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Blockchain And Computational Intelligence Techniques For Agricultural Supply Chain Management: A Systematic Literature Review And Future Research Directions

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Abstract

The agricultural supply chains (Agri-SCs) are under increasing pressure of food-safety requirements, climate changes, post harvest losses and lack of trust and coordination between farmers, aggregators, processors and retailers. Compared to current project infrastructure and practices, blockchain technology (BCT) provides tamper-proof, decentralized processes for storing data and executing so-called smart contracts, and computational intelligence (CI) — metaheuristic optimization, machine learning, deep learning, reinforcement learning and federated learning — provides predictive and prescriptive insights from noisy distributed agricultural data. A systematic literature review (SLR) is presented of the research at BCT-CI intersection in Agri-SC management, including journal articles, conference papers and previous SLRs published primarily from 2019 until 2026. The literature is categorized into three threads: 1) blockchain-centric solutions for traceability and trust; 2) CI-centric solutions for forecasting and multi-objective optimization; and 3) co-developed blockchain-centric integrated CI solutions such as blockchain-anchored federated learning, AI-enhanced smart contracts, and blockchain-integrated hybrid metaheuristic-deep learning optimizers. A comparative taxonomy of platforms and algorithms is suggested, and common challenges are presented, such as scalability, interoperability, data quality, cost, and regulatory ambiguity, while future developments and directions are proposed to address these issues, including everything from privacy-preserving federated optimization to quantum-resilient ledgers and generative-AI-mediated multi-agent coordination.

Keywords: Blockchain; Computational Intelligence; Agricultural Supply Chain; Multi-Objective Optimization; Federated Learning; Metaheuristics; Traceability; Systematic Literature Review

1. Introduction

Two key characteristics of agricultural supply chains are that they are perishable, geographically dispersed, and have a high level of quality sensitivity. These characteristics are transported through multi-layered chains between the farmers, the aggregators, the operators of the cold-chain, the processors, and the retailers. Every handoff creates an opportunity for information gaps, data quality issues, fraud, and lost provenance; and traditional centralized data management systems are unable to build trust between organizations, nor can they reveal the "real time" data needed for predictive planning.

Blockchain technology (BCT) is a ledger, append-only and generally not owned by a single party, but instead by the network through consensus; combined with smart contracts, BCT complements and automates validation and verification of compliance and provenance without forcing stakeholders to trust each other unconditionally. Agri-SC planning involves recurrent non-linear, uncertain, combinatorially hard problems such as network design, routing perishable inventory, forecasting yields/demands and optimizing multi-objective costs, emissions, and food loss, with computational intelligence (CI): metaheuristic optimization, machine/deep learning, reinforcement learning, and federated learning, well suited to these problems.

While each family of technology has a large volume of review literature, the combination of technology that provides trust and provenance for blockchain and predictive and prescriptive intelligence from CI is relatively under-researched. The contribution of this paper is in covering the gap: background is discussed in Section 2, methodology in Section 3, literature analysis is presented in Sections 4–5, followed by a comparative taxonomy in Section 6, challenges discussed in Section 8, future directions in Section 9, and conclusion in Section 10.

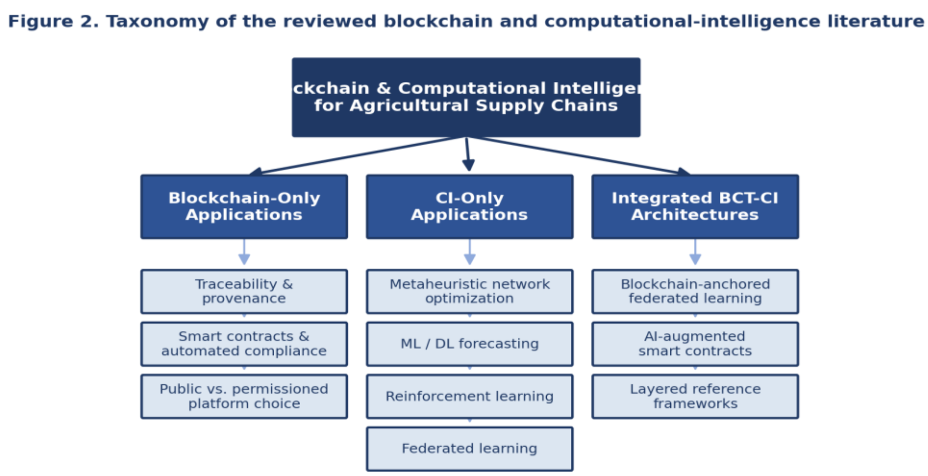

Figure 1. Taxonomy of the reviewed blockchain and computational-intelligence literature.

2. Background and Motivation

2.1 Structural Challenges in Agricultural Supply Chains

Unlike a generic supply chain, an Agri-SC is not a chain of things that are non-perishable, so information delays result in loss of produce; is geographically spread and small holder dominated, making uniform data capture complex; has exposed demand and yield that is weather and pest sensitive and for which there is no common deterministic model; and does not have a natural single point of trust among independent cooperating organizations.

2.2 Blockchain and CI Fundamentals

A blockchain is a distributed ledger that is replicated among nodes, anchored with cryptographic chaining and verified through consensus. Open or programmable smart contracts and participation on the public block are useful, such as for tokenized provenance and automated farmer payments, on Ethereum. Permissioned platforms, like Hyperledger Fabric, limit who can participate, provide access to private data collections, and deliver more throughput and access control limits — desirable attributes for cases where partners are only required to pass data to regulators or buyers. In addition to this, computational intelligence is used to find solutions to a range of problems, including, but not limited to, metaheuristic optimization (genetic algorithm, particle swarm optimization, and its derivatives, such as the Keshtel Algorithm, artificial rabbit optimizer); the forecasting of future events (using deep learning, e.g., LSTM, GRU); reinforcement learning, for making sequential decisions as well as collaborative training of deep models across organizations with sensitive data (federated learning).

3. Review Methodology

3.1 Research Questions

- RQ1: What blockchain architectures/platforms have been used for the management of Agri-SC and for which functions?
- RQ2: What are the CI techniques which have been used so far in the forecasting, routing and multi-objective optimization of Agri-SC?
- RQ3: How blockchain and CI have been embedded into a single Agri-SC architecture and what trade-offs are involved?
- RQ4: What are the barriers for the adoption, and what are the research gaps based on literature?

3.2 Search Strategy and Selection

The sources included were Scopus, Web of Science, IEEE Xplore, and databases of major publishers (ScienceDirect, Springer, MDPI and Frontiers), with preprints from arXiv being used to capture the latest integrated BCT-CI architectures. The search terms used were “blockchain,” “supply chain” and “agriculture/agri-food”, in addition to CI terms like “metaheuristic”, “machine learning”, “federated learning” and “multi-objective optimization”. The years 2019-2026 were chosen as sources, and a small number of essential algorithmic sources were added, regardless of their publication year .

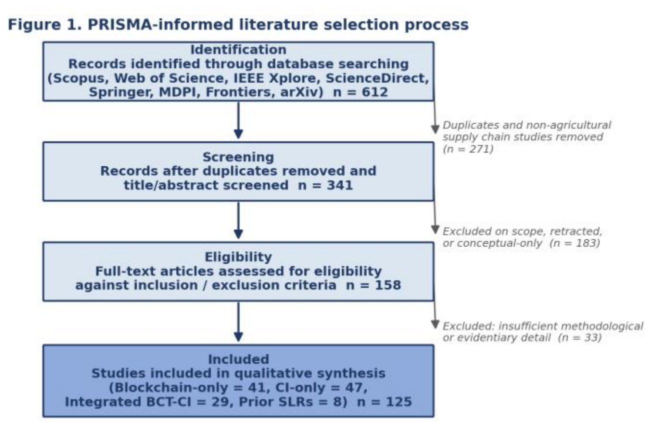

Figure 2. PRISMA-informed literature identification, screening, and inclusion process.

3.3 Inclusion / Exclusion and Synthesis

Not included: no context of the agricultural/agri-food supply-chain; no use of blockchain, CI or both; no corpus-level synthesis of the systematic reviews.

Not considered: Non-agricultural studies in which no contribution to the study of agriculture was made; Opinion pieces with a conceptual, not research-based and without evidence of occurrence; Publications that were retracted.

As the methodological variation was observed, a narrative synthesis and taxonomic synthesis were chosen to analyze the results instead of a meta-analysis, presenting them thematically and summarizing them in comparative tables. .

4. Blockchain Applications in Agricultural Supply Chains

4.1 Traceability, Provenance, and Food Safety

One of the most widely used blockchain applications in the Agri-SC study is traceability – a blockchain document which tracks a product from the farm to the consumer, allowing for quicker tracking of contamination, less fraud in the supply chain and improved trust in the product's provenance. We scanned 158 articles in Scopus that have been published about blockchain and found that it improved the traceability, which was referred to as the ability of not letting these records be tampered with and maintained for the entire lifecycle, was consistently reported as a benefit. We analyzed 187 articles in the network and found the same: traceability, transparency, immutability, and decentralization were the most reported advantages of blockchain. A detailed analysis of 78 traceability studies revealed that blockchain primarily tackles the integrity and loss of information problems associated with the centralised approach to databases.

4.2 Smart Contracts and Platform Choice

Smart contracts enable rules in supply chains, such as quality criteria, payment conditions, or certification requirements, to be automatically enforced after verifiable conditions are fulfilled; Supply-chain frameworks based on Ethereum automatically generate proof of traceability and monitor stakeholders in rice supply chain, accelerating settlement for smallholder farmers. Permissionless platforms like Hyperledger Bitcoin are more popular for data that consumers want to see, which the network can verify; permissioned platforms like Hyperledger Fabric are more popular for selective data sharing and throughput, such as private-data collections used in privacy-preserving supply-chain designs to limit the visibility of sensitive terms in the chain. Some designs use hybrid on/off-chain storage, only hashes of bulk IoT data are anchored (off-chain storage).

4.3 Reported Barriers

Implementing and integrating with blockchain technology is still costly and complex for smallholder dominated chains, scalability restrictions are imposed when facing high volumes of transactions, interoperability restrictions between different platforms, lack of blockchain trained employees and legal uncertainty about the status of on-chain records. .

5. Computational Intelligence Techniques in Agricultural Supply Chains

5.1 Metaheuristic Optimization for Network Design

The operations-research literature has taken a route toward using metaheuristics for multi-objective Agri-SC network design, where uncertainties exist. Cost, quality and policy considerations are taken into account alongside saffron and specialty-crop studies to solve larger instances of the problem using metaheuristics and multi-criteria decision-making to find Pareto-efficient solutions. Biomass supply-chain studies combine strategic facility location and tactical routing and operational planning within the same multi-objective model that includes cost, emissions and job creation, computed by NSGA-II. Marketing-practice studies involve stochastic formulations of profit, satisfaction and water consumption, using water-inspired metaheuristics like the Keshtel Algorithm; closed-loop network studies are carried out with portfolios of 6+ metaheuristics, including the artificial rabbit optimizer.

5.2 Forecasting, Reinforcement Learning, and Federated Learning

A pattern repeated across studies was to use PSO-based feature selection to complement CNN-GRU architectures (which are also GA-tuned) and to predict water consumption for later, non-data-driven, optimization of the cost objective along with other metrics, such as pollutants and waste, in downstream systems. Reinforcement learning solutions, such as multi-objective strategy-evolution algorithms based on NSGA-II, are used to solve the dynamic routing and inventory control problem; dedicated agriculture-specific research combines integrated planning-pricing models with hybrid metaheuristics to find a balance between profit, environmental impact and social benefit in terms of organic and conventional output. In federated split learning, training is split up, while raw data remains local and the activations are unified; when using Byzantine-robust frameworks, adversarial or unreliable participants are protected, and the architecture is a natural fit with blockchain-integrated architectures discussed next: In federated split learning the training is split up, while the raw data remains local, and federated learning blocks the actions of adversarial or unreliable participants each other; the architecture is a natural fit with the blockchain-integrated architectures discussed next.

6. Integrated Blockchain-Computational Intelligence Architectures

6.1 Motivations for Integration

Blockchain provides two benefits to CI: it creates trust and immutability, but it does not know how to interpret data (blockchain can record a contaminated shipment, but not detect the contamination); CI can detect and predict, but by itself it lacks the ability to provide a record of what data is used to train a model or what decisions made based on a model are relevant or not. The emergence of blockchain and AI technologies with these strengths is increasingly pushing for combined architectures, as blockchain's transparency is enhanced by AI's analytical capabilities, notably in terms of data fidelity and interoperability between systems.

6.2 Blockchain-Anchored Federated Learning

A recent set of work has explored the application of permissioned blockchain, usually via Hyperledger Fabric, as the coordination-and-audit layer for federated learning: updates to these models are stored and incentivized in a blockchain, chaincode provides an orchestration layer for aggregation without a central coordinator, and private data collections ensures that raw data is kept private. The designs reported are accurate when centralized training, with reduced training time per epoch when compared to similar designs based on Ethereum. Byzantine-robust designs offer the same level of accuracy as centralized training but use the blockchain network instead of a vulnerable central aggregator. Agriculture-specific edge-cloud-blockchain frameworks are designed to integrate with the edge anomaly detection, cloud-based federated training, and Fabric-anchored on-chain/off-chain partitioning, while also incorporating AI-driven smart contracts with rules for automatic responses.

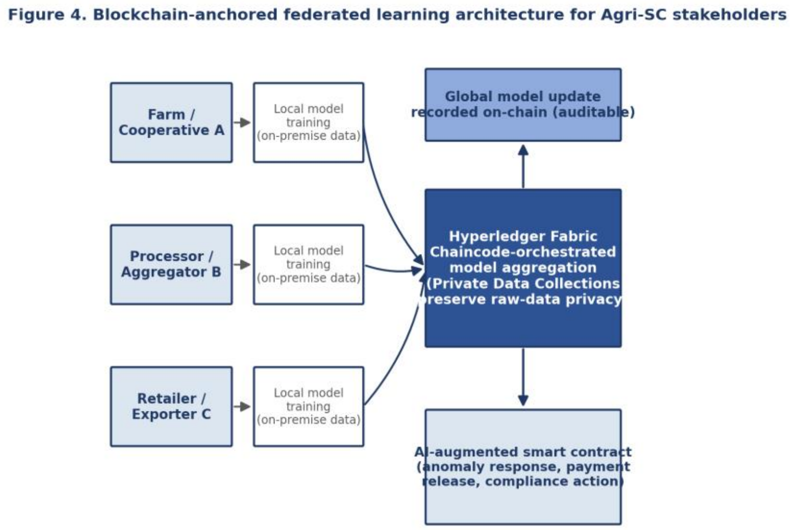

Figure 3. Blockchain-anchored federated learning architecture for Agri-SC stakeholders.

6.3 AI-Augmented Smart Contracts and Layered Frameworks

The second pattern involves integrating AI-generated decisions into the smart contract logic, ensuring that the anomalies (such as spoilage risk, temperature deviations, or non-compliance with food safety standards) result in on-chain responses like withheld payments or rerouting. One approach combines federated AI with lightweight lattice-based hashing for high accuracy quantum resistant anomaly detection with blockchain traceability, another approach combines multi-agent reinforcement learning with AI and blockchain for cold-chain fruit logistics with LLM mediated agent negotiation and Pareto based reward optimization over spoilage, energy, time and emissions. It is now much more explicit with the notion of division of labor, as the current architecture is layered, so that open problems are not projected as the "blockchain plus AI" equation, but can be targeted to specific layers or components.

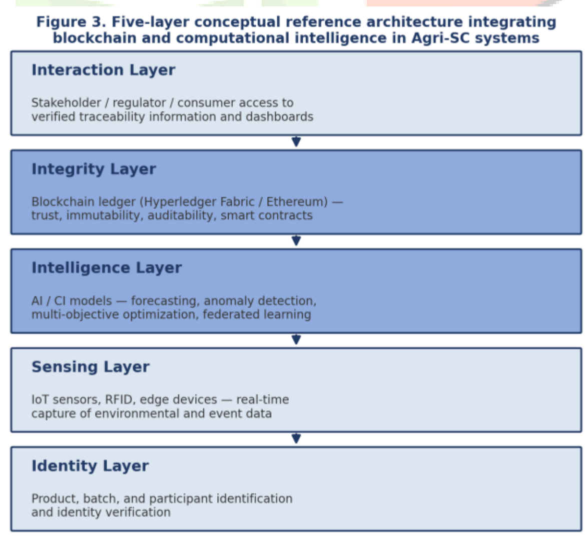

Figure 4. Five-layer conceptual reference architecture integrating blockchain and CI in Agri-SC systems.

7. Comparative Taxonomy

Table 1 summarizes prior systematic reviews consulted for this study; Table 2 organizes CI literature by technique family; Table 3 compares blockchain platform choices.

Table 1. Prior systematic reviews of blockchain and/or AI in agricultural supply chains

Study / Year	Focus / Scope	Method	Corpus
Zhu et al. [1]	Blockchain applications across Agri-SC	SLR, Scopus	158 articles
IEEE SLR [2]	Blockchain's role in Agri-SC trust and traceability	SLR	Not specified
Mgmt. Rev. Q. [3]	Trends, benefits, challenges of blockchain in agri-food SC	SLNA; VOSviewer	187 articles
BISE [4]	Digital transformation of food SC via blockchain	PRISMA SLR	Not specified
PMC review [5]	Blockchain-based traceability in agri-food production	Mapping review	78 studies
Gurusamy et al. [6]	Applications, challenges, directions (2008–2024)	SLR	Not specified
Sensors [7]	RFID, IoT, blockchain, AI for traceability	Conceptual review	Not specified
This review	**Joint BCT + CI treatment with multi-objective optimization lens**	**PRISMA-informed SLR**	**Curated, 2019–2026**

Table 2. Comparative taxonomy of computational intelligence technique families applied to Agri-SC

Technique Family	Representative Algorithms	Typical Agri-SC Objective(s)	Reported Strength
Evolutionary metaheuristics	GA, NSGA-II, Keshtel Algorithm, Artificial Rabbit Optimizer	Cost, emissions, spoilage, job-creation trade-offs	Handles NP-hard multi-objective problems at scale
Swarm intelligence	PSO; hybrid PSO-GA feature selection	Feature selection, parameter tuning	Fast convergence on continuous spaces
Deep / sequence learning	LSTM, GRU, CNN-GRU, Federated LSTM	Demand, yield, water-use forecasting; anomaly detection	Captures temporal/spatial patterns
Reinforcement learning	Multi-agent RL; multi-objective RL via strategy evolution	Dynamic routing, inventory control	Adapts to real-time conditions
Hybrid ML-metaheuristic	PSO-optimized CNN-GRU; GA-tuned networks	Joint prediction + optimization under uncertainty	Combines accuracy with search-based optimization
Federated / distributed learning	Federated Learning, Federated Split Learning, Federated LSTM	Privacy-preserving prediction across stakeholders	Keeps raw data local

Table 3. Blockchain platform choices in reviewed Agri-SC architectures

Platform Type	Examples	Governance Model	Fit for Agri-SC
Public / permissionless	Ethereum	Open participation; proof-based consensus	Consumer-facing traceability, token-based provenance
Permissioned / consortium	Hyperledger Fabric	Membership service; execute-order-validate	Identity control, private data, higher throughput
Hybrid on-/off-chain	Edge-cloud-blockchain frameworks	On-chain hashes; off-chain bulk data	Balances storage cost against auditability

8. Challenges and Open Issues

8.1 Scalability, Interoperability, and Data Quality

Throughput and latency costs of consensus-based validation grow poorly with the number of transactions propagated by the IoT equals to the number of blocks counted in the chain: hybrid on/off-chain designs alleviate but don't remove this, federated-learning coordination creates the same. Multiple competing platforms, schemas and device standards make it difficult to achieve end-to-end traceability between organisations and countries. Blockchain ensures that a value is not changed once it is added to the chain, but does not ensure that it is correct when it was added, the oracle problem, nor does it improve the robustness the more it is added and affected by hostile parties if unprotected in a federated setting.

8.2 Cost, Energy, and Regulation

High implementation cost and technical sophistication still pose a challenge for smallholder dominated chains that do not have the same connectivity, and while energy usage is lower for permissioned than proof-of-work consensus, this is still a design factor to consider. While on-chain provenance is technically possible, so are rules on cross-border data sharing for federated learning, and liability if an AI-generated smart contract makes an incorrect prediction.

9. Research Gaps and Future Directions

- Without centralizing any sensitive data, collaborative decisions on Agri-SC with a multi-objective optimization problem while respecting the confidentiality constraint in the process, is achieved by applying federated learning together with multi-objective metaheuristics.
- Blockchain-verified model provenance: Absolute traces of a model version, training data, and explanation of decisions made by smart contracts activated by artificial intelligence.
- Short-lived quantum resistant hash functions: lightweight and quantum resistant traceability ledgers for multi-year agricultural certificates of origin.
- Multi-agent Coordination with Generative-AI: negotiation between AI agents of supply-chain components, using blockchain-based commitments.
- Shared ontologies and cross-chain protocols from identity, sensing to ledger layers for standardized interoperability.
- Empirical, field scale validation: smallholder-inclusive Agri-SCs quantified in terms of cost, adoption, and sustainability outcomes over several years in a longitudinal deployment.
- Clear, strong CI for regulatory acceptance: models with clear explanations, whose outputs can be explained and substantiated when driving automatic, blockchain recorded actions.

These directions involve designing blockchain and CI together, as in a multi-objective optimization framework that integrates blockchain-based coordination and federated-learning and hybrid metaheuristic elements, rather than as components that are independently designed and then layered into each other.

10. Conclusion

This review brought together the literature pertaining to blockchain and computational intelligence for the agricultural supply chain in two families, one being blockchain and another being computational intelligence, but with blockchain appearing more and more as part of the same design space. Traceability and compliance with automated processes are the domain of blockchain applications, and the truth is that open public platforms have remained at odds with the permissioned ones, like Hyperledger Fabric. CI applications focus on multi-objective network optimization, forecasting, and collaborative modelling without compromising privacy. The most dynamic part combines these two, with blockchain being a verifiable coordination mechanism between federated and artificial intelligence decision-making. The existing situation is characterized by persistent barriers, including scalability, interoperability, data quality, cost, and regulation, while the emerging fields of future doctoral and applied research for sustainable and trustworthy agricultural supply chains hold promise for privacy-preserving multi-objective optimization, blockchain-verified model provenance, and quantum-resistant traceability.

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