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Improving Avocado Distribution Ecosystem using Blockchain Technology

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ABSTRACT

Objective: Indonesia is the world's second-largest avocado producer; however, it is not among the leading avocado-exporting countries because its supply chain has limited capacity to meet increasing consumer demands for product authenticity, organic certification, and traceability. This study aims to develop a blockchain-based traceability model that improves transparency, record reliability, and quality assurance throughout Indonesia's avocado supply chain.

Methods: The proposed model maps the participation and data-sharing roles of key supply-chain stakeholders, including farmers, a certification body, intermediaries, and retailers. Blockchain technology is used to record and connect product information across supply-chain stages, creating an immutable and transparent history of the avocado journey from production to retail.

Results: The developed model provides an integrated traceability framework in which authorized stakeholders can record and verify information related to product origin, certification, handling, distribution, freshness, and compliance with relevant standards. The model produces a reliable product history that can be accessed to support verification and respond to consumer traceability requirements.

Conclusion: The proposed blockchain-based model can strengthen assurance of avocado authenticity, freshness, organic status, and standards compliance by improving information transparency and preventing unauthorized alteration of supply-chain records. Its implementation may increase stakeholder and consumer trust, support the competitiveness of Indonesian avocados in export markets, and contribute to long-term value creation in Indonesia's horticultural sector.

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1. Introduction

Over the past few decades, the global avocado market has experienced rapid growth, driven by increasing consumer demand for healthier food choices. As one of the leading fruit commodities in Indonesia, avocados have become highly competitive in the marketplace. Indonesia's Ministry of Agriculture stated that there is an increasing preference for the consumption of fresh fruits and vegetables, making quality assurance a crucial factor in maintaining market trust and competitiveness (Hendayani & Fernando, 2022). However, maintaining avocado quality presents several challenges, including their susceptibility to damage, the need for intensive care, and the fact that their economic value is highly influenced by both freshness and aesthetic appeal. Given that avocados ripen immediately after harvesting, proper postharvest management is crucial to extend shelf life and maintain quality (Groom, 2022). Therefore, it is advisable to enhance control, supervision, and enhancement of these conditions in orchards. Packaging companies also find it difficult to determine rejected products. Which can lead to inefficiencies in sorting and quality control. The quality of avocados is significantly influenced by the management of the supply chain, spanning from farmers to consumers and including aspects such as packing, transportation, and storage conditions.

Supply chain management inefficiency can cause postharvest losses (Kailaku & Djatna, 2022), mainly if traditional methods are used to trace product origins and handling processes. Traditional supply chains encounter constraints like insufficient transparency, the participation of third parties, concerns regarding information security, and reliance on centralized information storage systems. This challenge highlights the need for advanced monitoring systems and standardized assessment criteria to ensure only high-quality avocados reach the market. Implementing better tracking and evaluation methods can help minimize waste and improve overall supply chain efficiency. Moreover, the emergence of cutting-edge technologies such as the Internet of Things (IoT), blockchain, and smart contracts offers promising solutions to effectively address many of these challenges (Raza et al., 2023). These technologies allow for more accurate real-time monitoring of product movement, condition, and compliance with quality standards, ultimately reducing waste and boosting consumer trust in the authenticity, freshness, and quality of the products. Blockchain technology emerges as a transformative solution, enabling immutable record-keeping and transparent verification of every step in the supply chain. It facilitates transparency regarding the origin of materials, the processes involved, and product distribution (Hendayani & Fernando, 2022).

To address these inefficiencies, a more comprehensive and interconnected approach is needed—one that transforms the traditional supply chain into a dynamic and collaborative ecosystem. Unlike linear supply chains, ecosystem-based models involve multiple farmers, distributors, retailers, and end-users, fostering a decentralized and participatory network. This model ensures that all stakeholders, from farmers to consumers, are actively involved in data sharing, product traceability, and quality assurance.

Through leveraging traceability features on the blockchain's decentralized ledger system, stakeholders can access real-time data about product origins, cultivation practices, processing methods, and quality assurance measures. Together with IoT, blockchain technologies can help create a secure, transparent, open, and innovative ecological agriculture system that engages all participants (Mane et al., 2022). Another significant benefit is the ability for farmers, who often face challenges in market access, to receive a fair price (Leduc et al., 2021). Blockchain technology enables farmers to track product movement and ensure they are compensated fairly.

This research constructs a model to transform the existing avocado supply chain into a blockchain-enabled process. We research one of the small and medium-size enterprise companies in Indonesia. Companies need to consolidate towards more measurable and sustainable business processes, given the market's demand for guaranteed product quality. This research not only focuses on developing a blockchain-based supply chain model but also establishes an integrated ecosystem where all stakeholders—from farmers and distributors to consumers—can interact within a transparent, efficient, and sustainable system. Thus, a blockchain for supply chain operation is inevitable. We organized the paper into a literature review in Section 2, the research methodology in Section 3, the result and discussion in Section 4, and finally, the conclusion and suggestion in Section 5.

2. Materials and Methods

Indonesia's avocado plays a vital role in both domestic and international markets (Zhang, 2023), with the fruit—locally known as "buah mentega"—valued for its creamy texture and distinctive taste. The country is home to various local avocado varieties such as Miki, Kendil, Pluwang, and Kelud (Tannady et al., 2023), each with unique flavors and commercial cultivation potential. Indonesian avocados are in high demand globally, with an annual export volume reaching around 400 tons (Rana et al., 2021). Indonesia avocado supply chain involves multiple stakeholders, with farmers playing a central role in cultivation, harvesting, and preparing the fruit for sale. Farming practices such as variety selection, pest control, and harvesting methods significantly influence the fruit's quality. Once harvested—typically while still unripe—the avocados are hand-transferred, washed, sorted, graded, and stored at controlled temperatures before reaching retailers.

Yet, challenges persist in connecting farmers to large-scale traders, often disrupting the supply chain (Helyanda, 2022). Traceability remains uncommon due to limited technological literacy, while existing centralized systems pose risks of data loss and lack transparency. By leveraging blockchain technology, each stage of the supply chain—from planting to delivery—can be securely and transparently recorded, enhancing buyer confidence and expanding Indonesia's potential in the global avocado market.

Blockchain technology was known for its wide range potential application especially on supply chain domain by enhancing the limited transparency and securing records through decentralization scheme. This was possible due to encrypted hash mechanism that connects each block which guarantee block's credibility while also providing a way to reverse track block activities (Guangjie Lv, 2023). Accordingly, blockchain can empowers consumer to make more informed purchasing decision (Rana et al., 2021). Blockchain-based solution applies to a wide variety of supply chain including halal food (Alamsyah et al., 2022; Hendayani & Fernando, 2022), land or real estates (Shuaib, Daud, Alam, & Khan, 2020; Veuger, 2020), transport/logistic (Baygin et al., 2022), agri-food (Rana et al., 2021; Nurhazizah et al., 2023; Xu et al., 2020; Raza et al., 2023) ; the blockchain also can improve recruitment process (Sulaiman et al., 2022) and foster trust through information sharing and reducing its asymmetry (Turgay & Erdoğan, 2023). The same also applies to fruit commodity where blockchain can be a trust machine to assure commodity's originality or compliance standards (Danese & Romano, 2025; Wang et al., 2022; Yap, et al., 2025; López-Pimentel et al., 2022).

Blockchain technology can improve supply chain effectiveness with its traceability features that increase data security and increase consumer confidence (Vikaliana et al., 2021). In supply chains, blockchain can record and trace each asset's journey, ensuring integrity, security, and offering consumers direct access to product origin information. The technology's capabilities are leveraged in various fields to achieve trust, transparency, and accountability for supply chain participants. Additionally, blockchain features offer significant potential for enhancing supply chains, both on a global and local scale, through improvements in operational efficiency, data management, responsiveness, transparency, and smart contract management (Dutta et al., 2020). The blockchain serves as a reliable and trustworthy source of information regarding crop conditions and product status because blockchain technology allows supply chain monitoring to be decentralized (Wang et al., 2022). Utilizing blockchain technology to track food provenance contributes to establishing transparent and reliable food supply chains, fostering trust between producers and consumers. In the agricultural sector, blockchain technology is becoming increasingly popular due to its capacity to shift away from the centralized model currently dominating the farm value chain. It also provides practical and transparent product tracking in the agriculture supply chain (Saranya & Maheswari, 2023). Integrating emerging technologies enables smart agriculture to tackle key farming goals and enhance productivity (Lezoche et al., 2020). By allowing consumers to access detailed information about the food production process, blockchain facilitates trust and transparency, improved business performance, increased consumer awareness of food safety and ethical sourcing, value-added branding opportunities, and the collaborative role of farmers' cooperatives (Yap, et al., 2025). Regulatory agencies also benefit from blockchain by accessing reliable and precise information for informed and efficient regulatory actions. Crucial data, such as pesticide residues in grains or vegetables, can be verified by any party involved in the product's supply chain. The use of pesticides must be considered because they have an impact on the environment (Munhuweyi et al., 2020). While gathering such comprehensive data for all products can be costly, sampling methods can be employed. Numerous blockchain-based solutions have been proposed to enhance the traceability of agricultural products.

Our review presents a solid theoretical foundation, identify research gaps, and inform subsequent research phases the details in Table 1:

1) Blockchain for Supply Chain: Various studies are analyzed to understand blockchain's impact on enhancing transparency, operational efficiency, and data security in the supply chain. Evaluating aspects such as the reduction of information asymmetry, improved tracking accuracy, and the acceleration of information flow between stakeholders are included. Moreover, the review discusses the implications of blockchain for streamlining logistics and minimizing fraud across different stages of the supply chain.
2) Blockchain for Agriculture: The review extends to the use of blockchain for the agricultural sector, particularly in enhancing traceability capabilities. Blockchain is viewed as a promising solution for addressing significant challenges, such as food safety and quality control. The study explores how blockchain technology can overcome the limitations of conventional systems in maintaining data transparency and integrity throughout the agricultural production process, from farm to consumer. Emphasis is placed on how blockchain can ensure real-time data availability and facilitate more effective monitoring and quality assurance practices.
3) Traceability for Fruit: The specific focus of this sub-topic is on the existing methods and frameworks for tracing fruits within supply chains. This analysis includes an evaluation of various approaches currently employed to ensure traceability, such as manual systems and IoT-based technologies, highlighting their limitations, such as data inaccuracy and a lack of integration between actors across the supply chain. Additionally, the potential benefits of implementing blockchain in overcoming these limitations are discussed, with an emphasis on improving consumer trust and ensuring product quality. Blockchain can provide an immutable record of information, including data about ripeness, transport conditions, and certifications, contributing to greater transparency for consumers.

Table 1. Literature Review Table

No	Topic Categories	References
1.	Blockchain for Supply Chain	(Danese & Romano, 2025), (Dutta et al., 2020), (Wang et al., 2022), (Duan et al., 2020), (Alamsyah et al., Blockchain-Based Traceability System to Support the Indonesian Halal Supply Chain Ecosystem, 2022), (Alamsyah et al., 2023), (Nurhazizah et al., 2023), (Hendayani & Fernando, 2022), (Nassar et al., 2024) (Zhu et al., 2020), (Baygin et al., 2022), (Sulaiman et al., 2022), (Veuger, 2020), (Javed et al., 2024), (Thakral et al., 2023), (Turgay & Erdoğan, 2023), (Osei et al., 2021), (Chopra, 2020)
2.	Blockchain for Agriculture	(Raza et al., 2023), (Mane et al., 2022), (Guangjie Lv, 2023), (Rana et al., 2021), (Lezoche et al., 2020), (Xu et al., 2020), (Kailaku & Djatna, 2022) , (Rana et al., 2021), (Shevchuk, 2019)
3.	Blockchain for Fruit	(Yap et al., 2025), (López-Pimentel et al., 2022), (Vikaliana et al., 2021)

Several findings from the literature review includes: (1) Blockchain framework models in the previous studies did not depict a developing country ecosystem such as Indonesia; (2) The existing models did not specify retailer types in the supply chain, hence data standardization across retailer types are not discussed; (3) lastly, previous studies tend to oversee the user interface of the proposed solution which may present unclear expectations. The findings from this review will serve as a robust basis for developing an effective model tailored to the needs of Indonesia's agricultural industry, particularly focused on enhancing product quality and safety.

3. Methodology

Our study follows a five-step methodological framework. The first step involves studying literature to explore the implementation of blockchain technology for enhancing traceability within the fruit supply chain. The second step is stakeholder interviews, which gather practical insights from farmers, distributors, and retailers to identify current practices, challenges, and requirements for blockchain integration. In the model construction phase, a conceptual model of the blockchain-based system is developed. Blockchain architecture is designed to serve as the structural foundation of the system and data records to establish the format and flow of data that will be recorded on the blockchain, ensuring that the system can support effective traceability. The fourth step is developing a prototype application to demonstrate the model's implementation of the model. Finally, the system evaluation phase assesses the prototype's performance based on criteria such as data integrity, usability, and scalability, to ensure it meets industry needs and provides benefits. Figure 1 displays the research methodology, which was modified from (Vikaliana et al., 2021).

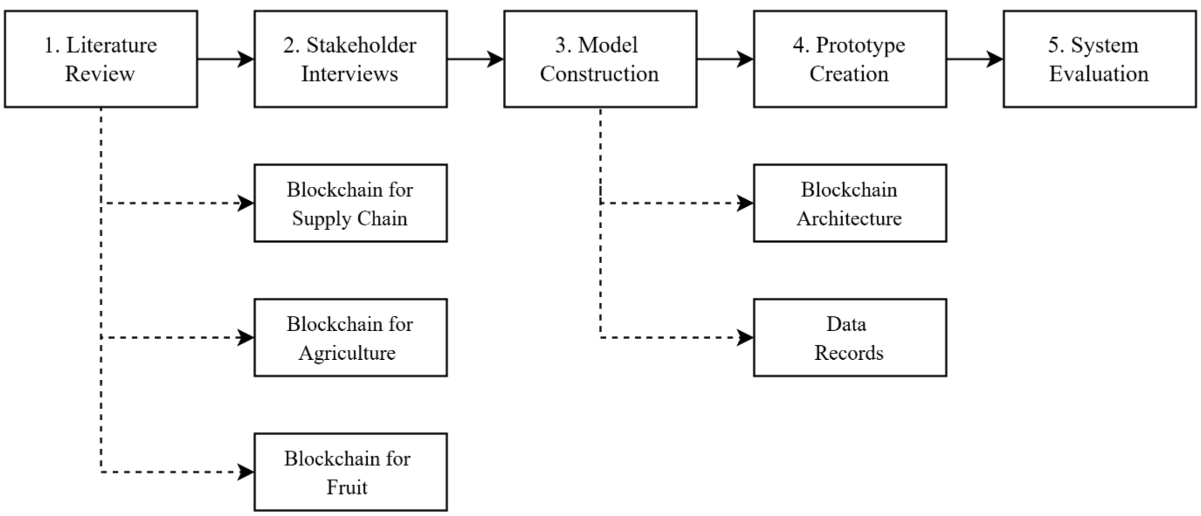

Figure 1. Research Workflow

During the stakeholder interview, we interview key stakeholders within the fruit supply chain, including farmer, distributor, and retailer, are interviewed. One of the interviewed parties is Warung1000Kebun, a small-medium enterprise (SME) promoting organic and sustainable agricultural practices in Indonesia. The collected data supplements the literature review by providing real-world perspectives and highlighting stakeholder-specific needs and concerns. Such qualitative insights are crucial to ensuring that the proposed solution is both practical and responsive to the nuances of the supply chain environment.

Based on the findings from the literature review and stakeholder interviews, a conceptual model for the blockchain-enabled traceability system is developed. Specifically, the model addresses key architectural components such as data collection points, verification mechanisms, data validation processes, and the roles and interactions of stakeholders within the system. The model also incorporates a trust and accountability framework, ensuring that data integrity is maintained and that all actors within the supply chain have clearly defined roles and responsibilities. The model comprises two essential components:

- Blockchain Architecture: This component defines the fundamental structure needed to support the traceability system, including the selection of appropriate blockchain protocols, consensus mechanisms, and the network configuration to ensure data security, scalability, and transaction efficiency. Special attention is given to selecting consensus algorithms that balance security and performance, tailored for supply chain use cases.
- Data Records: The structure and format of data records that will be stored on the blockchain. The records include essential information such as origin, quality, ripeness level, transportation conditions, and certification details. The design of these data records focuses on enabling complete transparency and accuracy, thereby allowing all stakeholders, especially end consumers, to verify the quality and history of the fruits.

Next, we developed of a prototype based on the constructed model. This prototype is intended to serve as a proof of concept to validate the practical applicability of the proposed blockchain-enabled solution, emphasizing real-time traceability and transparency. The development of the prototype focuses on several key components critical for realizing the envisioned benefits, particularly regarding real-time traceability and enhanced transparency across the fruit supply chain.

The final phase involves the evaluation of the developed prototype to determine its effectiveness and overall impact. Several performance indicators are used, including data integrity, system usability, scalability, transaction efficiency, and the impact on supply chain transparency and trust. Additionally, feedback is gathered from stakeholders, focusing on their experiences regarding the prototype's practical utility, ease of integration, and perceived value added to existing processes. This evaluation will help identify areas for refinement, allowing the system to be iteratively improved to better meet stakeholder requirements.

We have identified a critical issue through information gathering: the lack of transparency and traceability in supply chain data. To capitalize on the opportunity for improvement, we propose a model that adopts blockchain technology to enhance the existing supply chain. The proposed solution outlined streamlines the data collection process pertaining to fruit traceability from harvest to eventual sale and enhances the value proposition within the fruit supply chain (Xu et al., 2020).

4. Results

We have identified a critical issue through information gathering: the lack of transparency and traceability in Indonesian's avocado supply chain data. To capitalize on the opportunity for improvement, we propose a model as visualized in Figure 2 that adopts blockchain technology, not only to enhance traceability but also to establish a seamless and reliable quality assurance system, ensuring product integrity at every stage of the supply chain.

The model above outlines the key entities in the Indonesian's avocado supply chain ecosystem encompassing plantations, packing companies, distribution armada, retailers, and end consumers. The ecosystem encourages each entity to have multiple interactions, meaning a plantation can deliver the fruit to several packing companies, the packing companies can work with multiple distribution armada, and so on and so forth. Each stage in the supply chain generates a flow of products and information, which is securely recorded using blockchain technology to ensure traceability and transparency. There are three types of retailers based on their market segmentation and operational characteristics:

1) Small retails: includes convenience stores and traditional markets, which serve local communities with essential goods and everyday necessities
2) Specialty stores: focuses on specific product categories, such as a fruit-only store, offering specialized selections to meet niche consumer demands
3) Big retails: consist of large-scale commercial establishments like plazas and malls, providing a wide range of products and services.

The proposed solution streamlines the data collection process pertaining to avocado traceability from harvest to eventual sale and enhances the value proposition within the avocado supply chain (Xu et al., 2020).

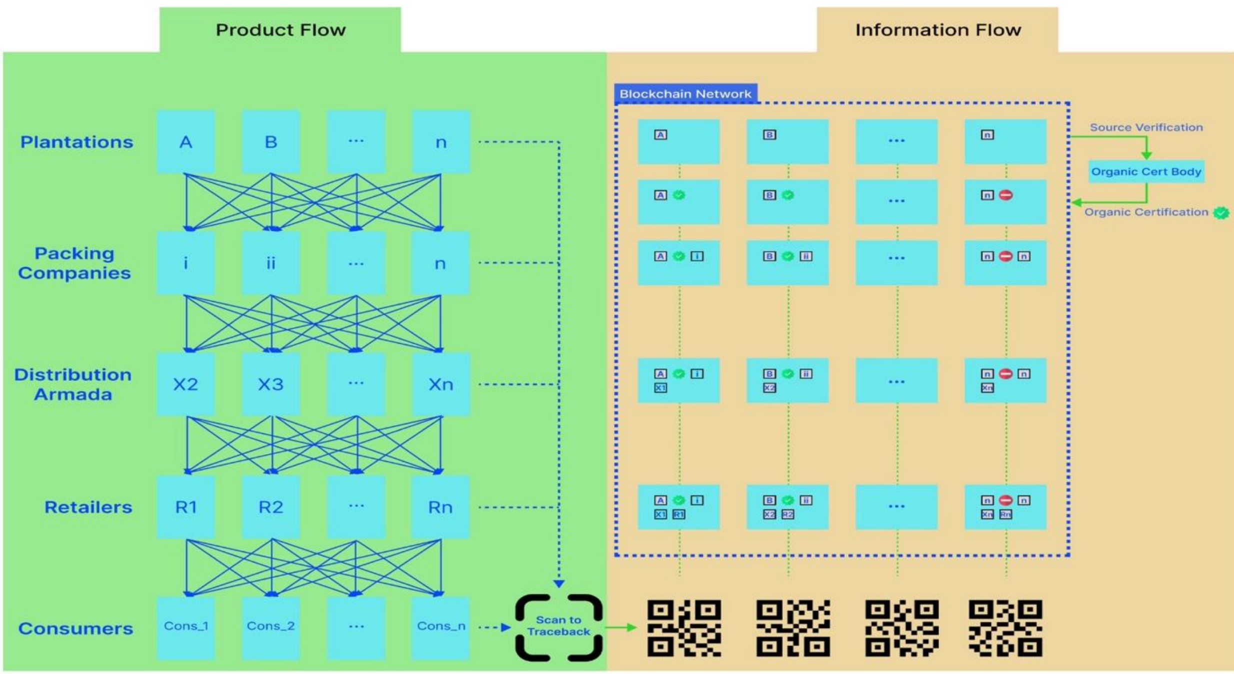

Figure 2. The Proposed Model

4.1 Physical Product Flow

The movement of avocados within the supply chain plays a crucial role in maintaining their quality, authenticity, and traceability. Avocados move from plantations to packing companies, then through distribution logistics before reaching retailers and, ultimately, consumers. Each step is recorded on the blockchain to guarantee authenticity and prevent fraud. The avocado supply chain follows a structured process to ensure quality and traceability. The process begins with cultivation, where avocados are grown and maintained until maturity. Once ripe, they are harvested and sorted based on quality standards. The selected avocados are then packed and labelled with traceability information before being transported and distributed to retailers. Retailers display and sell the avocados to consumers through various sales channels, including supermarkets and local stores. Finally, consumers purchase the avocados, benefiting from transparent information regarding their origin and quality. These processes is visualized in Figure 3 below.

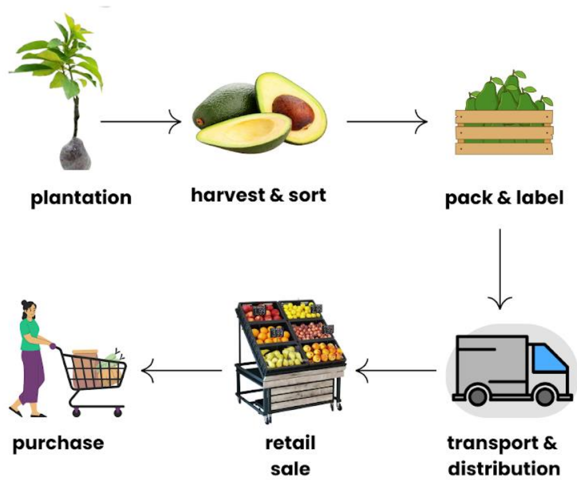

Figure 3 The Physical Product Flow

4.2 Information Flow

This subsection delves into the structure's flow of avocados, highlighting the key stakeholders involved and their contributions, as illustrated in Fig.3. Critical data such as product origin, cultivation methods, packaging processes, and distribution details are stored in the blockchain. Consumers can verify product authenticity through source verification technology, often using a simple QR code scan. In Fig.3, stakeholders can understand how to contribute to the avocado supply chain.

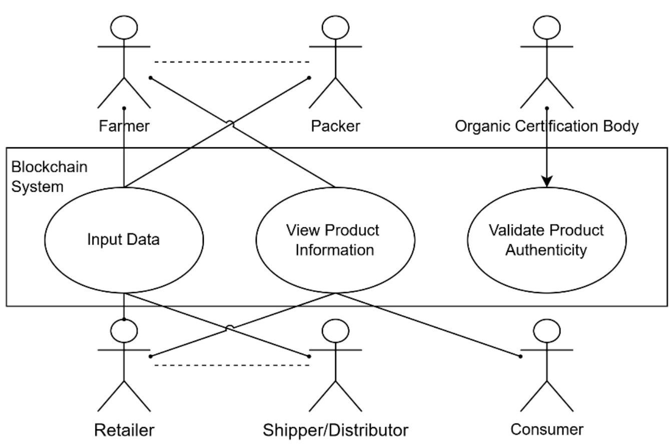

Figure 4. Avocado Blockchain Ecosystem Actors

Use case diagram visually represents the interactions between users and the system. We classify the fruit supply chain stakeholders into five distinct groups: farmer, packer, distributor, organic certification body, retailer, and consumers. The system encompasses three primary functions: input data, view product information, and validate product authenticity. The proposed model involved actors such as:

1) Plantations/Farmer: record avocado’s data using IoT devices and upload it to the blockchain network as the genesis block and can be traced back by others.
2) Packing Companies: provide processing information of the harvested avocados (packer, process date, etc.) to the blockchain network. In physical activities it is represented by labelling the packed avocados with barcodes containing the same processing information with the blockchain network (López-Pimentel et al., 2022).
3) Distribution Armada: upload information of the moving goods to the blockchain network (pick-up date, delivery process, driver, etc.)
4) Organic Certification Body: verifying the product meets organic standards and provides the organic assurance seal.
5) Retailers: trace and verify the seal of assurance (provided by the Organic Certification Body).
6) End consumers: track and trace products to view the avocado’s journey/supply chain processes, helping them decide to buy avocados with a desired organic assurance.

In the on-chain process, as illustrated in Fig. 4, the system will enable farmers to record detailed information about their produce, including cultivation methods, harvest dates, and geographic location. After that, packers will attach RFID tags, package the fruits, and input pertinent information into the system. By confirming the data supplied by farmers and, if required, carrying out on-site inspections, Organic Certification Bodies will confirm the authenticity of the product. The fruits' compliance with the necessary organic criteria is guaranteed by this validation procedure. Organic certification agencies can then validate this information and store it securely on the blockchain. Retailers can use this blockchain data to trace the journey of fruits from farm to store, providing consumers with comprehensive details about the product's origin and quality. This empowers consumers to make informed choices and verify the authenticity of the fruits they purchase. Ultimately, the system addresses concerns related to food safety, traceability, and sustainability within the Indonesian fruit supply chain.

4.3 Sequence Diagram & Data Records

Our proposed system encompasses three primary functions: recording process information, validating product authenticity, and tracing product details. Furthermore, we split system activities into two groups: off-chain and on-chain processes. The off-chain process refers to activities done outside the blockchain platform, while the on-chain is the opposite.

The on-chain process started when farmers upload harvested avocado batches data to the blockchain before delivering the goods to the packing company. Upon goods arrival, the packing company accesses the blockchain to verify the shipment, matching it against the recorded data earlier.

Once verified, the packing company updates the blockchain with logistics data which triggers a notification to the organic certification body for verification. An assessment is held to each batch to determine whether the avocados meet organic standards. If any discrepancies or spoilage are found, the certification body notifies the packing company to prevent rejected goods from entering circulation.

After the certification process, the packing company generates a QR code for each batch (organic approved or not), ensuring proper labeling process. The packing process is complete once all batches have been assigned their QR codes. The figure 5 below presents an illustrative depiction of the on-chain processes.

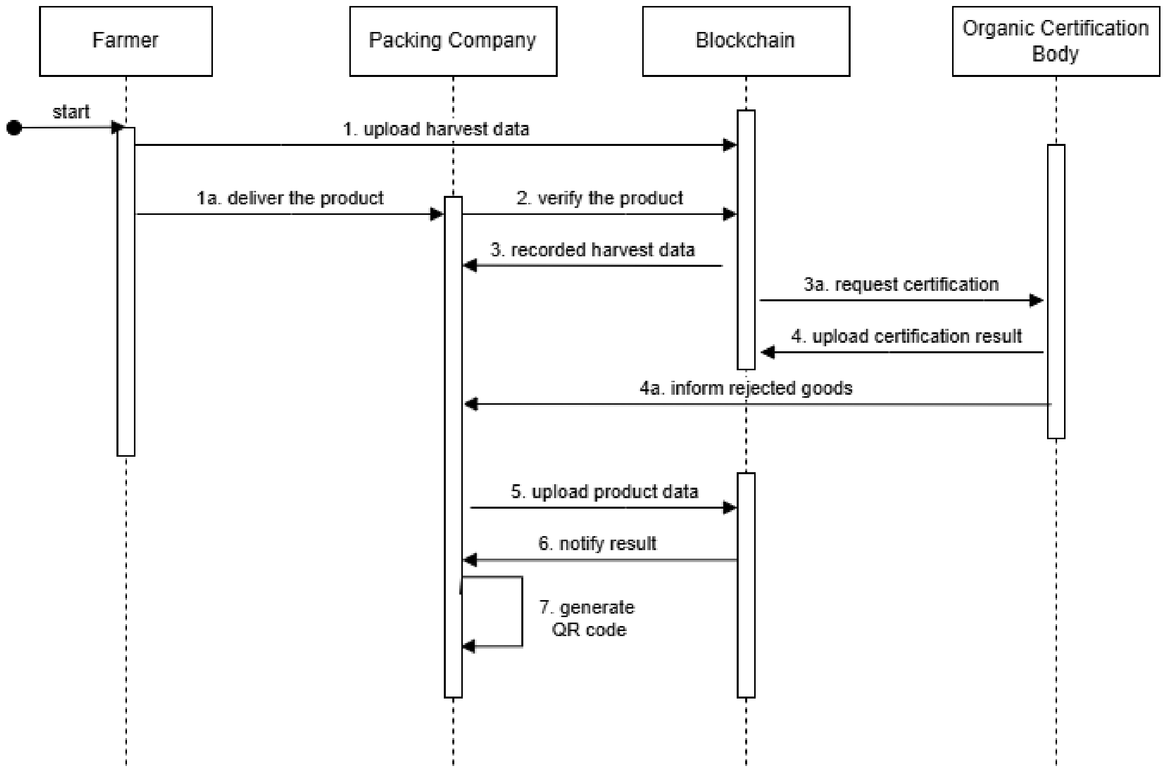

Figure 5. Proposed Sequence Diagram

Starting with the user's login into the application, access is subsequently verified by both the application and the blockchain. Once authenticated, the user is granted the necessary privileges to input and store data about the condition of the avocados. The data is subsequently posted to the blockchain for validation and secure storage. The interface application then facilitates user access to the stored data. Furthermore, the application generates a QR code for users to seamlessly track and verify the avocado journey in the supply chain's ecosystem.

During the on-chain process where the data flows in the blockchain platform, smart contracts should be placed to present automation of data validation, certification requests, also fitting the certification number to fruit batches. Such approach can enhance data integrity by eliminating human error on the mentioned activities.

The data records presented in Figure 6 below outline a comprehensive flow of information across multiple stages in the fruit supply chain, from the farmer to the consumer. Each entity in the chain contributes specific data elements essential for ensuring traceability, quality, and certification compliance, culminating in a QR code that facilitates transparent tracing for end consumers. They are also the data fields recorded in the blockchain platform.

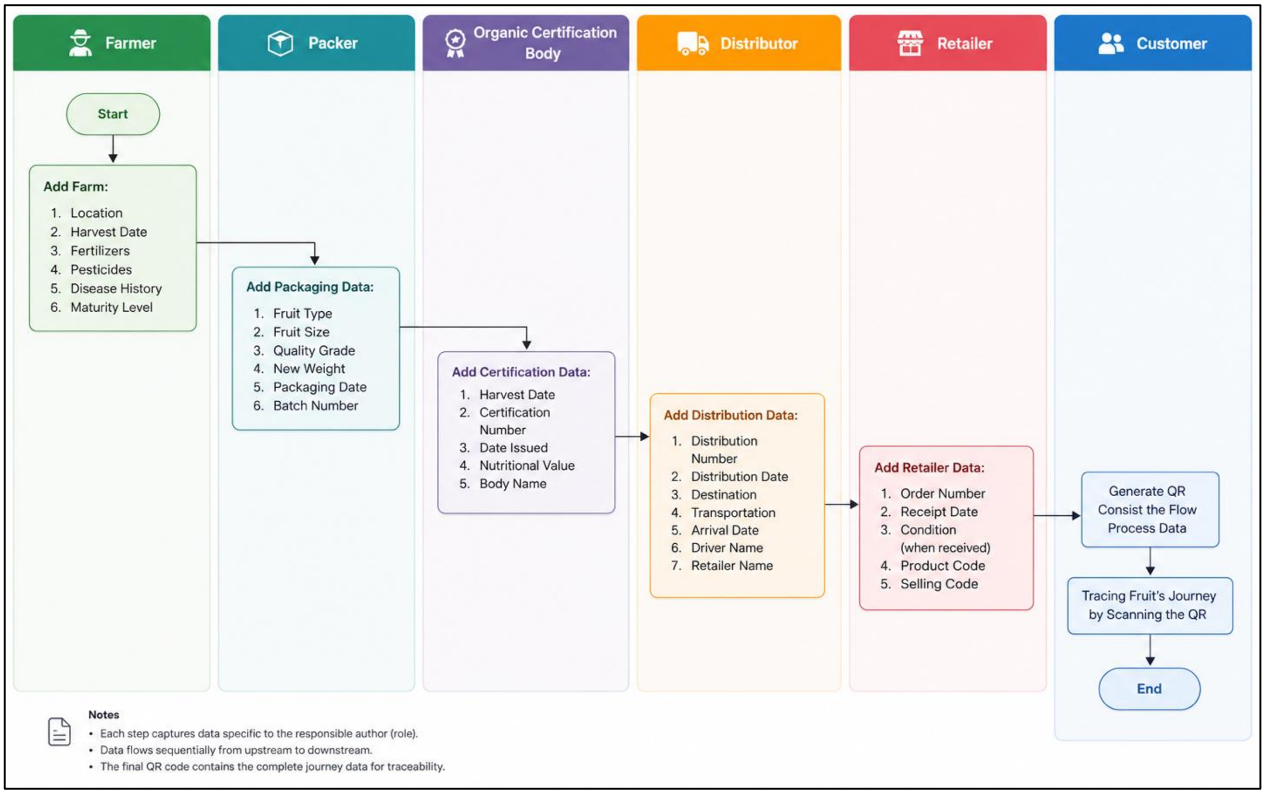

Figure 6. Data Records per Author

The journey of fruits begins with the planting process and continue through to harvesting process. Once harvested, the fruits undergo sorting and grading to ensure quality and consistency. During the process, farmers input fruits data to blockchain platform – data such as harvest's location and date, the usage of pesticide and/or fertilizers, fruit's ripeness (maturity level) and its historical disease. The data was later assessed by the Organic Certification body to determine its qualification as an organic product. After that, frutis were packaged in appropriate containers and labelled with unique RFID tags for easy tracking that also comes with additional information of the package including its quality grade, weight, packing date and its batch number.

The organic certification body then assess the uploaded data – it determine whether the packed fruit met the organic qualification or not and uploaded the result to the blockchain platform. At the same time, the fruits are distributed to various sales points through a cold chain logistics network, meaning that both certified and not can be hauled to each point simultaneously. The moving cargo tracks data and upload it to the blockchain platform – ensuring that fruits are stored and transported at the appropriate temperature to maintain freshness and prevent spoilage. Additionally, quality checks are conducted throughout the supply chain to ensure the fruits are pesticide-free and meet safety regulations. Our proposed solution also ensures nutritional information about the fruits is verified and documented – allowing consumers to easily check the origin, quality, and fruits' certificate before buying them.

4.4 The Prototype

The prototype is a mobile app allows consumers to scan a QR code on a fruit package to access information about the avocado's origin, journey, and nutritional value. This information helps consumers make more informed choices about the avocados they buy and supports sustainable farming practices. Through this interface, stakeholders can seamlessly input, monitor, and verify every stage of the avocado's journey, from the farm, through the packing process, and finally to the consumer. The use of blockchain and RFID technology provides real-time updates and immutable records, empowering consumers to trace the avocado’s origin, quality, and certification with confidence. The post-scan interface provides users with a comprehensive overview of the avocado's journey from farm to store. Key information displayed includes the avocado's variety, origin, harvest date, and organic certification. A visual timeline highlights the various stages of the supply chain, allowing users to trace the product's path. Additionally, the interface offers nutritional information, such as calorie count, vitamin content, and fat composition. A ripeness indicator, presented as a sliding scale, helps consumers determine the optimal time to consume the fruit. To enhance user engagement, a section dedicated to tips and recipes is included, providing suggestions on how to best enjoy the avocado. The mentioned features are visualized in the Figure 7 below.

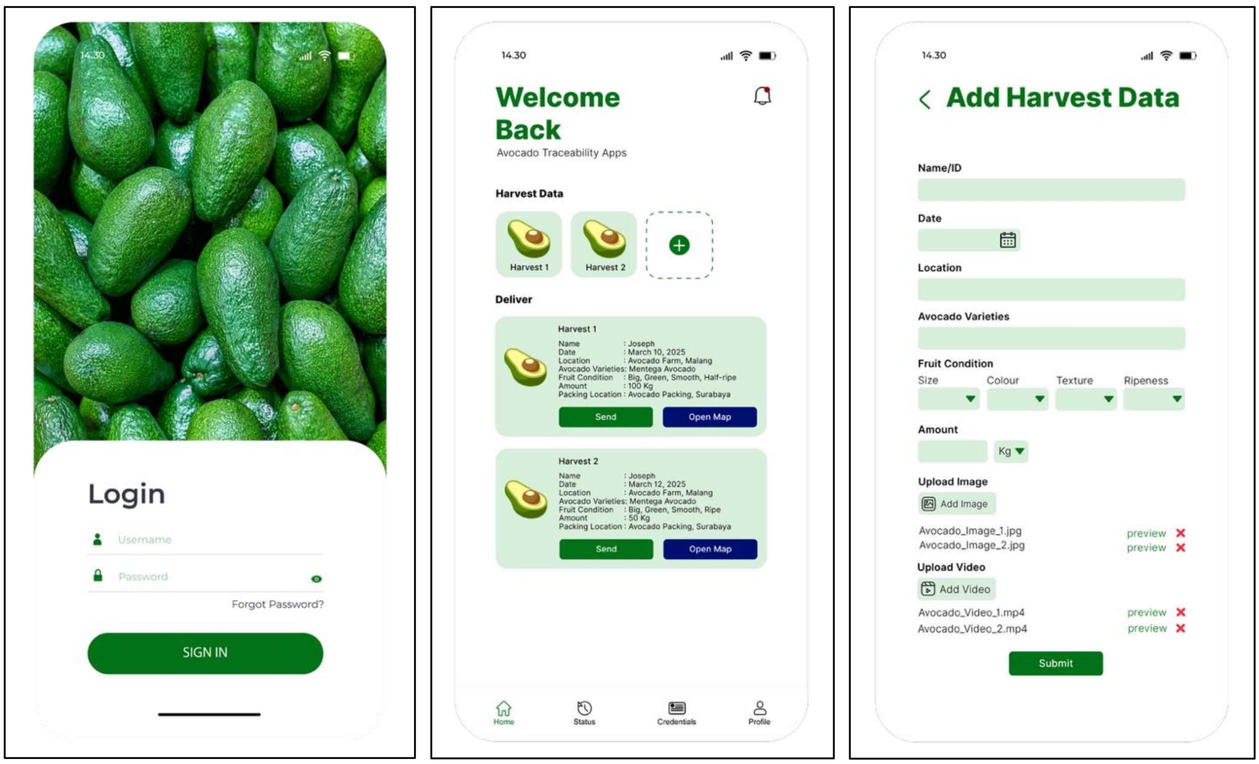

Figure 7. Farmer's Application User Interface Design

This page is the main entrance for users to access the avocado traceability application. Users a required to enter their username and password for authentication. There is also a “Forgot Password?” option to help users who have forgotten their password. A green “Sign In” button stands out as the main action. After logging in, the user is directed to the main page that displays the latest harvest data. At the top is a welcome greeting and the name of the app: Avocado Traceability Apps. The main features on this page include:

1) Harvest Data: Displays a list of harvest data such as farmer name, location, avocado variety, fruit condition, and packing location. Each card contains two buttons: “Send” to send the data to the next system or stakeholder and “Open Map” to view the geographical location of the packing process using the map integration
2) Add Harvest Data Button: Depicted with a “+” icon that allows users to add new harvest data.

At the bottom, there is a navigation bar with four main icons: Home, status, credentials, and profile for easy movement between pages. Next is the add harvest data page which is designed to enter detailed avocado harvest data. Farmers or related stakeholders can fill in various important information such as:

1) Name/ID, date, and location
2) Avocado variety
3) Fruit condition, including: size, colour, texture, and ripeness level
4) The amount of harvest (in kilograms)
5) Image and video upload: users can add visual documentation in the form of photos and videos to ensure harvest quality. There are also preview and delete features if you need to replace files

Finally, there is a green "Submit" button to save and send the harvest data to the system. The system is designed to ensure that every inputted data can be traced transparently and accurately by all involved stakeholders. With a user-friendly interface, the application supports efficient recording and real-time monitoring of product quality. Compared to the packing company that have different role in the supply chain, we make and visualize the user interface accordingly as shown in the Figure 8 below.

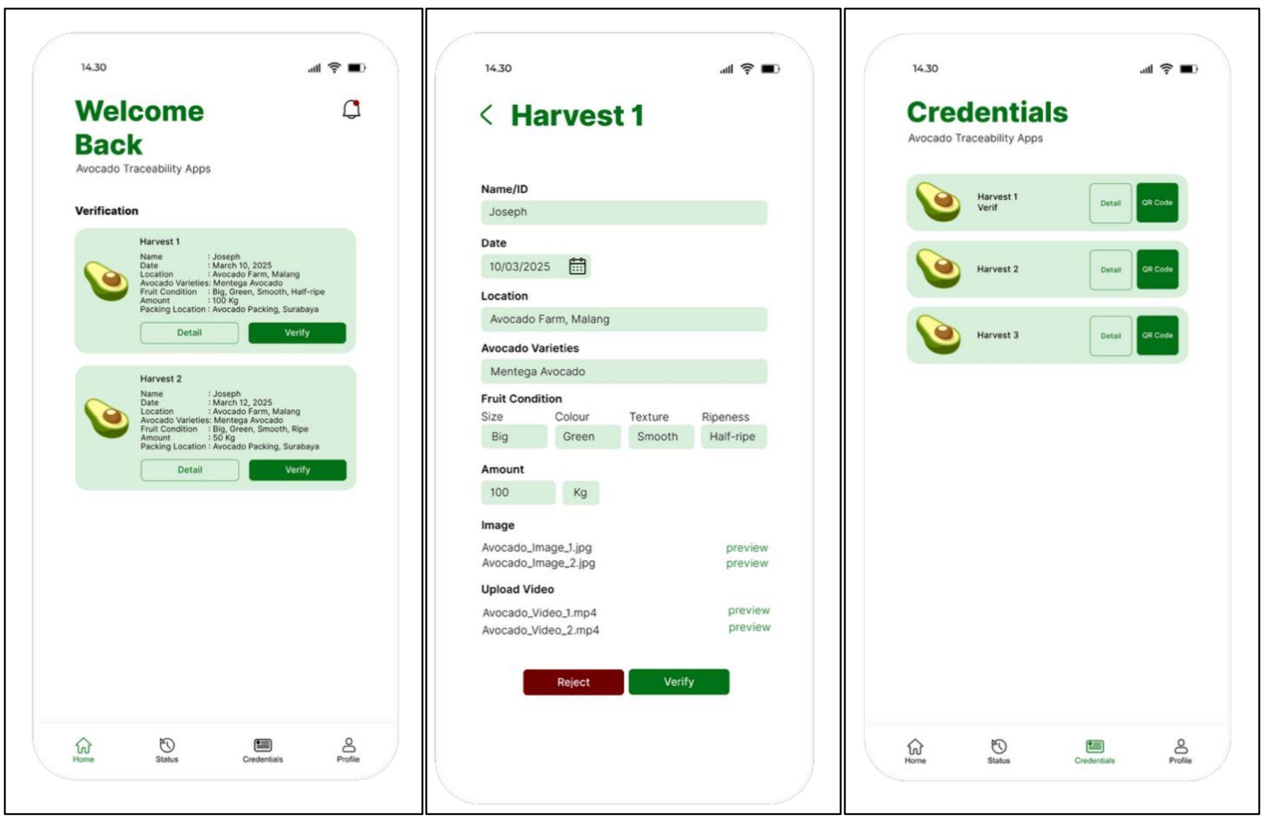

Figure 8. Packing Company's View

The set of user interface in the figure 8 above is designed specifically for the packing company, enabling them to verify the accuracy and quality of harvest data submitted by farmers. The intuitive design streamlines the validation process, ensuring that only high-quality avocados proceed to the next stage in the supply chain. Upon logging in, the packing company is greeted with a dashboard titled "Welcome Back" under the "Verification" section. Here, all submitted harvests are displayed in a clear and concise card layout, showing essential information, such as: farmer's name, harvest date, avocado variety, fruit condition, and packing location. Each harvest entry includes two action buttons: "Detail" which allows the user to view full information about the harvest, including images and videos, and "Verify", which lets them proceed with the approval process after reviewing the data. This interface empowers the packing company to efficiently review multiple harvests while maintaining traceability and product integrity.

The Harvest Detail page is accessed by clicking the "Detail" button. This page presents all relevant fields in a structured format, including harvest location and date, avocado variety, fruit condition indicators (size, colour, texture, and ripeness), harvest amount, and uploaded visual documentation (images and videos). By providing a combination of quantitative data and visual proof, this page helps the packing company assess the overall quality and readiness of each harvest with greater accuracy. Each element is clearly labeled and organized to reduce confusion and support faster decision-making. To maintain quality assurance, the company is provided with two action options: "Reject", if the harvest does not meet the required standards, or "Verify", if the harvest passes inspection. This detailed view reinforces accountability and transparency throughout the process, ensuring that only trusted and validated data is recorded and advanced to the next stage of the supply chain.

The credentials page functions as a repository of all verified harvests. These harvest are now traceable and eligible for further processing or distribution. Each verified entry includes the harvest name and relevant actions such as "Detail" to revisit the information, and "QR Code" to generate a unique traceability code linked to the harvest's blockchain record. This code serves as a digital fingerprint that can be scanned throughout the supply chain, ensuring that the product's journey remains transparent and tamper-proof. In addition, this feature allows downstream stakeholders—such as retailers and consumers—to access detailed information about the avocado's origin, condition, and certification status. By integrating traceability directly into the packing company's workflow, this user interface ensures data integrity and supports the delivery of high-quality avocados to consumers. It not only improves operational efficiency but also builds consumer trust by promoting openness and accountability in every transaction.

4.5 Model Evaluation

The model was evaluated through feedback sessions with key stakeholders, including representatives from Warung1000Kebun. Stakeholders emphasized the crucial role of organic certification in gaining consumer trust and meeting the stringent requirements of modern retail. The QR code scanning feature was particularly well-received, as it provides consumers with a clear and transparent view of the fruit's journey from farm to fork. During the discussion, we also present the model evaluation result that measure blockchain platform features to determine the potential platform to develop the proposed blockchain solution. The comparison result is visualized in Table 2 below.

Table 2. Blockchain Platform Comparison

Blockchain Platform	**Criteria**					
	Cryptocurrency	**Transaction per Second**	**Transaction Fee**	**Consensus Mechanism**	**Decentralize Apps**	**Cloud Storage**
Ethereum	ETH	25	>1 USD	POS	Yes	Yes
Polygon	MATIC	65.000	<1 USD	POS	Yes	No
Solana	SOL	13.000	<1 USD	POS	Yes	No
Binance Smart Chain	BNB	2200	<1 USD	POS	Yes	No
Avalanche	AVAX	1000-4500	<1 USD	POS	Yes	No

Source: (Kapoor, 2024)

Polygon was selected as the underlying blockchain platform for this project due to its compelling combination of scalability, low transaction fees, and Ethereum compatibility. Its ability to handle a high volume of transactions at a fraction of the cost made it an ideal choice for building a decentralized application and could efficiently track and verify the origin of organic fruits. By leveraging Polygon's capabilities, the model was able to provide a seamless and user-friendly experience for both consumers and stakeholders, while ensuring the integrity and transparency of the fruit supply chain. To summarize our evaluation, we compare the model performance with the existing supply chain traceability and visualize the result in the Table 3 below.

Table 3. Proposed Model vs Existing System

Evaluation Items	Existing System	Proposed Model
Data Transparency	Low – centralized record	High – Distributed record among stakeholders on the platform
Organic Certification Process	Days to weeks	Seconds – almost real time process
Data Reliability	Low – Record tampering is plausible	High – Blockchain provides security toward data tampering attempt
Traceability	Limited to information stamped on the fruit package	Rich information including all stakeholders involved

Based on the comparison, we can conclude that the proposed model offers better transparency, data reliability, and traceability. To broaden the perspective, smart contracts authorization on the blockchain platform can minimize human error and enhance data processing speed.

4.6 Challenges to Adoption

The proposed framework and prototype are meant to address the existing gaps mentioned earlier on the literature review section, however, there are still factors that can hinder blockchain solution implementation in Indonesia's avocado supply chain. First, investment cost of the potential blockchain solution is massive since most Indonesia's avocado supply chain stakeholders are still in its transition to digitalization, especially the farmers where they are not familiar with IoT and blockchain technologies. This can hinder blockchain solution if not addressed properly through government intervention such as dedicated workshop and incubation programs aimed to educate and embrace digitalization on the supply side. Next, the unification and data standardization of agriculture products are close to non-existent in Indonesia – this pose a great challenge to be tackled prior to implementing the proposed blockchain solution. Once again, government plays crucial roles in bridging the standardization also permit-related processes and at the same time provide regulatory support, hence Indonesia's avocado supply chain stakeholders wanted to adopt blockchain technology and solutions are backed by the law. Lastly, blockchain platform's scalability-related issues can cause limited distribution of the proposed blockchain solution since Indonesia's avocado supply chain has been dealing with a large amount of transaction and stakeholders in between.

Accordingly, to successfully adopt the proposed blockchain solution, we suggest Indonesian government to intervene with the process by providing adequate education and guidance needed by farmers and distributors, also facilitating the necessary digitalization process across the fruit industry. Additionally, a supporting regulation should be created to ease permit for stakeholders wanted to adopt blockchain solutions. Nevertheless, data sovereignty must be considered since using open-source blockchain platform pose its own data privacy and other security risks uncovered by the current study.

6. Conclusion

The proposed model represents the first work applying blockchain technology to Indonesian fruit's ecosystem, which can become a solution to ensure fruit's quality and freshness issues along with application's prototype. Our model serves as the foundation for enhancing the real-time traceability of Indonesia's fruit distribution ecosystem. We incorporate ecosystem's stakeholders including farmers, organic certification bodies, distribution armada, and retailers. Every participant can track the fruit asset on blockchain networks, which mirror the real-time condition of the commodity. Our platform functions as a dependable tracing tool that strengthens trust between farmers and other stakeholders by streamlining the fruit supply chain, doing away with the need for middlemen, and guaranteeing real-time tracking and reporting. In addition to bringing novel features directly facilitate fruit quality management, the model functions as a potent trust engine, enhancing the trust bond between farmers and stakeholders also raising Indonesia's fruit commodity's value. Consumers can trace each avocado fruit's distribution process and verify its quality status, as guaranteed by the organic certification body. Hence, lays the groundwork for a new era in agriculture, one in which trust, and transparency are attainable realities rather than merely ideals. Although this model was created especially for Indonesia's fruit, it can be broadened to other native commodities. The agricultural sectors of many developing nations deal with comparable problems in such distribution ecosystem such as distribution process inefficiencies, a lack of transparency, and fraud issues. Other areas with similar socioeconomic systems, robust giving traditions, and inadequate technological infrastructure to guarantee accountability and trust can adopt and expand the blockchain-based approach. Countries with different governance and regulatory environments can use decentralized ledger technology to enhance domestic agricultural efforts by increasing transparency.

Despite existing barrier to adoption such as technology acceptance, huge investment, and technological complexity, these are outweighed by the model's significant advantages, which establish it as an innovative approach to quality assurance of Indonesian fruit commodities. A careful balance between environmental sustainability and operational efficiency is shown in our strategic proposal to use Polygon Matic as the underlying blockchain platform. This concept has the power to completely reshape the nonprofit industry by guaranteeing contributions are handled efficiently and have the greatest possible impact. Our study provides a strong basis for future research, using internal alpha testing, pilot projects, and beta testing with specific user groups to evaluate viability, accessibility, and wider appeal. We could extract transaction information, use image, or video recognition based on Internet of Things (IoT) sensors and artificial intelligence algorithms. Additionally, it is essential to discuss the standards that would be implemented in determining the quality of fruits, primarily if the system utilizes blockchain technology. Also, Indonesian stakeholders must account data sovereignty matter before releasing the platform for public use.

Author Contributions

All authors contributed equally to the conceptualization of the article and writing of the original and subsequent drafts.

Data Availability Statement

Not applicable.

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Ethical considerations

The authors avoided data fabrication, falsification, and plagiarism, and any form of misconduct.

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Conflict of interest

The authors declare no conflict of interest.

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