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Design and Evaluation of a Blockchain-Based Traceability Model for Organic Rice Supply Chain

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Abstract

This study aims to design and evaluate a blockchain-based traceability model and prototype for the traceability of organic rice supply chains in Banten Province, Indonesia. The main problem identified is the absence of a digital system that can transparently trace the origin of organic rice, which has reduced consumer trust in product authenticity. This research adopts the Design Science Research Methodology (DSRM) to develop a traceability model and prototype capable of recording all supply chain activities from farmers to end consumers. The prototype was validated using the ISO/IEC 25010 standard with supply chain actors and further validated with end consumers. Validation results from supply chain actors indicate strong performance across maintainability (4.91), functional suitability (4.29), security (4.11), performance efficiency (3.98), compatibility (3.89), usability (3.85), reliability (3.80), flexibility (3.93), and safety (3.77). Meanwhile, validation with end consumers yielded an average score of 4.22 on a 1–5 Likert scale. These findings indicate that the system meets key quality attributes—particularly functionality, reliability, security, and maintainability—at a very good level. In conclusion, implementing blockchain technology for organic rice supply chain traceability can enhance transparency, improve data security, and strengthen consumer trust in organic rice products.

Keywords:

Supply Chain; Organic Rice; Traceability; Blockchain; DSRM; ISO 25010; SEM-PLS.

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1- Introduction

Agriculture encompasses crop cultivation, livestock production, dairy-related activities, fisheries, forestry, and other related sectors, and it holds substantial potential for pro-poor economic growth [1]. Agriculture can reduce poverty, foster prosperity, and help provide food for an estimated 9.7 billion people by 2050 [2]. It will remain central to the global economy and human survival in the coming decades by supplying food, jobs, and livelihoods for billions of people [3]. Accordingly, food systems are expected to address three major challenges: ensuring food security and nutrition, sustaining livelihoods for millions of workers across food supply chains, and contributing to environmental sustainability [4]. In Indonesia, the agricultural sector contributed 12.53% of GDP (current prices) in 2023, increasing by 0.13% compared to the previous year; within 2023 GDP, the food-crop agriculture sub-sector ranked third in contribution [5]. In addition, agricultural, forestry, and fisheries exports increased from USD 4,045.5 million (January–November 2023) to USD 5,129.9 million (January–November 2024), representing a rise of USD 1,084.4 million [6].

These factors indicate that the agricultural sector is one of the main drivers of Indonesia's grassroots economic development [7]. Agriculture is also a critical research domain because failures in this sector can have severe

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consequences. Currently, 815 million people experience hunger, and one in three people suffer from malnutrition—reflecting an imbalanced food system [8]. Agricultural failure can also increase unemployment and worsen food shortages [9]. Agriculture involves managing biological natural resources with the support of technology, capital, labor, and management to produce agricultural commodities—covering food crops, horticulture, plantations, and/or livestock within an agroecosystem [10]. Rice is a major commodity within fresh plant-based food, categorized under cereal grains. Rice is classified into two types: general rice and specialty rice; organic rice is one category of specialty rice [11].

Organic rice requires traceability because effective traceability helps ensure the authenticity of specialty rice [12], improves the performance efficiency of the organic rice supply chain [13], enhances food safety and transparency, and strengthens consumer trust [14]. Traceability is also essential for establishing a credible and traceable organic agricultural production system [15]. A traceability system typically records information on commodity type, quantity, origin, destination, condition, and time-stamps [16].

Several challenges in tracing organic agricultural supply chains include information gaps, limited willingness to share information, technological constraints on transparency, difficulties in obtaining timely and integrated information, and consumers' limited ability to access origin information and verify product authenticity [17]. Control and certification systems may contain weaknesses that make fraud difficult to detect, contributing to the phenomenon of "fake organic" products [18]. Other issues include certification fraud and misleading labeling, cost and technological barriers to implementing traceability, information asymmetry among supply chain actors, and limited transparency and regulatory support from government [19].

Blockchain technology is one option to support traceability in the organic rice supply chain. Blockchain can help prevent product counterfeiting, improve operational efficiency, and strengthen compliance with international regulatory standards [20], in addition, it enables accurate traceability of product origins, helps prevent fraudulent activities, and enhances trust between producers and consumers [18]. Moreover, blockchain provides a transparent, secure, and tamper-resistant record-keeping system [21].

The problem identified in this study is that the traceability of the organic rice supply chain in Banten Province, Indonesia, organic rice supply chain traceability is still conducted manually. As a result, tracing products (either paddy or organic rice) is difficult, and no stand-alone or web-based system is available. Regulators and supply chain actors—farmers, farmer group associations, business entities, retailers, and end consumers—cannot reliably verify the origin of the rice they transact. Consequently, trust in organic rice authenticity remains low.

The gap analysis in this study reveals that although numerous studies have examined traceability in agricultural supply chains, while many studies have examined traceability in agricultural supply chains, relatively few studies specifically on organic rice supply chain traceability using blockchain technology. Existing work remains limited in terms of developed models, implemented prototypes, and end-to-end evaluations of blockchain-based traceability systems for organic rice.

This study has three objectives. First, to identify the key factors that drive the adoption of blockchain technology for organic rice supply chain traceability in Banten Province. Second, to develop a blockchain-based traceability model and a corresponding prototype for the organic rice supply chain in Banten Province. Third, to validate the proposed model through a Focus Group Discussion (FGD) and to validate the prototype using ISO/IEC 25010. Validation involves organic rice supply chain actors (farmers, Farmers Cooperatives, business entities, retailers, and end consumers) as well as the Banten Provincial Food Security Agency as the regulator.

The main contribution of this study is the development of a blockchain-based organic rice supply chain traceability model and prototype using DSRM. The model is evaluated via FGD involving farmers, farmer group associations, business entities, retailers, end consumers, and domain experts (supply chain, organic rice, blockchain), as well as government representatives from the Banten Provincial Food Security Agency. The prototype is validated using ISO/IEC 25010 with supply chain actors, experts, and the Food Security Agency.

Several previous studies have investigated rice supply chain traceability using blockchain technology. One study implemented a permissioned blockchain application using the Microsoft Power Platform with a Proof of Authority (PoA) consensus mechanism, where Dataverse functioned as the blockchain ledger. The system incorporated QR codes on consumer packaging, demonstrating potential improvements in data consistency and transparency [22]. Other studies reported that blockchain implementations using platforms such as Ethereum, Hyperledger Fabric, IOTA, hybrid architectures, and Blockchain-as-a-Service (BaaS) were able to enhance overall supply chain performance [23]. Furthermore, the adoption of private or permissioned blockchain configurations, both dynamic and static, combined with QR code utilization, was shown to improve traceability, transparency, trust, and supply chain efficiency [24]. In the Indonesian context, a blockchain-based rice supply chain design utilizing the Ethereum platform and the Solidity programming language highlighted the advantage of transparently distributing recorded historical information among all stakeholders [25].

In this study, the proposed system was developed using the Multichain platform, JavaScript, ReactJS, PostgreSQL, and Visual Studio Code. The evaluation was conducted through Focus Group Discussions (FGD) to assess the existing model, followed by prototype evaluation based on the ISO/IEC 25020 quality measurement standard.

2- Literature Review

2-1- Design Science Research Methodology

Design Science Research (DSR) is a framework for research in the Information Systems field [26]. It is a problem-solving paradigm that seeks to improve the quality of human knowledge through the creation of innovative models. The outputs of DSR include new designs and design knowledge that provide a more comprehensive understanding through design theory [27]. This method covers project science, addressing needs, meaning, and how to operationalize solutions. In addition, DSR is strong from a literature perspective because it can significantly enhance learning understanding. The strength of DSR lies in its scientific rigor in building and evaluating models, aiming to develop models that address complex problems and thereby improve solutions derived from extensive literature [28]. DSR refines early theoretical conclusions that may be applicable to help explain solutions using abductive reasoning; starting from problems while simultaneously drawing on theory and evidence to generate insights and solutions [29]. Therefore, DSR has become well known among other research methods [30].

2-2- Blockchain Technology

Blockchain technology emerged prominently in 2008 with the publication of the whitepaper “Bitcoin: A Peer-to-Peer Electronic Cash System” by an individual or group using the pseudonym “Nakamoto” [31]. However, the history of blockchain-related concepts can be traced back to 1976, when Diffie and Hellman introduced the concept of public-key cryptography. In the 1980s, David Chaum developed DigiCash using blind signature technology. In 1991, Haber and Stornetta developed a digital timestamping system based on a hash chain, which later became a foundational structure for blockchain. In 1997, Adam Back introduced Hashcash, followed in 1998 by the concept of b-money. A major milestone occurred in 2008 when Satoshi Nakamoto introduced Bitcoin. Blockchain continued to develop and, by 2019, entered the era of enterprise blockchain, including initiatives such as Facebook’s Libra project that expanded the application of Distributed Ledger Technology (DLT) [32]. The main prospects of blockchain in business and management span six areas: finance; public services and government; healthcare; asset registration and tokenization; Industry 4.0 and the Internet of Things (IoT); and logistics and supply chain. In logistics and supply chains, applications include supply chain transparency, process automation, and product traceability, offering benefits such as transparency, resource savings, and real-time tracking [33].

Blockchain technology also plays a significant role in agricultural supply chains. It offers advantages such as increased transparency, accountability, and information reliability, which directly reduce fraud risk and transaction costs. Blockchain implementation not only creates economic value but also has the potential to foster a more transparent, fair, and ethical supply chain ecosystem [34]. It can enhance transparency, traceability, and trust throughout food supply chains. By recording data in a permanent and tamper-resistant manner, blockchain enables each supply chain actor to verify product origin, production processes, and distribution accurately and in real time. This advantage strengthens consumer trust in producers’ claims and helps companies meet food safety and sustainability standards [35]. In addition, blockchain adoption in coffee supply chains has been reported to support transparency, efficiency, fairness, and sustainability [35], as well as transparency, security, efficiency, sustainability, and trust [36]. In an agricultural context, blockchain can also improve farmer welfare through price transparency and more equitable market access, while supporting sustainability practices by recording environmentally friendly production data [37].

2-3- Traceability of Organic Products

Traceability is the ability to trace information about fresh agricultural food products back to cultivation, post-harvest, processing, packaging, and distribution stages through a recording scheme that can be accessed by relevant stakeholders [38]. Furthermore, a credible and traceable organic agricultural production system requires that organic farming activities be traceable [15]. If the activities include processing agricultural products, the recorded data should include information such as: (1) origin, type, and quantity of agricultural products delivered to preparation and packaging units; (2) type, quantity, and recipient of shipped products; and (3) other information such as origin, type, and quantity of materials, additives, and processing aids used in preparation and packaging units, as well as the composition of processed products [39]. Traceability is a crucial aspect of organic product production and distribution systems. Through transparent traceability systems, each stage in the supply chain can be verified to ensure that products are genuinely produced according to organic farming principles. Beyond ensuring product authenticity and safety, traceability increases consumer trust, supports producer transparency and accountability, and provides a basis for comprehensive Life Cycle Assessment [40]. Organic product traceability is needed to ensure transparency, certification integrity, and consumer trust; without adequate traceability, organic products are vulnerable to label fraud and a decline in public trust

[41]. Increasing transparency and traceability across food supply chains is an important aspect of improving organic certification systems. Traceability is considered crucial for ensuring organic authenticity, preventing fraud, and strengthening consumer trust in the "organic" label [42]

2-4- Organic Rice

Rice (Latin: Oryza sativa) is one of the most important cultivated crops in human civilization. Although it mainly refers to a cultivated plant species, "rice" can also refer to several species within the same genus, commonly known as wild rice [43]. "Organic" is a labeling term is a labeling term indicating that a product has been produced according to organic production standards and certified by an official certification body. Organic products are produced according to organic food system standards and include organic processed food raw materials, organic inputs, fresh plants and plant products, livestock and livestock products, processed plant products, and processed livestock products (including non-food products) [15]. Organic rice refers to rice cultivated without chemical pesticides, fertilizers, hormones, and drugs, using organic inputs such as manure or compost, thereby offering an alternative that supports environmental preservation [44]. Organic rice is rice produced through organic cultivation processes without using chemical fertilizers and pesticides [45].

Organic rice is considered safer for consumption because it contains lower pesticide and antibiotic residues than conventional rice; the use of natural fertilizers and biological pest control reduces the risk of harmful chemical accumulation in the human body [46]. Organic rice is produced without synthetic chemical fertilizers or pesticides, thereby reducing harmful food residues, protecting human and animal health, and lowering the risk of diseases related to agricultural chemicals [47]. With an average sustainability index of 68.56 (moderately sustainable), organic rice farming is described as an ideal model for strengthening food security and sustainable development in Indonesia [48]. Organic rice is free from pesticide residues, chemical fertilizers, and synthetic substances, making it safer for consumption and reducing the risk of diseases associated with chemical exposure. Furthermore, it offers environmental benefits [49]. Furthermore, organic rice farming can reduce environmental pollution, maintain soil and water quality, reduce harmful chemical residues, improve soil fertility, and reduce the risk of ecosystem degradation [50].

2-5- Supply Chain

A supply chain is defined as an integrated system that synchronizes a series of business processes to generate product demand, procure raw materials and components, transform these materials into finished goods, add value to products, manage distribution, and facilitate information exchange [51]. In achieving integration, six key strategies must be considered: supplier maximization, limited supplier selection, vertical integration, strategic collaboration, Keiretsu network formation, and virtual enterprises [52]. The goal of any supply chain is to maximize the overall value (profit) generated, which is derived from customer value minus supply chain costs; thus, the only source of revenue in a supply chain is the customer [53]. Supply chain management aims to ensure operational efficiency, optimize transportation and logistics systems, and focus on quality improvement [54]. Other sources state that supply chain management seeks to optimize profits and keep companies competitive by coordinating activities between suppliers and consumers, reflecting the logistics sector's commitment to efficient operations [55].

2-6- Hypotheses Development

To examine key characteristics that influence the adoption of blockchain technology, this study considers factors related to technology, organization, operations, data management, environment, knowledge, supply chain, quality, and culture. These factors are illustrated in Figure 1 and described through the following hypotheses:

H1: Technological Maturity affects Blockchain Technology Adoption;

H2: Organizational Resource affects Blockchain Technology Adoption;

H3: Operational Excellence affects Blockchain Technology Adoption;

H4: Data Management affects Blockchain Technology Adoption;

H5: Environment Conditions affects Blockchain Technology Adoption;

H6: Knowledge Management affects Blockchain Technology Adoption;

H7: Supply Chain Integration affects Blockchain Technology Adoption;

H8: Quality Assurance affects Blockchain Technology Adoption;

H9: Cultural Compatibility affects Blockchain Technology Adoption.

The hypothesis above is tested using Structural Equation Modeling Partial Least Squares (SEM-PLS) as the main analytical framework. Figure 1 presents the conceptual model based on the formulated hypotheses.

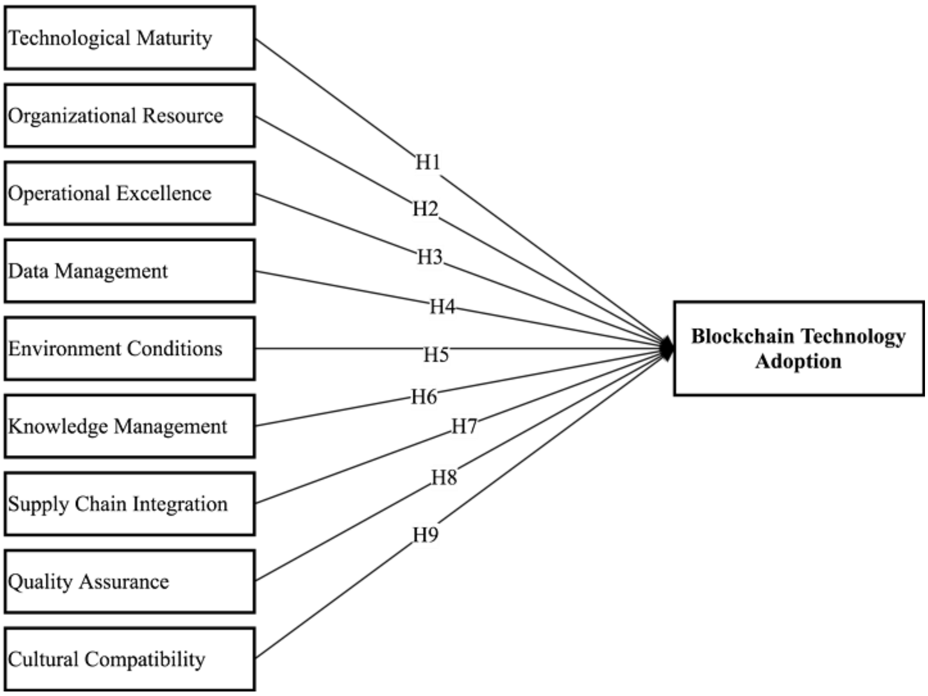


Figure 1. Conceptual and Hypothetical Model

3- Research Methodology

The research methodology comprises structured, efficient, and goal-oriented steps to obtain data aligned with the study objectives. The proposed methodology follows the Design Science Research Methodology (DSRM) developed by Sarstedt et al. [56]. The DSRM process adopted in this study is illustrated in Figure 2.

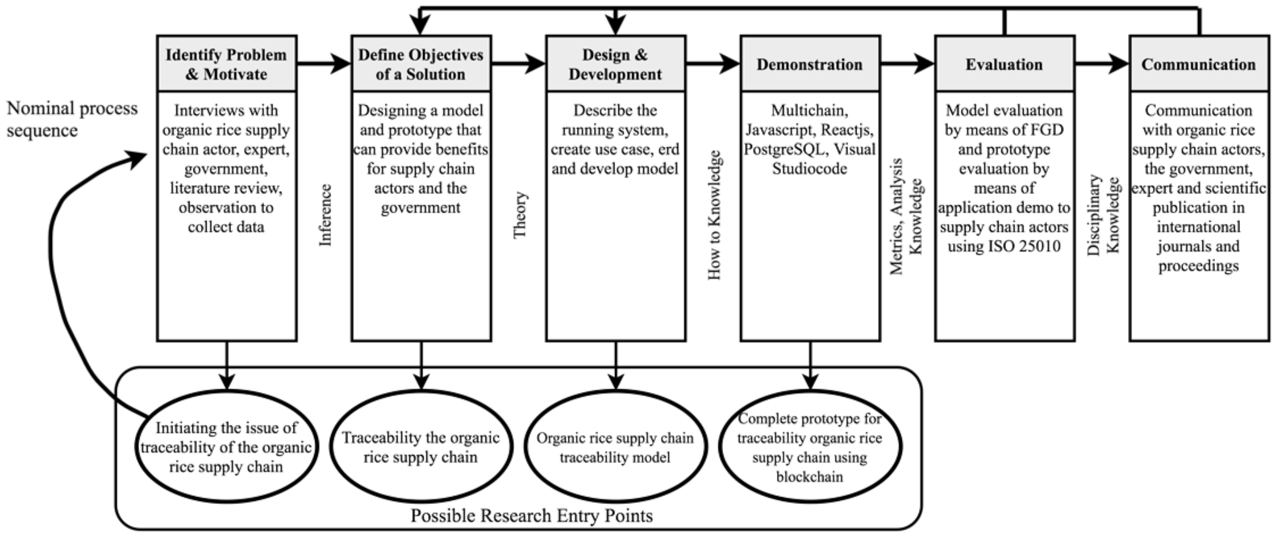


Figure 2. Model Design Science Research Methodology

3-1- Identify Problem & Motivation

Problem identification Problem identification is the first step of this study. Through this stage, the research initiates and specifies the traceability issues of the organic rice (*Oryza sativa* L.) supply chain in Banten Province. Field activities for problem identification were conducted through interviews with organic rice supply chain actors—farmers, farmer group associations/farmers cooperatives, business entities, retailers, and end consumers—in Banten Province. Interviews were also carried out with domain experts in organic rice supply chains, organic rice, and blockchain technology.

3-2- Define Objectives of a Solution

This study has three objectives. (1) to identify critical factors supporting the adoption of blockchain technology for organic rice (*Oryza sativa* L.) supply chain traceability; (2) to develop a blockchain-based traceability model and prototype for the organic rice supply chain; and (3) to validate the model through a Focus Group Discussion (FGD) and to validate the blockchain-based traceability prototype using ISO 25010. The developed model and prototype are expected to support traceability of transaction documents and/or Fresh Plant-Origin Food (PSAT) certification documents issued by the Banten Provincial Food Security Agency, thereby strengthening consumer trust.

3-3- Design & Development

In the third step, the research develops a traceability model and prototype for the organic rice supply chain in Banten Province. The process begins by examining the existing organic rice supply chain system. After establishing the current workflow, the next steps include designing the use case diagram and the entity relationship diagram (ERD) to produce the research artifact (i.e., the model). Developing the model required substantial time due to continuous coordination with supply chain actors, the Food Security Agency, and domain experts (supply chain, organic rice, and blockchain) to ensure that the artifact effectively addresses the identified problems.

3-4- Demonstration

The blockchain-based prototype for organic rice supply chain traceability was developed using the MultiChain blockchain platform. JavaScript was used for client-side web development. ReactJS was employed to build a dynamic, efficient, and well-structured user interface (UI) through reusable components. PostgreSQL was selected as an open-source relational database management system to store, manage, and process data efficiently, supporting ACID transactions, complex data types, replication, and integration with various programming languages for applications ranging from small to large scale. Visual Studio Code was used as a lightweight and flexible cross-platform source-code editor to support writing code, debugging, version control, and extension-based development, thereby improving efficiency, collaboration, and developer productivity.

3-5- Evaluation

This study conducted three forms of validation: validation of key factors influencing blockchain adoption, validation of the proposed model, and validation of the prototype. First, validation of adoption factors was performed by distributing a questionnaire consisting of 36 closed-ended questions and 3 open-ended questions via Google Forms to 220 respondents. Purposive sampling was applied with the criteria that respondents were directly involved in the organic rice supply chain and understood the blockchain technology under study. Respondents included farmers, farmers cooperatives, business entities, retailers, and end consumers. The responses from 220 participants were analyzed using Structural Equation Modeling–Partial Least Squares (SEM-PLS).

Second, model validation was carried out through a blended (hybrid) Focus Group Discussion (FGD) attended by 19 participants, comprising supply chain actors (farmers, Gapoktan, business entities, retailers, and end consumers), the Food Security Agency as the regulator, and domain experts in supply chain, organic rice, and blockchain technology. Third, prototype validation referred to the ISO/IEC 25010 standard (2023), which consists of nine quality characteristics. The prototype assessment involved 15 respondents (farmers, Gapoktan, business entities, and retailers). In addition, the QR-code functionality in the application was validated by 53 end consumers.

3-6- Communication

Communication is the final stage of DSRM, focusing on disseminating research results to the scientific community and relevant stakeholders. At this stage, the researcher disseminated the findings to supply chain actors, the Food Security Agency, domain experts, and end consumers. The developed blockchain-based prototype is able to trace the organic rice supply chain from farmers, farmers cooperatives, business entities, and retailers, thereby helping to ensure the authenticity and security of organic rice and potentially increasing consumer trust—contributing to improved welfare for supply chain actors, particularly organic rice farmers. Moreover, the technology can help shorten the supply chain by reducing the number of intermediaries, which may lead to lower retail prices for organic rice. The research report has been prepared and published in conference proceedings and international journals.

4- Results and Discussion

4-1- Identify Problem & Motivation

To identify traceability issues in the organic rice supply chain in Banten Province, Indonesia, interviews and field observations were conducted with all relevant supply chain actors. Interviews and observations with farmers and farmer group associations/farmers' cooperatives were carried out in four major rice-producing areas in Banten Province: Pandeglang Regency, Lebak Regency, Serang Regency, and Tangerang Regency. A total of six farmers and six farmers' cooperatives were selected as samples to explore the existing problems. In addition to farmers and farmer cooperatives, interviews were also conducted with two representatives of business entities, two retail companies, three end consumers, and the Banten Provincial Food Security Agency. The key issues identified through the interviews and observations are summarized as follows:

- Farmers and Farmers Cooperatives did not know where the harvested paddy was ultimately sold and faced difficulties marketing the organic rice they produced.
- Business actors stated that supply chain traceability is critically needed during organic audits. Without traceability, business actors cannot claim organic status. They also could not monitor organic rice stock owned by each Gapoktan.
- Retail companies could not trace the products they sold because no web-based traceability information system was available; they confirmed that such a system is strongly needed.
- End consumers emphasized that knowing the origin of organic rice is important to ensure that the rice consumed is genuinely organic and comes from a trusted source. They also reported obstacles in obtaining complete and transparent supply chain information.
- The Banten Provincial Food Security Agency highlighted that inadequate traceability may lead to counterfeit organic labels, resulting in consumer deception and potential consumption of rice that may contain chemicals. In the long term, consumer trust in organic rice could decline.
- The agency also explained that a major challenge in ensuring authenticity and safety is preventing mixing with non-organic rice during Good Handling Practices (GHP), Good Manufacturing Practice (GMP), and distribution. Therefore, physical quality and safety testing are needed to ensure organic rice is free from residue contamination, heavy metals, and microbes while maintaining acceptable physical quality.
- A supply chain expert stated that no technology is currently used to track organic rice from farmers to end consumers, indicating the need for blockchain-based technology to support traceability.
- An organic rice expert stated that traceability is necessary to ensure organic integrity in accordance with SNI 6729:2016. Without traceability, organic claims may become invalid.
- A blockchain technology expert noted that blockchain implementation for organic rice supply chain traceability remains limited, making further development toward a functional prototype feasible. Blockchain can improve transparency through its publicly verifiable nature, immutability, and secure data storage, enabling end consumers to track the movement of purchased organic rice products.

4-2- Define Objectives of a Solution

After identifying the problems in organic rice supply chain traceability, this stage determined the research objectives to ensure an effective solution. This study has three objectives: (1) identifying key factors influencing blockchain adoption, (2) developing a blockchain-based organic rice supply chain traceability model and prototype, and (3) validating the model and prototype.

Identifying critical factors for blockchain adoption was intended to strengthen the rationale that blockchain is important for traceability in Banten Province. Ten critical factors—transparency, traceability, security, smart contracts, immutability, decentralization, distributed ledger, tracking, efficiency, and fast system performance—were identified through a systematic literature review (SLR) published in international journals and validated by business actors and experts in organic rice, rice supply chains, and blockchain technology.

The artifact (model) was developed to address traceability problems faced by supply chain actors. The model is expected to resolve issues such as enabling farmers to upload harvested outputs to the system, allowing business actors to purchase organic harvests, and enabling consumers to view organic certification—thereby increasing trust and potentially increasing consumer purchases. Before organic certificates are entered into the system by the Banten Provincial Food Security Agency, authenticity verification is conducted through communication with the Organic Certification Body (LSO) that issued the certificate, ensuring only valid certificates are recorded.

The next objective was to design a prototype traceability system using blockchain technology. The prototype was developed using the Multichain platform and is capable of storing organic documents issued by the Banten Provincial Food Security Agency under the Fresh Food of Plant Origin (PSAT) framework, where these documents are validated through blockchain consensus. The prototype also supports transaction recording, enabling business actors to easily access data uploaded by farmer groups or farmers cooperatives, with user access permissions aligned to each actor's role.

4-3- Design & Development

4-3-1- Determining Key Factors for Blockchain Technology Adoption

To identify key adoption factors for blockchain in the organic rice supply chain, ten variables were used. These variables were operationalized into 36 indicators that became questionnaire items answered using a Likert scale (1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree). Data collection was conducted from March 13, 2025 to May 13, 2025 via Google Forms, yielding 220 respondents.

Convergent Validity Testing was performed to determine indicator factor loadings. Outer loading measures the strength of association between observed indicators and latent variables (LV). Some researchers consider a loading of 0.7 or higher as strong, while others accept 0.6 or 0.5 as thresholds; in more complex studies or those with smaller samples, lower thresholds may be applied.

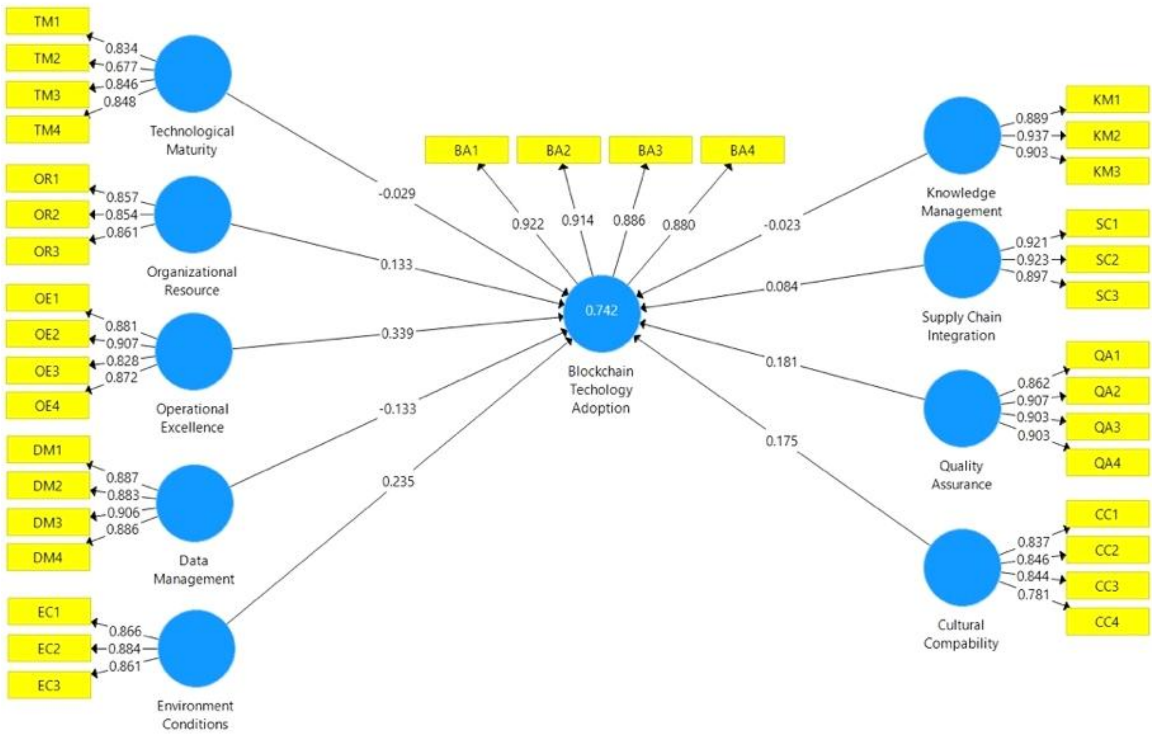


Figure 3. Results of the Outer Loading Test Using the PLS Algorithm

Figure 3 shows that the relationships between variables and indicators for blockchain technology adoption exceed 0.60. This suggests that the indicators have strong and significant relationships with the latent variables being measured and contribute meaningfully to construct measurement.

Path coefficient testing is an essential step in SEM-PLS or path analysis for evaluating the statistical significance of structural relationships among latent variables. In PLS-SEM, the structural model represents relationships among latent variables, and path coefficients capture the magnitude and direction of these relationships.

Table 1. Uji Path Coefficient

	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (|O/stdev|)	P Values
Operational Excellence → Blockchain Technology Adoption	0.339	0.338	0.090	3.777	0.000
Cultural Compatibility → Blockchain Technology Adoption	0.175	0.179	0.065	2.692	0.007
Environment Condition → Blockchain Technology Adoption	0.235	0.224	0.101	2.322	0.021
Quality Assurance → Blockchain Technology Adoption	0.181	0.184	0.086	2.097	0.036
Organizational Resource → Blockchain Technology Adoption	0.133	0.129	0.067	1.989	0.047
Data Management → Blockchain Technology Adoption	-0.133	-0.132	0.072	1.857	0.064
Supply Chain Integration → Blockchain Technology Adoption	0.084	0.080	0.090	0.938	0.349
Technological Maturity → Blockchain Technology Adoption	-0.029	-0.024	0.087	0.331	0.741
Knowledge Management → Blockchain Technology Adoption	-0.023	-0.016	0.089	0.256	0.798

Based on SEM-PLS results, five of nine tested paths affecting blockchain adoption had p-values < 0.05, namely Operational Excellence (p = 0.000), Cultural Compatibility (p = 0.007), Environmental Conditions (p = 0.021), Quality Assurance (p = 0.036), and Organizational Resources (p = 0.047). These factors exhibited positive and significant effects on adoption. In contrast, Data Management (p = 0.064), Supply Chain Integration (p = 0.349), Technological Maturity (p = 0.741), and Knowledge Management (p = 0.798) were not statistically significant (p > 0.05), and thus could not be concluded to meaningfully contribute to blockchain adoption in this model (Table 1).

4-3-2- Developing the Model

Model development was informed by interviews with experts from the Agricultural Instrument Standardization Agency (BSIP) and the Food Security Agency, leading to a refinement of the commodity scope from "special rice" to organic rice. Model-related interviews were conducted with six farmers/farmer groups/farmers cooperatives in Banten's rice production centers, one farmers cooperatives from Sleman (Yogyakarta), two business entities (PT Bionic Natura and PT Wahana Mutiara Agromedika), two retailers (PT Lion Super Indo and PT Matahari Putra Prima Tbk/Hypermart), two end consumers (Serang and Tangerang), and three experts (organic rice, rice supply chain, blockchain).

Figure 4 presents the proposed model for organic rice supply chain traceability using blockchain in Banten Province. The model consists of two layers: (1) a production-flow layer bridged by the regulator (government) and (2) an information-flow layer. Before reaching the information layer, governance is mediated by the regulator, represented by the Banten Provincial Food Security Agency, which is responsible for supervising and ensuring PSAT safety.

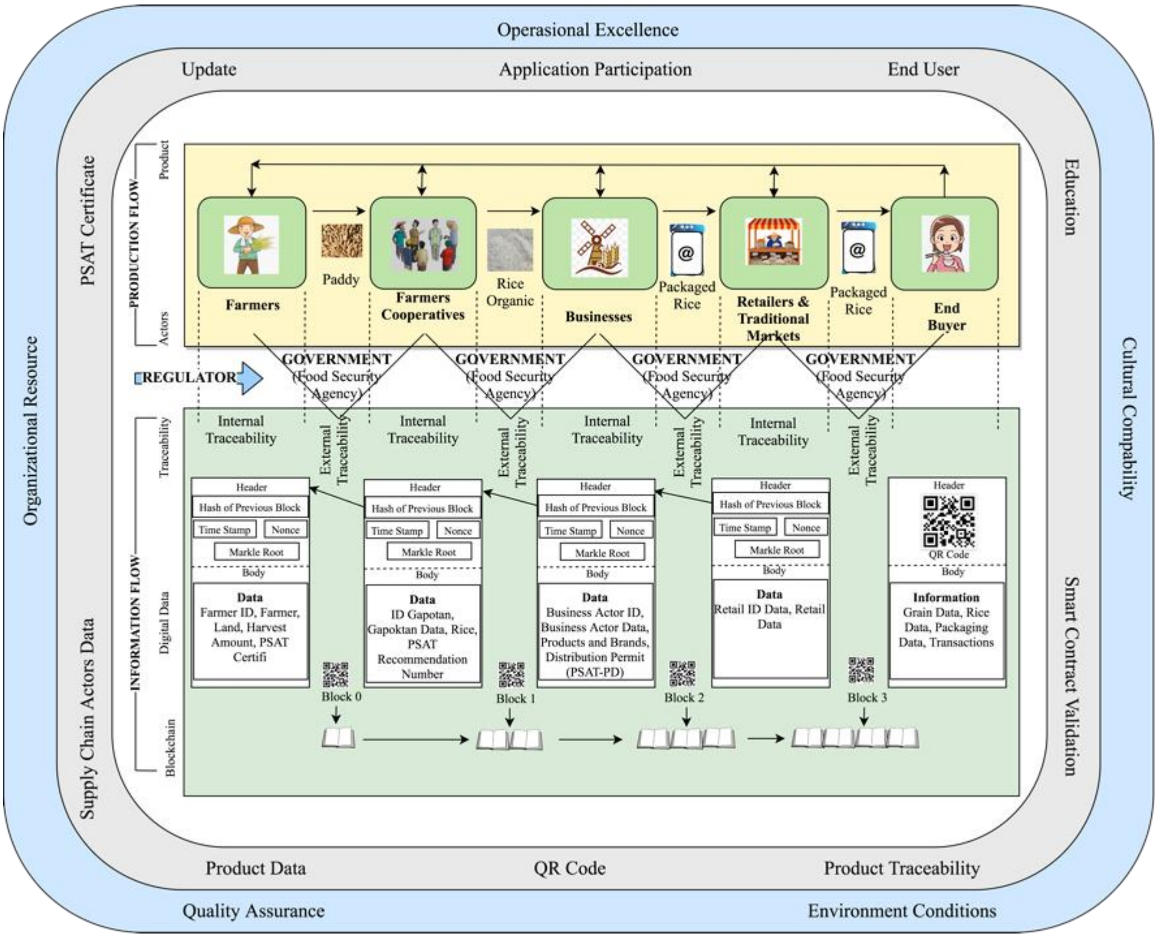


Figure 4. **Organic Rice Supply Chain Traceability Model Using Blockchain Technology**

The second layer captures information flows that were previously manual or fragmented. In the proposed model, information is stored on blockchain, representing a key distinction from prior processes. This layer includes three essential components: traceability processes, digital data, and the blockchain technology (Multichain). Traceability is divided into internal traceability (internal consensus members within each supply chain actor) and external traceability (consensus involving external parties such as the Food Security Agency). The model includes four internal traceability processes and four external traceability processes. Digital data represent records stored in blockchain blocks, linked sequentially.

Outside the two layers, two nested boxes represent additional aspects. The first (gray) box indicates that the blockchain-based system is expected to support ten functions: update, application participation, end user, application, smart contract validation, product traceability, QR code, product data, actor data, and PSAT certification. The second (outer, light blue) box indicates that adoption of the system is grounded in the SLR and supported by five significant variables identified from the nine tested variables: Operational Excellence, Cultural Compatibility, Environmental Conditions, Quality Assurance, and Organizational Resources, each with varying subcomponents.

The model was validated through a Focus Group Discussion (FGD) held on Thursday, June 5, 2025 (09:30–11:30) in a blended (online and offline) format. Nineteen participants attended, representing the Food Security Agency, supply chain experts, organic rice experts, blockchain experts, farmers, farmers cooperatives, business actors, retailers, and end consumers. Key feedback included: adding "traditional markets" alongside retailers due to legal terminology; incorporating "education" as an application capability given Indonesia's need for guidance on regulations and procedures; ensuring the model accommodates smallholder constraints (infrastructure and digital literacy); validating farmer-input data before recording; promoting fair profit distribution; and encouraging government regulation to support business purchases of organic rice sourced from Banten Province.

4-3-3- Designing the Prototype

(a) Business Process Modeling

The demonstration stage began by describing and modeling business processes carried out by supply chain actors: farmers/ farmers cooperatives, business actors, retailers, end consumers, and the Food Security Agency (regulator). The current business process is shown in Flowmap (Figure 5).

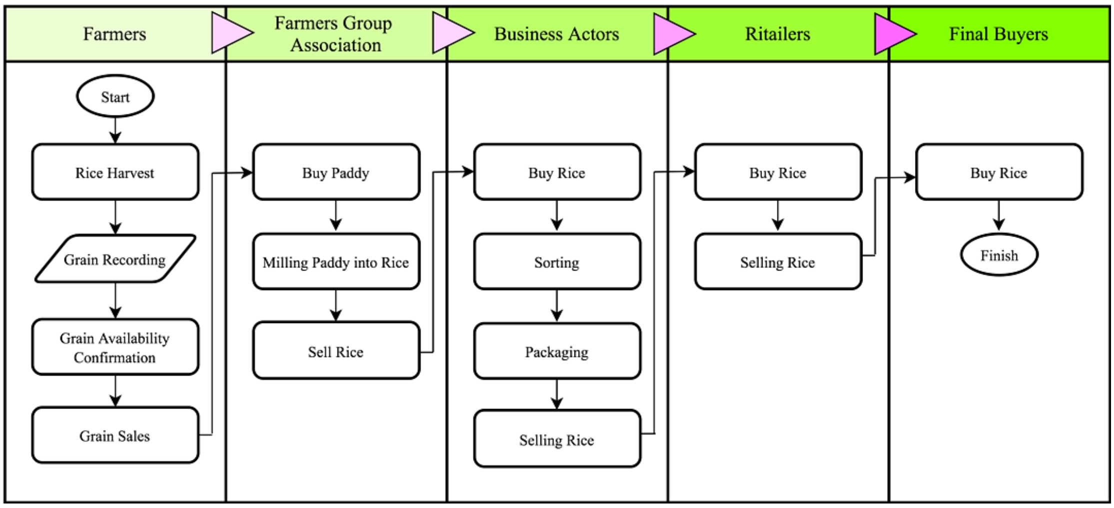


Figure 5. Manual System Business Process

Organic rice supply chain in Banten Province involves five actors: farmers, Gapoktan, business actors, retailers, and end consumers. The process begins with farmers harvesting organic paddy, processing it into paddy, and selling it. Next, farmers cooperatives purchase paddy, dry it, mill it, sort it, package it in large sacks, and sell it in bulk. Business actors (typically PT/CV) then purchase rice from farmers cooperatives, sort it, repackage it under their brand (1 kg, 2 kg, 5 kg), and market and sell it.

Retailers purchase from business actors and perform quality control; if the product meets standards, it is accepted and marketed, otherwise it is returned. Finally, end consumers purchase organic rice from retailers. Importantly, organic rice supply chains require monitoring of PSAT safety and quality under the Indonesian Ministry of Agriculture Regulation No. 53/Permentan/OT.040/12/2018.

(b) Use Case Diagram

The use case diagram (Figure 6) was used to identify system requirements and help developers and stakeholders understand system functions, including recording harvest results, distribution, packaging, and sales. Figure 6 shows six actors: farmers, Gapoktan, business actors, retailers, end consumers, and the Food Security Agency.

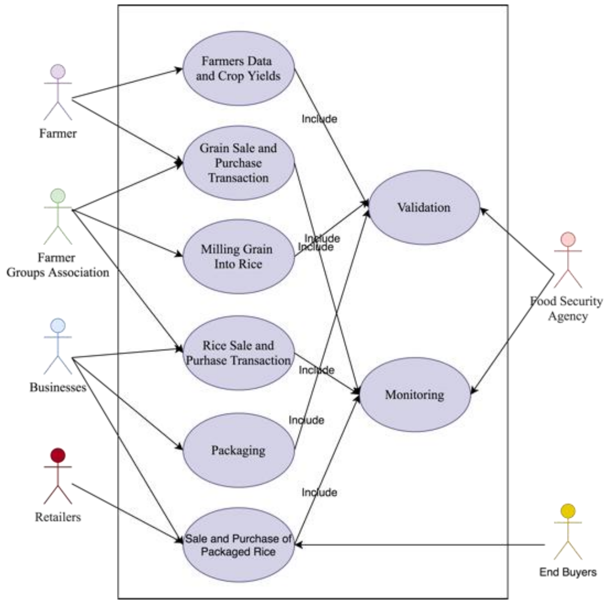


Figure 6. **Use Case Diagram**

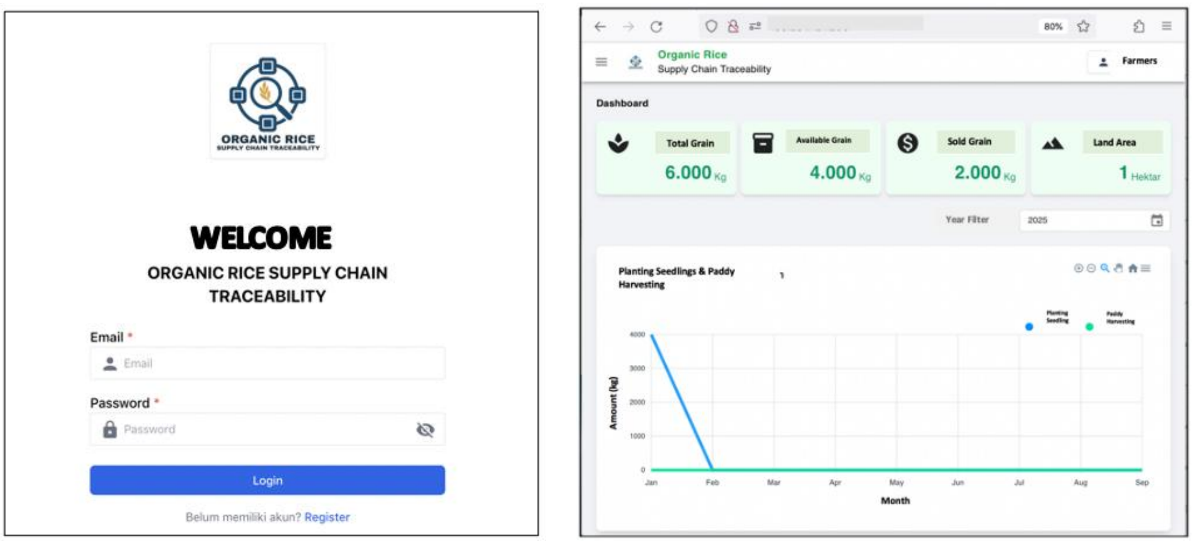
Figure 6 illustrates the interaction between actors and the system to be developed. There are six key actors involved in the model: farmers, farmer groups association, business actors, retailers, end consumers, and the Provincial Food Security Agency.

(c) Defining Tables, Fields and Data Types

Data within the database is organized and stored in tables. A total of 19 tables were created, each containing a set of fields along with their respective data types. These tables form the structural foundation of the blockchain-based traceability system for the organic rice supply chain. The tables include: user, farmer_profile, farmer_group_profile, business_profile, food security_service_profile, product, asset, grain, rice, rice_product, retail_product, transaction, transaction_item, PSAT distribution permit, PSAT distribution permit_request_header, PSAT distribution permit_detail, PSAT handling unit, and PSAT distribution permit_request_header.

4-4- Demonstration

Application was developed using the Multichain blockchain platform, JavaScript as the programming language, PostgreSQL as the database, and ReactJS for the user interface (UI), with Visual Studio Code as the text editor. The application is named "Organic Rice Supply Chain Traceability", reflecting its function of tracking and tracing the journey of organic rice products from farmers to end consumers, including transaction data, in an accurate and transparent manner. Based on the model presented in Figure 6, a corresponding UI was developed for supply chain actors, including farmers, farmer group associations, business entities, retailers, and the Food Security Agency.

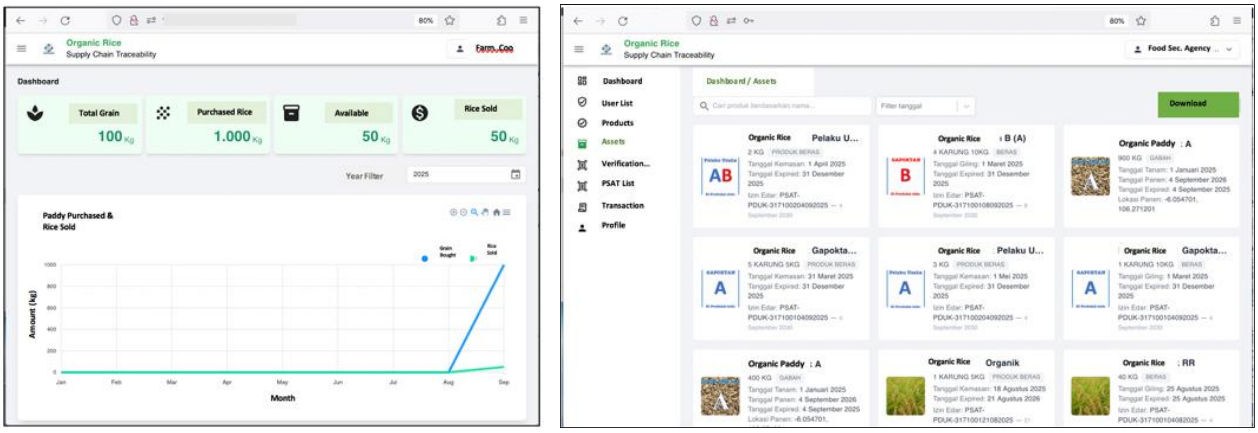


Login   Dashboard Farmers

Figure 7. **User Interface Login and Dashboard Farmers**

Figure 7 shows the login page and farmer dashboard. The login page serves as the entry point for all users, each with a unique account and differentiated forms and information access. The farmer dashboard displays total harvested paddy, available stock, sold quantities, and cultivated land area. It also includes a graphical view of seeds planted and detailed information on harvested paddy.

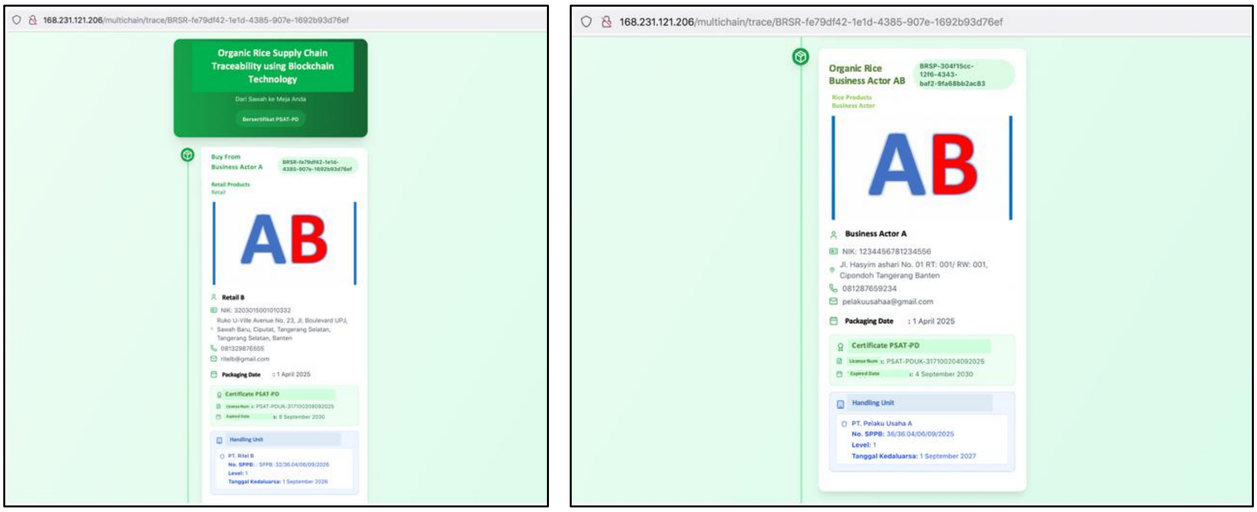
Figure 8 illustrates dashboard interfaces for the farmer group association and the Food Security Agency. The regulator interface provides access to user lists, product and asset information, PSAT certification verification and records, transaction history, and profiles. The product dashboard contains detailed quantities of rice and paddy held by different supply chain actors. In the developed application, each transaction—farmers selling paddy to farmers cooperatives, farmers cooperatives selling rice to business actors, and business actors selling packaged rice to retailers—includes a QR code. When the QR code is scanned, the system displays blockchain-based traceability information as shown in the following interfaces.



Farmers Group Association | Food Security Agency

Figure 8. User Interface Farmers Group Association and Food Security Agency

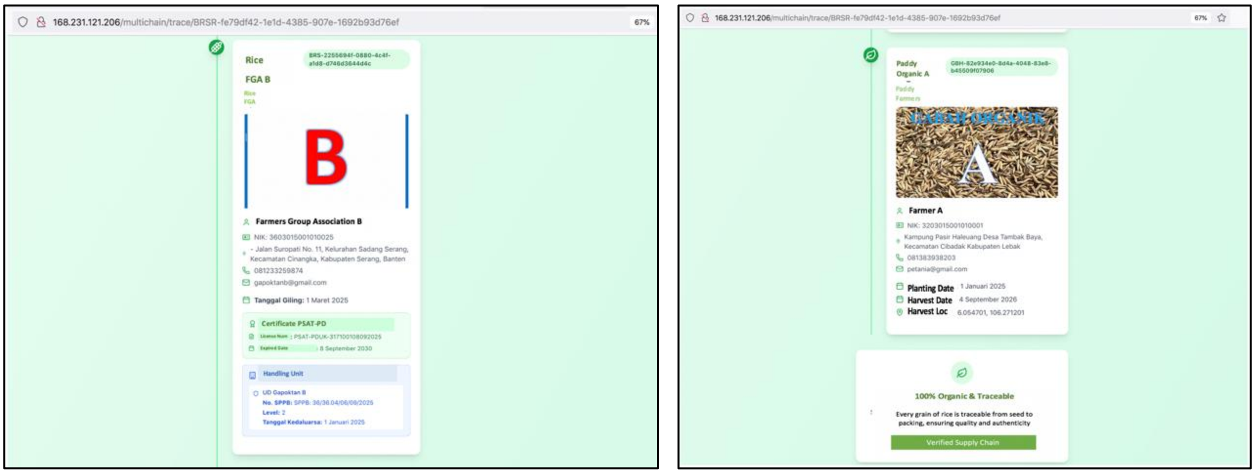
Figure 9 shows traceability information obtained by end consumers after scanning the QR code. Consumers obtain supply chain information starting from the retailer selling the organic rice (e.g., "Retail A"), including purchase links to the business actor ("Business Actor A"). Both retailer and business actor provide key information such as PSAT-PD certificate activation, packaging date, and handling unit details.



Retail B | Business Actor A

Figure 9. User Interface Retail A and Business Actor A

Figure 10 illustrates the traceability information accessible to end consumers after scanning the QR code. The data indicate that Retail A purchased rice from Business Actor A, who sourced the product from Farmers Group Association B, which in turn procured paddy from Farmer A. This traceability mechanism enables end consumers to obtain accurate, verifiable, and immutable information regarding the origin and transaction history of the organic rice. Furthermore, the QR code-based system ensures that all stakeholders—including farmers, farmer associations, business actors, retailers, the Food Security Agency, and the general public—can access the same transparent and validated supply chain data, thereby enhancing trust and accountability across the organic rice supply chain.



Farmers Group Association B — Farmers A

Figure 10. User Interface Farmers Group Association B and Farmers A

4-5- Evaluation

Prototype evaluation was conducted through validation based on ISO/IEC 25010 (2023), which includes nine characteristics with 40 sub-characteristics: (1) functional suitability, (2) performance efficiency, (3) compatibility, (4) usability (interaction capability), (5) reliability, (6) security, (7) maintainability, (8) portability (flexibility), and (9) safety. Respondents answered the evaluation items through interviews using a 1–5 Likert scale (1 = strongly disagree to 5 = strongly agree).

Validation was conducted in two stages. The first involved supply chain actors, the Food Security Agency, and experts, with a total of 14 validators. The second involved only end consumers (53 respondents) who did not input data but validated the system by scanning the QR code and completing the questionnaire.

For the first validation (14 validators), the highest scores were obtained for maintainability (4.91), functional suitability (4.29), security (4.11), performance efficiency (3.98), compatibility (3.89), usability (3.85), reliability (3.80), portability/flexibility (3.93), and safety (3.77). The overall mean score was 4.06, indicating that respondents generally agreed the system meets ISO 25010 quality criteria. This reflects good acceptance, although improvements are still recommended for aspects such as reliability and safety to achieve more evenly distributed quality across dimensions.

For the second validation (53 end consumers), the overall mean score was 4.22, indicating the system quality is in the very good category. Most aspects were consistently rated highly (approximately 4.17–4.29), suggesting stable performance across multiple dimensions. Overall, the results indicate that the system performs well in terms of functionality, efficiency, reliability, security, and maintainability. Nevertheless, enhancing flexibility would further strengthen the system's ability to adapt to future needs and operational environments.

4-6- Communication

Communication is the final stage of the Design Science Research Methodology (DSRM), focusing on disseminating research results to the scientific community and relevant stakeholders. At this stage, findings were disseminated to supply chain actors, the Food Security Agency, experts, and end consumers. The developed blockchain-based prototype is capable of tracing the organic rice supply chain from farmers to farmer group associations, business actors, and retailers. This supports assurance of authenticity and safety of organic rice and is expected to increase consumer trust, which may contribute to improved prosperity for supply chain actors—particularly organic rice farmers. Additionally, the technology is expected to shorten the supply chain by reducing the number of intermediaries, potentially lowering retail selling prices of organic rice. The research report has been prepared and published in international proceedings and journals.

5- Conclusion

This study successfully developed and evaluated a blockchain-based traceability model and prototype for the organic rice supply chain in Banten Province, Indonesia, using the Design Science Research Methodology (DSRM). The resulting model and prototype were designed to enhance transparency, authenticity, and efficiency in tracing organic rice from farmers to end consumers. The Partial Least Squares Structural Equation Modeling (PLS-SEM) results indicate that five key factors significantly influence blockchain adoption in the organic rice supply chain context: Operational Excellence, Cultural Compatibility, Environmental Conditions, Quality Assurance, and Organizational Resources. These findings suggest that successful blockchain implementation depends not only on technological readiness, but also on institutional capacity, organizational culture, and adequate regulatory support to enable digital transformation in the agricultural sector.

The proposed traceability model integrates regulatory oversight with blockchain-based data management to help ensure product authenticity, minimize fraud risks, and strengthen consumer trust in organic rice products. In addition, prototype validation using the ISO/IEC 25010 quality model yielded very good results, with an average score of 4.06 from supply chain stakeholders and 4.22 from end users. These scores indicate that the system satisfies key quality criteria; particularly in terms of functionality, reliability, security, and maintainability.

Overall, this study contributes theoretically by identifying the key determinants of blockchain adoption and by applying DSRM in an agri-food blockchain context. Practically, it delivers a validated traceability model and prototype that can serve as a reference for implementing digital traceability systems in agriculture, particularly in developing countries such as Indonesia.

Although the proposed model and prototype were developed and evaluated effectively, several opportunities remain for future work. Future studies are recommended to integrate Internet of Things (IoT) and Artificial Intelligence (AI) to enable automated, real-time, and predictive data recording, monitoring, and analysis across the supply chain. Expanding the approach to other agricultural commodities (e.g., coffee, cocoa, vegetables, or fruits) is also recommended. In the longer term, interdisciplinary research that integrates computer science, agricultural economics, and public policy is needed to accelerate the transition toward a more transparent, fair, and globally competitive food ecosystem. With synergy between technological innovation, stakeholder collaboration, and supportive policies, blockchain can become a core foundation for strengthening food security, product safety, and environmental sustainability.

6- Declarations

6-1- Author Contributions

Conceptualization, R.T., H.L.H.S.W., and H.S.; methodology, T.O. and R.T.; software, R.T.; validation, T.O., R.T., and H.S.; formal analysis, H.L.H.S.W.; investigation, R.T.; resources, R.T., H.S., and T.O.; data curation, H.L.H.S.W.; writing—original draft preparation, R.T.; writing—review and editing, T.O., R.T., and T.O.; visualization, R.T.; supervision, H.L.H.S.W., H.S., and T.O.; project administration, R.T.; funding acquisition, R.T. All authors have read and agreed to the published version of the manuscript.

6-2- Data Availability Statement

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

6-3- Funding

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6-4- Acknowledgments

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6-5- Institutional Review Board Statement

Not applicable.

6-6- Informed Consent Statement

Not applicable.

6-7- Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

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