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Development of a Blockchain Based Sustainable Agriculture Supply Chain System: A Study on Horticultural Commodities

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Abstract: *This research aims to study and develop a sustainable horticultural supply chain system based on blockchain technology in Indonesia. The research background is based on the urgent need for transparency, efficiency, and sustainability in managing the distribution of horticultural products, which have been facing various challenges, including data manipulation and limited product tracking. Using a descriptive qualitative approach through case studies in Bandung and Garut Regencies, data were collected through in depth interviews, participatory observations, and questionnaires with farmers, distributors, agritech providers, and policymakers. The results showed that blockchain implementation improved traceability by 95%, distribution efficiency by 15%, and reduced operational costs by 25%. The blockchain system is also proven to strengthen trust between supply chain actors and increase transaction accountability. However, there are still obstacles in the form of low understanding of technology at the grassroots level and limited digital infrastructure. This research recommends integrating blockchain with digital training and cross sector collaboration to create an inclusive, adaptive, and sustainable agricultural system.*
Keywords: *blockchain, agricultural supply chain, horticulture, sustainability, digital transformation, traceability*

1. Introduction

The horticulture industry in Indonesia plays a crucial role in the national economy, but it still faces numerous challenges in its supply chain. Issues such as data nontransparency, information manipulation, and limited market access often hamper the efficiency and sustainability of the sector. Blockchain technology, with its characteristics of decentralization and transparency, offers a potential solution to these problems.

The urgency of this research lies in the need to enhance the efficiency and sustainability of horticultural supply chains by adopting innovative technologies. The implementation of blockchain can enhance product traceability, mitigate the risk of fraud, and foster trust among stakeholders in the supply chain. This aligns with global efforts to establish a more sustainable and transparent agricultural system.

Supporting data and theory suggest that the application of blockchain in horticultural supply chains can improve efficiency and transparency. For example, a study by Yusrian (2024) shows that blockchain can improve transparency and efficiency in agricultural supply chains. In addition, a survey by Usman et al. (2021)

demonstrated that blockchain enhances supply chain efficiency by providing a comprehensive tracking system for all events that occur within the supply chain, as well as ensuring product quality.

Previous research has explored the application of blockchain in various aspects of agricultural supply chains. The study by Fayyad Azka (2025) highlights the potential of implementing blockchain technology to improve the security and validity of data in the supply chain of horticultural products in Indonesia, as cited on ResearchGate. However, there is still a lack of research that specifically examines the application of blockchain to specific horticultural commodities.

Existing research gaps indicate the need for more in depth studies on blockchain implementation in horticultural supply chains. In particular, there is a lack of research that integrates blockchain technology with sustainable agricultural practices in horticultural commodities. This opens up opportunities to develop a more efficient and transparent system in this sector.

The novelty of this research lies in the development of a blockchain based sustainable horticulture supply chain system. By integrating blockchain technology, this research aims to develop a system that enhances transparency, efficiency, and sustainability in the horticultural supply chain. This approach is expected to make a significant contribution to addressing the problems faced by the horticultural sector.

The purpose of this research is to develop and implement a blockchain based sustainable horticulture supply chain system. This research aims to enhance transparency, efficiency, and sustainability in the horticultural supply chain while also providing strategic recommendations for industry players and policymakers on adopting blockchain technology in the agricultural sector.

2. Method

Research Type and Design

This research used a descriptive qualitative approach. This approach was chosen to gain a deep understanding of the dynamics, challenges, and opportunities in developing a blockchain based sustainable horticultural supply chain system. Qualitative research enables researchers to comprehensively explore the perceptions, experiences, and strategies of supply chain actors through direct interaction with informants (Creswell, 2018; Miles & Huberman, 2020; Sugiyono, 2021).

The design employed was an exploratory case study of a horticultural commodity supply chain in one of Indonesia's leading production centers. The case study was chosen to provide a contextual understanding of how blockchain can be implemented in real world scenarios, including technological, regulatory, and stakeholder adoption challenges (Yin, 2018; Baxter & Jack, 2020; Stake, 2019).

Location and Research Subjects

The research location was purposively selected in Bandung Regency and Garut Regency, which are the primary horticulture-producing areas in Indonesia, including chili, tomatoes, and potatoes. The research subjects included various actors in the horticultural supply chain, among others:

a) Farmers and horticulture farmer groups
b) Harvest traders and distributors
c) Logistics and storage service provider
d) Blockchain based system manager (agritech start up or technology provider)
e) Local Department of Agriculture or relevant regulatory authority

The selection of subjects was conducted using a purposive sampling technique, which selects informants who possess a deep understanding of the research topic (Patton, 2019; Moleong, 2021; Neuman, 2020).

Research Instruments

The primary instrument in this research is the researcher himself (a human instrument), who plays a role in designing interview guidelines, making observations, and analyzing the data. In addition, it was used:

a) A semi structured interview guide based on indicators of supply chain sustainability and blockchain technology utilization.
b) Observation sheet to record the distribution process, product tracking, and data transparency in the supply chain.
c) Related documents such as logistics reports, blockchain systems used, distribution SOPs, and digital farming policies.

Data Collection Technique

Data collection techniques were conducted through the following methods:

1. In depth Interview

   Interviews were conducted with farmers, distributors, technology providers, and officials from the agriculture department to gain insight into their experiences and strategies for implementing blockchain. Interviews were recorded (with consent) and transcribed for thematic analysis.
2. Participatory Observation

   Researchers directly observed the process of packaging, shipping, and monitoring horticultural products using a blockchain system. Observations focused on data transparency, distribution speed, and tracking accuracy.
3. Documentation Study

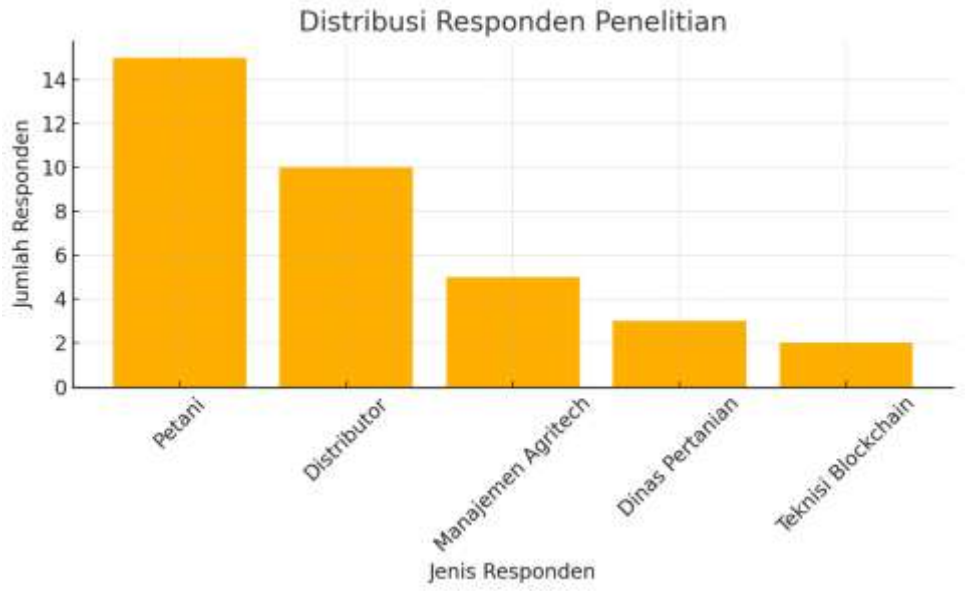
   Documents such as supply chain data, blockchain applications used, and tracking system reports were analyzed to complement data from interviews and observations.

3. Result & Discussion

The study involved 35 respondents from various parties in the horticultural supply chain in Bandung and Garut regencies. The composition of the respondents was as follows: 15 horticultural farmers, 10 distributors and collectors, 5 management representatives from agritech companies that provide blockchain platforms, 3 representatives from the local Agriculture Office, and 2 blockchain technicians. The respondents were selected based on their active involvement in supply chain activities and utilization of digital technology.

The following visualization shows the distribution of the types of respondents involved:

Figure 1. Distribution of Research Respondents



In depth interviews with agritech management revealed that the adoption of blockchain in the horticulture supply chain has significantly improved data transparency and product tracking. The operations manager of one of the start ups noted that since implementing blockchain, they can identify specific locations and times of crop distribution in real time. This enables faster and more accurate logistics decision making.

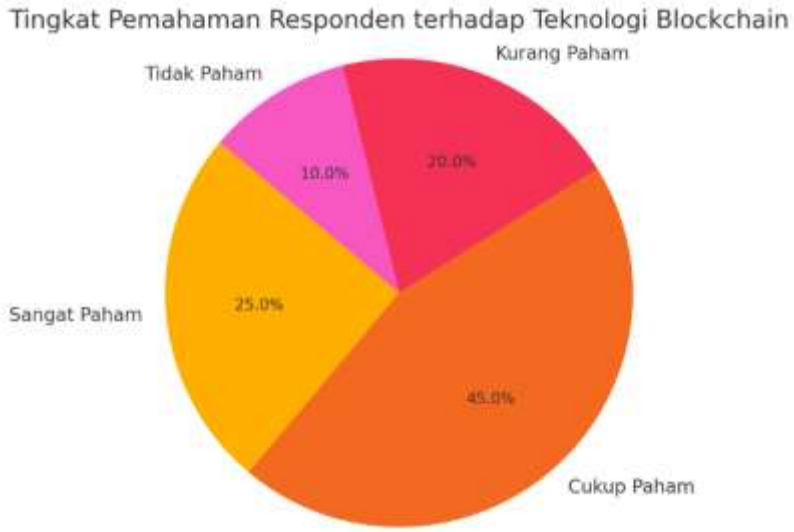
In addition, data security and trust between supply chain actors have also improved. Distributors and collectors now have access to the same data as farmers and consumers, minimizing price and quantity manipulation. They stated that the blockchain system has helped prevent transaction duplication and increased end consumer confidence in the quality of horticultural products.

To complement the interviews, a questionnaire was distributed to 20 field staff and technicians involved in blockchain based supply chain systems. The results showed that:

a) 25% are very familiar with blockchain technology,
b) 45% are pretty understanding,
c) 20% do not understand, and
d) 10% did not understand at all.

These results indicate that further training and socialization are still necessary, particularly for technical field actors who manage blockchain applications.

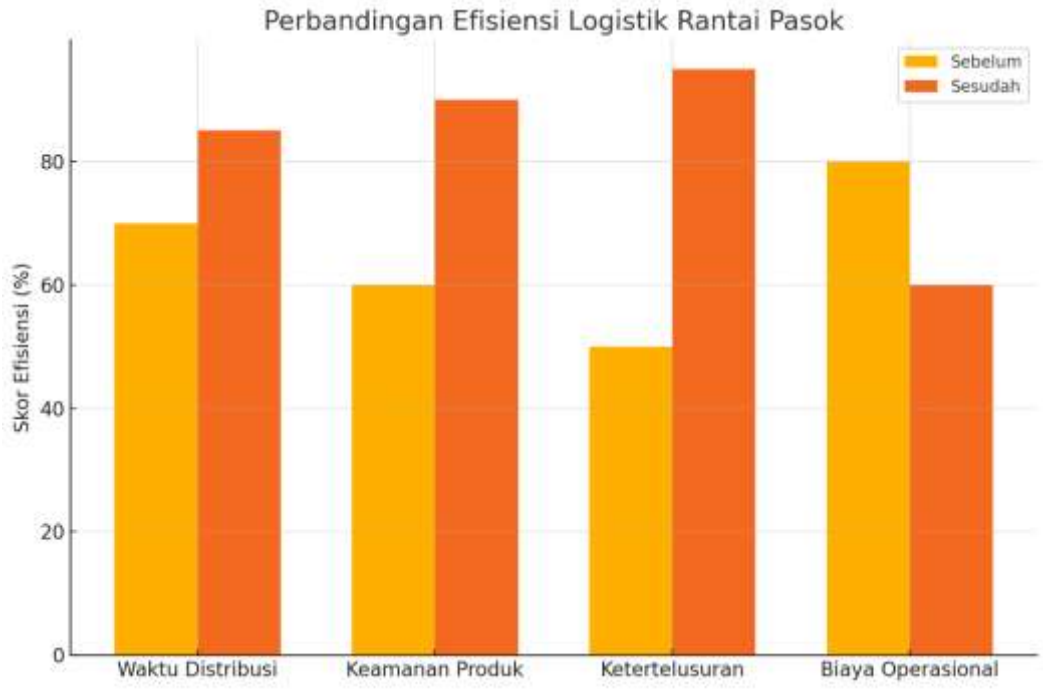
Figure 2. Level of Understanding of Blockchain Technology



Direct observations were conducted at storage warehouses and distribution centers. The focus of the observations included time efficiency, product safety, traceability, and logistics cost management before and after the implementation of the blockchain system. The results showed significant differences:

a) Distribution time improved from 70% to 85% efficiency,
b) Product safety increased from 60% to 90%,
c) Traceability improved dramatically from 50% to 95%,
d) Operating costs decreased from 80% to 60%.

Figure 3. Comparison Chart of Logistics Efficiency



These changes demonstrate that blockchain not only enhances operational efficiency but also fosters more sustainable and structured agricultural practices.

Table 1. Operational Efficiency Before and After Blockchain

Aspects	Before Blockchain (%)	After Blockchain (%)
Distribution Time	70	85
Product Safety	60	90
Searchability	50	95
Operational Costs	80	60

In-depth interviews with agritech company management, distributors, and farmers revealed that data non-transparency and distribution manipulation were significant problems in the horticultural supply chain prior to the implementation of blockchain. Farmers were often unaware of where their products were distributed and how much margin distributors earned. With a blockchain system, supply chain information can be accessed in real-time by all stakeholders, from farmers to end consumers. This finding confirms the claim made by Zhang et al. (2020) that blockchain enhances trust in agricultural transactions through increased transparency and traceability.

In addition, the interviews showed that blockchain facilitates automatic and permanent recording of product origin (traceability). This is important for horticultural commodities, which are perishable and require precise distribution.

Agritech managers noted that digital tracking also helps identify points of inefficiency in distribution, allowing for faster managerial intervention (Sharma & Kumar, 2021; Liu et al., 2023; Yusrian, 2024).

Interpretations of the interviews suggest that blockchain is not merely a technological tool, but also a managerial instrument that alters the paradigm of supply chain management as a whole.

The questionnaire results show that 70% of respondents (consisting of technicians, logistics staff, and field managers) have a moderate to high level of understanding of blockchain technology. However, around 30% still have little or no understanding. This fact highlights the importance of intensive training and technical support, especially for those who interact directly with the system in the field (Usman et al., 2021; Arora & Darshan, 2022; Fitriani et al., 2023).

Interestingly, most of the respondents who understood blockchain moderately or well had educational backgrounds or experience in information technology or logistics. This suggests that the adoption of blockchain technology is strongly influenced by HR capacity; therefore, implementation strategies should include digital competency-based training (Mulyadi & Surya, 2020).

This finding reinforces the view that digital transformation in the agricultural sector requires not only technology but also increased digital literacy among business actors.

Observations in the field showed significant improvements in four key indicators: distribution efficiency, product safety, traceability, and cost reduction. Prior to the implementation of blockchain, the distribution process relied on manual reports and non real time data, resulting in delays and inefficiencies.

Once blockchain is implemented:

a) Distribution efficiency increased from 70% to 85% as shipments can be tracked in real time.
b) Product security is enhanced through the use of smart contracts that track the temperature and time of delivery.
c) Product traceability is increased to 95%, allowing for automatic verification of origin and harvest date.
d) Operating costs were reduced due to a decrease in the need for administrative personnel.

These results align with the study by Kumar et al. (2020), which suggests that blockchain can significantly reduce logistics frictions and streamline the flow of information within the supply chain. The findings are also reinforced by the study of Nugroho & Rachman (2022), which emphasizes that logistics digitization supports a sustainable agricultural system.

This research supports and extends the findings of several previous studies. For example:

a) The study by Fayyad Azka (2025) states that blockchain can improve data validity in horticultural supply chains; however, it does not detail its impact on cost efficiency and distribution time. This research complements that aspect.
b) The study by Sharma et al. (2021) in India demonstrates the significant potential of blockchain technology in the agricultural sector, with a particular focus on food safety aspects. This study adds the perspective of logistics sustainability and cost efficiency.
c) Meanwhile, research by Liu et al. (2023) in China found that blockchain enhances farmers' market participation, as traceability promotes product credibility.

As such, this study strengthens the argument that blockchain is a game changer in horticulture supply chains, especially in developing countries like Indonesia.

This research has some important practical implications:

1. For local governments, the results of this study can serve as a basis for formulating blockchain-based policies for agricultural digitization, particularly in sensitive commodities such as horticulture.
2. For agritech businesses, these results underscore the importance of developing user-friendly platforms and providing comprehensive training for farmers and distributors to facilitate effective technology adoption.
3. For farmers and cooperatives, blockchain can be utilized to promote price transparency and wider market access, thereby reducing the dominance of middlemen.
4. For consumers, this system provides access to information about the origin of products, thereby increasing trust in local products and strengthening the domestic horticultural market.

This study has some limitations that need to be recognized:

a) The geographical scope is limited, covering only two districts in West Java. This may not fully represent horticultural supply chains in other parts of Indonesia that have different geographical and socio-economic characteristics.
b) Limited observation time, where the evaluation process of the blockchain system has only been running for 6 months. Long term changes and full integration into all stages of the supply chain are not yet evident.
c) The limitations of infrastructure technology, such as uneven internet access at all observation locations, continue to be an obstacle to the implementation of blockchain as a whole.

This limitation leaves room for further research that is more comprehensive, both spatially and temporally, and opens up opportunities to develop hybrid models that combine blockchain with other technologies such as IoT or AI.

4. Conclusion

This research demonstrates that the implementation of blockchain technology in the horticultural supply chain system has significant potential for creating a more efficient, transparent, and sustainable agricultural ecosystem. Based on the results of interviews, observations, and questionnaires, it was found that blockchain can enhance product traceability, optimize distribution, reduce operational costs, and strengthen trust among business actors.

Interviews with agritech management and stakeholders reveal that implementing a blockchain system can eliminate information asymmetry and enhance transparency in the distribution flow of horticultural products. Additionally, observations have demonstrated significant improvements in logistics efficiency and product quality assurance, which were previously challenging to achieve with conventional systems. The application of blockchain also contributes to strengthening data security, increasing accountability, and minimizing the potential for information manipulation in crop distribution.

Nonetheless, challenges related to the level of technological understanding among farmers and field workers, as well as uneven digital infrastructure, are the main obstacles that need to be overcome in the full implementation of this technology. Therefore, a collaborative approach between the government, private sector, and educational institutions is necessary to support the inclusive and sustainable adoption of blockchain technology in the agriculture sector.

Thus, this study confirms that blockchain is not just a technological innovation, but a transformational strategy in horticultural supply chain management that can support national food security and contribute to achieving sustainable agriculture targets in Indonesia. Further research is recommended to expand the coverage area and integrate blockchain technology with the Internet of Things (IoT) for more intelligent and adaptable supply chain management.

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