Advancing Transparency and Traceability in Agricultural Supply Chains Through Blockchain and IoT Technologies: A Critical Review

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***Abstract*—Agricultural supply chains require traceable records and reliable monitoring from production to distribution, yet fragmented information, inconsistent data capture and limited coordination undermine product visibility, food safety and accountability. Blockchain and the Internet of Things (IoT) offer complementary capabilities, but their integration does not automatically produce a practical traceability system. Connectivity gaps, incompatible platforms, data reliability, implementation costs and limited field validation constrain adoption.**

This review examines research published between 2023 and 2026 on digital traceability in agricultural and agri-food supply chains. It compares proposed systems and reported implementations across the data pathway: sensor-based monitoring and communication; edge and fog processing; blockchain platforms, consensus mechanisms and smart contracts; on-chain and off-chain storage; and QR/e-labelling-based access to product records. It also considers network dependence and offline support, performance, energy requirements, cost, privacy, scalability, interoperability and validation maturity.

The findings show that IoT enables condition monitoring and data capture, while blockchain can strengthen shared verification and record accountability. Hybrid storage and batch-level digital identification recur as ways to balance accessible information with verifiable records. However, intermittent internet access, sensor and input-data reliability, fragmented standards, transaction and infrastructure costs, stakeholder coordination and limited large-scale deployment remain persistent concerns. The review contributes a deployment-oriented, cross-layer synthesis linking architectural choices to traceability functions, connectivity resilience, evaluation evidence and adoption constraints. By distinguishing demonstrated capabilities from proposed benefits, it identifies the technical and operational conditions future systems must address to deliver dependable, affordable farm-to-fork traceability.

I. INTRODUCTION

Agricultural and agri-food supply chains involve multiple stakeholders and stages, including production, processing, storage, transportation and distribution. Throughout these stages, information related to product origin, handling conditions, movement and quality needs to be recorded and communicated. However, fragmented record-keeping, inconsistent information exchange and limited coordination among stakeholders can make product histories difficult to track and verify. These challenges affect transparency, accountability and the overall effectiveness of supply-chain traceability.

Blockchain technology offers potential solutions to these challenges through decentralised and immutable records, improved transparency and information availability. In agricultural supply chains, blockchain can support the recording and verification of product-related information. The Internet of Things (IoT) complements this approach by collecting environmental and operational data through connected sensors. Integrating blockchain with IoT can support product monitoring and information sharing across different supply-chain stages. Other technologies, including QR codes, edge computing and digital storage systems, can further support product identification, automated data collection and information management [16].

Despite these advantages, implementing digital traceability systems involves several technical and operational challenges. These include unreliable network connectivity, differences in data formats, sensor accuracy, implementation costs, data privacy and scalability. Furthermore, blockchain can protect recorded

information against unauthorised modification, but it cannot independently guarantee the accuracy of the original data entered into the system.

Recent review studies have examined digital transformation and blockchain adoption in food supply chains. Vasileiou et al. [20] investigated blockchain-based digital transformation with particular attention to food safety and traceability, while Khoualdi et al. [15] examined the integration of blockchain and IoT for improving agri-food traceability and addressing food safety, food waste and food fraud. However, a comparative examination of individual systems, their technological components, traceability functions, reported evaluation evidence and implementation constraints remains valuable. Such an examination helps distinguish between proposed system capabilities and features demonstrated through actual implementation or evaluation.

This paper reviews 30 selected research papers [1]– [30] published between 2023 and 2026. It presents a detailed comparative analysis of 15 studies [1]– [15], examining their technological architectures, data acquisition, communication, processing, storage, verification and product identification approaches. The analysis also considers reported technical, functional and economic evaluation evidence, along with connectivity, interoperability, scalability and implementation challenges. The remaining 15 studies [16]– [30] are incorporated into the broader literature synthesis to provide additional context and support the discussion of research developments in this field. The objective is to identify the technological approaches adopted, compare their strengths and limitations, and highlight areas requiring further research.

The study addresses the following research questions:

RQ1: What technological architectures and integration approaches are adopted in IoT-based, blockchain-based and blockchain–IoT-enabled agricultural and agri-food traceability systems?

RQ2: How do the selected systems compare in terms of data acquisition, communication, processing, storage, verification and product identification, and what technical, functional and economic evaluation evidence is reported?

RQ3: What technical and operational challenges are identified concerning data reliability, connectivity, interoperability, scalability, privacy, adoption and cost-effectiveness?

Organisation of the Paper

The remainder of this paper is organised as follows:

- Section I: Introduces the research topic, objectives and research questions, followed by the background and core concepts of digital traceability in agricultural and agri-food supply chains.
- Section II: Describes the research methodology, including the PRISMA-based study selection process.
- Section III: Presents the comparative analysis of 15 selected research studies from the 30-paper review corpus.
- Section IV: Discusses the findings, technological approaches, evaluation evidence and identified challenges.
- Section V: Highlights the limitations of the review.
- Section VI: Concludes the paper and outlines directions for future research.
- Section VII: References

A. BACKGROUND

Traceability is an essential component of agricultural and agri-food supply chains as it enables the identification and tracking of products across different stages, from production and harvesting to processing, storage, transportation and distribution. It involves maintaining information related to product origin, batch details, processing activities, storage conditions and movement between stakeholders. Traditional supply-chain systems often rely on paper-based records and separate information systems, making information exchange and product-history verification difficult across multiple stakeholders.

Digital technologies have introduced more efficient approaches to agricultural traceability through electronic recordkeeping and automated data collection. The Internet of Things (IoT) enables the collection of environmental and operational information through connected sensors, including temperature, humidity and location data. These readings can be transmitted through communication networks for monitoring and further processing. Such capabilities support the monitoring of product conditions during storage and transportation.

Blockchain technology provides a decentralized and tamper-evident approach to maintaining transaction records shared among supply-chain participants. Its

features, including data immutability and transparency, can support product-history verification and information sharing. The integration of blockchain with IoT combines sensor-based data collection with secure digital recordkeeping, creating opportunities for improved traceability in agricultural supply chains.
Other technologies, such as QR codes and edge computing, can further support digital traceability. QR codes allow product-related information to be accessed through product identification, while edge computing enables data processing closer to the source of collection. Together, these technologies contribute to data acquisition, communication, processing, storage and verification within digital traceability systems.

B. CORE CONCEPTS USED

Digital traceability systems in agricultural and agri-food supply chains involve several interconnected technologies and concepts. The following are the major concepts considered in this review.

1. Agricultural Supply Chain Traceability:
Traceability refers to the ability to track a product and retrieve its information throughout the supply chain, including its origin, movement, processing, storage and transportation.

2. Internet of Things (IoT):
IoT is a network of connected devices equipped with sensors that collect and exchange data. In agricultural supply chains, these sensors can monitor parameters such as temperature, humidity, location and movement.

3. Blockchain Technology:
Blockchain is a distributed digital ledger that maintains records across a network of participants. It provides a tamper-evident way of recording and verifying product-related transactions.
4. Smart Contracts:
Smart contracts are programmable rules deployed on a blockchain that execute predefined actions when specified conditions are met. They can automate transaction recording and validation.

5. QR Code-Based Product Identification:
QR codes are machine-readable codes that provide access to product-related information, such as origin, batch details and supply-chain history.

6. Edge Computing:
Edge computing involves processing data closer to the devices where it is generated. It can reduce communication delays and support local data processing, particularly where network connectivity is limited.

7. Data Integrity and Interoperability:
Data integrity refers to maintaining the accuracy and consistency of information, while interoperability refers to the ability of different devices and systems to exchange and use data effectively.

II. METHODOLOGY

A. RESEARCH DESIGN

This study follows a systematic literature review approach to examine existing research on blockchain, Internet of Things (IoT) and their integration in agricultural and agri-food supply-chain traceability. The review adopts a structured approach guided by three research questions to identify technological developments, examine their applications and understand the challenges associated with their implementation.

B. RESEARCH QUESTIONS AND REVIEW FRAMEWORK

The review is structured around three research questions, each addressing a specific aspect of agricultural and agri-food supply-chain traceability.

- RQ1: This question is addressed by identifying and examining the technological architectures and integration approaches used in the selected studies, including IoT-based, blockchain-based and integrated blockchain–IoT systems.
- RQ2: This question is addressed by examining the technological components and traceability functions of the selected systems, including data acquisition, communication, processing, storage, verification and product identification. Reported technical, functional and economic evaluation results are also considered.
- RQ3: This question is addressed by identifying the technical and operational challenges reported in the studies, particularly those related to data reliability, network connectivity, interoperability, scalability, privacy, adoption and cost-effectiveness.

Together, these research questions provide a structured framework for examining the existing literature and organising the review findings.

C. INCLUSION AND EXCLUSION CRITERIA

The following criteria were applied to select research papers relevant to the objectives of this review.

Inclusion Criteria:

- Research papers published between 2023 and 2026.
- Publications from Springer, Elsevier and IEEE.
- Studies addressing agricultural or agri-food supply-chain traceability.
- Research involving blockchain, IoT or their integration.
- Studies examining traceability systems, technological architectures, implementation, evaluation or associated challenges.

Exclusion Criteria:

- Publications outside the selected period or sources.
- Studies unrelated to agricultural and agri-food supply-chain traceability.
- Research focusing on blockchain or IoT without a traceability application.
- Studies providing insufficient information to address the research questions.
- Duplicate publications.

D. PRISMA-BASED STUDY SELECTION

- The study selection process followed the PRISMA framework. A total of 30 research papers were identified from three sources: IEEE Xplore (10), Elsevier (7) and Springer (13). No duplicate papers were identified or removed before screening.
- All 30 research papers proceeded through screening and eligibility assessment, with none excluded at either stage. Finally, all 30 papers were included in the review. The selection process is illustrated in Figure 1.

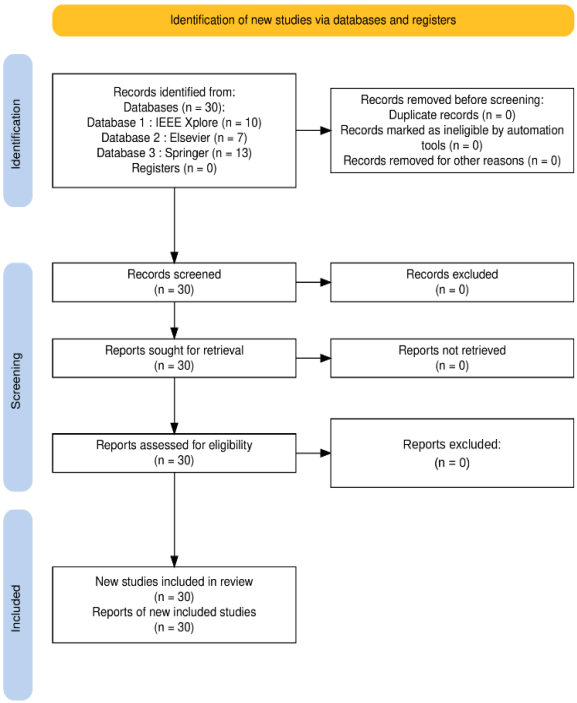

Fig. 1. PRISMA-based study selection process.

III. COMPARATIVE ANALYSIS

This section presents a comparative analysis of 15 selected research papers from the 30-paper review corpus. The studies are compared based on their research design, technologies used, traceability functions, evaluation findings and reported limitations.

The comparison identifies similarities, differences and research gaps across existing approaches to blockchain- and IoT-based agricultural and agri-food supply-chain traceability.

Table 1. Detailed Comparative Analysis of Selected Research Studies

Study (Author and Year)	Research Design and Context	Technologies Used	Traceability Functions	Evaluation and Key Findings	Limitations
1. Panigrahi et al. (2024)	Prototype development (dApp, ASBlock) with performance analysis; agricultural supply-chain use cases for farmers, suppliers/retailers, hotels and end users. Dataset and test set-up: Not reported. †	Blockchain only. Smart contracts; dApp. Platform, consensus, storage and IoT: Not reported. †	Supply-chain management across participant roles. Specific traceability functions: Not reported.	Reported in abstract: average gas utilisation ≈ 2.8 × 10^4; average smart-contract execution time ≈ 112 s. Test conditions: Not reported. †	(I) Only gas and execution time evaluated; no scalability or field results in abstract. † (A) Not reported.

2. Sathiya et al. (2024)	System proposal implemented as a single-company case study (seafood, India): one truck and one warehouse with MOKO G-Series trackers; up to 1,000 test transactions.	Integrated blockchain–IoT. IoT trackers; EOSIO (delegated Proof of Stake) smart contracts; ANFIS quality assessment; Docker; cloud storage.	Tracking of perishable food in a truck and warehouse; ANFIS-based quality assessment; traceability breadth and depth.	Precision 100%; submission time 247 ms; retrieval time 652 ms. Breadth 100% up to 50 transactions, 10% at 1,000; depth 100% up to 100 transactions, 15% at 1,000.	(A) Sensor effectiveness not validated; EOSIO scalability delays and costs; high initial investment. (I) Single case; ANFIS accuracy not reported.
3. Chunduri et al. (2024)	Consensus-algorithm design (t-PBFT) with analytical model and simulation against PBFT; conceptual traceability architecture. Docker-simulated nodes (Intel i5-8400, 8 GB RAM); 50 requests (delay), 500 (throughput); no field data.	Blockchain only (IoT: Not reported). t-PBFT and PBFT; consortium-blockchain architecture (Ethereum/Hyperledger Fabric mentioned); Docker.	Secure, optimised traceable scheme at consensus level; functions of the conceptual architecture: Not reported.	Communication overhead reduced ≈ 33% (theoretical asymptotic bound, ratio 2/3); average throughput 237–363 TPS (stated range); request delay versus node count (plotted only).	(A) Gap between algorithm and real deployment remains. (I) Simulation only; 33% is a theoretical bound.
4. Raza et al. (2023)	Business Process Modelling mapped to RAMI 4.0; Solidity smart contracts developed, deployed and tested for a typical agricultural scenario in a local test environment; no field deployment.	Blockchain–IoT framework (IoT stated; reported tests limited to smart-contract scenarios). † Solidity; Ganache; Truffle; RAMI 4.0. Blockchain platform and consensus: Not reported. †	Smart-contract automation of agri-food supply-chain processes. Specific traceability functions: Not reported.	Gas cost 13.89-fold lower than a traditional smart-contract model in a local test environment (intra-organisational contracts; baseline definition to verify). †	(I) Tested on contract scenarios only; no field, latency or throughput results in abstract. †
5. Saranya & Maheswari (2023)	System and consensus-algorithm design (PoTx) with user identification and access control. Dataset and test set-up: Not reported. †	Blockchain only. PoTx consensus (random validator selected by transaction count); access control. Smart contracts, storage and IoT: Not reported.	User identification and access control for agricultural traceability.	Stated design goals: scalability, lower communication and computation overhead, fault tolerance. Measured values: Not reported. †	(A) Not reported in abstract. † (I) No quantitative evidence at abstract level.
6. Daraghmi et al. (2024)	Architecture design (centralised, distributed, multi-blockchain) and AgroChain proof-of-concept prototype on an agricultural process model; no sensor-data field trial.	Blockchain only (IoT: Not reported). Quorum; Solidity smart contracts; Zero-Knowledge Proofs.	Record creation, record access, participant management, audit and tracking.	Evaluated by functional coverage; execution time stated as not critical. † Numerical results: Not reported.	(A) Future work: multi-blockchain, Hyperledger Besu, user interface, oracles, standardisation. †

7. Vern et al. (2025)	Case-based proof of concept with an agri-food organisation (Himmotthan Society) and technology provider (CropIn Technologies); honey and coriander-powder supply chains, India; cost analysis and stakeholder views. Pilot size: not verified. †	Blockchain with mobile applications (IoT: Not reported). Cosmos blockchain (Proof of Stake); Smartfarm/Smartware apps; smart contracts; batch IDs; QR codes.	Batch-level traceability using batch IDs and QR codes; data sharing.	Traceability coverage, data sharing, development and operating costs, challenges and perceived benefits assessed. Numerical results: Not reported. †	(A) Limited pilot data; high volumes not simulated. † (I) Findings specific to one country and two commodities.
8. Bazie et al. (2025)	Prototype validated on a Ganache test network with ADJENDE case parameters (≈ 150 smallholders: cassava, sesame, shea; Burkina Faso) under simulated low bandwidth (2–10 Mbps); not field-deployed.	Blockchain only (IoT: Not reported). Ethereum private network (Ganache); Solidity; NextJS; MySQL; QR e-labelling.	Registration, update and deletion of records; QR e-labelling.	Operation time: registration ≈ 25 s, update ≈ 20 s, deletion ≈ 17 s; gas ≈ 6 M units (≈ US$0.15–0.30); utilisation 89.2% (checked against authors' slides only). †	(A, slides) Testnet only, not production; future work: Layer-2, offline use, mobile money. †
9. Villegas-Ch. et al. (2025)	Architecture design with performance evaluation; reported test set-up of 10 nodes and 50 IoT sensors (simulation or testbed: not confirmed); no commercial field deployment identified. †	Integrated blockchain–IoT. Lightweight blockchain; Proof of Authority; MQTT; temperature and location sensors.	Monitoring of perishable products through temperature and location sensing.	Response time ≈ 105 ms; throughput up to 720 TPS; energy 9.6 mJ/transaction; recovery time 5 s (abstract values, not independently verified). †	(I) Small test configuration; no field deployment identified. (A) Not available (full text not accessed). †
10. Mallick et al. (2026) †	Simulation-based framework evaluation (millet supply-chain system model), compared with other systems; no field data identified. Journal, volume, DOI and author list not independently confirmed (only a matching framework abstract was located); manual verification required. †	Integrated blockchain–IoT (IoT/IoVT) with fog computing. Queueing theory; smart contracts; IPFS; PBFT-based fog consensus. Consensus and architecture details: to verify. †	Millet supply-chain transparency and integrity; IPFS-based file storage, retrieval and verification.	Throughput, latency, smart-contract execution time, file retrieval and verification time, scalability and cost evaluated; values in figures only (Not reported). †	(A, to verify) Future work: energy, AI-based decisions, cross-chain interoperability; no real-world millet evaluation. †
11. Luo et al. (2026) †	System development validated in a citrus-orchard case study (monitoring, disease detection, task reporting). Sample size: not verified. Whole record (authors, title, year, journal, DOI, case-study	Integrated blockchain–IoT. IoT sensors; Ethereum smart contracts; IPFS; hybrid on-chain/off-chain storage	Data integrity, traceability and multi-party verification, from data collection to trust verification.	Storage-cost reduction versus on-chain storage reported as > 99.9% (unverified). † Other quantitative results: Not reported.	(A, to verify) Scalability and farmer usability. †

	details) not independently confirmed; verify before citing. †	(as reported; unconfirmed). †			
12. Habib et al. (2024)	Qualitative exploratory multiple-case study; semi-structured interviews with thematic analysis; three Australian vegetable supply chains plus industry experts (thesis: 19 chain members, 3 technology providers, 3 experts; article sample to confirm). †	Monitoring without blockchain. Temperature data loggers; no blockchain prototype. IoT connectivity: Not reported.	Environmental (temperature) monitoring practices; adoption analysis rather than a traceability system.	Adoption barriers identified: cost, compatibility, information sharing, product mixing, status-quo bias, responsibility shirking. No quantitative results.	(I) Three Australian chains; qualitative evidence limits transferability. † (A) Not verified.
13. Lamberty & Kreyenschmidt (2025)	Stakeholder interviews (17†; Germany, Netherlands) followed by scenario-based cost–benefit assessment (vine tomatoes, strawberries, apricots).	IoT only. IoT temperature monitoring (GFoxx and LCT systems). Blockchain: Not reported.	Temperature monitoring of fresh plant-based produce; monetary assessment rather than a traceability system.	Set-up cost per pallet with three sensors: €1,137 (LCT), €419 (GFoxx). † Avoided loss, hardware reuse and net savings assessed; values: Not reported.	(A, to verify) Results depend on three scenarios and on assumptions about losses and hardware reuse. †
14. Pongnumkul et al. (2025)	Model-based cost comparison of 13 deployment scenarios for a Thai broiler supply chain; industry-level IT usage as input, with Monte Carlo simulation for undisclosed values. Not observed expenditure.	Centralised IT versus blockchain (IoT: Not reported). On-premises and cloud deployment; Hyperledger Fabric via Amazon Blockchain-as-a-Service.	Infrastructure support for food traceability; cost components: compute, storage, data transfer, internet.	Modelled blockchain infrastructure cost ≈ 43% lower than the practical centralised approach.	(A, to verify) Assumption-based estimates; personnel, legacy-integration and verification costs excluded. †
15. Khoualdi et al. (2026)	PRISMA systematic literature review of 41 studies; modular reference architecture proposed and evaluated qualitatively only; no empirical dataset.	Review: blockchain–IoT traceability. Reviewed literature: Ethereum and permissioned chains (Hyperledger Fabric, Sawtooth). Proposed architecture: hybrid blockchain with role-based access control, smart contracts for policy logic, and encrypted	Reviewed literature: food safety, food fraud and food waste objectives. Proposed architecture: role-based access control (design feature only). Implemented or evaluated: none reported; role-based access control was not experimentally validated.	Reviewed literature (41 studies): 48% target safety, 21% fraud, 9% waste; 61% use public and 39% permissioned chains; 75% do not discuss governance. Proposed architecture: qualitative evaluation only; no empirical or experimental results.	(A) Reviewed studies often lack implementation detail; privacy, governance and legal aspects are under-addressed. Limitations of the review itself: not verified. † (I) Proposed architecture not deployed or empirically validated.

		off-chain storage (IPFS or cloud) (design features). IoT components: IoT and access layer with sensors and gateway edge device (design feature). Implemented: None reported.			

Note: (A) = author-stated; (I) = inferred from the available evidence, not an author statement; † = requires verification against the original paper (abstract-level, secondary or unconfirmed source or bibliographic information). “Not reported” = not given in the source consulted, not evidence of absence. Values are not comparable across studies (different metrics, platforms and test conditions); simulation, test-network and model-based results are not field validation. For Study 15, “Reviewed literature” = findings about the 41 reviewed studies; “Proposed architecture” = features of the authors’ reference architecture (a design, not an implemented system); “Implemented or evaluated” = what was actually built or tested. ANFIS = Adaptive Neuro-Fuzzy Inference System; IPFS = InterPlanetary File System; MQTT = Message Queuing Telemetry Transport; PBFT = Practical Byzantine Fault Tolerance; PoTx = Proof of Transaction; RAMI 4.0 = Reference Architecture Model Industrie 4.0; TPS = transactions per second.

Table 2. Cross-Study Synthesis of Research Findings

Dimension	Common Patterns	Important Differences	Studies
Research design and evaluation approach	Most studies propose a system, framework or algorithm and evaluate it in controlled or limited settings rather than at operational scale.	Designs: prototype, proof-of-concept or architecture studies (1, 2, 4, 6, 7, 8, 9, 11); consensus-algorithm design (3, 5); simulation-based framework evaluation (10); model- or scenario-based cost analysis (13, 14); qualitative interview study (12); systematic review (15). Settings: test network (4, 8), simulation (3, 10), case or pilot settings (2, 7, 11), prototype demonstration (6), reported test configuration of unconfirmed type (9†), interviews (12, 13), cost modelling (13, 14). Test set-up not reported: 1, 5.	1–15
Blockchain platforms and consensus mechanisms	Smart contracts are the most frequently reported component (1, 2, 4, 6, 7, 8, 10, 11). They are an application layer, distinct from the blockchain platform and the consensus mechanism, both of which are reported less consistently.	Blockchain platforms: Ethereum (8, 11); Quorum (6); EOSIO (2); Cosmos (7); Hyperledger Fabric (14); lightweight blockchain (9). Not clearly named: Solidity/Ganache/Truffle test tooling without a named platform (4); Ethereum and Hyperledger Fabric only mentioned for a consortium architecture (3). Review: Ethereum, Hyperledger Fabric and Sawtooth among reviewed studies, hybrid blockchain proposed (15). Not reported: 1, 5, 10. Consensus mechanisms: delegated Proof of Stake (2); Proof of Stake (7); Proof of Authority (9); PBFT variants (3, 10); Proof of Transaction (5). Not reported: 1, 4, 6, 8, 11, 14. Public versus permissioned chain types are examined only in the review (15). Smart contracts: Solidity (4, 6, 8); EOSIO (2); Ethereum (11); language or platform not stated (1, 7, 10). Not reported: 3, 5†, 9, 14. Study 15's proposed architecture uses smart contracts for policy logic (design feature only). Studies 12 and 13 involve no blockchain.	1–11, 14, 15

Dimension	Common Patterns	Important Differences	Studies
IoT integration	IoT is used for product monitoring and data collection, although the reported sensor functions and integration details vary across studies.	Integrated blockchain–IoT (2, 4, 9, 10, 11); IoT-based temperature monitoring without blockchain (13); temperature data loggers without blockchain, IoT connectivity not reported (12); blockchain without reported IoT (1, 3, 5, 6, 7, 8, 14). Reported sensor functions differ: trackers for perishable food in a truck and warehouse (2); temperature and location sensors with MQTT (9); IoT/IoVT with fog computing (10); IoT sensors for orchard monitoring, disease detection and task reporting, sensor types not reported (11); temperature monitoring for cost–benefit assessment (13). Study 4 states IoT but reports contract-level tests only. Study 15 reviews IoT-based approaches; its proposed architecture includes an IoT and access layer with sensors and a gateway edge device (design feature only).	2, 4, 9–13, 15
Data storage approaches	Storage design is reported in only a minority of studies.	IPFS for off-chain files (10, 11), hybrid on-chain/off-chain storage (11), cloud storage (2), relational database (8). Study 14 treats storage only as a modelled cost component. Study 15's proposed architecture uses encrypted off-chain storage (IPFS or cloud) and local storage (design feature only). Not reported: 1, 3, 4, 5, 6, 7, 9, 12, 13.	2, 8, 10, 11, 14, 15
Traceability functions	Among studies proposing traceability systems, common functions include record creation, updating, access and verification.	The functions explicitly reported differ: record creation, update and deletion (8); record creation and access with participant management, audit and tracking (6); batch-level identification, QR codes and data sharing (7); file storage, retrieval and verification (10); data integrity and multi-party verification (11); condition tracking or quality assessment of perishables (2, 9); user identification and access control (5); contract-level process automation (4). Specific functions not reported: 1; consensus-level scheme only (3). Study 15 is a review: its role-based access control is a feature of a proposed reference architecture, not an implemented or experimentally validated function, and its safety, fraud and waste objectives describe the reviewed literature. Studies 12–14 address monitoring adoption, monitoring cost or infrastructure cost rather than a traceability mechanism.	1–11, 15 (15: proposed architecture only)
Evaluation metrics	Technical studies report efficiency metrics; economic studies report cost.	Gas (1, 4, 8); execution or operation time (1, 8, 10); response, access or latency measures (2, 3, 9, 10); throughput (3, 9, 10); energy and recovery time (9); communication overhead (3); traceability breadth, depth and precision (2); utilisation (8); cost or cost components (7, 10, 11, 13, 14); adoption barriers (12); proportions within the literature (15); design goals or qualitative assessment only (5, 6, 7). Values depend on platform, workload, test conditions and baseline and should not be ranked across studies.	1–15
Evidence maturity	Few studies reports evidence from real-organisation case or pilot settings; most evaluations are controlled,	Case or pilot settings (2, 7, 11): Study 2 reports quantified system-performance results in a case-study setting; Study 7 reports no numerical results†; Study 11 reports one unverified figure†. Test-network or simulation evidence with reported values (3, 4, 8). Reported test configuration of unconfirmed type with abstract-level values (9†); prototype with abstract-level values and unreported set-up (1); simulation with values in figures only (10†). Design or functional	1–15

Dimension	Common Patterns	Important Differences	Studies
	simulated, model-based or qualitative.	demonstration without numerical results (5†, 6). Interview- or model-based evidence (12, 13, 14); review with qualitative evaluation of a proposed architecture (15). Source level of reported values: full text (2, 3); abstract (1, 4, 14, 15); authors' slides (8); not re-verified (9, 13); unconfirmed record (11). Numerical findings are not classed as verified beyond this. Manual verification priority: 10, 11 (record), 5, 6, 9 (abstract-level).	
Identified research gaps	The gap between prototype or model and real-world deployment recurs across studies.	Author-stated: scalability (2, 11); sensor validation (2); limited pilot data and untested high volumes (7); deployment beyond test settings (3, 8, 10); cross-chain interoperability, energy and AI-based decisions (10); standardisation, oracles and user interface (6); farmer usability (11); offline use and Layer-2 (8); privacy, governance and legal aspects in the reviewed literature (15); assumption-dependent cost results (13, 14). Inferred: narrow or non-quantitative evaluation scope (1, 4, 5); single-case or single-region evidence (2, 7, 12); small test configuration (9); non-deployed proposed architecture (15). Author-stated items for 6–8, 10, 11, 13 and 14 remain to be verified. †	1–15

Note: Study numbers refer to Table 1. † = requires verification against the original paper (see Table 1). Blockchain platforms, consensus mechanisms and smart contracts are listed separately. Study 15's proposed architecture is a design, not an implemented system. IoT = Internet of Things; PBFT = Practical Byzantine Fault Tolerance; IPFS = InterPlanetary File System; MQTT = Message Queuing Telemetry Transport

IV. RESULTS AND DISCUSSION

The comparative analysis of the 15 selected studies reveals varied approaches to agricultural and agri-food supply-chain traceability. While blockchain and IoT offer complementary capabilities, their implementation, evaluation and demonstrated outcomes differ considerably. The findings are discussed below in terms of technological approaches, traceability functions, evaluation evidence and unresolved challenges.

A. TECHNOLOGICAL TRENDS

Blockchain-based systems primarily use smart contracts for managing records, controlling access and automating supply-chain processes. IoT-based approaches focus on collecting product and environmental data, particularly temperature and location information. Their integration combines physical monitoring with blockchain-supported data recording and verification. However, integrated blockchain–IoT architectures are reported in only some of the selected studies. Other studies examine blockchain without reported IoT integration or IoT monitoring without blockchain. Thus, the literature reflects multiple technological approaches rather than a single established architecture.

B. TRACEABILITY CAPABILITIES

The reviewed systems address different stages and functions of traceability, including product registration, record updating, participant identification, data access, auditing and verification. QR codes and batch identification support product-level information access, while IoT sensors enable monitoring of handling and environmental conditions. However, the extent of traceability varies across implementations. Some approaches provide specific functions, such as temperature monitoring or record management, rather than demonstrating continuous end-to-end tracking across the entire supply chain. Therefore, the presence of blockchain or IoT alone does not establish comprehensive traceability.

C. EVALUATION AND IMPLEMENTATION EVIDENCE

Evaluation methods include prototype testing, simulations, test-network experiments, case studies, interviews and cost modelling. Reported measures cover

transaction throughput, execution time, gas consumption, communication overhead, traceability coverage and infrastructure cost. However, these results reflect different platforms, workloads, assumptions and testing environments and cannot be treated as directly comparable performance benchmarks. Moreover, several studies provide limited numerical evidence, while others evaluate proposed architectures without empirical deployment. The available findings therefore demonstrate technical potential under specific conditions, rather than consistent validation at operational agricultural supply-chain scale.

D. RESEARCH GAPS AND CHALLENGES

The comparison identifies recurring challenges involving scalability, interoperability, data reliability, network connectivity, implementation cost and practical adoption. Limited field validation remains a significant concern, particularly where systems are evaluated mainly through simulations, controlled tests or conceptual architectures. Sensor validation, farmer usability, offline operation, privacy and governance also require further attention. Future research should therefore prioritise integrated systems supported by reliable data collection, interoperable infrastructure, cost-effective deployment and evaluation under actual supply-chain conditions.

V. LIMITATIONS

This review has certain scope and evidence-related limitations. The literature search was restricted to IEEE Xplore, Elsevier and Springer publications from 2023–2026; therefore, relevant studies published outside this period or through other sources may not be represented. Although 30 studies were included in the review, detailed comparative analysis was conducted on 15 selected studies, while the remaining studies contributed to the broader literature synthesis. Consequently, the depth of comparison was not uniform across all included publications.

Furthermore, the reviewed studies differ in their technological architectures, evaluation methods, platforms and testing conditions. Their reported performance metrics are therefore not directly comparable. Some publications also provided limited technical or bibliographic information, requiring verification against original sources. Finally, this review evaluates findings reported in existing literature and does not independently test the proposed systems or validate their performance in operational agricultural supply chains.

VI. CONCLUSION AND FUTURE SCOPE

This review examined recent developments in blockchain, Internet of Things (IoT) and their integration for agricultural and agri-food supply-chain traceability. The analysis highlights the complementary roles of these technologies: IoT enables the collection of product and environmental data, while blockchain supports record integrity, information verification and automated supply-chain processes through smart contracts. Their integration provides a technological foundation for improving traceability and information visibility across supply-chain activities.

The comparative findings also reveal that the adoption of these technologies remains uneven. Studies differ in their architectures, traceability functions and evaluation approaches, with several relying on simulations, prototypes or limited case-based assessments. Although reported results indicate technical potential, the available evidence does not yet establish consistent performance or large-scale operational effectiveness across agricultural supply chains. In particular, the gap between proposed architectures and validated real-world implementations remains significant.

Future research should move beyond isolated prototypes towards integrated, cost-effective and interoperable traceability systems. Most selected systems remain prototypes, simulations, test-network deployments or cost models, and few report evidence from operating supply chains.

The following directions address gaps that recur across the reviewed studies.

1) Field validation in real, multi-stakeholder settings.
Evaluation is mostly confined to controlled settings: test networks [4], [8], simulations [3], [10] and a single-company case study [2]. Future work should deploy integrated systems across several supply-chain stages and commodities, and report operational outcomes rather than platform-level metrics alone.

2) Validated integration of IoT with blockchain.
Seven of the fifteen compared studies are blockchain-only with no reported IoT component [1], [3], [5], [6], [7], [8], [14], and the reported tests in [4] are limited

to smart-contract scenarios. Where sensors are used, their effectiveness was not validated [2]. Future research should test sensor calibration, fault handling and data authenticity at the point of capture, since blockchain protects recorded data but cannot verify the accuracy of data entered into it.

3) Connectivity-resilient and offline-capable architectures.

Offline use and Layer-2 scaling [8], together with edge and fog processing [10], are proposed but not field-tested. Evaluations should include intermittent or low-bandwidth rural conditions, local buffering and later synchronisation.

4) Interoperability and standardisation.

Cross-chain interoperability [10], standardisation and oracle mechanisms [6], and differences in data formats remain open. Future work should examine common data models and interoperable identifiers across platforms and stakeholders.

5) Privacy, governance and legal aspects.

The reviewed literature under-addresses privacy, governance and legal considerations [15]. Future systems should define who controls access, how data are shared, and how responsibility is allocated among farmers, processors and retailers.

6) Farmer-centred usability and adoption.

Farmer usability [11] and adoption barriers such as cost, compatibility, information sharing and status-quo bias [12] are reported as constraints. Future work should involve end users in system design and measure ease of use alongside technical performance.

7) Realistic cost and sustainability assessment.

Existing cost results are assumption-dependent [13], [14], and the estimates in [14] exclude personnel, legacy-integration and verification costs. Future studies should use observed expenditure from deployments and include energy consumption [10].

8) Standardised evaluation and reporting.

Reported metrics differ in platform, workload and baseline, so results cannot be ranked across studies, and several studies leave the platform, consensus mechanism or test set-up unreported. A common reporting framework would make future results comparable.

Overall, blockchain and IoT represent promising complementary technologies for advancing agricultural supply-chain transparency. However, achieving reliable and practical traceability will depend not only on technological integration but also on effective implementation, validation and adoption across the supply chain.

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