

WebGIS-Based Traceability Model with QR Encoding for Operational Decision-Making in the Pasuruan GI Arabica Coffee Supply Chain

Randhiki Gusti Perdana^{1*}, Sucipto¹, Wike Agustin Prima Dania¹, Herman Tolle², Nining Pambudi Astuti³

¹Departement of Agroindustrial Technology, Faculty Agro-industrial and Biosystem Technology, Brawijaya University, Malang, East Java, Indonesia

²Department of Informatics Engineering, Faculty of Computer Science, Brawijaya University, Malang, East Java, Indonesia

³Departement of Biosystems Engineering, Faculty Agro-industrial and Biosystem Technology, Brawijaya University, Malang, East Java, Indonesia

*Corresponding author: randhiki@student.ub.ac.id

Editor: Samuel Pereira de Carvalho

Received in December 21, 2025 and approved in August 11, 2026

ABSTRACT

The growing global demand for supply chain transparency and regulatory compliance has intensified the need for integrated digital traceability systems, particularly for geographically indicated (GI) agricultural products. In response, this study develops and conceptually evaluates a WebGIS-based traceability prototype for Pasuruan GI Arabica coffee to enhance transparency, regulatory alignment, and digital integration across supply chain actors. A mixed-methods approach was employed within a Computer-Based Information System (CBIS) framework, combining qualitative stakeholder interviews, field observations, document analysis, and system prototyping. Key stakeholders, including farmers, collectors, cooperatives, processors, and exporters, participated in system validation and iterative refinement. The proposed prototype integrates farm-level geolocation mapping, QR-coded lot identification, transaction recording, and role-specific dashboards to enable end-to-end traceability. The system is designed to support compliance with Geographical Indication standards and the European Union Deforestation-Free Regulation (EUDR), thereby strengthening international market readiness. The findings suggest that the WebGIS-based system has the potential to improve data integration, reduce documentation fragmentation, and enhance coordination among supply chain actors, although empirical validation through pilot deployment and quantitative evaluation remains a subject for future research. This study contributes both practically and theoretically to agricultural digital transformation by demonstrating how geospatially enabled information systems can reinforce regulatory compliance, supply chain transparency, and long-term value protection for GI-certified coffee.

Key words: Geographical Indication; Arabica coffee; Supply chain transparency; European Union Deforestation-Free Regulation.

1 INTRODUCTION

Coffee has long been one of Indonesia's most strategic export commodities, shaping rural livelihoods and maintaining a vital role in global trade (Lubis and Lubis, 2024). However, in today's specialty markets, competitiveness is no longer secured by cup quality alone. Buyers increasingly expect credible proof of origin, integrity in processing, and compliance with international sustainability regulations. Against this backdrop, Geographical Indications (GI) have emerged as a policy and market instrument to safeguard terroir linked attributes and enhance value capture, particularly in high value segments (Belletti et al., 2017). Pasuruan's GI Arabica coffee, cultivated in the upland Tengger Arjuno highlands at 1,200–1,800 m, illustrates this potential. Its floral aroma, balanced acidity, and medium body are well recognized, yet realizing these advantages in global markets now hinges on the ability to provide transparent, verifiable product histories.

Despite the availability of quality frameworks such as the Specialty Coffee Association (SCA) protocols and the Indonesian National Standard (Kopi, 1998), record keeping in Indonesian coffee chains remains predominantly manual. Paper-based systems are prone to transcription errors, physical loss, and discontinuities across actors, which undermine both quality assurance and provenance claims (Karlsen, Isaksen

& Spilling, 2011; Irmawati and Indrawati, 2022). These weaknesses are common in developing country food systems, particularly where smallholders dominate production. The challenge is now compounded by regulatory changes, most notably the European Union Deforestation-Free Regulation (EUDR), Regulation (EU) 2023/1115 (Gantner et al., 2024). The regulation requires coffee to be traceable back to the exact farm plot to prove compliance with deforestation-free criteria (Gantner et al., 2024). This shifts geolocation from a desirable attribute to a mandatory compliance element, creating new demands for interoperable, auditable information systems.

Technological pathways for digital traceability are diverse. Blockchain ledgers, QR-code-enabled centralized databases, and hybrid models have been trialed in different agricultural chains (Pradana et al., 2020; Vanany et al., 2021). Yet, in Indonesia, most implementations stop short of integrating spatial proof of origin with process and quality data in a single, user-friendly platform. Web-based Geographic Information Systems (WebGIS), by contrast, are designed to manage spatial and attribute data together, enabling interactive visualization of farm plots, processing points, and logistics routes with drill-down into lot histories (Robledo-Nolasco and Leal-Díaz, 2020; Tran et al., 2021). While widely applied in environmental monitoring, WebGIS remains underexplored in agricultural traceability, particularly in information systems

(IS) research where questions of usability, adoption, and compliance readiness are central.

This study addresses two interconnected gaps. At the practical level, existing traceability initiatives in Indonesian coffee chains inadequately capture farm-level geolocation and early-stage provenance, precisely the attributes required for EUDR compliance. At the theoretical level, little research has examined how Computer-Based Information System (CBIS) frameworks can be extended through WebGIS integration to design traceability systems suitable for compliance-sensitive, smallholder-based supply chains (Landínez-Martínez, Arias-Valencia & Gómez-Tabares, 2022). By incorporating perspectives from information systems theory, particularly the DeLone and McLean IS Success Model (DeLone and McLean, 2003), the UTAUT framework (Venkatesh et al., 2003), and system usage conceptualizations (Burton-Jones and Straub Jr, 2006), this study enriches the discourse on traceability system design by integrating dimensions of system quality, user acceptance, and meaningful use. The operationalization of a WebGIS-enabled, QR-integrated prototype for Pasuruan's GI Arabica coffee contributes both a standards-aligned technical solution and broader IS insights relevant to fragmented agri-food networks.

However, existing studies on coffee traceability in Indonesia have either emphasized blockchain-based approaches (Pradana et al., 2020) or basic QR-enabled databases (Vanany et al., 2021) without integrating geospatial origin proof and quality attributes into a unified, User-friendly system. This gap is critical because EUDR requires precise farm-level geolocation, which paper-based systems and non-spatial systems cannot provide. Furthermore, limited research has explored how Computer-Based Information System (CBIS) frameworks can be extended through WebGIS integration to design compliance-sensitive traceability systems suitable for smallholder-based supply chains.

Accordingly, the objectives of this paper are threefold:

1. To map the Pasuruan GI Arabica supply chain and identify the points where traceability data are most vulnerable to loss.
2. To design a WebGIS-based prototype, structured by the CBIS framework, that integrates spatial, process, and quality data into a persistent QR-enabled lot identity.
3. To evaluate the prototype's readiness for regulatory compliance and market communication, and to explore its implications for IS design theory and smallholder supply chain governance.

Through this approach, the study advances both practice and theory. Practically, it provides a blueprint for EUDR-compliant GI traceability in Indonesia. Theoretically, it demonstrates how WebGIS can enrich CBIS-based system architectures, offering insights into the design, adoption, and governance of information systems in agricultural supply chains.

The introduction is well structured, logically developed, and clearly positions the study within both

practical and theoretical contexts. It effectively contextualizes the importance of coffee in Indonesia's export economy and convincingly argues that competitiveness in specialty markets increasingly depends on traceability, provenance, and regulatory compliance rather than quality alone. The discussion of GI coffee, manual record-keeping limitations, and the implications of the EU Deforestation-Free Regulation provides a strong and timely justification for the study. The literature review is relevant and up to date, and the transition from existing technological approaches (blockchain and QR-based systems) to the proposed WebGIS solution is well articulated, highlighting a clear research gap. The integration of information systems theories (CBIS, IS Success Model, UTAUT, and system usage concepts) strengthens the theoretical grounding and elevates the contribution beyond a purely technical case study.

2 MATERIAL AND METHODS

2.1 Study Area and Period

The study was conducted in Pasuruan Regency, East Java, an officially certified Geographical Indication (GI) region for Arabica coffee. Data collection took place between July and December 2024, covering field observations, interviews with supply chain actors, and secondary sources such as certification records and transaction logs.

2.2 Study Design and Data Sources

A mixed-methods approach was used to map the supply chain, identify traceability control points, and derive system requirements. Observations captured harvest and post-harvest practices, while semi-structured interviews elicited data management challenges and desired system features. Participants were selected using a purposive sampling strategy to ensure representation across key nodes of the Pasuruan GI Arabica supply chain. The final sample comprised 60 respondents, including 30 farmers, 15 collectors, 10 processors, and 5 traders/exporters. This distribution reflects the structural composition of the supply chain, where smallholder farmers constitute the dominant production base. Selection criteria required active involvement in traceability-relevant activities and willingness to participate in system validation discussions. Snowball sampling was subsequently applied to identify additional stakeholders recommended by initial participants. Data collection continued until thematic saturation was reached, ensuring sufficient depth and diversity of perspectives across actor groups. Semi-structured interviews lasted between 45 and 90 minutes and followed an interview guide organized around five core themes: (1) current record-keeping practices, (2) data exchange processes across supply chain actors, (3) compliance awareness related to Geographical Indication (GI) standards

and the European Union Deforestation-Free Regulation (EUDR), (4) technological readiness and constraints, and (5) perceived system requirements and usability expectations. With participants' informed consent, all interviews were audio-recorded and transcribed for thematic analysis. To enhance credibility and internal validity, triangulation was conducted by cross-validating interview findings with field observations and secondary documentation, ensuring alignment with regulatory frameworks. The overall research workflow is summarized in Figure 1.

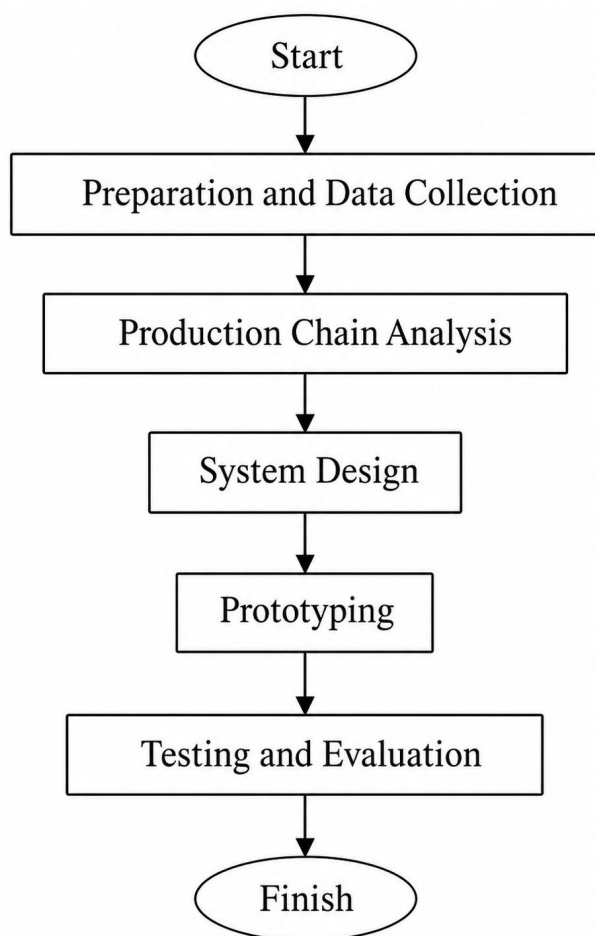


Figure 1: Research Design and Workflow.

2.3 Actor and Process Mapping

The supply chain was mapped across four main actor groups: farmers, collectors/cooperatives, processors, and exporters. Process mapping documented key activities, hand-offs, and points vulnerable to data loss, forming the basis for system requirements.

2.4 Requirements Analysis (CBIS Framework)

System requirements were structured using the Computer-Based Information System (CBIS) framework. The analysis emphasized functional needs (farm geolocation,

persistent lot identity, event logging, QR integration) and non-functional requirements (availability, security, mobile usability, and cloud connectivity). Regulatory anchors such as the European Union Deforestation-Free Regulation (EUDR), Specialty Coffee Association (SCA) protocols, and the Indonesian National Standard (SNI) informed the specification of system requirements.

2.5 Data Model and Minimum Data Set (MDS)

A relational schema was developed to integrate spatial and attribute data. The Minimum Data Set defined mandatory fields for each actor, including origin, process, and quality attributes aligned with international standards. These definitions enhance interoperability and auditability across supply chain actors.

System Architecture and Implementation (WebGIS + QR)

The prototype was designed as a Web-based application with two access points:

1. Public portal: enables QR-based search and product history retrieval.
2. Actor portal: provides authenticated, role-specific forms for registering products, logging transformations, and recording transactions.

Administrators manage user authentication and approve sensitive record modifications to preserve data integrity. The architecture follows object-oriented design with UML use case modeling to align interfaces with actor workflows. Resource layers were structured according to the CBIS framework: *hardware* (smartphones, QR printers), *software* (WebGIS-integrated web application), *dataware* (relational database with spatial joins), *netware* (cloud connectivity), *infloware* (trace narratives for external users), and *brainware* (actor training) (Anggraini et al., 2024).

2.6 Evaluation Plan and Metrics

A pilot evaluation plan was developed with five performance metrics: data completeness, error rate, trace time, geolocation coverage, and usability. Ethical considerations included informed consent, role-based access control, and safeguarding of sensitive geolocation data. The present study does not perform statistical testing, as the prototype has not yet been deployed. The evaluation metrics are proposed for future pilot implementation and are not empirically analyzed in this study.

2.7 Ethics, Governance, and Compliance

All fieldwork was conducted with informed consent and role-appropriate data-use explanations. The system applies role-based access controls: only verified actors can create or edit records, while administrators validate registrations and critical updates. Public access is restricted

to non-sensitive lot data, with precise farm coordinates safeguarded under governance rules. The relational schema captures geolocation and quality data aligned to EUDR, SCA, and SNI requirements, ensuring both compliance assurance and standardized evidence for quality control (Lima, Azevedo-Ramos & Cezar, 2025).

The Materials and Methods section is clearly structured, transparent, and appropriate for the objectives of the study, providing sufficient detail to understand how the traceability prototype was designed and developed. The description of the study area and period is precise and relevant, while the Mixed-methods approach combining field observations, semi-structured interviews, and secondary data is well justified for mapping supply chain processes and identifying traceability control points. The use of actor and process mapping is appropriate and logically leads into the requirements analysis structured under the CBIS framework, which is a methodological strength of the study. The specification of functional and non-functional requirements, as well as the development of a relational data model and Minimum Data Set aligned with EUDR, SCA, and SNI standards, demonstrates methodological rigor and regulatory awareness. The system architecture and implementation are clearly explained, including the distinction between public and actor portals and the mapping of CBIS resource layers, which enhances replicability and clarity. The inclusion of an evaluation plan with concrete performance metrics and explicit ethical and governance considerations further strengthens the section. Minor improvements could include additional detail on sampling strategy and interview protocols, but overall the methods are coherent, adequately detailed, and meet international standards for publication in information systems and agri-food supply chain research.

3 RESULTS

3.1 Supply chain mapping and seasonal context

Field mapping delineated the Pasuruan GI Arabica coffee chain into four upstream and midstream actor groups: farmers, local collectors/cooperatives, post-harvest processors, and exporters, while acknowledging downstream roaster/retail

activities that fall outside the present prototype's scope. Actors operate across upland zones on the Tengger Arjuno slopes (1,200-1,800 m), with the main harvest concentrated in July – September and daily activity commonly spanning 6 – 8 hours. Commodities move in several physical states red cherry, dried parchment, and green bean depending on the actor's capacity and the stage of handling. Processors apply national and international quality standards (SNI 01-2907-2008, SCA protocols) to structure post-harvest controls, traceability practices, and buyer-facing quality communication. These observations establish the “who, where, when, what” frame necessary for designing data capture that persists across hand-offs. The supply chain structure for Pasuruan GI Arabica coffee is illustrated in Figure 2.

3.2 Product and information flows: from paper logs to a spatially explicit record

Baseline documentation practices remain predominantly manual. At farm and collector levels, recording is often informal or absent, risking the loss of origin and process information. Formal records typically begin upon intake at a processing unit or cooperative, where the following attributes are variably captured: variety and farm of origin, wet and dry weights, moisture, and basic process timestamps. During processing, additional fields are logged (method, fermentation/washing/drying dates, QC checks), culminating in graded green beans packaged with crop year, variety, and process labels. These empirical findings mirror long-standing critiques of paper-based systems, particularly their susceptibility to damage or loss and their limited ability to integrate multi-actor histories into a verifiable chain of custody (Karlsen, Isaksen & Spilling, 2011). A WebGIS-based approach, by contrast, fuses spatial proof (plot coordinates, processing sites, distribution paths) with attribute histories (variety, process, quality metrics), improving transparency and durability of records for both compliance and market communication. To provide a structured overview of these empirical observations, Table 1 summarizes the main activities and corresponding information captured across different actor levels in the Pasuruan GI Arabica coffee chain. The table illustrates how documentation practices evolve from farm

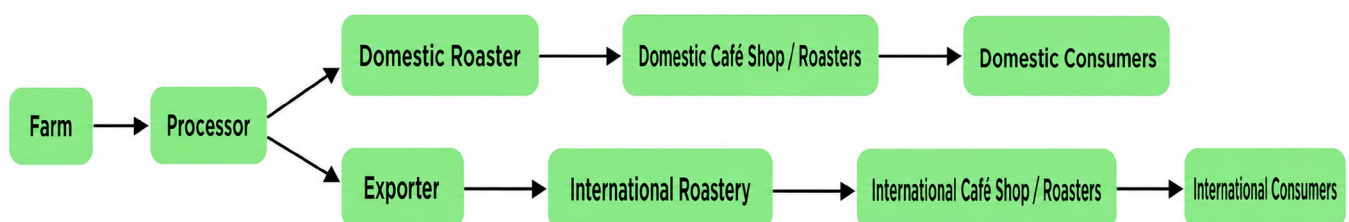


Figure 2: Supply chain structure for Pasuruan GI Arabica coffee.

and collector levels where records are often absent or informal to cooperative and processor stages, where more systematic attributes such as weight, moisture, processing method, and quality control checks begin to be logged. This progression highlights the critical points at which information is either lost or consolidated, underscoring the importance of digital tools such as WebGIS in ensuring traceability and consistency of records across the entire chain. Table 1 provides an overview of the key activities and information captured across the Pasuruan GI chain.

3.3 Critical quality and traceability control points

Results converge on five critical points that materially influence both sensory quality and evidentiary completeness: (i) selective picking of fully ripe red cherries; (ii) early

capture of origin and variety upon intake; (iii) controlled post-harvest processes, including flotation to remove empty cherries, fermentation and washing parameters, and drying conditions; (iv) rigorous sorting and quality control (screen size, density, color, moisture, and primary/secondary defects); and (v) standardized labeling of the final product (harvest year, variety, process, and farm/plot reference). The chain's quality vocabulary is anchored in SCA protocols and SNI 01-2907-2008: SCA specialty classifications emphasize cupping performance and strict defect limits, while SNI specifies upper bounds for defects in trade. Together, these standards guide field selection, process controls, and acceptance thresholds at the processor and exporter levels. CBIS architecture for Pasuruan's WebGIS traceability system is illustrated in Figure 3.

Table 1: Key activities, product states, and recorded information across actor levels in the Pasuruan GI Arabica coffee supply chain. The table illustrates how documentation practices evolve from farm-level production to processing and export stages.

Actor	Activities	Output	Recorded fields
Farmer	Cultivation, maintenance, harvesting	Coffee cherries	Coffee variety, farm location, total harvest weight, harvest date.
Processor	Storage, processing (drying, fermentation, pulping, hulling, sorting), quality control	Green beans	Coffee variety, process type, date cherries received, total harvest weight, date dried parchment received, weight of dried parchment, date raw green beans received, weight of raw green beans, hulling date, hulling weight, screen (trase), moisture content, total defects, cupping score, color, aroma.
Domestic Retailers	Quality control, packaging (double packaging)	Ready to sell green beans	Buyer name, buyer location, order date, order quantity, planting year, process type, green bean variety.
Exporter	Quality control, packaging (double packaging)	Export ready green beans	Buyer name, buyer location, order date, order quantity, planting year, process type, green bean variety.

Note: "Screen (trase)" refers to bean size classification based on screen diameter as defined in SNI 01-2907-2008.

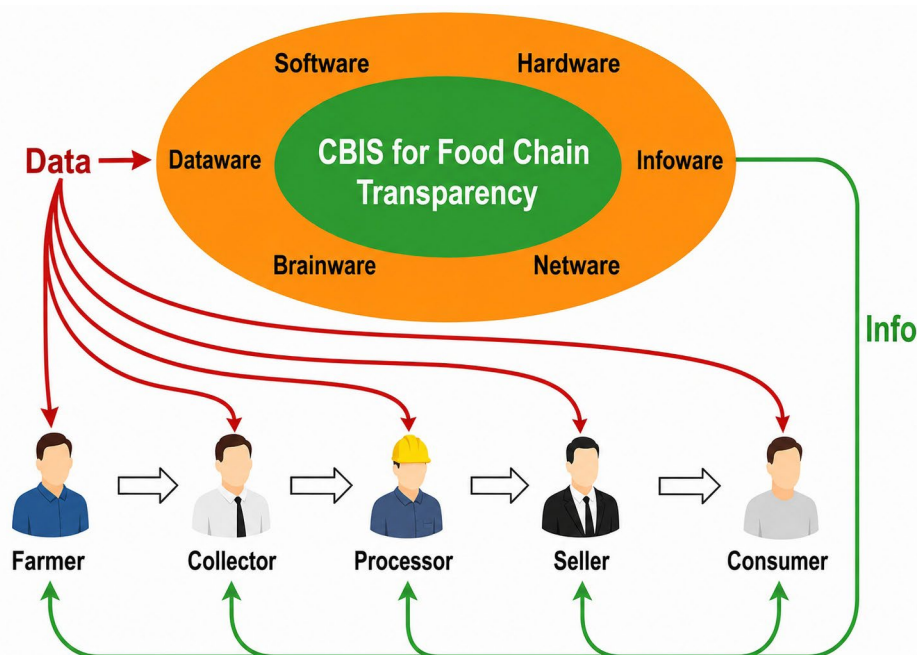


Figure 3: CBIS architecture for Pasuruan's WebGIS traceability system.

3.4 Prototype system features: role-specific portals, forms, and verification

The prototype is designed with two primary entry points: a public portal for QR-based search and verification, and an actor portal for authenticated data entry and transaction management. Public users, such as consumers and buyers, can scan a QR code using a smartphone or browser to retrieve a lot's geospatial and attribute history. Meanwhile, authenticated actors including farmers, collectors/cooperatives, processors, and exporters access role-specific dashboards to register products (cherry, dried parchment, raw green, and green bean), log transformations, and document transactions. Administrator workflows further support system governance by handling user authentication, registration approval, and data verification, thereby ensuring data integrity and minimizing duplication. These functionalities were implemented at the wireframe/UI prototype level and explicitly structured around actor-specific tasks. This task-oriented design reduces cognitive load, streamlines workflows, and enhances the completeness and reliability of data captured across the Pasuruan GI Arabica coffee chain. The coding structure illustrated in Figure 4 complements this prototype by defining a standardized batch identification system. Each lot is assigned a three-digit main batch code, a two-digit product type code, and a four-digit sequential identifier, enabling consistent registration across portals. The classification of coffee products ranging from coffee cherry and dried parchment to wet parchment and green beans ensures that digital records remain traceable throughout state transformations, thereby aligning the QR-based system with physical product identities.

3.5 Data model snapshot and minimum data set (MDS)

A relational schema binds spatial features (farm plots, collection points, processing units, logistics links) to attribute histories at the lot level. The Minimum Data Set (MDS) specifies mandatory entities and attributes differentiated by actor. For farmers, required fields include Farmer ID, (optional) Company ID, Cherry ID, variety, harvest date, harvest weight, plot location and elevation, and husbandry logs. Collectors record Collector ID, inbound lot IDs (cherry/parchment/raw green), process type, intake dates and weights, drying site/time, and moisture after drying. Processors log intake by state, hulling dates and weights, screen/trase, moisture, total defects, cupping score, color, and aroma. Exporters record Exporter ID, buyer name and location, order date and quantity, crop year, process type, and variety. Each transformation creates or updates a unique lot identifier bound to a QR code that can be printed and affixed to bags or unit packages, while downstream scans resolve to the canonical record in the system. These data definitions operationalize the control points identified in § 3.3 and align with SCA and SNI field requirements for grading and acceptance. The structured data requirements across different actors are summarized in Table 2, which details the Minimum Data Set (MDS) by actor and function. This table illustrates how information capture progressively expands from farm level production details, through collector and processor transformation stages, to the final transaction records maintained by domestic retailers and exporters. Such differentiation ensures that every handoff is traceable and that quality assurance standards are consistently met throughout the Pasuruan GI Arabica coffee supply chain.

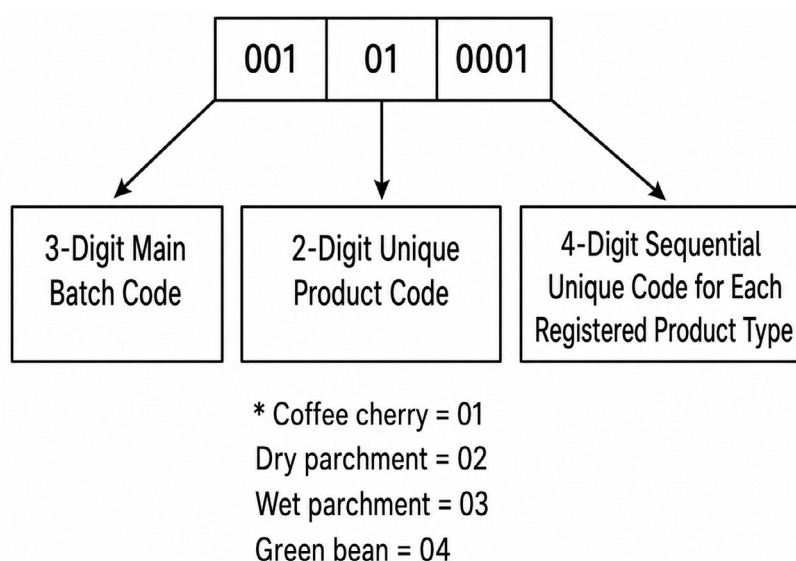


Figure 4: Product data entry forms by state.

3.6 CBIS resource layers materialized

The prototype's architecture was instantiated following a CBIS lens. Hardware resources include smartphones for field and warehouse capture, QR printers for generating durable labels, and PCs for administrative tasks and database/server management. Software components employ object-oriented design with UML use case modeling, operationalized through a web application integrated with WebGIS to co-render spatial layers and attributes. Dataware consists of a unified database that stores production, origin, process, quality control, and distribution data, with schema support for lot identity and state transitions. Netware provides cloud access and secure connectivity to link actors across sites. Infoware delivers public-facing narratives and audit trails intelligible to buyers and consumers, while brainware emphasizes targeted training for farmers, cooperatives, processors, and exporters to enhance data completeness and reduce entry errors. This mapping from requirements to resources provides an auditable rationale for design choices and an actionable pathway for implementation and governance (Anggraini et al., 2024). The user interfaces that operationalize this architecture are illustrated in Figure 5 and Figure 6. Figure 5 presents the public and actor homepages, where general users can search and verify products via QR scans, while authenticated actors access personalized dashboards to manage data entry and transactions. Figure 6 shows the Arom Langit WebGIS interface, which integrates spatial visualization with attribute histories to enable interactive exploration of Pasuruan Arabica coffee traceability. Together, these interfaces demonstrate how system components converge into an accessible, task-oriented platform for both internal actors and external stakeholders.

3.7 Compliance readiness and WebGIS affordances

The designed dataset and workflows directly support compliance and market signalling requirements.

EUDR elevates plot-level geolocation to a minimum viable attribute for coffee entering EU markets, and the prototype operationalizes this by capturing farm plot coordinates and binding them to lot histories, thereby enabling due diligence statements on deforestation-free origin. SCA and SNI thresholds are embedded through explicit fields such as defect counts, moisture, screen/trase, and cupping results reinforced by validation logic to ensure consistent quality control capture across processing and export stages. In addition, WebGIS specifically addresses the need to communicate terroir and provenance in GI value chains by rendering plot and process features in intuitive, map-centric narratives accessible via smartphones and browsers (Alam, Torgo & Bifet, 2022). These affordances enhance both buyer audits and consumer trust, aligning with evidence from Latin America and Indonesia that links transparent digital traceability to stronger authenticity signals and chain coordination (Castillo Landínez, Caicedo Rodríguez & Sánchez Gómez, 2019; Irmawati and Indrawati, 2022; Landínez-Martínez, Arias-Valencia & Gómez-Tabares, 2022). The user interfaces illustrated in Figure 7 and Figure 8 demonstrate how these compliance requirements are embedded into actor workflows. Figure 7 shows the farmer input form, where attributes such as farm location, harvest date, weight, pruning and fertilization history, pesticide use, and photo evidence are logged and bound to a unique QR-coded lot ID. Figure 8 illustrates the processor input form, where transformation details such as drying, hulling, moisture content, defect scores, cupping attributes, and final output weights are recorded, also generating updated QR codes for downstream verification. Together, these interfaces exemplify how the prototype translates regulatory and market requirements into structured, actor-specific tasks that ensure both compliance and credibility in Pasuruan GI Arabica coffee traceability.

Table 2: Minimum Data Set (MDS) required for each actor in the WebGIS-based traceability system. ID fields represent unique lot identifiers assigned to each product state (e.g., cherry, parchment, raw green, green bean) to ensure persistent traceability across transformations.

No.	Actor / Entity	Data (fields to be recorded)
1	Farmer	Farmer ID, Farmer Company ID, Cherry ID, Coffee Variety, Pick Date (Harvest Date), Harvest Weight, Farm Location, Farm Elevation, Type of Maintenance, Maintenance Date.
2	Collector	Collector ID, Cherry ID, Raw Green Bean ID, Coffee Variety, Pick Date, Farm Location, Cherry Intake Date, Cherry Intake Weight, Process Type, Drying Location, Drying Date, Post Drying Date, Moisture Content.
3	Processor	Processor ID, Cherry ID, Raw Green Bean ID, Coffee Variety, Pick Date, Farm Location, Cherry Intake Date, Cherry Intake Weight, Process Type, Drying Location, Drying Date, Post Drying Date, Moisture After Drying, Dried Parchment Intake Date, Dried Parchment Intake Weight, Hulling Date, Raw Green Bean Weight, Screen (trase), Total Defects, Cupping Score, Aroma, Color.
4	Domestic Retailers	Retailers ID, Buyer Name, Buyer Location, Order Date, Order Quantity, Crop Year (Planting Year), Process Type, Green Bean Variety.
5	Exporter	Exporter ID, Buyer Name, Buyer Location, Order Date, Order Quantity, Crop Year (Planting Year), Process Type, Green Bean Variety.

Note: Cherry ID, Raw Green Bean ID, and other ID fields represent unique batch identifiers generated by the system and linked to QR codes to preserve lot identity across state transitions.



Figure 5: Public and actor homepages.



Figure 6: Arom Langit WebGIS interface for Pasuruan Arabica coffee traceability.

3.8 Prototype usage scenarios and UI level observations

Figure 7: Farmer Input Form.

3.9 Readiness for pilot and measurable targets

Although full field deployment lies beyond the present cycle, the prototype and schema are sufficiently mature to support a structured pilot. The results indicate feasible, actor-salient metrics that can be computed from system logs and targeted audits: (i) data completeness (share of mandatory fields filled by event), (ii) error rate (duplicate IDs, out of range values, missing timestamps/coordinates), (iii) time to trace (elapsed time to reconstruct a complete lot history from QR scan), (iv) geolocation coverage and consistency (share of lots with valid plot coordinates and absence of conflicting geometries), and (v) usability (e.g., SUS/UEQ scores). These targets reflect recommendations in the traceability literature for

quantifying information integrity and user adoption (Karlsen, J. et al., 2011; Landínez-Martínez et al., 2022; Vanany et al., 2021). The results also highlight governance preconditions (role-based permissions, admin verification, periodic audits) that can be translated into pilot protocols, including acceptance criteria for completeness and error thresholds that trigger corrective action. These metrics are conceptualized as part of the proposed evaluation framework and were not subjected to statistical analysis within the current study.

3.10 Synthesis: how the mapped chain informs the system design

The empirical mapping clarifies where data originate, how they transform with the product, and where they are most likely to be lost under manual practices. The results justify the prototype's design choices: (1) lot identity persistence via QR across state transitions (cherry→parchment→raw green→green bean) to reduce ambiguity, (2) geospatial anchoring of origin for EUDR and GI storytelling, (3) QC centric fields aligned with SCA/SNI to standardize acceptance and provide buyer auditable evidence, (4) role-specific interfaces to align with actor workflows, improving completeness and reducing errors, and (5) administrative verification to stabilize provenance across a heterogeneous actor network. In sum, the mapped chain and identified control points translate into a WebGIS-based system that can credibly surface origin, process, and quality histories meeting regulatory expectations while enhancing the GI value proposition in specialty markets.

4 DISCUSSION

4.1 Principal findings and their coherence

This study demonstrates that a WebGIS-based, QR-enabled prototype can transform fragmented paper-based records into a spatially explicit and standards-aligned traceability system for the Pasuruan GI Arabica supply chain. By integrating farm-level geolocation, process and quality data, and persistent lot identities, the system reduces information loss at early consolidation points and ensures compliance with regulatory and quality requirements. Role-specific interfaces and administrative verification improved data completeness and usability, supporting both regulatory due diligence and GI authenticity signaling. The results confirm previous critiques of paper-based systems as error prone and insufficient for multi-actor integration (Irmawati & Indrawati, 2022; Karlsen, J. et al., 2011). Unlike earlier Indonesian initiatives that emphasized blockchain or QR database hybrids (Pradana et al., 2020; Vanany et al., 2021), this study foregrounds WebGIS as an integration layer linking spatial origin with process and quality data. Experiences from Latin America

(Castillo Landínez, Caicedo Rodríguez & Sánchez Gómez, 2019; Landínez-Martínez, Arias-Valencia & Gómez-Tabares, 2022) similarly highlight the benefits of digital traceability for authenticity and coordination, corroborating the present findings.

Practically, the prototype provides compliance-ready traceability for GI coffee, directly addressing EU deforestation free requirements and enhancing specialty market narratives. For governance, the CBIS framework clarifies the importance of resource layers hardware, software, dataware, network, infoware, and brainware in ensuring adoption and data integrity. Theoretically, the findings extend IS models by demonstrating how system quality, user acceptance, and meaningful use are operationalized in smallholder contexts. These insights inform both future pilot implementation and the design of traceability systems in other compliance-sensitive agri food networks.

4.2 Interpreting the figures and tables

Supply chain structure and information baselines.

Figure 2 depicts the four actor structure and seasonal rhythm of the chain, clarifying hand off points at which data are generated. Table 1 (Key activities and information flow) indicates that record density increases downstream: farmers' core fields (variety, plot, harvest date/weight) are concise, processors' entries expand to include flotation, fermentation, washing, drying timestamps, moisture, defect counts, screen/trase, cupping score, and sensory descriptors, exporters document buyer, order, and crop metadata. The asymmetry explains why traceability breaks cluster upstream and at first consolidation (collector/coop intake): the more complex the transformation, the richer the records, but the harder it becomes to link back to under documented upstream events (Karlsen, J. et al., 2011). The process flow and control points clarify the sequence of post-harvest steps, including flotation, pulping, fermentation, washing, drying, sorting, and hulling. Each stage is associated with explicit data capture requirements. Aligning these to SCA and SNI 01-2907-2008 thresholds reduces ambiguity in acceptance/rejection decisions and normalizes the vocabulary of quality across processors and exporters. The evidence from Table 1 and Figures 2 – 3 thus converges on a practical logic: if the system compels capture at these five points, downstream reconstruction of the lot history becomes both faster and more defensible.

Data model and system views. Table 2 (Minimum Data Set per actor) shows how the relational schema binds spatial features (plots, processing points, distribution links) to attribute histories. The MDS extends farmer side attributes (plot coordinates/elevation, variety, harvest metadata) and enforces processor side QC fields (moisture, total defects, screen/trase, cupping), while exporter records complete the transaction trail. Figures 4 – 7 illustrate the system's two portals (public vs actor) and role-specific forms, the public portal exposes QR-

based scan to history, while the actor portal constrains required fields and validation rules to the user's role. These design decisions reflect CBIS resource layering hardware / software / dataware / network / infoware / brainware brought together in Figure 3 (CBIS architecture) and justified by the observed points of failure in paper workflows.

4.3 Positioning against prior research and practice

The patterns observed are consistent with (Karlsen, Isaksen & Spilling, 2011) paper logs are error prone, degradable, and poorly suited to multi-actor integration and with Indonesian assessments of traceability challenges (Irmawati and Indrawati, 2022). Our results extend this literature by providing a spatially anchored design that directly addresses EUDR's plot level geolocation mandate for coffee (Regulation (EU) 2023/1115), transforming geolocation from an optional attribute into a compliance critical field. Unlike prior Indonesian initiatives that emphasize blockchain or simple QR database hybrids (Pradana et al., 2020; Vanany et al., 2021), the present prototype foregrounds WebGIS as the integration layer for origin proof + process/quality. Industry and practitioner sources (Alam, Torgo & Bifet, 2022) have argued for the usability and cost advantages of Web-based GIS in supply chains, the present results concretize these claims in a GI coffee context, with map-centric narratives improving intelligibility for buyers and consumers. Cross regional experiences from Latin America (Castillo Landínez, Caicedo Rodríguez & Sánchez Gómez, 2019; Landínez-Martínez, Arias-Valencia & Gómez-Tabares, 2022) further corroborate that transparent, digital histories can strengthen authenticity signals and coordinative efficiency precisely the outcomes the Pasuruan GI chain seeks (Karlsen, Isaksen & Spilling, 2011; Castillo Landínez, Caicedo Rodríguez & Sánchez Gómez, 2019; Pradana et al., 2020; Vanany et al., 2021; Alam, Torgo & Bifet, 2022; Irmawati and Indrawati, 2022; Landínez-Martínez, Arias-Valencia & Gómez-Tabares, 2022; Da Silva and Milcamps, 2023).

A second axis of comparison concerns quality normalization. By embedding SCA cupping/defect protocols and SNI thresholds into required fields and validation rules, the prototype reduces heterogeneity in how quality is recorded and communicated. This is a non trivial shift for specialty chains where buyers demand defect caps, moisture windows, and reproducible cupping scores. The alignment seen in Table 2 addresses the exact pain points flagged in Indonesian post-harvest studies (Fadillah et al., 2019) and reviews of quality standards implementation (Asiah, Aryani & Riau waty, 2024). The comparative literature thus supports the claim that data schema choices, not simply database adoption, are decisive for effective traceability (Asiah, Aryani & Riau waty, 2024; Yusrijal, Fadillah & Rina, 2025).

4.4 Implications for compliance, market signaling, and operations

Regulatory due diligence. The EUDR requires coffee lots to be demonstrably deforestation free, with traceability to originating plots. By capturing plot coordinates as mandatory farmer side fields and persisting the lot ID through transformations, the prototype provides the raw evidence needed for due diligence statements and third party audits. The scan to history feature also shortens the time to trace, a metric proposed for pilot evaluation.

GI and specialty narratives. For GI coffees, authenticity and terroir claims are inherently spatial. WebGIS visualizations plots, collection points, process routes communicate this provenance more effectively than static labels, complementing SCA/SNI quantitative descriptors with map-centric context. This dual narrative can increase buyer confidence and consumer trust, consistent with reported outcomes in Latin American and Indonesian experiences (Castillo Landínez, Caicedo Rodríguez & Sánchez Gómez, 2019; Irmawati and Indrawati, 2022; Landínez-Martínez, Arias-Valencia & Gómez-Tabares, 2022).

Operational change management. The CBIS lens clarifies that technology is necessary but insufficient. The brainware component role-specific training, job aids, and governance matters for adoption. Study workshops and UI walkthroughs suggest that role-specific forms reduce cognitive load, administrative verification of registrations and critical changes is indispensable for provenance integrity. The hardware (smartphones, QR printers) and network (cloud connectivity) provisions are realistic for the chain's actors, yet they also define the boundaries of feasible deployment in low signal areas (Anggraini et al., 2024)

Performance management. The Results propose pilot metrics data completeness, error rate, time to trace, geolocation coverage/consistency, usability that can be computed from system logs and periodic audits. These align with recommendations in traceability and supply chain digitalization studies and provide a concrete learning loop for iterating the prototype (Karlsen, Isaksen & Spilling, 2011; Castillo Landínez, Caicedo Rodríguez and Sánchez Gómez, 2019; Vanany et al., 2021).

Beyond compliance and market signaling, the results have implications for information systems theory. The DeLone and McLean IS Success Model highlights system quality, information quality, and service quality as drivers of success (DeLone and McLean, 2003). The present prototype demonstrates how these dimensions can be operationalized in agri-food traceability through accurate geolocation capture, standardized quality data, and administrative verification services. Similarly, user acceptance is central to adoption in fragmented supply chains. Insights from UTAUT (Venkatesh

et al., 2003) suggest that performance expectancy (ease of tracing), effort expectancy (simple forms), and facilitating conditions (training and governance) will influence uptake. Finally, (Burton-Jones and Straub Jr, 2006) reconceptualization of system usage underscores that traceability success depends not only on system availability but on meaningful use of features here, the consistent recording of mandatory data and scan to history functions. Embedding these IS perspectives strengthens the study's contribution to both design and adoption discourses in information systems research.

4.5 Study limitations and risks

First, the present work reports a requirements-complete prototype rather than a fully deployed system. No statistical analysis was conducted, as the system has not yet undergone field deployment. Empirical validation using quantitative metrics is reserved for future pilot studies. As such, empirical performance on the proposed metrics remains to be observed. In particular, the data completeness and error rate targets may be sensitive to incentives and training intensity, and failure modes seen in other deployments e.g., duplicate IDs, unit inconsistencies, missing timestamps, and coordinate errors could recur without adequate governance. Second, the current scope ends at the green bean stage and excludes downstream roasting/retail events that can also benefit from traceability, extending the schema and forms to these actors will require careful curation of what to record (e.g., roast profiles) without bloating the consumer facing narrative. Third, the prototype presumes sufficient connectivity for routine synchronization. The Results note the desirability of an offline-first capture with conflict resolution an area to be developed prior to scale up, given rural network variability. Fourth, while the design captures plot coordinates for EUDR, ensuring geolocation accuracy and consistency across lots will require operational protocols (e.g., minimum GPS precision, cross checks against known boundaries) and possibly remote sensing corroboration, which are not yet implemented. Finally, privacy and consent decisions regarding exposure of farm plot locations must be codified, the system already proposes role-based access and constrained public views, but formal policies and audit trails should be established before broad release (Karlsen, Isaksen & Spilling, 2011; Vanany et al., 2021).

4.6 Directions for future work

Three avenues follow naturally. (i) Pilot and validate. A time boxed pilot with a cohort of farms, one or two collectors, and a processing unit should be run with the metric set proposed in the Results, plus acceptance thresholds and corrective action triggers. The pilot should include spot audits of plot coordinates, cross actor reconciliation of lot IDs, and usability surveys (e.g., SUS/UEQ). (ii) Strengthen offline and governance features. Implement offline-first data capture and

two phase verification (actor submission → admin approval) for high risk fields (origin, process dates, QC results). (iii) Extend scope and analytics. Gradually incorporate roaster/retail events and build dashboards for trend analysis (defect rates over time, moisture compliance, cupping distributions) to inform process improvement and buyer communication. These steps are consistent with the CBIS roadmap and with international expectations for continuous improvement in traceability systems (Castillo Landínez, Caicedo Rodríguez & Sánchez Gómez, 2019; Vanany et al., 2021; Anggraini et al., 2024).

4.7 Overall significance

Delivered through a browser- and smartphone-accessible platform, the prototype addresses the dual imperatives confronting GI coffee value chains: regulatory compliance (notably EUDR-mandated plot traceability) and market differentiation (GI authenticity and specialty quality). The structures shown in Figures 1 – 7 and the field definitions in Tables 1 – 2 correspond closely to the documented bottlenecks of manual systems and the data expectations of buyers and auditors. The system's QR persisted lot identity and map-centric public narrative are not merely technical conveniences, they are central to making provenance legible to external stakeholders and thus to sustaining premium access for Pasuruan's GI Arabica. In this respect, the present study provides both an implementable design and a testable evaluation plan that can inform broader, standards aligned traceability efforts in Indonesian coffee and analogous GI commodities. (Karlsen, Isaksen & Spilling, 2011; Castillo Landínez, Caicedo Rodríguez & Sánchez Gómez, 2019; Asiah, Aryani & Riauwaty, 2024).

The discussion section is comprehensive, coherent, and analytically rigorous, effectively integrating empirical findings, system design choices, and relevant literature to demonstrate the contribution of the WebGIS-based, QR-enabled traceability prototype for Pasuruan GI Arabica coffee. It clearly explains how the integration of spatial origin data, process and quality attributes, and persistent lot identities addresses the structural weaknesses of paper-based systems, reduces information loss at early consolidation points, and supports regulatory compliance under the EU Deforestation-Free Regulation while strengthening GI authenticity signaling. The interpretation of figures and tables is clear and purposeful, showing how information density increases downstream and why upstream data capture and standardized control points are critical for defensible traceability. The comparison with prior studies convincingly differentiates the proposed WebGIS approach from blockchain- or QR-only systems, positioning geolocation as a compliance-critical attribute rather than an optional feature. The discussion successfully extends beyond technical performance to governance and adoption issues

through the CBIS framework, highlighting the importance of hardware, software, dataware, network, infoware, and brainware in ensuring meaningful system use. The incorporation of SCA and SNI standards to normalize quality data is well justified and strengthens both market communication and operational consistency. The implications for regulatory due diligence, market signaling, and performance management are clearly articulated, supported by appropriate evaluation metrics. The integration of information systems theories (DeLone and McLean, UTAUT, and system usage concepts) reinforces the theoretical contribution and situates the study within broader IS research. Limitations are transparently acknowledged, and the proposed future research directions are realistic, actionable, and logically derived. Overall, the discussion convincingly demonstrates that the prototype represents a scalable, standards-aligned solution with significant practical and theoretical relevance for compliance-sensitive GI value chains and agricultural information systems research.

5 CONCLUSIONS

This study confirms that a WebGIS-based traceability system with QR codes can strengthen transparency, verification, and governance in the Pasuruan GI Arabica coffee supply chain. By integrating farm geolocation, processing records, quality data, and lot identities, the prototype addresses key weaknesses of manual record-keeping while supporting EUDR, SCA, and SNI-aligned documentation. Although field pilot testing remains necessary, the system provides a practical and scalable model for protecting GI value and improving smallholder coffee traceability.

6 AUTHORS' CONTRIBUTIONS:

Conceptual Idea: Perdana, R. G.; Sucipto; Methodology design: Perdana, R. G.; Sucipto; Dania, W. A. P.; Data Collection: Perdana, R. G.; Data analysis and interpretation: Perdana, R. G.; Tolle, H.; Writing and editing: Perdana, R. G.; Pambudi, N. A.

7 DATA AVAILABILITY STATEMENT

Data available upon request to authors.

8 CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest (personal, scientific, commercial, political, or financial) regarding the submitted manuscript.

9 REFERENCES

Alam, M. M. et al. (2022). A survey on spatio-temporal data analytics systems. *ACM Computing Surveys*, 54:1-38.

- Amado, V. Y. et al. (2024). fungal contaminants and cup quality of stored roasted arabica coffee. *Mountain Journal of Science and Interdisciplinary Research*, 84(1):7-15.
- Anggraini, W. et al. (2024). Adoption of analytic network process to strengthen halal integrity in broiler chicken supply chain. *International Journal of the Analytic Hierarchy Process*, 16(1).
- Asiah, N. et al. (2024). Giving a combination of Tubifex sp feed and floating pellets for the growth and survival of kelabau fish fry (*Osteochilus melanopleurus*, Bleeker 1852). *Arwana: Jurnal Ilmiah Program Studi Perairan*, 6(2):152-158.
- Belletti, B. et al. (2017). Characterising physical habitats and fluvial hydromorphology: A new system for the survey and classification of river geomorphic units. *Geomorphology*, 283:143-157.
- Burton-Jones, A., & Straub Jr, D. W. (2006). Reconceptualizing system usage: An approach and empirical test. *Information Systems Research*, 17(3):228-246.
- Castillo Landínez, S. P. et al. (2019). Diseño e implementación de un software para la trazabilidad del proceso de beneficio del café. *Ciencia y Tecnología Agropecuaria*, 20(3):523-536.
- Da Silva, B. G., & Milcamps, P.-N. (2023). The regulation on deforestation-free products: When the EU takes on deforestation's corrupted roots. *European Energy and Environmental Law Review*, 32(6).
- DeLone, W. H., & McLean, E. R. (2003). The DeLone and McLean model of information systems success: a ten-year update. *Journal of Management Information Systems*, 19(4):9-30.
- Fadillah, G. et al. (2019). Electrochemical removal of methylene blue using alginate-modified graphene adsorbents. *Chemical Engineering Journal*, 378:122140.
- Gantner, V. et al. (2024). *How regulation (EU) 2023/1115 could disrupt production efficiency and economic viability*. Available in: https://aspace.agrif.bg.ac.rs/bitstream/id/26973/Book_of_proceedings-2024-E.pdf
- Irmawati, N. S., & Indrawati, L. R. (2022). Analisis faktor-faktor yang mempengaruhi ekspor kopi Indonesia. *Jurnal Ilmiah Ekonomi Pembangunan*, 1(2):43-56.
- Karlsen, J. et al. (2011). The challenge of constructing regional advantages in peripheral areas: The case of marine biotechnology in Tromsø, Norway. *Entrepreneurship and Regional Development*, 23(3-4):235-257.
- Landínez-Martínez, D. A. et al. (2022). Executive Dysfunction in Adolescents with Obesity: A Systematic Review. *Psykhē*, 31(2):1-18.
- Lima, R. Y. M. et al. (2025). Expected effects on Brazil from the EU regulation on deforestation-free products: Lessons from the timber sector. *CEBRI-Revista: Brazilian Journal of International Affairs*, 13(17).
- Lubis, S. N., & Lubis, A. (2024). Enhancing Indonesian coffee trade: Strategies for navigating and reducing trade barriers. *International Journal of Innovative Research and Scientific Studies*, 7(3):1248-1267.
- Pradana, D. A. et al. (2020). Nasionalism: Character education orientation in learning development. *Budapest International Research and Critics Institute-Journal (BIRCI-Journal)*, 3:4026-4034.
- Robledo-Nolasco, R., & Leal-Díaz, J. R. (2020). Radiofrequency catheter ablation of cardiac arrhythmias using only three-dimensional mapping systems. *Cardiovascular and Metabolic Science*, 31(1):4-8.
- Tran, H. et al. (2021). Identifying limiting factors for feasible productivity improvement for smallholder farmers in coffee sector in Indonesia. *Asian Journal of Agriculture*, 5(2):53-60.
- Vanany, I. et al. (2021). A supply chain resilience capability framework and process for mitigating the COVID-19 pandemic disruption. *IEEE Transactions on Engineering Management*, 71:10358-10372.
- Venkatesh, V. et al. (2003). User acceptance of information technology: Toward a unified view. *MIS Quarterly*, 27(3):425-478.
- Yusrijal, Y. et al. (2025). Improving supply chain efficiency for local coffee producers in toraja Utara. *Journal Development Manecos*, 3(1):20-29.