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Optimizing Agricultural Supply Chain Transparency in Indonesia through Blockchain and Smart Contracts

Konita Lutfiyah[1*], Harlis Setiyowati [2], Cicilia S Bangun [3], Amroni [4], Carlos Perez [5]
[1]Faculty of Business, IPB University, Indonesia
[2]Department of Doctoral Management, Budi Luhur University, Indonesia
[3]Faculty of Industrial Engineering, University of Esa Unggul, Indonesia
[4]Department of Management, University of Catur Insan Cendekia, Indonesia
[5]Faculty of Science and Technology, Ilearning Incorporation, Colombia
[1]qonita13qonita@apps.ipb.ac.id, [2]harlis.setiyowati@budiluhur.ac.id, [3]cicilia.bangun@esaunggul.ac.id, [4]amroni@cic.ac.id, [5]carloszz11@ilearning.co
***Corresponding Author**

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ABSTRACT

This research explores the integration of blockchain technology within Smart Farming 4.0 to improve efficiency, transparency, and sustainability in Indonesia's agricultural sector. **the challenge** of transforming traditional agriculture into a modern, data-driven system remains significant, especially for smallholder farmers. By leveraging blockchain, the Internet of Things (IoT), and Artificial Intelligence (AI), In **this study**, investigates how these technologies can optimize supply chains, enhance product traceability, and reduce distribution costs. Employing a mixed-method approach, data were collected through interviews with farmers utilizing blockchain-based systems and surveys targeting millennial farmers. **The findings** reveal that blockchain significantly improves traceability and logistics efficiency, while highlighting key barriers such as low digital literacy and limited access to technology. **The results** emphasize the importance of government and private sector collaboration in providing incentives, digital literacy training, and infrastructure support. Ultimately, the study offers practical insights into accelerating digital transformation in agriculture and promoting sustainable food systems through technological innovation.

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1. INTRODUCTION

The development of digital technology has led to various innovations that drive efficiency and sustainability across sectors, including agriculture. Technologies such as Artificial Intelligence (AI), the Internet of Things (IoT), and blockchain play a key role in supporting the implementation of Smart Farming 4.0, a data-driven and automated agricultural system [1]. This concept allows farmers to monitor soil conditions, weather, and plant nutrients in real-time to improve productivity.

However, Indonesia faces serious challenges in the agricultural sector. The majority of farmers in Indonesia are over 50 years old, while younger generations tend to shy away from the sector due to perceptions that it is outdated, exhausting, and risky [2]. The phenomenon of "elderly farmers" has become a major obstacle to the long-term sustainability of food production.

Global food demand is projected to increase by up to 56% by 2050, signaling the urgent need for transformation in the agricultural sector to improve productivity, efficiency, and appeal to younger generations

[3].

The implementation of Smart Farming 4.0 is seen as one potential solution. The use of an automated irrigation system based on IoT and LoRa can increase water usage efficiency by up to 30% [4]. This technology allows for accurate and scheduled monitoring of soil moisture.

Blockchain, which has been proven to improve transparency and efficiency in Smart Cities [5], demonstrates how decentralized systems can manage complex data environments securely. Similarly, in agriculture, Blockchain can be integrated to ensure transparent transactions, enhance product traceability, and reduce inefficiencies in the supply chain.

On the other hand, Blockchain technology emerges as a strategic off-farm solution to optimize transparency within Indonesia's agricultural supply chain. By enabling decentralized and immutable recording of transactions and product information, Blockchain enhances traceability and accountability at every stage—from farm to consumer. This technological advancement fosters stronger trust among Indonesian farmers, distributors, and end consumers. Furthermore, the integration of Smart Contracts automates transaction processes, eliminating the need for intermediaries. This not only accelerates distribution but also contributes to reducing logistics costs and inefficiencies in the national agricultural sector.

The key factors driving agricultural transformation in Indonesia through Smart Farming 4.0 are summarized in Table 1.

Table 1. Key Factors in Agricultural Transformation

Factors	**Description**
Technologies (AI, IoT, Blockchain)	Use of advanced technology for efficient and sustainable agricultural systems
Global Population Increase	Projected food demand to increase by up to 56% by 2050.
Agricultural Labor Crisis	Majority of farmers are elderly, with minimal generational renewal
Urgency of Smart Farming	Need for technology adoption to ensure food security
Adoption Barriers in Indonesia	High costs, low digital literacy, and uneven infrastructure.
Role of Blockchain in Supply	Transparency, efficiency, and automation in the agricultural supply chain.

As illustrated in Table 1, the transformation of Indonesia's agricultural sector requires the integration of advanced technologies, improvements in human resources, and supportive policies. The urgency to adopt Smart Farming 4.0 is driven by demographic shifts, environmental pressures, and the need to ensure national food security. Several recent studies support these points:

1. The integration of IoT and Blockchain has already been implemented in Indonesian agriculture, including in melon distribution and algae farming. These technologies enhance efficiency, traceability, and reduce dependency on manual monitoring systems [6].
2. The readiness of smart farming in Java's coffee plantations was analyzed, finding that digital infrastructure and IoT usage improve crop quality control and waste management, especially in areas with high digital penetration [7].
3. A smart agricultural monitoring system using IoT sensors and Blockchain was designed. The framework automatically records agricultural data, verifies transactions using smart contracts, and enhances decision-making through real-time analytics [8].
4. In a global review, the synergy between IoT and Blockchain was affirmed as key drivers for smart agriculture, offering real-time environmental monitoring, disease detection, irrigation control, and secure logistics [9].
5. A Blockchain-enabled smart farming model was proposed to ensure data integrity, transparency, and security in sensor-based agricultural environments, protecting farms from data manipulation and cyberattacks

Thus, it becomes essential to explore how technologies such as Blockchain and IoT can be effectively integrated into Indonesia's agricultural system. This research aims to address these needs by examining the potential of Smart Farming 4.0 in enhancing efficiency, transparency, and sustainability within the sector.

SDG 9: Industry, Innovation, and Infrastructure The adoption of Smart Farming 4.0 supports the development of innovative agricultural practices and infrastructure in Indonesia. Through the integration of cutting-edge technologies like Blockchain and IoT, the study contributes to building resilient infrastructure, fostering industrial innovation, and ensuring the sustainable development of the agricultural sector.

2. LITERATURE REVIEW

2.1. Smart Farming 4.0: Integration of IoT and Robotics

A review of robotics applications in IoT-based Smart Farming has shown that automation can significantly reduce human involvement and increase agricultural productivity [10]. The study, which analyzed 116 scientific articles, provides a framework for implementing agricultural robots in Indonesia's farming sector, where such technology plays a pivotal role in improving efficiency.

2.2. IoT Connectivity and Infrastructure for Modern Agriculture

Connectivity challenges remain a significant obstacle in the application of IoT in agriculture. Tests on Low Power Wide Area Network (LPWAN) technologies such as LoRaWAN, NB-IoT, and Sigfox, compared with 5G cellular signals, revealed that a hybrid LPWAN + 5G model improved reliability by up to 30% and reduced operational costs [11]. The combination of IoT sensors and edge AI computing has proven effective in reducing latency in smart irrigation systems, enabling real-time decisions directly on the farm level [12]. Recent innovations in AI-based prediction models, such as deep LSTM for accident forecasting, show potential to be adapted for crop yield and climate impact predictions in smart farming scenarios [13]. Comparable deep learning frameworks have demonstrated success in complex prediction tasks, such as lung disease classification, which highlights their versatility for agricultural use cases [14].

2.3. Blockchain and Security in Smart Farming

A Blockchain-based security framework for Smart Farming systems integrated with IoT can detect security threats in real time while improving data integrity and authenticity through Smart contracts on the Ethereum Rinkeby testnet [15]. The interoperability between IoT devices and blockchain platforms remains a key challenge in creating a unified agricultural data ecosystem in Southeast Asia [16]. This approach aligns with the use of blockchain as an authenticated system previously applied in smart university environments [17].

2.4. Blockchain, AI, and Trust in Agricultural Supply Chains

Only about 10% of studies in agriculture have combined Blockchain and AI, though this number has been increasing in recent years. This integration offers new solutions for building trust in AI systems through transparent Blockchain record-keeping [18]. Farmers' willingness to adopt blockchain is influenced not only by digital access but also by perceived transparency and pricing control offered by decentralized systems [19].

2.5. Policy and Regulatory Support in Digital Agriculture

The development of Smart Farming 4.0 requires more than just technological advancement it also depends on supportive policies and clear regulations. Without legal frameworks that accommodate digital innovation in agriculture, many initiatives may face obstacles in implementation. Government support in the form of infrastructure investment, digital training, and simplified regulations can significantly help farmers adopt new technologies. Policy alignment is essential to ensure that digital agriculture grows inclusively and sustainably.

2.6. Blockchain in Urban Agriculture Supply Chains in Indonesia

Implementation of Blockchain with RFID, Raspberry Pi, and BitTorrent protocol in a peer-to-peer system effectively reduces data falsification and enhances transparency between producers, distributors, and consumers at the scale of urban agriculture SMEs [20].

2.7. Smart Farming Adoption and Research Gaps in Indonesia

Smart Farming is a form of connectivity between digital platforms and technological devices such as tablets and smartphones to collect vital agricultural data like soil nutrient levels, humidity, and weather conditions [21]. This technological approach aligns with the national agenda set forth by the Indonesian Ministry of Agriculture, which advocates for Smart Farming 4.0 as a strategic pathway to build an advanced, independent, and modern agricultural sector [22]. A visual representation of this concept is shown in Figure 1.

Figure 1. Smart Farming 4.0

Data Source: https://www.hashmicro.com/

Smart farming not only enables farmers to monitor agricultural conditions in real time but also supports more accurate and efficient decision-making. With data collected from various sensors and digital devices, farmers can determine the optimal planting time, irrigation needs, and the precise amount of fertilizer required. As shown in Figure 1, this approach is often realized through the use of drone technology and automated systems that allow for real-time monitoring and precision agriculture practices. This technology enhances productivity, reduces resource waste, and minimizes the risk of crop failure. Such innovation represents a crucial step in transforming Indonesia's agricultural sector into a more modern and sustainable system.

Interestingly, the integration of Artificial Intelligence (AI) and the Internet of Things (IoT) in other sectors, such as energy systems, has shown significant improvements in efficiency and predictive accuracy. These same technologies can be applied in agriculture to monitor crop conditions, assess soil health, and track environmental factors with high precision [23].

From the above literature review, it is evident that while there is extensive international research on the integration of IoT and Blockchain in agriculture, there is a lack of empirical studies in Indonesia that evaluate the holistic implementation of Smart Farming 4.0. This includes the adoption of technology by millennials, government policies, and collaboration between startups and local farmers. Therefore, this study focuses on exploring the implementation of these technologies at a local scale in Indonesia, combining technical aspects (IoT + Blockchain) with social factors (adoption by millennial farmers and the role of regulation), an area that has been underexplored in existing research.

Considering the pivotal role of millennial farmers as digital natives, understanding their adoption behavior is crucial to ensure the long-term success of Smart Farming technologies.

3. RESEARCH METHOD

3.1. Research Design

This study employs a mixed-method approach, integrating both qualitative and quantitative methods to examine the potential implementation of Blockchain technology in Smart Farming 4.0 in Indonesia. This approach enables a comprehensive analysis of Blockchain's impact on supply chain efficiency and the adoption behavior among millennial farmers [24]. The research utilizes case studies, in-depth interviews, and surveys as primary data collection methods, supported by descriptive and regression analysis for data interpretation.

The selection of this research design aligns with the key transformation drivers identified in Table 1, which emphasize the urgency of adopting advanced technologies to enhance efficiency, food security, and sustainability in the agricultural sector

3.2. Data Collection

3.2.1. Primary

Primary data will be collected from two main sources: in-depth interviews and surveys. The selection of respondents is crucial to ensure the relevance and depth of the information obtained. In particular, millennial farmers are prioritized as they are considered digital natives who are more likely to adopt and experiment with emerging technologies such as IoT and Blockchain. By focusing on this demographic, the study aims to explore not only technological readiness but also behavioral, motivational, and contextual factors that influence adoption. Their experiences and perceptions serve as critical indicators for assessing the feasibility and scalability of Smart Farming 4.0 initiatives across rural and urban agricultural settings in Indonesia.

The detailed criteria for selecting participants are summarized in Table 2, which outlines the roles, qualifications, and relevance of both interviewees and survey respondents to the study objectives. These respondents are expected to represent key stakeholder groups in the digital transformation of agriculture in Indonesia and provide meaningful insights into the potential adoption of Blockchain technology.

Table 2. Criteria for Selecting Respondents in Primary Data Collection

Respondent Type	Criteria	Justification
Interviewees	Millennial farmers (ages 25–40) who use digital toolsin agriculture (e.g., Smart irrigation, mobile apps, IoT-based devices)	To capture real experiences in the digital transformation of agriculture and perceptions regarding Blockchain
Survey Respondents	Millennial farmers with access to digital farming platforms or applications	To assess broader perspectives, awareness, and perceived barriers to the adoption of Blockchainin agriculture

Table 2 presents the selection criteria for respondents involved in the primary data collection phase, divided into two main groups: interviewees and survey participants. Both categories focus on millennial farmers actively engaged with digital agricultural technologies, such as IoT-based tools, smart irrigation systems, or mobile farming applications. The purpose is to gather relevant insights into their experiences with digital transformation and their perceptions of Blockchain adoption, including opportunities and perceived barriers.

3.2.2. Secondary Data

Secondary data will be obtained through an extensive literature review encompassing a range of academic and empirical sources relevant to the research topic. This review aims to enrich the conceptual framework and support the analysis of Blockchain implementation in Smart Farming 4.0. The literature includes:

1. Peer-reviewed journal articles and prior studies have examined the application of Blockchain technology in agriculture, particularly within developing countries that share similar socio-economic characteristics with Indonesia. For instance, several studies have highlighted the challenges and opportunities of Blockchain adoption in the agricultural sectors of countries like India and Bangladesh, which face comparable infrastructural and digital literacy barriers[25].

2. Documented case studies of both successful and failed implementations of Blockchain in Smart farming systems, offering practical insights and comparative perspectives on its opportunities and limitations [26].

3. Publications from research institutions, technology journals, and international organizations discussing the role of AI, IoT, and Blockchain in enhancing agricultural supply chain efficiency at both global and local scales [27]

4. Literature addressing the levels of digital literacy among farmers, government policy frameworks, and socio-cultural factors that influence the adoption of digital agricultural technologies in Indonesia [28].

3.3. Data Collection Procedures

1. Respondents will be selected through purposive sampling, focusing on millennial farmers who are known to be early adopters or innovators in the use of smart farming technologies. Each interview is expected

to last 30–60 minutes, will be audio-recorded with consent, transcribed verbatim, and analyzed thematically. In-depth interviews are crucial for exploring the personal experiences of early adopters, especially when adopting emerging technologies like blockchain in agriculture [29]. This method allows researchers to delve deeper into the challenges and experiences of participants, which may not be captured through other data collection methods.

2. The questionnaire will be distributed both online (e.g., via Google Forms or email) and offline (via agricultural cooperatives or field agents). Survey items will use Likert scales and multiple-choice questions focusing on attitudes toward Blockchain, perceived usefulness, ease of use, and challenges. A pilot test will be conducted to ensure the clarity and reliability of the instrument. Likert scale surveys are often used to assess attitudes and perceptions regarding the usability and usefulness of new technologies, such as blockchain, in various fields [30].

3.4. Data Analysis Techniques

To clarify the theoretical foundation of this study, Figure 2 presents a conceptual framework that illustrates the relationship between enabling factors and Blockchain adoption in the smart farming context. Specifically, the framework demonstrates how digital literacy and access to technology are expected to influence the adoption of Blockchain, which subsequently enhances supply chain efficiency. This framework is crucial for understanding the expected relationships and identifying key variables in the study [31]. It will guide both the quantitative analysis (regression analysis) and the qualitative coding (thematic analysis) processes.

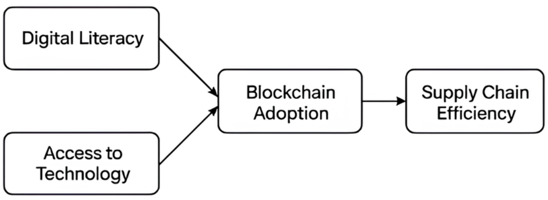

Figure 2. Conceptual Framework of Blockchain Adoption in Smart Farming

As depicted in Figure 2, Blockchain adoption serves as a mediating variable between enabling conditions and positive agricultural outcomes. The framework forms the analytical basis for understanding how digital literacy and access to technology drive blockchain adoption, which ultimately enhances agricultural productivity [32]. This model provides insights into the expected effects and will help interpret the data in the research.

To analyze adoption patterns and predict behavioral intentions of millennial farmers toward technology, machine learning techniques such as Naive Bayes or hybrid models can offer significant insights. Similar hybrid approaches have also been used effectively in digital behavior prediction, such as cyberbullying detection in social platforms [33]. This has been successfully implemented in educational settings to predict student outcomes based on behavioral data [34].

3.5. Validity and Reliability

To ensure the validity and reliability of the data, this research will employ triangulation by comparing interview results with survey data and case studies. Additionally, focus group discussions (FGD) will be conducted to confirm the consistency of findings and ensure that the conclusions reflect the conditions experienced by stakeholders. Triangulation remains a widely used and reliable method for enhancing research credibility by integrating multiple data sources and perspectives [35]. This strengthens the overall trustworthiness and robustness of the findings.

The use of triangulation and FGD is essential in ensuring the research's findings are consistent and reflective of real-world conditions. These methods help to improve the overall validity and reliability of the conclusions drawn from the study [36].

4. RESULT AND DISCUSSION

The integration of Blockchain, IoT, and AI technologies within the Smart Farming 4.0 framework demonstrates significant potential to improve transparency, operational efficiency, and product traceability in Indonesia's agricultural sector. A survey of 105 millennial farmers revealed that 78% believe Blockchain increases trust in agricultural transactions, while 64% stated that the technology helps reduce reliance on intermediaries. In depth interviews with 15 digitally literate farmers further support these findings. They reported that using Blockchain based platforms enabled broader market access and greater control over pricing. However, major challenges such as limited internet connectivity, lack of technical training, and insufficient digital support continue to hinder adoption.

Regression analysis of the conceptual framework (refer to Figure 2) showed that digital literacy and access to technological infrastructure are significant predictors of Blockchain adoption ($p < 0.01$). The model explains 67% of the variance in adoption behavior ($R^2 = 0.67$), aligning with previous studies.

3 illustrates the overall landscape of Blockchain adoption among millennial farmers in Indonesia. It captures key aspects such as increased trust, reduced dependence on intermediaries, as well as the opportunities and technical barriers experienced in the field.

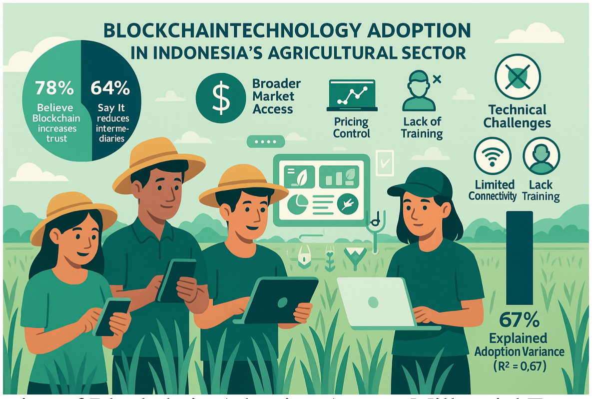

Figure 3. Illustration of Blockchain Adoption Among Millennial Farmers in Indonesia.

Figure 3 further emphasizes the contrast between the promise of Blockchain in improving agricultural systems and the persistent digital challenges in its implementation. It highlights how millennial farmers are at the forefront of this transition, navigating both the benefits and barriers of technology adoption. This study reaffirms that Blockchain technology has strategic potential to revolutionize agricultural supply chains by enhancing product traceability, transaction efficiency, and payment transparency.

Smart contracts emerge as a pivotal feature, enabling automated transactions once predefined conditions are met. This reduces delays and improves cash flow [37].

Nevertheless, adoption is uneven. Farmers with reliable internet access and digital skills are more likely to adopt the technology, while those in underserved areas face substantial barriers [38].

Despite high interest among millennial farmers, a gap remains between intention and actual use. This reflects the "intention-behavior gap" described in the literature, driven by a lack of technical support and complex digital interfaces.

From a sustainability standpoint, combining Blockchain with IoT sensors yields positive results. Some respondents reported up to a 25% reduction in water usage through precise irrigation informed by real-time soil moisture data [39].

However, effective implementation depends not only on technological readiness but also on institutional support. Government-led digital agriculture programs remain underutilized, while agritech startups often struggle to scale beyond pilot projects [40]. Government support in the form of tax incentives and infrastructure grants significantly boosts the adoption rate of smart farming technologies among smallholder farmers [41].

Furthermore, the successful integration of Blockchain into agriculture requires not just technical innovation but also a cultural shift among stakeholders. Farmers, suppliers, and regulators must be equipped not only with tools, but also with the mindset to embrace decentralized systems, which demands transparency, accountability, and continuous learning. This human factor is equally critical to ensure long-term sustainability and impact.

Similar to how audiovisual media was utilized to promote art and culture in Tangerang through engaging digital content and creative tools [42], smart farming adoption can benefit from the same promotional strategies such as visual demonstrations, storytelling content, and farmer testimonials on social platforms. These approaches can effectively raise awareness, improve trust in technology, and inspire behavioral change among digitally hesitant farming communities.

4.1. Synthesis

Overall, Blockchain technology within Smart Farming 4.0 offers transformative opportunities to improve traceability, financial independence, and sustainability in Indonesia's agriculture sector. However, these benefits can only be realized through supportive policies, equitable infrastructure, and continuous capacity-building programs.

A phased implementation strategy starting with digitally advanced regions and gradually expanding via training and policy interventions is recommended. Collaboration among governments, the private sector, and farming communities is essential to building a resilient, inclusive digital agricultural ecosystem.

The integration of Blockchain in Smart Farming has resulted in a range of empirical outcomes, highlighting both its potential benefits and implementation challenges. These outcomes include improvements in product traceability, automated transactions through smart contracts, reduced water consumption, and enhanced supply chain efficiency. However, the effectiveness of these innovations is often influenced by external factors such as internet infrastructure, digital literacy, and the presence of supportive government policies. To present these findings more clearly, the study organizes them into thematic categories that summarize key observations from the field along with their broader policy and practical implications.

To provide a clearer and more structured understanding of the empirical findings, a summary table is presented below. This table synthesizes the core aspects of Blockchain implementation in Smart Farming, outlining the observed outcomes from the field and their broader implications for agricultural development in Indonesia. The categorization helps to highlight the multidimensional benefits and barriers, serving as a practical reference for policymakers and stakeholders.

To summarize the key findings and implications, Table 3 presents an integrated overview:

Table 3. Key Findings and Implications of Blockchain Implementation in Agriculture

Aspect	Key Findings	Implications
Product Traceability	78% stated Blockchain enhances transparency in distribution	Builds consumer trust and improves export credibility
Transaction Efficiency	Smart contracts reduce transaction time and costs	Faster payment cycles for farmers
Technology Access	Significant disparities in internet infrastructure across regions	Need for equitable digital infrastructure
Digital Literacy	Strong predictor of adoption (R^{2} = 0.67, p <0.01)	Digital training programs are essential
Water Usage Efficiency	IoT-Blockchain integration reduces water use by up to 25%	Promotes sustainable resource management
Adoption Gap	High interest not matched by real-world implementation	Requires technical support and intuitive platforms
Government Role	Absence of dedicated Blockchain policies in agriculture	Calls for incentives, regulation, and multi-sector partnerships

This Table 3 reinforces the idea that the challenges in adopting Blockchain go beyond technological availability. Instead, they lie in ecosystem readiness, especially in terms of digital literacy, equitable access, and regulatory frameworks. Hence, Smart Farming 4.0 in Indonesia must be systematically developed through an adaptive, inclusive, and collaborative approach.

5. MANAGERIAL IMPLICATIONS

This study presents several strategic managerial implications that can guide agricultural policymakers, technology developers, and agribusiness leaders in accelerating the integration of Blockchain technology within Indonesia's agricultural system.

1. User-Centric Technology Design

   The adoption of Blockchain by farmers especially millennials is strongly influenced by their level of digital literacy and their ability to engage with the technology intuitively. Therefore, developers must ensure tabel platforms are accessible and user friendly, even for farmers with limited technical backgrounds [43].

2. Integration of Smart Contracts in Agribusiness Models

   Smart contracts enable automated transactions based on predefined conditions, reducing friction in payment cycles and increasing cash flow efficiency. This mechanism has also been effectively used in higher education settings through gamification schemes powered by smart contracts [44]. Managers should incorporate smart contracts into agribusiness systems to improve financial transparency and empower farmers to negotiate pricing more independently [45].

3. Addressing the Digital Infrastructure Divide

   Digital disparities across regions remain a challenge. A phased implementation strategy starting in digitally ready regions can be scaled nationally with the support of government training programs and targeted infrastructure investment [46].

4. Regulatory Innovation and Legal Frameworks

   The absence of formal regulations on Blockchain in agriculture hinders technological innovation. Government regulators must take the lead in creating supportive legal frameworks, providing financial incentives, and protecting smallholder farmers from digital exploitation [47].

5. Cross-Sector Collaboration for Scalable Adoption

   Collaboration between agritech startups, cooperatives, academic institutions, and local governments is vital. Joint initiatives, such as pilot projects or digital farming grants, can accelerate early adoption and build shared ownership of technological innovation [48].

6. Human-Centered Digital Transformation

   Technology alone is not sufficient; a human-centered approach that respects local culture, values, and learning styles is essential. Managers must empower farming communities not only with tools, but with the mindset and confidence to navigate decentralized systems [49].

7. Youth Engagement Through Digital Education

   Youth Engagement Through Digital Education Youth involvement in agriculture increases significantly when gamification and digital storytelling are integrated into agricultural training programs. These innovative educational methods appeal to younger audiences and foster a more engaging learning experience [50].

6. CONCLUSION

This study highlights the crucial role of Blockchain technology in supporting Smart Farming 4.0 to enhance efficiency, transparency, and sustainability in Indonesia's agricultural sector. The integration of Blockchain, along with IoT and AI, offers a promising solution to long-standing challenges in the agricultural supply chain such as price volatility, inefficient distribution, and lack of product traceability. By enabling decentralized data management and automated transactions, Blockchain empowers farmers with greater control over pricing and market access.However, the implementation of this technology is not without obstacles. Limited digital literacy, high initial costs, and unequal infrastructure access, particularly among small-scale farmers, remain major barriers to adoption. To address these issues, this study recommends the provision of financial incentives, infrastructure support, and targeted digital literacy programs.

Collaboration between government, the private sector, and farming communities is essential to ensure successful adoption. Public policies should facilitate the integration of Blockchain in agricultural logistics while providing training and subsidies for relevant technologies. With the right institutional support, Blockchain has the potential to become a key driver of Indonesia's digital agricultural transformation improving productivity, ensuring food security, and promoting long-term sustainability. Ultimately, this research contributes to the growing body of knowledge on digital agriculture by offering an applied perspective on how emerging technologies can be localized and scaled in developing countries like Indonesia.

7. DECLARATIONS

7.1. About Authors

Konita Lutfiyah (KL) -

Harlis Setiyowati (HS) https://orcid.org/0000-0003-3773-3454

Cicilia S Bangun (CS) https://orcid.org/0000-0002-6329-9180

Amroni (AA) https://orcid.org/0009-0008-6742-359X

Carlos Perez (CR) https://orcid.org/0009-0006-5344-6833

7.2. Author Contributions

Conceptualization: KL, HS, CS, AA and CR; Methodology: KL; Software: AA; Validation: HS and CS; Formal Analysis: CR and CS; Investigation: AA; Resources: CR; Data Curation: MM; Writing Original Draft Preparation: KL and HS; Writing Review and Editing: CS Visualization: AA; All authors, KL, HS, CS, AA and CR have read and agreed to the published version of the manuscript.

7.3. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

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7.5. Declaration of Conflicting Interest

The authors declare that they have no conflicts of interest, known competing financial interests, or personal relationships that could have influenced the work reported in this paper.

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