption barriers” AND Indonesia, as well as the Indonesian phrase “adopsi teknologi petani” (farmer technology adoption).

2. Inclusion and Exclusion Criteria

Subsequently, articles were screened based on clearly defined inclusion and exclusion criteria. The inclusion criteria required that documents be journal articles or conference proceedings, written in either English or Bahasa Indonesia, focused on the agricultural sector in Indonesia, available as open access, and relevant based on title and abstract. Articles that did not meet these standards were excluded from the analysis. As a result, 84 articles were selected for bibliometric analysis.

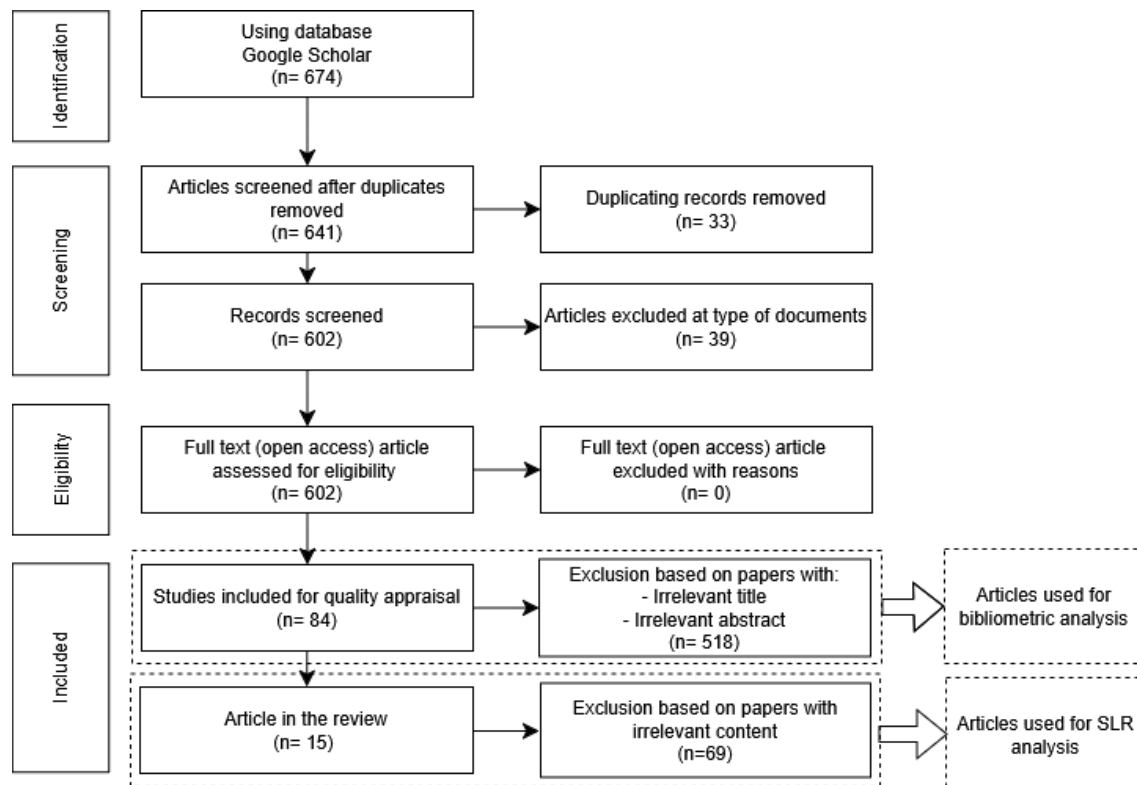
3. Quality Assessment

To ensure the quality of the review, all 84 articles were then evaluated for their relevance and content rigor. Only those with a strong alignment to the study's objectives and a high level of scholarly quality were retained. Following this assessment, a final set of 15 articles was used as the basis for the systematic literature review.

Tools or Instruments Used. The bibliometric analysis was conducted using VOSviewer, with keyword co-occurrence (co-word) as the primary metric. The visualization parameters were set with a minimum keyword occurrence of three, a threshold value of 235, and selection of 60% of the most relevant terms from a total of 141 detected keywords. This process resulted in the identification of 73 key terms, which were used to generate three types of visualizations: network, overlay, and density maps.

Data Analysis Methods. Data analysis consisted of two stages: (1) Bibliometric Analysis: Co-word analysis was conducted to identify keyword linkages and publication trends within the selected dataset and (2) Systematic Review: The 15 selected articles were analyzed qualitatively through thematic abstraction of their titles, abstracts, findings, and discussions. The extracted information was structured into tables covering technology categories, adoption challenges, and policy implications. The framework of the PRISMA systematic review process is shown in Figure 1.

Figure 1
Framework of Systematic Review Using PRISMA Method



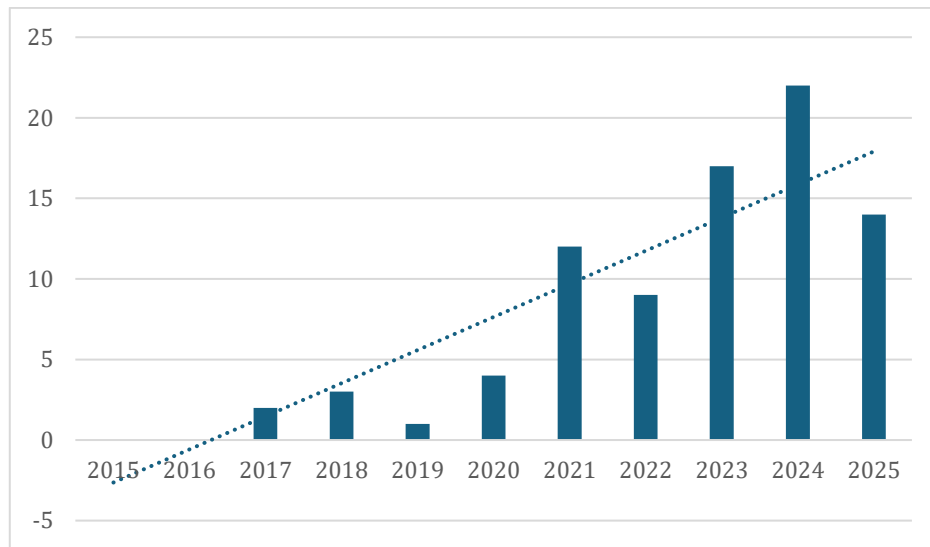
RESULTS AND DISCUSSION

Tren Publikasi Adopsi Teknologi Digital Pertanian di Indonesia

The results of the data analysis reveal a growing trend in publications related to the adoption of digital agricultural technologies in Indonesia during the period from 2015 to 2025. A significant surge in publications has been observed over the past six years, particularly since the onset of the COVID-19 pandemic. The pandemic appears to have acted as a catalyst for digital innovation in agriculture, especially in the downstream segment, including marketing and distribution activities. This is evident from the increased number of studies focusing on digital marketing tools and ICT-based access during that period. Additionally, the rapid advancement of information technology has further supported the development and diffusion of agricultural digitalization initiatives, as reflected

in the growing volume of academic publications. The publication trends from 2015 to 2025 are illustrated in Figure 1.

Figure 1
Number of Publications in 2015 – 2025



A review of the most cited articles (presented in Table 1) shows 11 publications that have received significant scholarly attention. Among them, the most cited paper is by (Rachmawati, 2020), titled “Smart Farming 4.0 untuk Mewujudkan Pertanian Indonesia Maju, Mandiri dan Modern” (Smart Farming 4.0 to Realize Advanced, Independent, and Modern Agriculture in Indonesia). These frequently cited articles predominantly cover topics such as smart farming, ICT adoption, artificial intelligence, sustainable agriculture, and digital agricultural tools.

Table 1
Most Cited Articles in the Period 2015 – 2025

Number of Citations	Reference	Title
132	(Rachmawati, 2020)	Smart farming 4.0 untuk mewujudkan pertanian Indonesia maju, mandiri, dan modern
66	(Mariyono et al., 2022)	Usage of mobile phones to support management of agribusiness activities in Indonesia
43	(Wihartiko et al., 2021)	Blockchain dan kecerdasan buatan dalam pertanian: studi literatur
20	(Hidayat et al., 2023)	To migrate or not to migrate: Internet use and migration intention among rural youth in developing countries (case of Malang, Indonesia)
14	(Kamakaula, 2024)	Sustainable agriculture practices: economic, ecological, and social approaches to enhance farmer welfare and environmental sustainability
12	(Dharmawan et al., 2023)	Pemanfaatan komunikasi inovasi digital pertanian perkotaan di masa pandemi Covid-19
12	(Yudianti et al., 2023)	Digitalisasi desa berbasis aplikasi “simpeldesa”: inovasi dalam mewujudkan ketahanan pangan berkelanjutan di desa cibiru wetan
12	(Kushartadi et al., 2023)	Theme mapping and bibliometric analysis of two decades of smart farming
11	(Widaningsih et al., 2021)	Application of digital agricultural tools in Indonesia: From creativity towards rural community innovation
11	(Suwanan et al., 2021)	The critical review of agriculture technological transfer in the era of decentralization
8	(Seminar & Sarwoprasodjo, 2019)	ICTs for small scale farmers in Indonesia: how to make it possible?

Visualization of Research Trends

Figure 2 presents a network visualization illustrating the co-occurrence relationships among keywords in publications concerning agricultural technology adoption in Indonesia. Each node represents a specific keyword, and the links between nodes indicate the frequency with which these keywords appear together in the same documents. The color of each node corresponds to its assigned cluster, and the proximity between nodes reflects the strength of their association (Van Eck & Waltman, 2013).

The co-word mapping analysis generated six main thematic clusters:

- Cluster 1 (Red): Contains 16 keywords, including *age, agricultural extension, agricultural extension agent, agricultural system, climate change, digital innovation, extension worker, farmer group, interview, policymaker, production, rice, rice farmer, smallholder farmer, West Java Province, and Yogyakarta*.
- Cluster 2 (Green): Comprises 15 keywords, such as *agricultural commodity, agricultural product, environmental sustainability, farmers' income, farmers' welfare, initiative, internet use, modern technology, participation, policy support, rural area, rural population, sustainable agriculture, and younger generation*.
- Cluster 3 (Blue): Consists of 12 keywords including *Bogor, collaboration, descriptive analysis, digital skill, effectiveness, government policy, human resource, marketing, motivation, readiness, socialization, and utilization*.
- Cluster 4 (Yellow): Includes 12 keywords, namely *adverse effect, blockchain, drone, efficiency, food demand, integration, IoT, potential benefit, smart agriculture, smart farming, survey, and technology*.
- Cluster 5 (Purple): Composed of 10 keywords, including *cultivation technique, hand tractor, irrigation, pest control, recommendation, risk, superior seed, technology adoption, tolerance attitude, and vegetable pesticide*.
- Cluster 6 (Aqua): Contains 8 keywords, including *accessible, adoption interview, depth interview, digital infrastructure, digital literacy program, importance, practical implication, and small scale farmer*.

Figure 2
Network Visualization

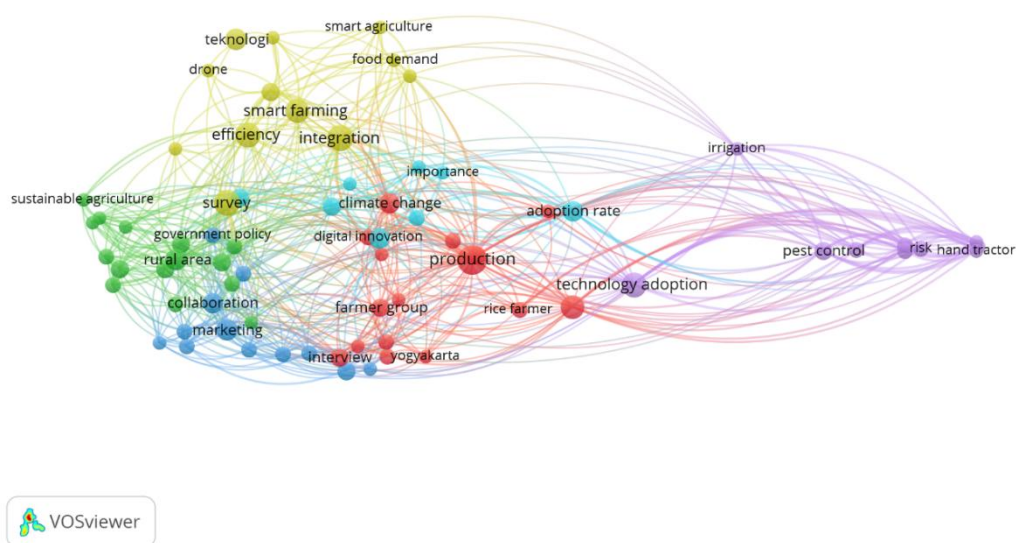
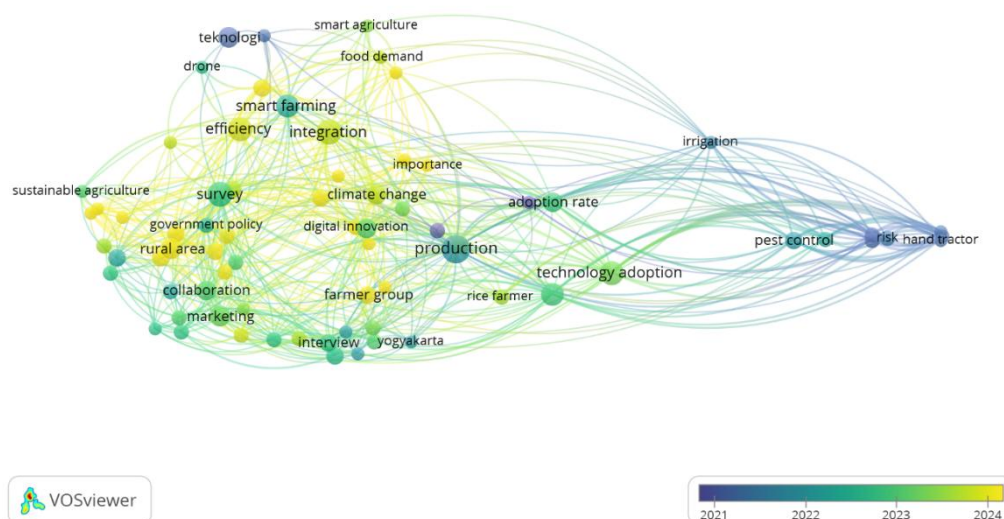


Figure 3 presents an overlay visualization, which reflects the temporal distribution of keywords. In this visualization, yellow nodes represent keywords that have appeared more frequently in recent publications, whereas blue nodes indicate terms that were more prevalent in earlier studies. The

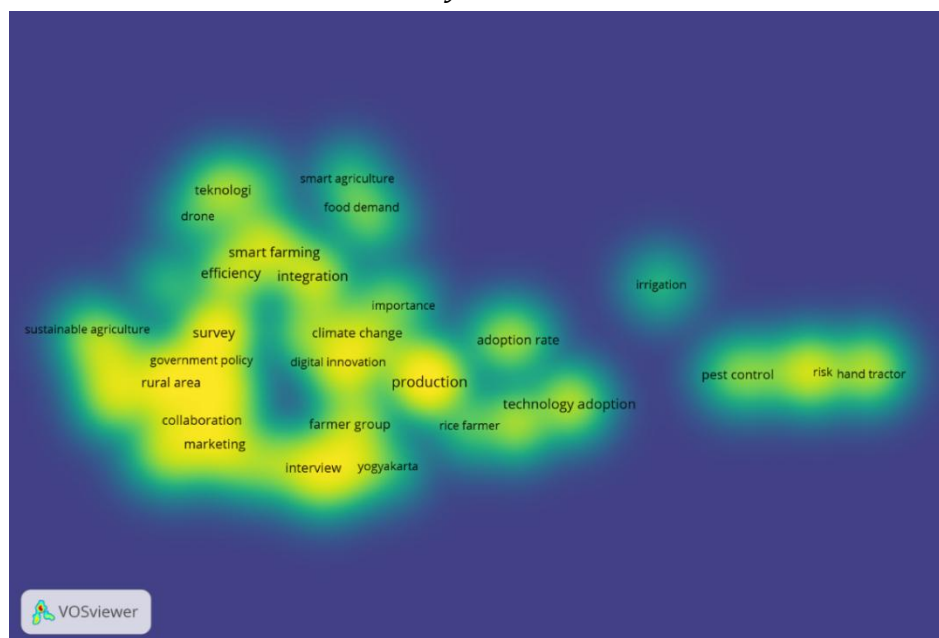
results show that keywords such as smart farming, efficiency, integration, food demand, and sustainable agriculture appear in yellow, suggesting these are emerging and currently evolving themes. In contrast, terms like production, agricultural system, and superior seed are depicted in blue, indicating that they were more frequently addressed in earlier research.

Figure 3
Overlay Visualization



Meanwhile, Figure 4 provides a density visualization, highlighting the intensity of keyword appearances across the dataset. The color gradient ranges from blue (low density) to green (moderate density) and yellow (high density), indicating the concentration of keywords in specific thematic areas. The most prominent topics based on this visualization—those represented in bright yellow—include smart farming, production, rural area, and food demand. This confirms that these issues are central to the scholarly discourse on digital agricultural technology adoption in Indonesia.

Figure 4
Density Visualization



Identification of Agricultural Digital Technologies

A systematic review of 15 peer-reviewed articles reveals the diverse landscape of digital technologies applied in Indonesia's agricultural sector over the past decade. The scope and objectives of the reviewed research are summarized in Table 2. The technologies discussed in these studies can be

broadly classified into four major categories: Information and Communication Technologies (ICT), smart farming, precision agriculture, and integrated agricultural systems (see Table 3).

Table 2
Research Objectives of the Reviewed Articles

No	Title	Objective	Sitasi
1	ICTs for Small Scale Farmers in Indonesia: How to Make It Possible?	Examines how participatory approaches are used in introducing ICT innovations to farmers	(Seminar & Sarwoprasodjo, 2019)
2	Usage of Mobile Phones to Support Agribusiness Activities in Indonesia	Assesses the contribution of mobile phone use to farmers' income and market access	(Mariyono et al., 2022)
3	Mobile Application Design for Digital Marketing and Management of Horticultural Crops	Designs a mobile application to support local horticultural marketing	(Luckyardi et al., 2022)
4	Digital Communication Competence and Technology Adoption	Analyzes the role of ICT in agriculture, especially among millennial farmers, focusing on the relationship between digital communication competence and farmer performance	(Sasmita et al., 2024)
5	Smart Farming 4.0 untuk Mewujudkan Pertanian Indonesia Maju, Mandiri dan Modern	Evaluates the potential of smart farming 4.0 technologies to support efficient and modern agriculture	(Rachmawati, 2020)
6	Promoting Smart Farming-based Digital Business Technology in the Context of Agricultural Transformation in Indonesia	Analyzes the potential of digital technologies in transforming agricultural business	(Sudaryanto et al., 2022)
7	Are Indonesian Rice Farmers Ready to Adopt Precision Agricultural Technologies?	Measures the readiness of rice farmers to adopt precision agriculture technologies	(A. B. Santoso et al., 2024)
8	Towards User Friendly Smart Precision Farming: Assessing ThingsBoard as an Interface for IoT Based Farming System Using System Usability Scale	Assesses the usability of ThingsBoard as an interface for small-scale smart farming systems	(Darmaastawan et al., 2024)
9	Integrated Smart Farming System in Developing Potential Products of The Village	Describes a technology-based integrated farming system in Bali through the Simantri Program	(AP et al., 2021)
10	How Smart Farming Encourages Agricultural Transformation: Evidences from Budi Cakep's Innovation in Pasuruan	Presents a case study on Budi Cakep's smart farming innovation in enhancing chili productivity and sustainability	(Sihidi et al., 2025)
11	Digitalized Smart Solar Powered Agriculture Implementation in Palembang, South Sumatera	Explains the implementation of solar-powered digital farming as an independent energy solution	(Oktarina et al., 2023)
12	The Future of Coffee, Digital Technology and Farmer's Income	Analyzes the impact of digital technology on coffee production and farmers' income	(Panggabean & Arsyad, 2023)
13	Adapting to Smart Farming: Communication Media and Local Knowledge in Overcoming Technical Challenges	Explores how farmers adapt to smart farming using local communication media	(Rasmira et al., 2025)
14	Internet Use and Farm Earnings: An Analysis of The Indonesia Labor Force Survey	Examines the relationship between internet use and farmers' income using data from the 2022 Indonesian Labor Force Survey	(Sukma et al., 2025)
15	Digital Inequality and Development: Using Short Message Service for Agricultural Development in Indonesia	Investigates digital inequality and the effectiveness of SMS in disseminating agricultural information in rural areas	(Lubis & Sulistiawati, 2021)

Among these, ICT-based technologies appear as the most frequently addressed in the literature. This includes mobile applications, SMS-based information systems, and internet platforms that facilitate farm management, crop marketing, and agricultural information access. These technologies play a crucial role in enhancing the connectivity between farmers and markets, especially in rural areas. (Mariyono et al., 2022), for instance, demonstrated that participatory approaches involving mobile phone use significantly improved market access and production efficiency for smallholder farmers.

The advancement of smart farming has also emerged as a notable trend in Indonesia's agricultural digital transformation. This category comprises technologies such as drones, soil and weather sensors, automated irrigation systems, and solar-powered devices. Studies by (Rachmawati, 2020), (Darmaastawan et al., 2024), and (Sihidi et al., 2025) suggest that smart farming has considerable potential to enhance agricultural efficiency and sustainability. The case of the “Budi Cakap” innovation, for example, illustrates how smart farming has been instrumental in improving productivity while also encouraging youth participation in agriculture.

Table 3
Categories and Applications of Agricultural Digital Technologies

No	Kategori Teknologi	Contoh Penerapan Teknologi	Sumber (Penulis/Institusi)
1	ICT (Information and Communication Technology)	Mobile applications, SMS, digital marketing information systems, internet usage	(Seminar & Sarwoprasodjo, 2019), (Mariyono et al., 2022), (Luckyardi et al., 2022), (Sasmita et al., 2024), (Panggabean & Arsyad, 2023), (Sukma et al., 2025), (Lubis & Sulistiawati, 2021)
2	Smart Farming	Drone sprayers, soil and weather sensors, smart irrigation, AWR, Siscrop, ThingsBoard, agrivoltaic systems	(Rachmawati, 2020), (Sudaryanto et al., 2022), (Darmaastawan et al., 2024), (AP et al., 2021), (Sihidi et al., 2025), (Oktarina et al., 2023), (Rasmira et al., 2025)
3	Precision Agriculture	GPS, sensors, mapping systems	(A. B. Santoso et al., 2024)
4	Integrated Farming	Simantri Program	(AP et al., 2021)

On the other hand, precision agriculture adoption remains limited and is often focused on specific commodities, such as rice. This approach typically involves GPS-based mapping and sensor technologies to support data-driven decision-making. According to (A. B. Santoso et al., 2024), although precision agriculture can improve input efficiency and crop yields, the technical readiness of farmers to adopt such systems remains a major barrier.

The fourth category involves integrated farming systems, such as those developed under the Simantri program in Bali (AP et al., 2021). These systems combine crop cultivation, livestock management, waste processing, and cooperative-based marketing through digital platforms. Such models not only optimize local resource use but also serve as a foundation for developing community-based agribusiness powered by digital tools.

Challenges and Barriers to Digital Technology Adoption in Agriculture

Despite the proliferation of digital innovations, the adoption of these technologies among Indonesian farmers continues to face significant challenges. Based on the synthesis of 15 studies, seven primary categories of barriers were identified (see Table 4).

The most frequently cited issue is the lack of digital infrastructure. Challenges such as limited internet access, inadequate hardware, and unreliable electricity—especially in rural and remote areas—remain fundamental obstacles. These conditions hinder the dissemination of internet-based systems and smart farming technologies, as discussed by (A. B. Santoso et al., 2024), (Panggabean & Arsyad, 2023), and (Sukma et al., 2025).

The second barrier is digital literacy, particularly among older and small-scale farmers who often struggle to access and utilize digital tools effectively. At least eight studies underscore that low levels of digital competence severely constrain farmers' ability to engage with digital transformation processes.

Table 4
Challenges in the Adoption of Agricultural Digitalization

Reference	Technology	Crop/ Commodity	Digital Literacy	Infrastructure	Social Psychological	Investment Cost	Policy	Socio-economic Disparities	Operational Technical
(Seminar & Sarwoprasodjo, 2019)	ICT	All crop	X		X				
(Mariyono et al., 2022)	ICT	All crop	X						
(Luckyardi et al., 2022)	ICT	Horticulture	X						
(Sasmita et al., 2024)	ICT	All crop		X	X				
(Rachmawati, 2020)	Smart Farming	All crop		X	X	X			
(Sudaryanto et al., 2022)	Smart Farming	All crop		X	X		X		
(A. B. Santoso et al., 2024)	Precision Agriculture	Rice		X					X
(Darmaastawan et al., 2024)	Smart Farming	All crop	X						
(AP et al., 2021)	Smart Farming	All crop	X						
(Sihidi et al., 2025)	Smart Farming	Chili		X				X	
(Oktarina et al., 2023)	Smart Farming	All crop		X					
(Panggabean & Arsyad, 2023)	ICT	Coffee	X	X					
(Rasmira et al., 2025)	Smart Farming	All crop		X					X
(Sukma et al., 2025)	ICT	All crop	X	X				X	
(Lubis & Sulistiawati, 2021)	ICT	All crop	X					X	

Data Source : Primary Data (2025)

Third, socio-psychological factors also influence adoption. Resistance to change, distrust in new technologies, and low motivation to learn are frequently encountered barriers, as reported by (Rachmawati, 2020) and (Sudaryanto et al., 2022).

Fourth, the high cost of initial investment presents a substantial hurdle. Technologies such as drones, precision sensors, and automated irrigation systems require considerable financial resources, which many smallholder farmers cannot afford without external assistance or subsidies.

Fifth, socio-economic disparities further exacerbate the digital divide. Unequal access to technology between Java and non-Java regions, or between wealthy and resource-poor farmers, reinforces polarization within the agricultural innovation ecosystem.

Sixth, there are notable technical and operational limitations. These include difficulties in operating equipment, interface mismatches with local contexts, and insufficient field-level technical support—issues particularly pronounced in smart farming implementation.

Finally, institutional and policy-related weaknesses persist. Top-down approaches to technology dissemination often overlook the local realities and needs of farmers. Several studies highlight the need for policy reforms to strengthen the role of agricultural extension agents as facilitators of community-based digital transformation.

Towards Inclusive Agricultural Digitalization

Although academic interest in digital agriculture is on the rise and innovations are increasingly being introduced, the process of digital transformation in Indonesia remains largely non-inclusive.

Inclusivity in this context extends beyond mere access to technology. It involves the equitable distribution of resources, capabilities, and benefits among diverse farming communities. This includes addressing not only the digital divide between rural and urban regions but also generational gaps, gender inequalities, and broader socio-economic disparities.

Achieving inclusive agricultural digitalization requires strategic interventions. First, digital literacy must be prioritized. Training programs should be localized and responsive to the unique cultural and learning needs of farming communities. Participatory methods and extension networks can be leveraged to promote meaningful engagement. In addition, infrastructure development must be treated as a foundational pillar of inclusive digital transformation. Investments in internet connectivity, electricity networks, and access to affordable digital devices must be prioritized, particularly in rural and remote areas. National and local governments should collaborate with the private sector to expand broadband coverage and establish community-based digital service centers. Second, technology development must be co-designed with farmers, ensuring that innovations are rooted in the lived realities and aspirations of smallholders, including women, youth, and indigenous groups. Third, policy interventions must be place-based and equity-driven. This means providing differentiated support mechanisms for marginalized regions and incentivizing inclusive technology deployment across the agricultural sector.

CONCLUSION

This study systematically reviewed 84 open-access articles related to agricultural technology adoption in Indonesia published between 2015 and 2025, from which 16 of the most relevant studies were selected for in-depth analysis. Bibliometric analysis using VOSviewer identified 73 frequently occurring keywords, which were grouped into six thematic clusters reflecting key focus areas in digital agriculture research. Overlay and density visualizations revealed emerging themes such as smart farming, efficiency, integration, and food demand, which have gained increasing attention in recent years. The systematic review showed that the most widely adopted technologies were ICT-based tools (e.g., mobile applications and digital communication systems) and smart farming innovations (e.g., IoT-based devices, sensors, and drones), applied across a variety of crops including rice, horticulture, and coffee. However, several barriers to adoption were consistently identified, with infrastructure limitations noted in 9 of the 15 studies, digital literacy constraints in 8 studies, and social psychological gaps in 4 studies. Socio-economic disparities and operational technicals were also recognized as key obstacles. These findings emphasize the importance of adopting an inclusive, multi-stakeholder approach to digital transformation in agriculture. Future initiatives should prioritize the development of accessible infrastructure, farmer-friendly technology design, and targeted policy support to enable equitable and sustainable adoption across rural communities in Indonesia.

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