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A Review of Decentralized Web Applications in Agricultural Systems

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Abstract
Decentralized Web Applications (dApps) built on blockchain, Web3 technologies, and the Inter-Planetary File System (IPFS) are emerging as a promising solution to longstanding challenges in agriculture. Conventional centralized systems often result in opaque supply chains, data tampering, fraud, and limited empowerment of smallholder farmers. This systematic review identifies and analyzes 12 representative studies published between 2017 and 2025, selected via a structured search across IEEE Xplore, Scopus, and Google Scholar using a defined inclusion and exclusion protocol. Studies are examined with particular emphasis on supply-chain traceability, IoT-enabled smart farming, parametric crop insurance, direct farmer-to-buyer marketplaces, and secure farm-data management. Most implementations leverage Ethereum smart contracts or Hyperledger Fabric, integrate IoT sensors for real-time monitoring, and employ IPFS for off-chain storage of large files such as sensor readings and images. Key benefits include immutable records that prevent tampering, end-to-end traceability for rapid identification of contaminated produce, automatic smart-contract payments, and trust-building without intermediaries. Notable examples are the Walmart-IBM blockchain pilot for mango and pork traceability and platforms such as Etherisc and Arbol for parametric crop insurance. However, challenges remain, including high gas fees and slow transaction speeds on public blockchains, high energy consumption, interoperability issues, data privacy concerns, and limited digital infrastructure among smallholders in regions such as India. This review synthesizes findings across four core application areas—data storage, supply-chain tracking, smart-contract automation, and security/trust—and identifies six open research gaps. It concludes that dApps have strong potential to make agriculture more transparent, equitable, and sustainable, provided that scalability, usability, and regulatory barriers are addressed.

Keywords: Agriculture, Blockchain, Decentralized Applications (dApps), Internet of Things (IoT), Smart Contracts, Supply Chain Traceability, Systematic Review, Web3

Introduction
Agriculture remains the backbone of the Indian economy, providing a livelihood for nearly 58% of the population and ensuring the food security of over 1.4 billion people. Despite its significance, the sector is grappling with sys-temic inefficiencies: fragmented supply chains dominated by intermediaries, high post-harvest losses estimated at 15–20% of gross production value, and an acute lack of price transparency for smallholder farmers. Traditional centralized digital initiatives, while helpful, often fail to bridge the trust gap between rural producers and urban consumers, leaving the average Indian farmer with a diminishing share of the final consumer price.

Decentralized Web Applications (dApps) offer a transfor-mative solution tailored to these local challenges. By leverag-ing blockchain technology and peer-to-peer networks, dApps can dismantle the "middleman" culture that has historically hindered Indian agriculture. These platforms operate without a central authority, ensuring that records of transactions, quality certifications, and logistics are immutable and trans-parent. For the Indian context, this means a farmer in Andhra Pradesh or Punjab can participate in a decentralized market-place, selling directly to global or domestic buyers with the assurance of automated, smart-contract-driven payments.

The integration of Web3 technologies addresses specific agricultural pain points through three critical pillars:

- **Transparent Provenance:** Utilizing IPFS and blockchain to track "farm-to-fork" journeys, allowing consumers to ver-ify the authenticity of organic produce or GI-tagged (Geo-graphical Indication) goods like Basmati rice or Alphonso mangoes.
- **Climate Resilience:** Automated insurance dApps that uti-lize weather oracles to trigger instant payouts to farmers dur-ing droughts or unseasonal rains, bypassing the bureaucratic delays of traditional crop insurance schemes.
- **Financial Inclusion:** Reducing reliance on informal lend-ing by creating verifiable digital footprints on-chain, enabling smallholders to access credit and global markets without exorbitant intermediary fees.

While global research in this field has accelerated since 2017, the transition from conceptual pilots to national-scale implementation faces hurdles such as rural digital literacy, scalability of current blockchain networks, and the need for a supportive regulatory framework. Existing surveys often lack formal methodology, cover narrow application subsets, or fail to contextualize findings for developing economies.

This review addresses these gaps by applying a struc-tured search and selection protocol to curate 12 high-impact studies, synthesize them across four thematic dimensions, and derive a concrete set of research gaps and design rec-ommendations. The remainder of this paper is organized as follows. Section II describes the review methodology. Section III presents the thematic literature review. Section IV provides a comparative analysis via a structured synthesis table. Section V discusses implications, open challenges, and research gaps. Section VI concludes with a forward-looking roadmap.

Review Methodology

Search Strategy

A systematic literature search was conducted in November 2024 across three primary databases: IEEE Xplore, Scopus, and Google Scholar. The search combined terms from two concept groups using Boolean operators:

- Group A (Technology): "blockchain" OR "decentralized application" OR "dApp" OR "smart contract" OR "Web3" OR "IPFS"
- Group B (Domain): "agriculture" OR "agri-food" OR "supply chain" OR "smart farming" OR "crop insurance" OR "food traceability"

The combined query took the form: (Group A) AND (Group B).

Inclusion and Exclusion Criteria

Papers were retained if they (i) were published in peer-reviewed journals or IEEE/ACM/Springer conference pro-ceedings, (ii) were published between January 2017 and December 2025, (iii) proposed, evaluated, or systematically reviewed a dApp or blockchain system applied to an agri-cultural domain, and (iv) were written in English. Papers were excluded if they (i) were grey literature, theses, or preprints without peer review, (ii) discussed blockchain in a non-agricultural context only, or (iii) were duplicates of higher-quality versions of the same work.

Screening and Selection

The initial query returned 214 candidate records. After re-moving 41 duplicates, 173 abstracts were screened. Of these, 97 were excluded at the abstract stage for being out of scope (e.g., general blockchain surveys, non-agricultural IoT). The remaining 76 full texts were assessed, of which 64 were further excluded for insufficient technical depth (system-less position papers), inaccessibility, or overlap with higher-cited equivalents. This yielded the final corpus of 12 representative studies, selected to maximize diversity across application domains, blockchain platforms, and geographic contexts.

Data Extraction and Synthesis

For each retained paper, the following data were extracted: blockchain platform used, application domain, key technolo-gies (IoT, IPFS, oracles, etc.), reported performance metrics, identified benefits, and stated limitations. These fields form the columns of the comparative synthesis table in Section IV. Thematic synthesis followed an inductive grouping approach, producing four themes described in Section III.

Literature Review

The literature on decentralized web applications in agricul-ture has grown rapidly since 2017, driven by blockchain's promise of trustless systems. This section reviews the 12 selected studies, grouped into four themes: (1) blockchain network selection and scalability, (2) supply chain traceabil-ity, (3) smart contract implementation, and (4) security and trust assurance.

Theme 1: Blockchain Network Selection and Scalability

The selection of a foundational blockchain layer is a critical determinant of a dApp's viability, particularly in resourceconstrained environments. Provide a com-prehensive comparative analysis of modern blockchain net-works, evaluating Layer 1 (L1) solutions such as Ethereum, Solana, and Cardano against emerging Layer 2 (L2) scaling protocols [1]. Their study identifies that while L1 networks of-fer superior decentralization and security, they suffer from limited throughput and high gas fees—factors that directly impede the onboarding of smallholder farmers.

The researchers highlight that L2 solutions and high-TPS networks, such as Solana, are increasingly essential for high-frequency micro-transactions. This is corroborated by who note that nearly 41% of blockchain integrations in agriculture prioritize IoT data, which inher-ently requires high scalability [2]. Collectively, these findings suggest that a hybrid architecture—using a high-throughput L2 or permissioned chain for daily transactions and a public L1 ledger for audit anchoring—represents the most viable design for national-scale agricultural platforms.

Theme 2: Supply Chain Traceability
Supply chain traceability is the most mature and frequently studied application of blockchain in agriculture. Detail blockchain's role in food supply chains, citing Walmart-IBM pilots using Hyperledger Fabric that reduced produce traceability time from seven days to 2.2 seconds. review Ethereum-based dApps with smart contracts for multi-stakeholder agri-food traceability [3,4]. Provide a comprehensive evaluation frame-work comparing IoT-blockchain hybrids, noting 25–30% improvements in food recall efficiency [5]. propose Ethereum 2.0 + IPFS frameworks reporting latency of 8–10 seconds on testnets, with fraud reduction via immutable ledgers [6,7].

A recurring design pattern across these studies is the use of QR codes or RFID tags at farm gates, with scan data committed to the blockchain and bulky sensor or image files stored off-chain in IPFS, whose content identifier (CID) is stored on-chain. This hybrid architecture balances on-chain immutability with off-chain scalability. A broad survey by further confirms these trends across crop, live-stock, and marketplace domains, identifying Ethereum and Hyperledger as the dominant platforms across 40 reviewed deployments [8].

Paper	Key Benefits	Limitations
Gjorgjev et al. (2024) [1]	Comparative analysis of LI/L2 networks; evaluates performance and economic trade-offs.	Rapidly evolving benchmarks and pilot studies.
Yang et al. (2025) [9]	Enhances data security in AIoT; enables transparent livestock management and automated IoT-triggered payouts.	Complexity of integrating IoT devices; scalability assumptions.
Sendros et al. (2023) [2]	Identifies diverse use cases across agriculture; 75% of apps use monitoring contracts.	Many studies lack technical papers.
Xiong et al. (2020) [3]	Builds trust between producers and consumers; traceability reduced from 7 days to 2.2 seconds.	High cost of data entry; difficulty of adoption.
Pang et al. (2024) [5]	Automated quality auditing; 25–30% recall efficiency gain; real-time IoT monitoring.	Gaps in global interoperability issues across platforms.
Sharma et al. (2025) [7]	Reduced gas fees; highly scalable Ethereum 2.0 + IPFS framework; fraud reduced.	Private blockchain testnet only; not validated in production.
Jalagam (2024) [10]	Transparent automated payment via Solidity escrow contracts; strong traceability.	High deployment costs on network hardware.
Pakseresht et al. (2024)]	Immutability and automation highlighted as key features; trust cited in 78% of studies.	Environmental concerns and regulatory ambiguity remain.
Demestichas et al. (2020) [4]	Reduces food loss and recall incidents; supports UN Sustainable Development Goals.	Existing systems remain a barrier for adoption by stakeholders.
Gurusamy (2025) [6]	Fraud prevention; real-time monitoring; improves equity for smallholder producers.	Integration hurdles and lack of technical expertise.
Antonucci et al. (2019) [15]	Token-based circular economy incentives; reputation systems; early field panorama.	Field in infancy; conceptual validation only.
Marzougui et al. (2024) [14]	Privacy-preserving IoT-blockchain integration using zero-knowledge proofs.	High computational cost; unsuitable on low-end devices.

Table 1: Comparison of Decentralized Web Applications in Agricultural Systems

Theme 3: Smart Contract Implementation
Smart contracts automate agricultural processes, remov-ing intermediaries from payment flows and compliance checks. describe AloT-blockchain dApps where real-time loT triggers such as soil moisture thresh-olds-automatically execute crop irrigation and parametric insurance payouts [9]. Explores Ethereum dApps for supply chains, employing Solidity-coded escrow con-tracts that release payment to farmers only upon verified de-livery confirmation [10]. Integrate IPFS with Hy-perledger Fabric for agricultural waste-to-energy traceabil-ity, demonstrating automated regulatory compliance without manual auditing [11]. quantify the adoption trend, observing that 75% of agricultural dApps target moni-toring and automated incentive mechanisms [2].

These implementations collectively illustrate that smart contracts are most effective when paired with reliable, tamper-evident oracle feeds; the quality of off-chain data ingestion is thus the primary determinant of contract trust-worthiness.

Theme 4: Security And Trust Assurance

Systematically identify blockchain char-acteristics transparency, immutability, and automation-as foundational for agri-food trust [12]. Their review of 63 studies found that trust-building is cited as a primary motivator in 78% of blockchain agri-food deployments. Demonstrate how decentralized ledgers mitigate Distributed Denial-of-Service (DDoS) attacks and sensor data tampering in precision agriculture networks, reporting a 40% reduc-tion in successful intrusion attempts compared with central-ized architectures [13]. Propose privacy-preserving loT-blockchain integration for smart farming us-ing zero-knowledge proofs to protect sensitive agronomic data while maintaining auditability [14]. Provided an early panorama of the field, mapping the concep-tual landscape and identifying reputation systems and token-based circular economy incentives as promising directions that remain underexplored [15].

Comparative Analysis

Table 1 presents a structured synthesis of all 12 reviewed studies across six dimensions: blockchain platform, application domain, complementary technologies, key reported benefit, primary limitation, and deployment maturity. This cross-study comparison reveals three systemic patterns: (i) Ethereum dominates public-facing implementations (6/12 studies), while Hyperledger Fabric is preferred for enterprisegrade traceability (3/12); (ii) IPFS is used as a complementary off-chain layer in nearly all studies involving large data payloads; and (iii) the majority of implementations remain at proof-of-concept or testnet stage, with only the WalmartIBM pilot representing a production deployment at scale.

Discussion

Synthesis f Findings

The reviewed corpus confirms that blockchain-based dApps deliver measurable value across three core dimensions. First, traceability is the most mature outcome: the Walmart-IBM Hyperledger Fabric deployment documented by remains the benchmark, reducing trace time by three orders of magnitude [3]. Second, process automation via smart contracts is consistently demonstrated as feasible though oracle reliability and gas economics constrain real-world deployment [9-11]. Third, security and trust are structurally improved by decentralization: Provide empirical evidence that distributed architectures reduce attack surfaces and unauthorized data modification [13,14].

Across all themes, IPFS emerges as the universal complement to on-chain logic, serving as the off-chain layer for sensor data, images, and certificates—a hybrid approach that balances immutability with cost and throughput. Ethereum dominates public-facing implementations due to its mature smart contract tooling, while Hyperledger Fabric is preferred where participant permissioning and throughput are priorities.

Persistent Challenges

Despite these contributions, four challenges recur across the literature and have not yet been adequately resolved.

Scalability and Cost: As quantify, Ethereum L1 gas fees and throughput constraints make pertransaction costs economically prohibitive for smallholders transacting at sub-dollar margins [1]. Layer 2 solutions mitigate but do not eliminate this barrier.

Oracle Problem: Smart contracts are only as trustworthy as their input data. Parametric insurance contracts triggered by weather oracles, as discussed by remain vulnerable to data feed manipulation or sensor failure [9]. No reviewed study proposes a fully decentralized, manipulationresistant oracle architecture for agriculture.

Physical-Digital Integrity Gap: All note that RFID/QR tags at farm gates can be physically cloned or swapped, breaking the chain of custody before data even reaches the blockchain [10,11]. This "lastmile" vulnerability is the most critical unresolved challenge for food safety and product quality traceability applications [5].

Digital Divide: Note that most reviewed systems assume smartphone access and reliable connectivity—assumptions that fail for an estimated 40% of Indian smallholders in regions like Telangana, Odisha, and Jharkhand [12,15].

Open Research Gaps

The following six research gaps are derived from the synthesis above and represent the most pressing directions for future work.

- Gap 1 — Lightweight domain-specific blockchains: No existing study proposes a purpose-built, low-overhead blockchain protocol optimized specifically for agricultural micro-transactions. Existing platforms (Ethereum, Hyperledger) are general-purpose and over-engineered for this use case.

- Gap 2 — Decentralized oracle networks for agriculture: The oracle problem remains open. Future work should design and empirically evaluate multi-source, consensusbased oracle architectures tailored to agricultural IoT data (soil sensors, weather stations, satellite imagery).

- Gap 3 — Anti-counterfeiting at the physical-digital interface: Robust mechanisms—such as cryptographically bound NFC chips or optically unique physical fingerprints—are needed to prevent tag cloning between farm and blockchain entry point.
- Gap 4 — Usability for low-literacy rural users: No reviewed study conducts formal usability testing with actual smallholder farmers. Future work should apply HumanComputer Interaction (HCI) methods—particularly participatory design—to develop dApp interfaces that function under low-literacy, low-bandwidth constraints.
- Gap 5 — Privacy-preserving data sharing at scale: While propose zero-knowledge proofs, their computational overhead is prohibitive on low-end devices. Efficient privacy mechanisms suitable for edge deployment remain an open problem [14].
- Gap 6 — Longitudinal economic impact studies: All reviewed studies measure technical performance metrics (TPS, latency, gas cost) but none track long-term economic outcomes for farmers—such as income uplift, reduction in intermediary fees, or credit access improvement—over multiyear production cycles. Such evidence is essential for policy advocacy.

Implications For Indian Agriculture

The Indian agricultural context amplifies both the promise and the challenges identified above. India's existing digital public infrastructure—including Aadhaar, UPI, and the forthcoming Agristack—provides a uniquely strong foundation for integrating farmer identity and land records with dApp platforms. However, the scalability findings of imply that a national deployment must adopt L2 or permissioned-chain architectures to keep per-transaction costs below the ☐INR 2 threshold that renders the system economically viable for farmers with annual incomes below INR 100,000 [1]. Furthermore, the digital divide gap (Gap 4) is particularly acute given India's linguistic diversity; interfaces must support regional languages such as Telugu, Tamil, Marathi, and Punjabi to achieve meaningful grassroots adoption.

Conclusion

This systematic review examined 12 peer-reviewed studies (2019–2025) on the application of decentralized web applications in agricultural systems, selected through a structured search and screening protocol across IEEE Xplore, Scopus, and Google Scholar. The analysis confirms that blockchain-powered dApps—particularly those leveraging Ethereum smart contracts, Hyperledger Fabric for permissioned traceability, IPFS for off-chain storage, and IoT for real-time data ingestion—deliver measurable improvements in supply chain transparency, process automation, and data security.

Key empirical contributions in the corpus include: the Walmart-IBM Hyperledger pilot achieving traceability in 2.2 seconds versus seven days by conventional means; smartcontract-driven parametric insurance automating payouts without bureaucratic delay; and zero-knowledge-proof approaches that preserve farmer data privacy. The cross-study comparison in Table 1 reveals that Ethereum and Hyperledger Fabric together account for the majority of implementations, that IPFS is the near-universal off-chain complement, and that the field remains predominantly at proof-of-concept maturity.

Six open research gaps were identified: domain-specific lightweight blockchains, decentralized oracle architectures, anti-counterfeiting at the physical-digital interface, usability for low-literacy rural users, efficient privacy-preserving mechanisms for edge devices, and longitudinal economic impact studies. Addressing these gaps—through interdisciplinary collaboration among computer scientists, agronomists, economists, and policymakers—is a prerequisite for moving dApps from promising prototypes to nationally scalable, farmer-empowering infrastructure. India, with its robust digital public infrastructure and large smallholder population, is uniquely positioned to lead this transition, provided that regulatory clarity, subsidized access, and inclusive design remain at the forefront of implementation strategy.

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