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Smart Farming Technologies for Indonesia Agriculture Productivity and Sustainability

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Abstract

Purpose: To systematically map and review the landscape of smart farming technology in Indonesia, focusing specifically on its impact on the productivity and sustainability of the agricultural sector.

Methodology/approach: This research utilizes a Systematic Literature Review (SLR) guided by the PRISMA protocol. A qualitative thematic synthesis was performed on 10 selected articles published between 2021-2025, which were sourced from the IEEE Xplore, ScienceDirect, and Emerald Insight databases.

Results: The analysis shows that the Internet of Things (IoT), sensors, Big Data, and Machine Learning are the most predominantly applied technologies. Their implementation yields significant positive impacts, including enhanced plant growth (up to 26.3% taller) and more efficient resource use, such as a 4.75% savings in electrical energy.

Conclusions: The strategic integration of smart farming offers great potential for revitalizing the Indonesian agriculture sector. However, its success is highly dependent on overcoming major challenges, such as high investment costs, a rural digital infrastructure gap, and low digital literacy among farmers.

Limitations: This review is based on a limited set of 10 final articles, which, while relevant, may not encompass the full spectrum of smart farming applications and unpublished case studies in Indonesia.

Contributions: This study provides an evidence-based foundation for Indonesian policymakers to formulate targeted policies that address economic and infrastructure barriers. It also guides researchers and practitioners in developing more affordable and locally relevant technological solutions to accelerate the digital transformation in the agricultural sector.

Keywords: *Agriculture, Productivity, Smart Farming, Technology*

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1. Introduction

The agricultural sector serves as the backbone of the national economy in many countries, including Indonesia, and plays a crucial role in providing employment and ensuring food security for a growing population (Musa & Basir, 2021). However, this vital sector faces increasing pressure from global challenges, such as climate change, land degradation, and water scarcity (Roy & Medhekar, 2025). Climate change, in particular, triggers weather anomalies such as droughts and floods, which threaten crop productivity and the stability of the food supply (Yuan et al., 2025). To address these complex challenges and meet future food demands, a fundamental transformation from traditional agricultural practices to a more efficient, resilient, and sustainable approach is required (Paudel, Riaz, Teng, Kolluri, & Sandhu, 2025).

In response to these challenges, the paradigm of smart farming, or Agriculture 4.0, has emerged as a transformative solution that integrates advanced information and communication technologies into agricultural practices (Paudel et al., 2025). This concept leverages technologies such as the Internet of Things (IoT), Big Data, Artificial Intelligence (AI), and robotics to enable data-driven decision-making (Alfred, Obit, Chin, Haviluddin, & Lim, 2021). The application of these technologies allows for real-time monitoring of field conditions, optimization of inputs such as water and fertilizers, and an overall increase in operational efficiency (Liu, Chen, Wang, Ala, & Pethuraj, 2024). Consequently, smart farming not only has the potential to significantly boost productivity but also addresses sustainability demands by minimizing the ecological footprint of agricultural activities (Bashiru, Ouedraogo, Ouedraogo, & Läderach, 2024).

In Indonesia, an agrarian country with a large population and diverse geographical challenges, the adoption of smart farming technology is highly relevant for revitalizing the agricultural sector (Susilawati et al., 2025). These technologies offer opportunities to increase crop yields, strengthen farmers' resilience to climate variability, and ensure the sustainability of the national food production system (Yuan et al., 2025). Despite its immense potential benefits, research synthesizing empirical evidence on the application and impact of smart farming technologies within the specific context of Indonesia remains limited (Halawa, 2024). Therefore, this study aims to conduct a Systematic Literature Review to identify, evaluate, and synthesize existing research on the utilization of smart farming technologies to enhance productivity and sustainability in the Indonesian agricultural sector (Mulyono, Apnitami, Wangi, Wicaksono, & Apriono, 2022).

Therefore, this study aims to conduct a Systematic Literature Review to identify, evaluate, and synthesize existing research on the utilization of smart farming technologies to enhance productivity and sustainability in the Indonesian agricultural sector (Kurniawan & Mahendrawathi, 2025). This review critically examines the current state of smart farming applications, focusing on technologies that have proven effective in similar agrarian contexts (Kumar et al., 2024). By aggregating insights from various studies, this research aims to highlight gaps in the current literature and provide a clearer understanding of the specific challenges and opportunities in Indonesia's agricultural sector (Budiawati, Gunawan, & Suherna, 2025). Additionally, it seeks to offer actionable recommendations for stakeholders, including policymakers, agricultural experts, and technology developers, to foster the widespread adoption of smart farming technologies (Khanna 2024). Ultimately, the goal is to support a transformative shift towards a more efficient, sustainable, and resilient agricultural system that can help Indonesia meet its food security goals in the face of emerging global challenges.

The significance of this study lies in its potential to contribute to the growing body of knowledge on Agriculture 4.0 in Indonesia, particularly by synthesizing empirical findings related to data-driven decision-making, IoT integration, AI and robotics, and Big Data applications in agricultural practices (Rachmawati, 2020). As the country faces challenges such as climate change, limited water resources, and fluctuating crop yields, adopting these technologies is vital for improving crop production and essential for minimizing the environmental impact of agriculture. Through real-time data collection and precision farming, these technologies can optimize the use of resources, such as water, fertilizers, and energy, thus contributing to more sustainable farming practices.

Moreover, this study will explore how smart farming technologies can enhance farmer resilience by providing timely and relevant information to mitigate the risks posed by adverse climatic conditions (Chang et al., 2025). This aspect is crucial for the rural population, as farmers' ability to adapt to climate variability directly impacts the stability of the nation's food supply. By focusing on Indonesia's unique geographical and socioeconomic context, this review aims to provide a comprehensive understanding of how these technologies can be applied to meet local needs while supporting national food security (Rahmawati et al., 2025). Finally, this review examines the barriers to the adoption of these technologies, such as cost, infrastructure limitations, and knowledge gaps, and proposes strategies to overcome these challenges, ensuring that smart farming is accessible and beneficial to all farmers across Indonesia (Talero, Parra-Sanchez, & Diaz, 2023).

2. Literature Review

2.1. The Concept of Smart Farming and Agriculture 4.0

Smart farming represents a significant evolution from conventional agricultural practices, heralding a new era known as Agriculture 4.0 (Paudel et al., 2025). This concept is centered on the utilization of data as a primary asset to optimize the entire agricultural production chain, from seeding to post-harvest (Soussi, Zero, Sacile, Trinchero, & Fossa, 2024). Agriculture 4.0 is characterized by the integration of cyber-physical systems, where machinery and devices in the field are digitally connected to enable autonomous communication and decision making (Alfred et al., 2021). The goal is to create an intelligent, responsive, and interconnected agricultural ecosystem that enhances efficiency and productivity.

The foundation of smart farming is its ability to collect, process, and analyze large volumes of data (Big Data) from various sources to generate actionable insights (Paudel et al., 2025). These insights allow farmers to shift from a one-size-fits-all approach to precision management tailored to the specific conditions of each field part (Roy & Medhekar, 2025). Thus, smart farming is not merely about implementing technology but also about a managerial mindset shift towards being more proactive and evidence-based in addressing in-field variability (Yuan et al., 2025).

Fundamentally, Agriculture 4.0 aims to achieve three main pillars: increased productivity, enhanced sustainability, and improved food security (Fragomeli, Annunziata, & Punzo, 2024). Productivity gains are achieved through input efficiency and automation, whereas sustainability is realized by reducing environmental impacts, such as greenhouse gas emissions and excessive water use. Food security can be strengthened by creating agricultural systems that are more adaptive to climate and market shocks, ensuring a stable and high-quality supply for the population (Roy & Medhekar, 2025).

2.2. Key Technologies in Smart Farming

The successful implementation of smart farming relies heavily on the synergy of various advanced technologies. These technologies serve as the backbone that enables data collection, analysis, and execution of precision actions in the field (Raj & Prahadeeswaran, 2025). Among the many innovations, three core technologies are most prominent: the Internet of Things (IoT) and sensors, Big Data and Analytics, and Artificial Intelligence (AI) and Machine Learning (ML) (Yuan et al., 2025).

The Internet of Things (IoT) in agriculture refers to a network of interconnected physical devices, such as soil sensors, weather stations, drones, and smart tractors, equipped with the ability to collect and transmit data over the Internet (Alfred et al., 2021). Sensors play a crucial role in this network, acting as "digital senses" in the field to continuously monitor vital parameters such as soil moisture, pH levels, nutrient content, and ambient temperature (Liu et al., 2024). These real-time data provide an accurate picture of the micro-conditions on the farm, forming the basis for timely and targeted interventions (Widura, Hadiatna, & Anugerah, 2023).

The data generated by IoT devices are the fuel for Big Data Analytics. The sheer volume of data, high velocity of its collection, and variety of its formats are key characteristics of Big Data in the agricultural sector (Paudel et al., 2025). Advanced analytics platforms are then used to process raw data and identify patterns, trends, and correlations that are invisible to the human eye. Through techniques such as Machine Learning (ML), systems can "learn" from historical and real-time data to create accurate predictive models, for instance, to forecast crop yields, detect pest and disease outbreaks early, or recommend optimal irrigation schedules (Alfred et al., 2021). As such, AI and ML function as the "brain" of smart farming systems, turning data into intelligent decisions that can enhance efficiency and reduce risk (Yuan et al., 2025).

2.3. Research Gap

Based on a review of previous studies, a significant research gap was identified. Most existing literature tends to focus on the application of smart farming in the context of developed countries or provides a general overview at a broad regional level, such as Asia (Yuan et al., 2025). While these studies offer valuable insights into technological trends and their potential impacts, they often do not address the unique challenges and opportunities faced by developing countries with specific agrarian characteristics, such as Indonesia.

Specifically, there is a lack of comprehensive and systematic research synthesis that focuses exclusively on Indonesia's agricultural landscape. Many existing case studies are sporadic and fragmented, addressing a single type of technology or specific commodity without providing a holistic picture (Alfred et al., 2021). Consequently, understanding how various smart farming technologies interact within the Indonesian agricultural ecosystem and how socioeconomic factors and local policies affect their successful implementation remains limited.

Therefore, this study was designed to fill this gap. By conducting a systematic literature review focused on Indonesia, this study gathered and synthesized scattered evidence to build a coherent understanding of the current status, key challenges, and tangible impacts of smart farming technology adoption on productivity and sustainability in Indonesia. The findings of this study are expected to serve as an evidence-based foundation for policymakers, researchers, and practitioners to formulate more effective and locally relevant strategies for smart farming development.

3. Methodology

3.1. Design and Research Approach

This study implements a Systematic Literature Review (SLR) design. The SLR approach was chosen because it is the most powerful method for synthesizing existing research evidence in a comprehensive, transparent, and replicable way (Abbasi, Martinez, & Ahmad, 2022). Given that the purpose of this study is to map the use of information technology, analyze its impact on competitiveness, and identify challenges within the context of Indonesian agribusiness, where the existing literature is extensive and fragmented. An SLR is the most appropriate approach for producing solid and evidence-based conclusions (Mustapha, Sakariyau, Zubairu, & Afang, 2022).

To maintain methodological quality and accuracy, this study strictly adhered to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol. PRISMA is a recognized international standard for reporting systematic reviews, providing checklists and flowcharts to guide the process from start to finish. In addition, the Research Questions (RQs) that guided this review were formulated using the PICO framework to ensure the focus, clarity, and relevance of each article analyzed (Mustapha et al., 2022).

Based on the established research objectives, this study is guided by one main question: How is smart farming technology utilized to enhance productivity and sustainability in the Indonesian agricultural sector? To systematically answer this broad question, the research is broken down into three specific analytical focuses (Tamimi, 2024). First (RQ_1), this study identified the most dominant types of smart farming technologies discussed in the literature related to the Indonesian agricultural context. Next (RQ_2), this study analyzes the specific impacts of implementing these technologies on key indicators of productivity and sustainability. Finally (RQ_3), this study maps the main inhibiting and supporting factors that influence the successful adoption of this technology by agricultural actors in Indonesia.

3.2. Literature Search and Selection Process

To gather relevant literature, a systematic search was conducted across several leading international academic databases, including IEEE Xplore, ScienceDirect, and Emerald Insight (Kurniawan & Mahendrawathi, 2025). The search strategy focused on a combination of core keywords: "smart farming," "technology," "agriculture," and " Indonesia " to ensure specific and relevant coverage for the research context. A stringent set of inclusion criteria was applied to guarantee the quality and relevance of selected studies.

The primary criterion was topical relevance, where each article must explicitly address the intersection of smart farming technology and the agricultural sector within the specific context of Indonesia. To maintain academic rigor, only peer-reviewed publications, such as journal articles and conference proceedings were considered. Furthermore, the publication timeframe was limited to the last five years

(2021–2025) to capture the most recent technological advancements, and only studies written in English were included to ensure their international comparability.

Conversely, studies that did not meet the inclusion criteria were systematically excluded. Articles were omitted if their topics were not substantially relevant to the research focus of this review. Non-scientific publication types, such as editorials, book reviews, and opinion articles, were also excluded. Practical limitations in data analysis and verification also led to the exclusion of studies that were not accessible in full-text format or published in languages other than English. The study selection process will follow the four stages of the PRISMA flowchart, which will be documented in detail in the research report. The study selection process follows four stages in the PRISMA flowchart, as you have visualized. This process will be documented in detail in this paper, including the presentation of the PRISMA flowchart.

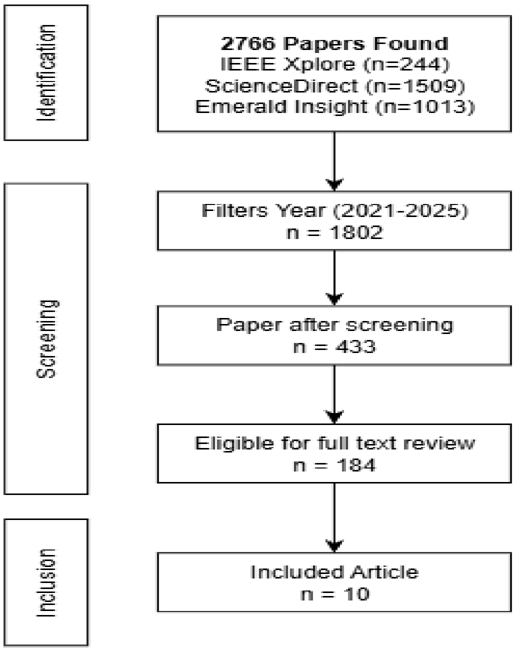

Figure 1. PRISMA Flow Diagram

At the initial identification stage, a search through an electronic database yielded 2766 articles during the screening process based on the research year covering only the last five years, as many as 1802 articles. Furthermore, 433 articles that passed were prepared for the eligibility stage, but 303 of them could not be accessed in full. The remaining 184 articles were then evaluated in depth through full-text reading, of which 10 articles were excluded for not meeting specific inclusion criteria. After a rigorous selection process, a final set of 30 studies was obtained that were considered the most relevant and of high quality for inclusion in the qualitative synthesis analysis of this study.

The entire flow of this process is visually documented in the PRISMA diagram to ensure methodological transparency. Data analysis was conducted using a qualitative Thematic Synthesis approach. The process began with an in-depth reading of the 30 articles selected to identify and record all information relevant to the Research Question (RQ). Key information, such as the type of technology discussed, reported impacts, and identified barriers, will be systematically extracted and compiled to facilitate comparisons between studies.

3.3. Ethical Considerations

This study is based entirely on secondary data sourced from publicly accessible published scientific articles. As there was no direct interaction with human participants, approval from an ethics committee was not required. Nevertheless, the ethical principles of academic research will be strictly upheld, including the accurate and objective representation of findings from the reviewed studies and correct citation practices to acknowledge the intellectual contributions of previous researchers. The entire methodological process will be reported with full transparency to ensure the integrity and validity of this study.

4. Results and Discussions

4.1. Dominant Smart Farming Technologies in Literature Related to Indonesia

Table 1. Dominant smart farming technologies in literature related to Indonesia

Technology Category	Example Implementation and Function	References
Internet of Things (IoT) & Sensors	Use of pH, nutrient, temperature, and humidity sensors for real-time monitoring of land and crop conditions.	(Liu et al., 2024; Widura et al., 2023)
Intelligent Control Systems	Implementation of fuzzy logic to automatically and dynamically manage actuators (irrigation pumps and lights) based on sensor data.	(Roy & Medhekar, 2025)
Big Data & Machine Learning (ML)	Analysis of sensor and image data for yield prediction, early disease detection, and classification of crop types and grain quality.	(Alfred et al., 2021)
Drones & UAVs	Utilization of Unmanned Aerial Vehicles (UAVs) for land mapping, aerial crop health monitoring, and precision input application.	(Al-Khowarizmi, Lubis, Lubis, & Rahmat, 2022; Sambas et al., 2023; Yuan et al., 2025)

Based on the literature analysis, the most prominent technologies in the Indonesian agricultural context are those based on the Internet of Things (IoT) and sensor systems. Case studies, such as that conducted by Widura et al. (2023) in Bandung, demonstrate the concrete implementation of pH, nutrient, temperature, and light sensors to monitor hydroponic conditions in real time. The data from these sensors are processed by intelligent control systems, such as fuzzy logic, to automate actions, such as watering or lighting, indicating a shift from manual intervention to data-driven automated management.

Furthermore, the utilization of Big Data and Machine Learning (ML) is a major trend, especially in the analysis of large-scale agricultural data. Alfred et al. (2021) highlighted the use of ML for various rice production tasks, such as yield prediction and disease detection, which is highly relevant for Indonesia, one of the world's largest rice producers. The use of drones and satellite imagery as data sources for these ML models is also frequently discussed, showing a convergence of remote sensing technology and artificial intelligence in modern agricultural practices in Asia, including Indonesia (Al-Khowarizmi, Lubis, Lubis, & Rahmat, 2022; Sambas et al., 2023; Yuan et al., 2025).

4.2. Specific Impacts of Smart Farming Technology in Indonesia

Table 2. Specific impacts of smart farming technology in Indonesia

Impact Category	Key Indicator and Result	References
Productivity Enhancement	Increased Plant Growth: Height of water spinach increased by 26.3% in a fuzzy-based hydroponic system compared to natural methods.	(Liu et al., 2024; Paudel et al., 2025; Roy & Medhekar, 2025; Widura et al., 2023)

Sustainability Improvement	Resource Efficiency: Electrical energy savings of 4.75% in an intelligent control system compared with a schedule-based system. Reduced water consumption through precision irrigation. Environmental Mitigation: Potential reduction of Greenhouse Gas (GHG) emissions through better input management and conservation agriculture practices.	(Musa & Basir, 2021; Roy & Medhekar, 2025)

The impact of implementing smart farming technologies in Indonesia has proven to be significant in two main pillars: productivity and sustainability. On the productivity side, empirical evidence shows measurable improvements in yields (Halawa, 2024). Widura et al. (2023) quantitatively reported that a hydroponic system controlled by fuzzy logic produced water spinach that was 26.3% taller than that produced using natural methods. This indicates that precise and dynamic input management can directly enhance growth and ultimately increase crop yield.

On the sustainability front, the impact is observed in resource efficiency and a reduced environmental footprint. The same study showed energy consumption savings of 4.75% compared to a fixed-schedule automation system, proving that intelligent systems can optimize energy use (Widura et al., 2023). More broadly, the literature confirms that precision agriculture practices, such as smart irrigation and variable-rate fertilization, effectively reduce water consumption and greenhouse gas emissions, aligning with sustainable development goals (Musa & Basir, 2021; Roy & Medhekar, 2025).

4.3. Drivers and Barriers to Technology Adoption

Table 3. Factors influencing the adoption of smart farming technology in Indonesia

Factor Types	Specific Factors	Reference
Inhibiting Factors (Barriers)	Economic: High initial investment costs for hardware and software are required. Technical: Limited digital infrastructure and Internet connectivity in rural areas. Social: Lack of digital literacy and technical skills among the farmers. Institutional: Issues related to data security, privacy, and ownership.	(Alfred et al., 2021)
Supporting Factors (Enablers)	Policy: Government support through incentives, subsidies, and clear regulatory frameworks. Innovation: Investment in R&D for more affordable and locally relevant technologies. Education: Availability of training, extension, and advisory programs for farmers. Market: Clear potential for increased profitability and efficiency as an adoption incentive.	(Liu et al., 2024; Paudel et al., 2025; Roy & Medhekar, 2025; Widura et al., 2023)

The successful adoption of smart farming technology in Indonesia is influenced by several driving and inhibiting factors. The main barriers consistently identified in the literature are the high initial investment costs for hardware and software, which pose a significant burden on small-scale farmers (Roy & Medhekar, 2025). Additionally, uneven digital infrastructure, especially weak Internet connectivity in rural areas, presents a serious technical obstacle. A lack of digital literacy among farmers and concerns about data privacy and security also represent significant social and institutional hurdles (Paudel et al., 2025).

However, several enabling factors can accelerate adoption. Supportive government policies, in the form of financial incentives and a conducive regulatory framework, play a crucial role (Yuan et al., 2025). Continuous investment in Research and Development (R&D) to create more affordable and locally appropriate technologies is vital (Lee & Kim, 2022). Finally, effective education and training programs to enhance farmers' digital skills, along with clear demonstrations of the economic benefits of technology adoption, can be powerful drivers for digital transformation in Indonesia's agricultural sector (Maula, 2025; Roy & Medhekar, 2025)

5. Conclusions

5.1. Conclusion

This systematic literature review was conducted to map the landscape of smart farming technology in Indonesia, focusing on its impact on productivity and sustainability. The analysis shows that technologies based on IoT, sensors, Big Data, and Machine Learning are the most predominantly applied. The implementation of these technologies has been proven to have significant positive impacts, such as increased plant growth and more efficient use of resources (energy and water), directly supporting the pillars of productivity and sustainability in Indonesian agriculture.

However, the adoption of this technology is not without obstacles. This study identifies major challenges including high investment costs, a digital infrastructure gap in rural areas, and a need to improve farmers' digital literacy. However, enabling factors, such as strong government policy support and effective educational programs, are key to accelerating digital transformation in the agricultural sector. The balance between overcoming barriers and strengthening enablers will determine the speed and success of nationwide smart farming implementation.

These findings have important implications for the stakeholders. The government needs to formulate more targeted policies to address economic and infrastructural barriers, while practitioners and researchers should develop more affordable and locally relevant technological solutions. Future research is recommended to explore long-term implementation case studies and to analyze the socioeconomic impacts of smart farming adoption in greater depth. Overall, the strategic integration of smart farming technology holds great promise for revitalizing Indonesian agriculture, making it more productive, sustainable, and resilient in the face of future challenges.

In conclusion, the systematic literature review revealed that smart farming technologies, particularly those based on the IoT, sensors, big data, and Machine Learning, significantly improve productivity and sustainability in Indonesian agriculture. These technologies have proven effective in increasing crop yields and optimizing the use of vital resources, such as water and energy. Despite these positive outcomes, the adoption of smart farming faces critical challenges, including high initial investment costs, limited digital infrastructure in rural areas, and the need to enhance farmers’ digital literacy levels. Addressing these barriers, alongside leveraging enablers such as government policy support and comprehensive training programs, is crucial for accelerating the adoption of smart farming on a broader scale.

The role of stakeholders, including government entities, practitioners, and researchers, is vital for overcoming these challenges and fostering the widespread implementation of smart farming technologies. Targeted policies must be developed to address economic and infrastructural limitations, and more affordable and context-specific technological solutions must be designed to cater to the local needs of farmers. Moving forward, further research is necessary to explore long-term case studies of smart farming applications and analyze the socio-economic impacts of these technologies in more detail. Overall, the integration of smart farming presents an exciting opportunity to revitalize Indonesia’s agricultural sector, ensuring greater productivity, sustainability, and resilience in the face of future challenges in the agricultural sector.

5.2. Research Limitations

This study is limited by the small sample size of 10 articles selected for review. Although these articles were relevant to the topic, they may not encompass the full spectrum of smart farming applications in Indonesia. Additionally, this review only focused on literature published between 2021 and 2025, which may exclude valuable insights from earlier studies or unpublished practical case studies in the field.

5.3. Suggestions and Directions for Future Research

It is suggested that future research incorporate a larger pool of studies, including grey literature, to capture a broader range of applications and innovative practices in smart farming. Policymakers should focus on creating comprehensive policies that address both economic and infrastructural barriers to technology adoption in rural areas. Moreover, training programs to improve digital literacy among farmers should be prioritized to ensure effective technology integration and adoption across the agribusiness sector. Further research should focus on quantitative studies that assess the economic impact and return on investment (ROI) of adopting smart farming technologies, particularly for smallholder farmers and MSMEs. Longitudinal studies are needed to evaluate the long-term effectiveness of smart farming technologies in enhancing agricultural productivity and sustainability. Additionally, case studies exploring the integration of multiple technologies (such as IoT, AI, and Big Data) in real-world settings could provide deeper insights into the practical challenges and synergies of these technologies in Indonesia's agricultural sector.

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