e-ISSN 2581-0405
Asian Journal of Applied Research for Community Development and Empowerment
Journal home page: http://ajarcde-safe-network.org ISSN 2581-0405

Digital Transformation of Rice Supply Chain: A Systematic Literature Review Towards Traceability-Based Digital Business Ecosystem

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ARTICLE INFO

Article History:
Received: 23 February 2026
Final Revision: 17 March 2026
Accepted: 19 March 2026
Online Publication: 21 March 2026

KEYWORDS

Digital Business Ecosystem, Traceability, Rice Supply Chain, Smart Farming, Literature Review.

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A B S T R A C T

Classic issues in Indonesia's rice agro-industry supply chain include fragmented distribution channels, price volatility, and a lack of quality assurance (traceability) for consumers. While there are several digital solutions out there, including agricultural e-commerce and QR Code-based tracking systems, the majority of these solutions are operating in silos. This article reviews the state of the art of digital technologies for rice commodities and proposes a framework based on Digital Business Ecosystem (DBE). Building on a Systematic Literature Review (SLR) of 20 selected studies (2016-2025), the research highlights three main trends: (1) the predominance of e-commerce platforms oriented towards final sales, (2) the establishment of technical traceability systems that are not yet market-integrated, and (3) poor adoption of ecosystem strategies. A unified digital ecosystem integration between production management systems (on-farm), quality validation (traceability), and market platforms (marketplaces) is deemed to be crucial for enhancing competitiveness among producers, while also securing consumer trust.

Contribution to Sustainable Development Goals (SDGs):
SDG 2: Zero Hunger
SDG 8: Decent Work and Economic Growth
SDG 9: Industry, Innovation, and Infrastructure
SDG 12: Responsible Consumption and Production)

1. INTRODUCTION

1.1. Background

Rice is not merely a primary food commodity in Indonesia but also a strategic product with a highly complex supply chain. This complexity often leads to information asymmetry between farmers as producers and the public as end consumers. In-depth studies confirm that supply chain inefficiencies and the dominance of middlemen result in low added value for farmers [1], while consumers face uncertainty regarding the quality and authenticity of the rice they purchase. Recent research also emphasizes the importance of value-added development strategies to strengthen the rice agro-industry [2]. In the Industry 4.0 era, consumer demands have shifted from simple stock availability to guarantees of food safety and clear product provenance. Therefore, modernizing the rice agro-industry system through digital technology has become an absolute necessity.

In response to these challenges, the last five years (2019-2024) have seen an explosion of digital innovations focusing on marketing or downstream aspects. Based on a literature review, the majority of technological developments are directed toward the creation of e-commerce platforms and Android-based marketing applications [3], [4]. Research demonstrates how mobile applications can shorten the distribution chain by connecting farmers directly to consumers [3], [4]. Furthermore, the utilization of digital marketing through social media and global marketplaces has been proven to significantly increase the market reach of agro-industrial products [5], [6], [7]. To

accelerate technology adoption by MSMEs, the use of Content Management Systems (CMS) has also been developed to build efficient online stores [8].

Conversely, one group of researchers is entirely dedicated to the technical aspects of quality assurance through traceability systems. Key studies [9], [10] have laid the foundational architecture for web-based and QR Code-based tracking systems, which allow for transparent data transfer from land-to-table. This facet was later developed into specific traceability models for corn and rice commodities, showing detailed actors of the supply chain [11], [12]. Digitalization in the upstream sector has also included processes such as digital seed certification systems to ensure the quality of production inputs from inception [13].

In addition, at the next level of technological innovation, with ingredients such as Smart Packaging and IoT to provide real-time monitoring for product quality degradation [14]. Other positive developments in the upstream sector include digital seed certification systems to increase the use of high-quality seeds [13] and web-based on-farm recording applications designed to facilitate agricultural record keeping [15]. The infrastructure needed to ensure rice quality is technically already, at least partly, available from these various studies.

Taking into account dozens of available literature towards innovation, the advancement nature within both upstream traceability and downstream marketing has been rapid, an analysis of 20 selected literatures reveals a significant fragmentation of systems (silos):

1. Marketing applications tend to focus primarily on sales aspects without incorporating rigorous origin-tracking features [16], [17].
2. Conversely, traceability systems often end up as mere technical prototypes that are not integrated with the market or economic incentives; consequently, farmers are reluctant to adopt them as they are perceived to increase workload without providing direct financial benefits [9], [11].
3. Current business strategies have not yet fully accommodated the integration of these two technologies into a single platform [18], [19]. There is still no comprehensive framework that connects certification and production data at the upstream level with tracking systems during processing and sales platforms at the downstream level into a unified system.

To overcome this fragmentation, this article proposes a paradigm shift from a Single Application toward a Digital Business Ecosystem (DBE). The concept of DBE in this context is defined as a collaborative digital environment where traceability (quality) data is used as a primary asset to increase selling value in the marketplace. This system does not only record product history but also creates a mutually beneficial business ecosystem between seed providers, farmers, millers, and consumers.

1.2. Objective

This article aims to conduct a Systematic Literature Review (SLR) of 20 related studies to:

1. Map the current status of digital technology in the rice supply chain.
2. Analyze the strengths and weaknesses of existing partial solutions.
3. Formulate a conceptual design for a rice traceability system based on a Digital Business Ecosystem that integrates production management, quality assurance, and digital marketing to enhance the competitiveness of the national rice agro-industry.

2. MATERIALS AND METHODS

This study employs the Systematic Literature Review (SLR) method with a qualitative descriptive approach. This method was selected to identify, assess, and interpret all relevant research findings related to the digitalization of the rice supply chain. The research stages adopt a literature selection protocol that includes data collection, screening, and data analysis.

2.1 Literature Search Strategy

The literature search was conducted across major academic databases (Google Scholar) and institutional repositories of universities in Indonesia. The search was limited to documents published between 2016 and 2025 to ensure the relevance of the technologies discussed.

The keywords used in the search included combinations of:

1. Rice Traceability System
2. Digital Marketing in Agriculture
3. Agricultural Product Marketing Applications
4. Rice Supply Chain
5. Digital Business Ecosystem

2.2 Inclusion and Exclusion Criteria

To obtain 20 high-quality and relevant primary literatures, the authors established the following selection criteria:

Table 1. Inclusion and Exclusion Criteria

Criteria	Inclusion (Accepted)	Exclusion (Rejected)
Topic	Directly related to agricultural technology, marketing information systems, traceability, or agro-industry supply chain management.	Pure agricultural articles (cultivation/agronomy) without information technology or business management aspects.
Document Type	National/International Journal Articles, Undergraduate Thesis (Skripsi), and Master's Thesis.	Popular news articles, blogs, or opinions without empirical data.
Publication Year	2017 – 2025 (The last 5-8 years).	Publications below 2017 (except for fundamental theories).
Language	Indonesian and English.	Languages other than Indonesian and English.

Based on the selection results, 20 final documents were obtained, consisting of accredited journal articles, undergraduate theses (skripsi), and master's theses, which serve as the primary data for this review.

2.3 Data Extraction and Analysis

Data from 20 selected studies were analyzed using thematic analysis. The author categorized the literature into three main thematic clusters to facilitate synthesis:
1. Digital Marketing Cluster (Downstream): Studies discussing e-commerce applications, marketplaces, and digital marketing strategies.
2. Traceability Technology Cluster (Upstream): Studies discussing the design and development of tracking systems (traceability), QR Codes, and digital certification.
3. Strategic Management Cluster: Studies discussing supply chain analysis, added value, and farmer institutional development.

Synthesis was conducted by comparing features, methods, and results across clusters to identify research gaps, which serve as the foundation for the proposed Digital Business Ecosystem (DBE) concept.

3. RESULT AND DISCUSSION

3.1. Literature Synthesis

Based on data extracted from the 20 selected documents, a comprehensive map of the current status of technology in the rice agro-industry supply chain was developed. A summary of the literature is presented in Table 2 below.

Table 2. Literature Synthesis Matrix: Technology in the Agro-industry Supply Chain

No	Author "Title"	Development Methodology	Main Findings/Features	Critical Notes (Gap/Limitation)
A. Digital Marketing & E-Commerce Cluster (Downstream)				
1	**Fadilla [3]** "Design of Solok Rice Marketing System Based on Android Application in West Sumatra"	Android Studio, Waterfall Method	Mobile-based rice sales catalog application to shorten the supply chain.	Features are limited to a store storefront; no data validation features for cultivation or quality (blind trust).
2	**Puspitasari et al. [5]** "Implementation of Digital Marketing Technology to Improve Tiwul Snack Marketing Strategy"	E-commerce Integration, Social Media	Utilization of social media to expand the market reach of processed products.	Heavily dependent on third-party platforms (Instagram/FB); weak customer data ownership.
3	**Rahmat [17]** "Design and Development of Agricultural Provider Management Application (Tanimart) Based on Android"	Android, Firebase, Google Maps API	Geolocation feature (Maps) to track harvest locations and distributor positions.	No mechanism for real-time stock verification at the farmer level (prone to stockouts)
4	**Fryonanda [16]** "Information System Design for Website-Based Agricultural Product Marketing E-Commerce"	Website, Waterfall Method	Web platform to cut out middlemen through direct transactions.	Consumer trust issues regarding fresh product quality (freshness) remain unresolved.
5	**Pendong et al. [8]** "Creation of Agricultural Product E-Commerce Applications Based on Content Management System (CMS)"	CMS OpenCart	Utilization of CMS templates to create agricultural online stores instantly.	Low flexibility; difficult to customize for unique/specific traceability features.
6	**Gaol et al. [20]** "User Interface Design of Agricultural Product Marketing Applications in Humbang Hasundutan Regency"	Prototyping Tools	User-friendly interface design specifically for farmers in rural areas.	Limited to visual design (mockups); does not yet have database functional logic.
7	**Kholili & Hidayatulloh [4]** "Mobile-Based Agricultural Product Sales Transaction Information System"	Mobile App Development	Efficiency in recording buying and selling transactions in the field via mobile phone.	Lacks accommodation for Quality Control (QC) aspects within the application flow.
8	**Saragih et al. [6]** "Utilization of Digital Marketing as a Marketing Medium in Efforts to Increase MSME Export Contributions in the 4.0 Era"	Literature Review	Identification of the role of digital marketing as an absolute requirement to penetrate export markets.	Does not provide a technical solution (system architecture) for implementation.

https://doi.org/10.29165/ajarcde.v10i1.947

No	Author "Title"	Development Methodology	Main Findings/Features	Critical Notes (Gap/Limitation)
9	**Viddiastuti & Winowatan [7]** "Implementation of Digital Marketing in Increasing Sales of Fabil Natural Products"	Qualitative, Observation	Importance of visual content and storytelling in increasing sales conversion.	The study object is not food (skincare); requires contextual adaptation for rice products..
10	**Wirayuda et al. [19]** "Design of Agro-industry Product Marketing Information System Based on Educational Website at Gapoktan Minggirsari Blitar"	Website, User Acceptance Test (UAT)	Integration of e-commerce features with educational modules to improve farmer/consumer literacy.	System scalability for high transaction volumes is unproven; logistics features are not yet detailed.
B. Traceability & Production Management Cluster (Upstream)				
11	**Irsyaputra et al. [9]** "The Development of a Traceability System on Organic Rice Production Chain"	Web-based, QR Code, MVC Architecture	Complete data tracking architecture from land to consumer (land-to-table).	Stand-alone system (Silo); not integrated with payment systems or marketplaces.
12	**Rahardjo et al. [13]** "Analysis and Design of Digital Rice Certification System as a Marketing Tool and to Increase Seed Adoption"	Web-based, RELIEF Algorithm	Digital quality feature selection system for rice seed certification.	The system is quite complex for lay farmers; focus is only on upstream (seeds), not yet for consumption rice.
13	**Sulaiman et al. [10]** "Design and Development of Cocoa Traceability System Based on Web Application and QR Code"	PHP, MySQL, QR Code	Prototype of an affordable and easy-to-adopt upstream-downstream tracking system (QR Code).	Lacks data security features (such as blockchain), so admin data is still prone to manipulation.
14	**Dananjaya [15]** "Design and Development of Agricultural Production Application with Laravel Framework"	Laravel Framework	Detailed real-time recording of cultivation activities (fertilizer, irrigation).	Focuses only on internal use (farm management); no output information for consumers.
15	**Ramilda [12]** "Design and Development of Corn Traceability System Based on Website and QR Code"	Website, QR Code Generator	Validation that QR Code is the most cost-effective technology for bulk commodities.	Still at the laboratory/campus prototype scale; has not been tested in mass markets.
16	**Pratama [11]** "Design of Organic Rice Traceability System Model"	Soft System Methodology (SSM)	Complete supply chain actor map (Farmers, RMU, Distributors) and their information needs.	Still a conceptual model/system design; not yet implemented as finished software.
17	**Alisiya [14]** "Quality Monitoring System and Automatic Price Adjustment Based on Smart Packaging"	IoT, Smart Label, Dynamic Pricing	Innovative automatic quality detection connected to price adjustments.	Per-package implementation costs (unit cost) are likely still high for medium-grade rice.
C. Strategy & Supply Chain Management Cluster				
18	**Saragih et al. [1]** "Rice Product Supply Chain in Cibeber District, Cianjur Regency"	Qualitative Descriptive	Empirical data regarding inefficiencies and price disparities in traditional markets.	Pure field study; does not offer technological intervention solutions.
19	**Pertiwi [18]** "Rice Product Marketing Strategy at PT. Pertani (Persero) Makassar City, South Sulawesi"	SWOT Analysis, IFAS/EFAS Matrix	Formulation of marketing mix strategies (4P) for large-scale rice companies.	Only in the form of managerial strategy analysis; does not produce concrete technological products/systems.
20	**Nofalia [2]** "Development Strategy	Hayami Method (Added	Economic analysis proving that	Focuses on economic aspects; does

No	Author "Title"	Development Methodology	Main Findings/Features	Critical Notes (Gap/Limitation)
	for Rice Agro-industry in Agam Regency"	Value)	processing/branding increases profit margins.	not discuss technical information system specifications.

3.2 Discussion

Based on the data synthesis in Table 2, it is found that the current development of technology in the rice supply chain is still polarized into two separate poles operating independently: the marketing pole (market-oriented) and the technical traceability pole (traceability-oriented).

3.2.1 Dominance of E-Commerce Without Quality Validation (Downstream)

The majority of the literature in Cluster A [3], [16], [4] proposes solutions in the form of marketplace or e-commerce applications. The primary advantage of this approach is its ability to bypass long distribution chains, a longstanding issue in the agro-industry, as identified in studies on rice supply chain inefficiencies [1].

However, a fundamental weakness of these platforms is the lack of a transparent quality-validation mechanism. Consumers are presented only with product photos and prices, with no empirical evidence on seed origin or cultivation processes. This creates a new form of digital asymmetric information. One study attempted to address this by incorporating educational features into the marketing information system; however, it has not yet reached the stage of real-time product data verification [19]. Without validation data, rice e-commerce will merely become an arena for price wars, ultimately disadvantaging farmers of premium-quality rice.

3.2.2 Isolated Traceability Systems (Upstream)

On the other hand, Cluster B shows that the technology needed to ensure rice quality is already available. The architecture for a QR Code-based traceability system developed by Irsyaputra et al. [9], and further refined for other commodities by Sulaiman et al. [10] and Ramilda [12], has proven capable of recording product footprints from land-to-table. Furthermore, Dananjaya has provided a highly detailed on-farm recording module for documenting production activities [15].

However, the implementation of this technology faces significant adoption challenges. These systems tend to be silos (stand-alone) and are not directly connected to the market. Farmers are often reluctant to adopt complex recording systems if there is no direct economic incentive, such as an increase in selling price or easier market access. This is why many traceability projects end as mere pilot projects and do not proceed to a commercial scale.

3.2.3 *Integration Urgency: The Digital Business Ecosystem (DBE) Concept*

The primary gap identified in this review is the disconnection between quality data (from the traceability system) and financial transactions (in the marketplace system). Therefore, this journal proposes a new framework based on the Digital Business Ecosystem (DBE). Unlike a single-purpose application, a DBE is a digital environment that integrates various actors and systems.

In this proposed concept, systems are no longer isolated but instead provide mutual added value:

1. **Data Input (Upstream):** Farmers utilize a production recording module to document fertilizer usage and seed varieties as the primary baseline data [15].
2. **Validation (Processing):** This data is converted into a Traceability QR Code to guarantee transparent product information [9].
3. **Monetization (Downstream):** The QR Code is displayed on the marketplace platform as a "Verified Quality" label to enhance the product's market value [3].
4. **Smart Logistics:** The shipping process is accurately monitored using geolocation features to ensure distribution security [17].

This integration addresses gaps identified in the previous literature: traceability systems gain a viable marketing channel—serving as an incentive for farmers—while marketplace systems gain quality assurance, building consumer trust. Future innovations, such as Smart Packaging, can be integrated into this ecosystem as a premium feature to monitor product quality in real-time for high-end market segments [14]. The proposed Digital Business Ecosystem (DBE) framework is illustrated in Figure 1.

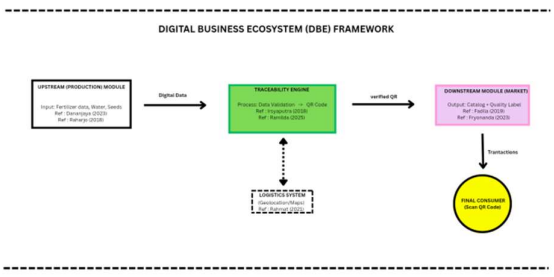

Figure 1. Framework Digital Business Ecosystem (DBE)

3.2.4 Strategic Perspective and Economic Added Value

Beyond technical aspects, the literature review in Cluster C emphasizes that the sustainability of digital systems heavily depends on the resulting economic added value. An analysis of the rice agro-industry in Agam Regency proves that rice products with branding and quality assurance, such as organic or premium rice, yield significantly higher profit margins compared to ordinary bulk rice [2]. This reinforces the urgency of implementing a Digital Business Ecosystem (DBE), where technology serves not merely as a recording tool but as a value creation engine.

Furthermore, supply chain studies highlight inefficiencies in conventional models dominated by intermediaries [1]. With a digital ecosystem, the market structure can be significantly shortened. However, this transformation requires a mature marketing strategy to enable farming businesses to compete with large corporate players [18]. Therefore, the DBE framework proposed in this research must also include a strategic management module that enables farmers or cooperatives to monitor price trends and consumer preferences in real time—a feature achieved through the integration of Smart Packaging and web-based monitoring systems [14].

https://doi.org/10.29165/ajarcde.v10i1.947

Thus, the integration of technology (Clusters A & B) and business strategy (Cluster C) is the primary key to the successful digitalization of the rice supply chain.

4. CONCLUSION AND RECOMMENDATIONS

4.1. Conclusion

From the systematic literature review analyzing 20 studies on the digitalization of the rice agro-industry supply chain, three major conclusions can be drawn:(1) Technological Fragmentation: The rice agroindustry sector is currently developing into two technological silos. The initial group is for marketing digitalization (e-commerce), which can shorten the distribution chain but is poor at validating product quality. The second group is data-driven regarding traceability operations, yet weak at market adoption and economic viability; (2) Integration Needs This has uncovered no business model holistic enough to integrate upstream production management data (on-farm) with downstream market transaction mechanisms. Without this integration, traceability data is nothing but extra work for farmers and ultimately does not create a monetary incentive; (3) Digital Business Ecosystem (DBE) Framework: This study suggests using Digital Business Ecosystem (DBE) as a comprehensive solution. In this ecosystem, high-quality data (certification and cultivation history) is converted into digital assets (QR Codes) that increase the product's market value. Theoretical underpinnings indicate that this approach would enhance consumer trust and provide economic benefits to farmers.

4.2. Recommendations for Future Work

This study is still limited to a literature review and conceptual design. Future studies are suggested to: (1) Create a DBE software prototype that implements a data integration architectural layer between the production and sales modules; (2) Initiate a pilot project to measure farmer acceptance (user acceptance) of the integrated system through field tests, and (3) investigate the application of Blockchain technology in the ecological context to protect traceability data in an unalterable manner.

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