International Journal of Basic and Applied Sciences, 14 (4) (2025) 256-268

International Journal of Basic and Applied Sciences

Website: www.sciencepubco.com/index.php/IJBAS
https://doi.org/10.14419/hy951113
Research paper

Fusion of Blockchain in The Digital Agriculture Food Supply Chain: A Comprehensive Review

Priya Patel [1], Nitesh Sureja [2] *

[1] Research Scholar, Department of Computer Science and Engineering, Krishna School of Emerging Technology and Applied Research, Drs. Kiran and Pallavi Patel University, Vadodara, INDIA
[2] Department of Computer Science & Engineering, Krishna School of Emerging Technology and Applied Research, Drs. Kiran and Pallavi Patel University, Vadodara, INDIA
**Corresponding author E-mail: nmsureja@gmail.com*

Received: June 30, 2025, Accepted: August 7, 2025, Published: August 10, 2025

Abstract

Blockchain technology operates as a decentralized digital ledger, ensuring data integrity and enabling asset tracking. Its unique features offer potential improvements to conventional agri-food supply chains. Blockchain-based traceability solutions enhance producers' ability to monitor their goods while fostering consumer confidence in product origins and authenticity. However, current research lacks a comprehensive evaluation of both the advantages and limitations of Blockchain in the agri-food sector. This study addresses that gap by conducting a systematic review of 153 research papers published in the duration of 2016 to 2024, answering six key research questions. The analysis explores the benefits and challenges of Blockchain adoption, particularly from an industry perspective. Key findings highlight crucial research areas, including the need for specialized training for both stakeholders and businesses, the integration of complementary technologies such as Big Data and Edge Computing, and the development of practical tools to support developers.

Keywords: *Agriculture; Blockchain; Smart contracts; Transparency; Security; Food supply chain*

1. Introduction

This Blockchain technology is a subset of Distributed Ledger Technologies (DLTs) and facilitates transaction recording across a decentralized network of nodes. By leveraging cryptographic methods, it ensures that once data is recorded, it remains unaltered, enhancing both security and transparency. This makes Blockchain an effective tool for tracking assets and verifying information integrity [1]. In the agri-food sector, Blockchain has the potential to revolutionize food traceability by enabling end-to-end tracking throughout the supply chain. From production to consumer purchase, every stage can be securely documented, improving accountability and strengthening consumer trust in food authenticity [2]. This system not only enhances food safety and quality control but also benefits producers by increasing their visibility in the supply chain.

Additionally, Blockchain can be employed to establish digital identities for food products, incorporating key details such as origin, production processes, and certifications. This level of traceability empowers consumers to make well-informed purchasing decisions while promoting sustainable and ethical food production practices. By increasing transparency and security within the supply chain, Blockchain technology can foster greater consumer confidence in the food industry. Despite its potential, a thorough evaluation of Blockchain-based traceability systems is still missing in existing literature, particularly concerning technical implementation, as well as their advantages and limitations. To bridge this gap, this study conducts a literature review to assess the maturity of Blockchain applications in the agri-food domain. Six key research questions are formulated to examine the role of Blockchain in supporting supply chain operations from both consumer and stakeholder perspectives. The analysis is based on 153 selected studies, identified and filtered using the PRISMA framework [3]. This review also explores industry involvement in adopting decentralized architectures and examines relevant security considerations. Furthermore, the paper outlines potential research directions for industry adoption and Blockchain developers.

The structure of this paper is as follows: Section II introduces Blockchain technology, highlighting its benefits within the agri-food supply chain industry and presenting a common system architecture. Section III reviews some existing literature and based on that, it provides the review strategy used in this review. Section IV discusses the review carried out based on the research questions framed. Lastly, Section V concludes with a discussion on key insights and future opportunities.

2. Background

2.1 Blockchain

Blockchain technology is characterized by its decentralized nature, with data distributed across multiple devices rather than being stored in a single centralized server. Unlike traditional systems, Blockchain and other Distributed Ledger Technologies (DLTs) operate independently of a central authority, allowing data to be shared and maintained collectively by all participants. Each participant in the network possesses a copy of the ledger, and any updates are synchronized across all copies, ensuring consistency and reliability. This decentralized approach enables Blockchain to function as a secure and trustworthy intermediary [4]. Once transactions are recorded on the Blockchain, they become permanent and immutable. These records are structured into blocks, and the computers responsible for processing Blockchain transactions are known as nodes.

The process of adding new blocks to the Blockchain, known as mining, involves solving complex cryptographic puzzles using hash functions. This computational process plays a crucial role in maintaining the integrity and security of the chain. To further enhance security, all shared data within the network is encrypted.

2.2 Application of blockchain in the agriculture food supply chain

The inherent features of Blockchain technology enable systems to be transparent and highly reliable. One of its key advantages is traceability, which is achieved through the immutability of recorded data. In the context of supply chains, traceability refers to the ability to reconstruct a product's journey from production to distribution [5]. This capability helps define the responsibilities of each participant in the supply chain, ensuring accountability and strengthening consumer confidence in food safety and quality. However, given the complexity and scale of supply chains, tracking products from raw materials to final consumers can be costly [6], necessitating an efficient and scalable solution. Such a system must be able to maintain consumer trust [7].

Blockchain technology provides a viable solution due to its unique characteristics: (i) it operates as a decentralized system, eliminating reliance on a single server that could create a point of failure, (ii) its immutability ensures that recorded data remains unchanged, making it easier to trace information while preventing tampering, and (iii) it can function as either a public or private system [8], [9], allowing it to be tailored to specific use cases while still ensuring transparency and fraud prevention.

Most proposed frameworks identify two primary participants: the end consumer and the producer. The producer role can extend to include farmers, distributors, and retailers, with each entity acting as a node within the decentralized network. Consumers can access immutable traceability data directly from their devices by scanning a QR code or using an RFID tag [10]. On the other hand, producers can input new data, which is managed by predefined smart contracts. These contracts play a critical role in verifying the authenticity of the data before it is added to the Blockchain. Additionally, data may also be collected from IoT sensors, processed by a central unit, and then recorded onto the Blockchain. The stored transactions can subsequently be uploaded to the InterPlanetary File System (IPFS) [11]. A widely accepted architecture summarizing various approaches to agri-food traceability through Blockchain technology is illustrated in Figure 1.

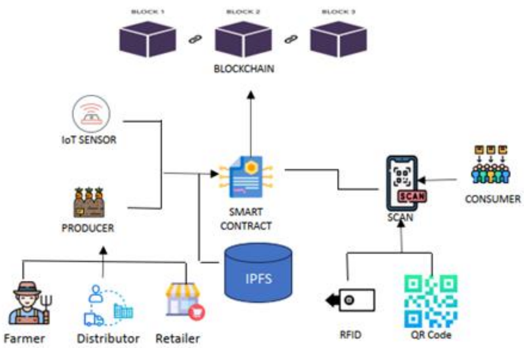

Fig. 1: Agri-food traceability through Blockchain.

The figure illustrates a comprehensive agri-food traceability framework leveraging Blockchain technology, IoT, and smart contracts to ensure transparency, security, and accountability across the food supply chain. The process begins with IoT sensors deployed at the production level, capturing real-time data related to environmental conditions, farming activities, or product handling. This data is then transmitted to a smart contract, which acts as an autonomous, self-executing protocol, ensuring that information is securely validated and stored. All validated data is logged onto the Blockchain ledger via multiple distributed nodes (Blocker 1, 2, and 3), ensuring immutability and decentralization. The system also integrates IPFS (InterPlanetary File System) for efficient, distributed data storage.

From the producer end, the data flows through key stakeholders—farmer, distributor, and retailer—with each transaction or movement being recorded in the blockchain. For end-user interaction, products are embedded with QR codes or RFID tags, which consumers can scan using their smartphones. This action retrieves the full traceability record—from origin to point-of-sale—offering transparency and fostering trust in the product's authenticity and safety. This blockchain-powered system thus strengthens traceability by creating an unalterable chain of data that all stakeholders, including consumers, can access and verify at any point in the agri-food supply chain.

3. Literature Review

Several literature reviews have explored Blockchain's role in supply chain management. Zhao et al. reviewed studies on Blockchain applications in supply chains up to 2019, covering manufacturing, water management, traceability, and security [1]. Niknejad et al. examined Blockchain in smart agriculture, emphasizing traceability and IoT sensors [12]. Other studies focus on Blockchain's integration with Industry 5.0 technologies, addressing food traceability, composition monitoring, and waste reduction [13]. Some reviews analyze cybersecurity concerns in Blockchain-based supply chains, while others assess technical implementations, noting limited real-world applications and cost-related challenges [14].

Taxonomy-based analyses have been conducted on Blockchain adoption models [15], with some studies focusing on sustainability in agri-food supply chains [16]. Research also highlights Blockchain's benefits, such as fraud prevention, decentralized structures, and improved quality control [17][18]. Additionally, studies examine adoption trends across different countries [19] and discuss Blockchain's early-stage development [20]. Another review applies a SWOT analysis to Blockchain adoption in supply chains, identifying benefits like anti-counterfeiting and increased trust while noting challenges such as industry standards and interoperability issues [21]. Our study differs by examining not only product traceability but also the broader impact of Blockchain on agri-food, security concerns, and the integration of additional technologies. We also assess industry participation and their willingness to adopt this technology, considering both advantages and limitations. This review covers literature from 2016 to 2024, aiming to help new researchers identify key areas in Blockchain-based agri-food traceability and explore future research directions.
To ensure a structured and systematic approach, this review on Blockchain in the agri-food Supply Chain was designed around six key research questions (RQs), addressing critical themes, trends, challenges, and security considerations. The review planning involved the following steps from 3.1 to 3.6.

3.1 Defining the Research Questions

The research questions were formulated using the PICOC framework to systematically investigate blockchain applications in agri-food supply chains:

- Population (P): Studies exploring blockchain applications in agri-food supply chains.
- Intervention (I): Blockchain-based solutions for traceability, transparency, and security.
- Comparison (C): Blockchain-based systems versus conventional supply chain management methods.
- Outcomes (O): Effectiveness in addressing stakeholder challenges, improving data accessibility, and ensuring security.
- Context (C): Implementation of blockchain in real-world agri-food supply chain environments.

The research questions guiding this review are:

- RQ1: What are the key research trends in blockchain for agri-food since 2016?
- RQ2: What main themes have been studied in blockchain and agriculture?
- RQ3: How can blockchain address stakeholder challenges in the agri-food supply chain?
- RQ4: What information can stakeholders access and integrate through blockchain?
- RQ5: What research gaps exist between blockchain's benefits and limitations?
- RQ6: How is security considered in blockchain applications, and to what extent?

3.2 Selecting Research Databases

To comprehensively capture relevant literature, a systematic search was conducted across three leading academic databases:
- IEEE Xplore – Covering blockchain innovations, smart contracts, and security applications.
- Scopus – Encompassing multidisciplinary research on agriculture, supply chain management, and blockchain integration.
- Science Direct – Providing access to peer-reviewed studies on blockchain applications in
- agri-food systems.

These databases were selected based on their extensive coverage of high-impact studies relevant to RQ1 (research trends) and RQ2 (main themes in blockchain and agriculture).

3.3 Developing a Search Strategy

To ensure comprehensive article extraction, the search strategy incorporated key terms aligned with the research questions: "Blockchain," "agri-food supply chain," "food traceability," "smart contracts," "supply chain transparency," "data integration," and "blockchain security." Boolean operators (AND, OR) were used to refine the search queries, ensuring a thorough examination of literature relevant to RQ3 (stakeholder challenges) and RQ4 (information access and integration).

3.4 Inclusion Criteria:

- Studies were included based on the following conditions to ensure relevance to RQ5 (research gaps in blockchain benefits and limitations) and RQ6 (security considerations in blockchain applications).
- Published between 2016 and 2024 in peer-reviewed journals (aligned with RQ1's focus on research trends).
- Focused on blockchain applications within agri-food supply chains, addressing traceability, security, and stakeholder collaboration.
- Provided quantitative or empirical findings on blockchain's effectiveness in the industry.
- Written in English to ensure accessibility and consistency across studies.

3.5 Exclusion Criteria:

The following studies were excluded to maintain methodological rigor:
- Review articles, editorials, and non-peer-reviewed studies.
- Studies unrelated to blockchain-based solutions in agri-food supply chains.
- Articles lacking empirical data on blockchain implementation, security, or stakeholder impact.

3.6 Performin1g Review

This step is divided and performed in the following two steps: 3.6.1 and 3.6.2

3.6.1 Primary Search: Identifying Relevant Studies

A structured search was conducted across three major databases, selected for their relevance to blockchain technology and supply chain management:

- IEEE Xplore – 94 records (blockchain innovations, smart contracts, security).
- Scopus – 79 records (blockchain applications in supply chains and agriculture).
- Science Direct – 84 records (peer-reviewed research on blockchain in agri-food systems).

This initial search yielded a total of 257 records. After removing 83 duplicates and out-of-scope records, the remaining 153 records were screened based on titles and abstracts to assess their relevance to the research questions:

- RQ1 (Research Trends in Blockchain for agri-food) → Studies covering blockchain developments from 2016 to 2024.
- RQ2 (Main Themes in Blockchain and Agriculture) → Studies categorizing blockchain applications in traceability, transparency, security, and efficiency.
- RQ3 (Stakeholder Challenges and Blockchain Solutions) → Studies discussing blockchain's role in improving trust, reducing fraud, and ensuring data integrity.

3.6.2 Secondary Search: Expanding Coverage

To strengthen the review's depth and rigor, a secondary search was conducted by:

- Reviewing the references of selected articles during the full-text review stage.
- Identifying additional relevant studies that aligned with RQ4 (Stakeholder Information Access & Integration) and RQ5 (Research Gaps Between Benefits & Limitations).
- Ensuring studies also addressed RQ6 (Security Considerations in Blockchain Applications), particularly regarding data protection, smart contracts, and encryption mechanisms.

To ensure transparency and reproducibility, the study selection process adhered strictly to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. This process was designed to systematically filter and assess the relevance of studies in alignment with the predefined research questions (RQ1–RQ6) and inclusion/exclusion criteria. A total of 153 studies met all criteria and were included in the final synthesis, forming the empirical foundation for analyzing:

- Blockchain trends and themes in the agri-food domain (RQ1, RQ2),
- Stakeholder-specific applications and challenges (RQ3, RQ4),
- Identified benefits vs. limitations and research gaps (RQ5),
- Blockchain security considerations across implementation contexts (RQ6).

This stepwise selection ensures methodological rigor, thematic coverage, and alignment with the review's objectives, as visualized in the PRISMA flow diagram (Figure 2) [22]. A PRISMA diagram (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) is a standardized flowchart used to transparently illustrate the selection process of studies included in a systematic review or meta-analysis. It helps readers understand how many records were identified through various sources (such as databases or manual searches), how many were screened, how many were excluded (and why), and how many were ultimately included in the qualitative and/or quantitative synthesis. The diagram is typically divided into four key phases: Identification, Screening, Eligibility, and Inclusion. In the Identification phase, all potential records are gathered. During Screening, duplicates are removed, and titles/abstracts are reviewed for relevance. In the Eligibility stage, full-text articles are assessed based on pre-defined inclusion/exclusion criteria. Finally, the included section lists the number of studies that meet all criteria and are included in the final analysis. The PRISMA diagram thus ensures transparency, reproducibility, and methodological rigor in literature reviews by clearly documenting each step of the study selection process. Following the screening process, 153 studies were selected. Data extraction and classification address the research questions, as summarized in Table 1. Table 2 gives a literature review idea in tabular form.

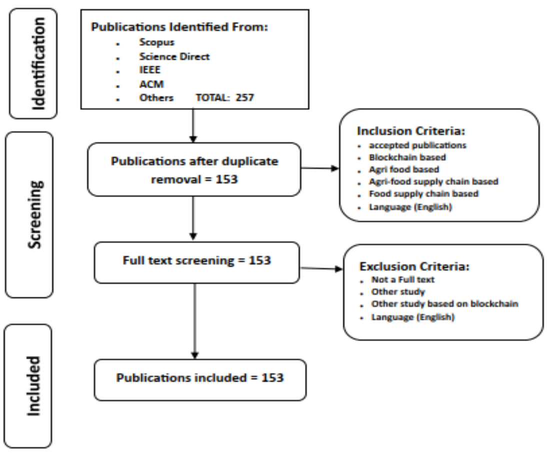

Fig.2: Research Methodology for Literature Review based on PRISMA

Table 1: Research questions and their answers

Data	Answer	RQ
Year of Publication	Since 2016	RQ1
Type of search	How is the topic analyzed?	RQ1
Area of Search	What type of analysis is performed?"	RQ2
Knowledge or software-based	Is the study focused on software or knowledge?	RQ2
Target problem solution	How is the target problem solved?	RQ3
Industries involvement	Is the industry involved?	RQ3
Information about the Product	What aspect of the product does the publication cover?	RQ4
Additional technologies	Which additional technologies were used?	RQ4
boundaries and benefits gap.	Are benefits greater than limitations?	RQ5
Traceability (Security) Topic	Is the Traceability analyzed?	RQ6

4. Results and Discussion

In this section, we show the main results obtained after the analysis of the selected papers. Results are categorized based on the RQs identified in Section 2. Table 2 shows the selected papers' details based on the research questions. This systematic review explores how blockchain is being used to help agri-food supply chains. To ensure accuracy and reliability, the study followed a clear, structured approach. paragraphs must be justified alignment. With justified alignment, both sides of the paragraph are straight.

Table 2: Literature Review details based on Research Questions

Research Question	References
RQ1	[9] [11] [12] [13] [22] [13] [22] [41] [42] [43] [44] [45] [47] [49] [50] [52] [58] [62] [70] [72] [90] [94] [100] [101] [106] [108] [110] [126] [141] [145] [151] [153] [[159]
RQ2	[10] [11] [12] [13] [14] [16] [18] [22] [25] [41] [42] [43] [44] [45] [46] [47] [48] [50] [51] [53] [54] [[55] [56] [57] [58] [59] [60] 61] [62] [63] [64] [65] [66] [67] [68] [69] [70] [71] [72] [[73] [74] [75] [76] [77] [78] [79] [80] [81] [82] [83] 84] [85] [86] [87] [88] [89] [91] [92] [[93] [94] [95] [96] [97] [98] [99] [100] [103] [104] [105] [106] [107] [109] [111] [112] [113] [114] [117] [118] [121] [125] [127] [129] [130] [131] [134] [135] [136] [138] [142] [149] [150] [152] [155] [169] [172] [174]
RQ3	[1] [5] [6] [7] [8] [10] [14] [15] [19] [20] [21] [23] [26] [30] [32] [33] [34] [35] [42] [49] [53] [55] [56] [63] [69] [73] [83] [86] [87] [91] [93] [95] [96] [103] [104] [107] 121] [123] [127] [129] [130] 131] [133] [135] 137] [138] [143] [148] [154] [158] [161] [162] [165] [171]
RQ4	[1] [5] [6] [7] [8] [10] [14] [15] [19] [20] [25] [27] [28] [29] [31] [34] [35] [36] [37] [38] [39] [40] [41] [43] [46] [48] [49] [50] [51] [52] [[54][55] [56] [57] [60] [61] [63] [66] [67] [68] 69] [71] [75] [80] [81] [82] [[84] [92] [93] [98] [105] [107] [111] [112] [114] [125] [133] [139] [147] [156] [164] [173]
RQ5	[12] [15] [16] [19] [24] [25] [[58] [64] [72] [74] [88] [90] [101] [102] [115] [116] [119] [124] [132] [144] [160] [167] [170]
RQ6	[5] [6] [8] [10] [15] [20] [26] [37] [38] [39] [44] [45] [48] [57] [61] [75] [76] [77] [78] [85] [89] [97] [99] [117] [118] [119] [128] [136] [137] [139] [140] [146] [157] [166] [168]

4.1 RQ1: Blockchain Research Trends in Agri-food Since 2016

Figure 3 shows a growing interest in Blockchain for agri-food, with research increasing over time. A slight decline between 2020 and 2021 may be due to the pandemic, but practical implementations began gaining traction from 2022 to address rising food demand [23].
Figure 4 categorizes the studies:

- 47% propose new solutions, but many remain unvalidated.
- 8% focus on implementations, though adoption is slow due to Blockchain's immaturity.
- 20% provide evaluative opinions, 10% focus on validation, and 15% are experimental, indicating ongoing practical assessments.

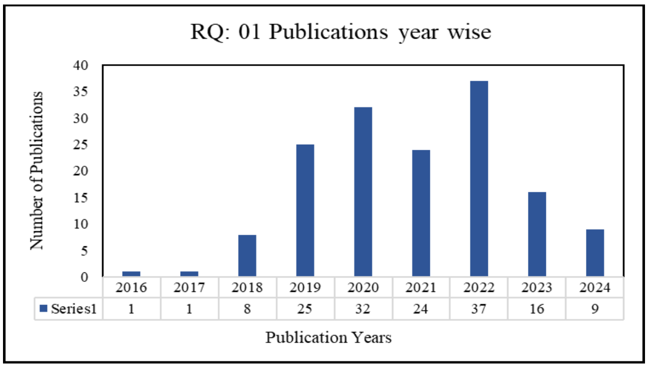

Fig. 3: Publication's distribution.

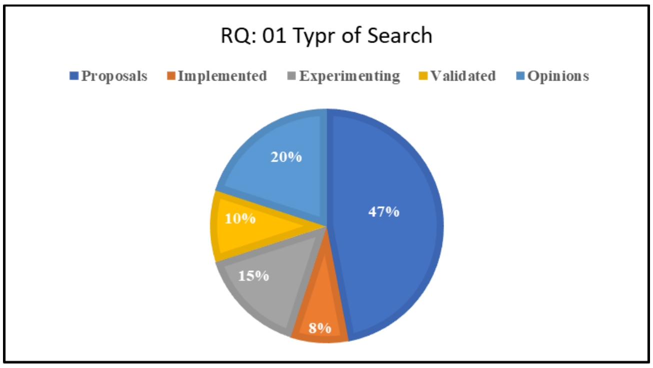

Fig. 4: Publication's distribution search type.

4.2 RQ2: Key Research Themes in Blockchain and Agriculture

Figure 5 shows the focus areas. Here, 57 papers cover technology, 37 discuss architecture, 13 papers represent business, 7 papers discuss quality, 16 papers discuss reliability, and 23 address performance. In addition to this, 78 software-based papers and 75 knowledge-based studies maintain a balance between technological development and theoretical advancements. Despite Blockchain's potential, several challenges affect real-world adoption [14]:

- Technical barriers: A gap exists between research and real-world application.
- Limited diffusion: Some sectors lack advanced traceability systems.
- Early-stage adoption: Investment risks hinder widespread use.
- Scalability issues: Expanding distributed networks can be complex.

Validating Blockchain solutions across all supply chain participants remains essential.

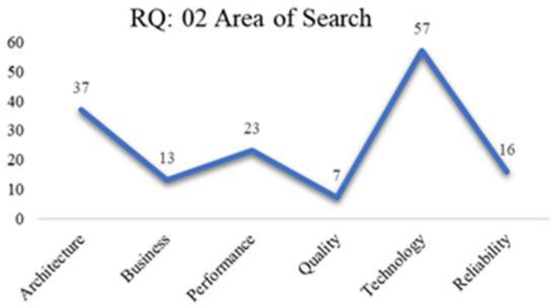

Fig. 5: Publication's distribution area of search.

4.3 RQ3: How Can Blockchain Address Stakeholder Challenges in Agri-food?

Blockchain enhances product identification, supply chain management, and traceability, as evidenced in 79 of the analyzed studies. It ensures end-to-end transparency by tracking agricultural products from production through distribution to retail. However, only four papers explicitly focus on interoperability—a critical but underexplored area. This limited attention is primarily due to the technical and organizational complexities involved in integrating Blockchain with legacy client-server architectures, enterprise resource planning (ERP) systems, and diverse IoT platforms. Unlike greenfield implementations, real-world supply chains often rely on heterogeneous IT infrastructures, which lack standard protocols for blockchain interoperability. Additionally, many current Blockchain solutions are designed in silos, without considering data formats, APIs, or governance models needed for seamless integration across systems and stakeholders.

The underrepresentation of interoperability in research has significant implications for adoption. Without interoperable solutions, stakeholders—especially SMEs and traditional agricultural operators—face high entry barriers, including data migration challenges, operational disruptions, and vendor lock-in risks. This discourages adoption and limits Blockchain's scalability across regions and sectors. Moreover, lack of interoperability hinders cross-border trade, real-time regulatory compliance, and data sharing across multiple supply chain actors. Transitioning to interoperable Blockchain systems also requires substantial investment in infrastructure, workforce training, and standards development—all of which remain underfunded and insufficiently coordinated.

Consequently, industry participation remains low, with 114 studies excluding direct industry involvement (only 8 involved actual industrial collaborators). This lack of engagement further slows down the development of practical, interoperable systems, as industries should ideally co-develop standards and lead quality assurance initiatives. While research interest in Blockchain peaked around 2018, a noticeable decline occurred post-2020, possibly due to the shift toward emerging technologies like AI or edge computing. Additionally, the absence of mature developer tools and integration frameworks continues to hinder real-world implementation of Blockchain-based traceability systems.

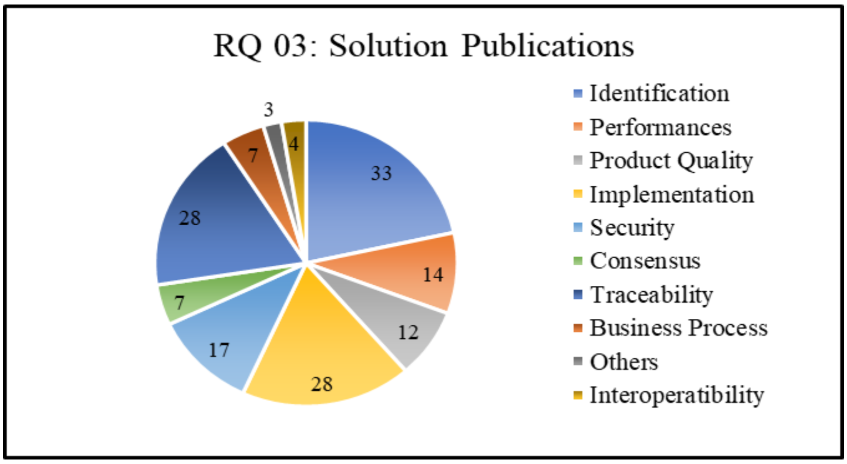

Fig. 6: Publication's distribution Solution.

4.4 RQ4: What Information Can Stakeholders Access Through Blockchain?

Blockchain optimizes agri-food traceability by recording a product's origin, transport, storage, and processing details (Figure 6). It also supports quality certification standards like HACCP, reducing counterfeiting risks and enhancing food safety.

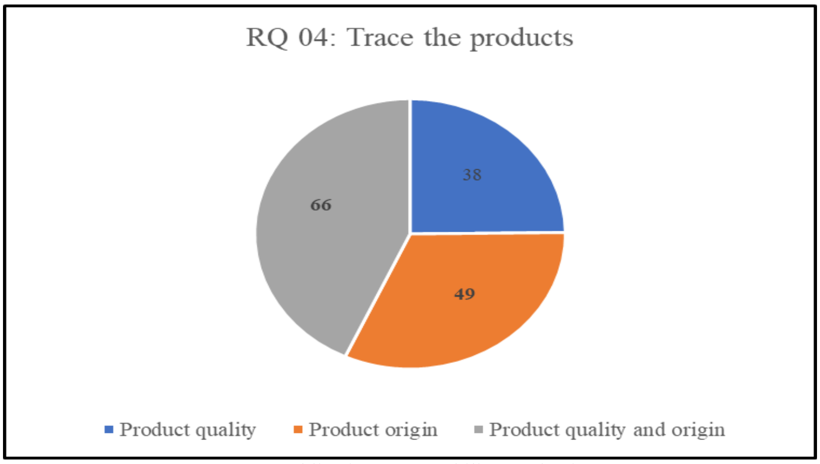

Fig. 7: Publication's Traceability mechanism.

The study also shows increased use of IoT and Big Data alongside Blockchain. IoT sensors help monitor factors like humidity, temperature, and transportation conditions. Edge computing further enhances data security and consumer interactions, making supply chains more efficient.

4.5 RQ5: What Are the Research Gaps Between Blockchain's Benefits and Limitations?

Studies highlight Blockchain's potential in agri-food supply chains but also its challenges, particularly in security and consensus mechanisms. Key benefits include product traceability, defect identification, and streamlined data management, all contributing to improved customer trust and operational efficiency. Additional advantages are:

- Supply chain enhancement
- Smart agriculture and predictive analytics
- Perishable food management
- Integration with existing technologies
- Crop monitoring via decision-support systems
- Regulations influencing stakeholder adoption

However, adoption barriers remain. Many stakeholders hesitate due to complexity, financial constraints, and regulatory uncertainty. Over 76% of studies lack real industry applications, highlighting a gap between research and practice. Additionally, the absence of user-friendly Blockchain tools, IoT integration, and initial investment support limits adoption. Shifting research focus from consumer trust to business confidence and practical tools could drive wider industry acceptance.

4.6 RQ6: How Is Security Addressed in Blockchain Applications?

Security in Blockchain-based traceability is gaining significant research attention. Among the 153 studies reviewed, 83 comprehensively address both data security and traceability, 37 focus specifically on infrastructure-level security, and 25 emphasize traceability assurance mechanisms. Only 8 studies fail to explicitly consider security aspects. Blockchain's inherent decentralization, immutability, and transparency naturally enhance fraud resistance and data integrity, especially when integrated with IoT in agri-food supply chains.

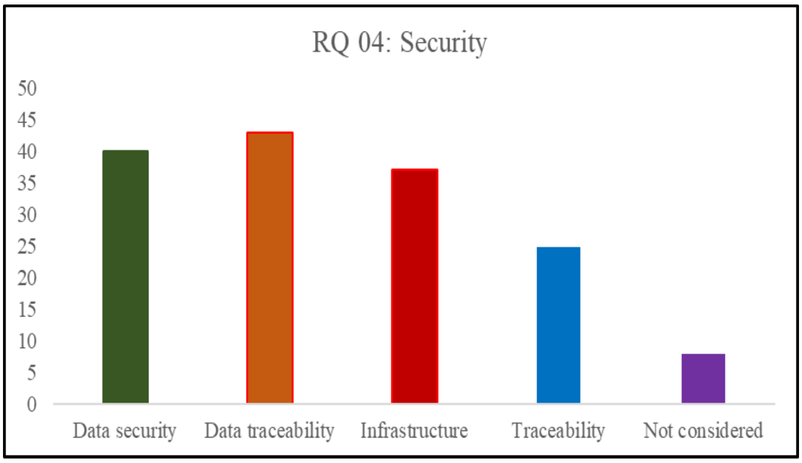

Fig. 8: Publication's security mechanism.

As IoT adoption continues to expand in agricultural environments—tracking environmental data, logistics, and product conditions—the demand for robust security architectures also grows. This is particularly important due to IoT's vulnerability to attacks such as spoofing, tampering, or data interception. Blockchain's ability to secure these data streams through distributed consensus and encrypted storage becomes essential.

Many studies, including Vangala et al. (2021) [77, 78], emphasize the use of cryptographic hash functions (e.g., SHA-256) to ensure data integrity. These hash functions generate unique, fixed-size outputs from input data, making tampering evident and enabling secure, verifiable records in the blockchain ledger. This is crucial in traceability applications, where even a minor alteration in supply chain records could lead to significant economic or public health consequences.

Digital signatures (based on public-private key cryptography) further enhance security by verifying the authenticity of transactions and participants (e.g., farmers, distributors). Elliptic Curve Cryptography (ECC) is increasingly adopted due to its strong security with lower computational overhead, making it suitable for resource-constrained IoT devices.

Consensus mechanisms such as Proof-of-Work (PoW), Proof-of-Stake (PoS), and Practical Byzantine Fault Tolerance (PBFT) play a central role in securing the blockchain network. While PoW offers strong resistance to tampering, it is energy-intensive and less suitable for agri-food systems with lightweight nodes. In contrast, PBFT and PoS are preferred in permissioned or consortium blockchains deployed in agricultural contexts due to their lower energy demands and faster finality.

However, several security vulnerabilities have been identified in this integration. For instance, smart contract exploits, such as reentrancy attacks, integer overflows, or logic errors, can compromise traceability systems if contracts are not rigorously tested or audited. Moreover, Sybil attacks and 51% attacks remain concerns in public blockchain implementations.

5. Conclusion

This paper reviews literature on Blockchain-based agri-food traceability, analyzing 153 studies from an initial pool of 257 references. The selection process ensures scientific validity through strict inclusion and exclusion criteria, offering a comprehensive overview of Blockchain's role in agri-food supply chains. Interest in this field has grown since 2016, shifting from theoretical proposals to practical implementations. While 55% of studies focus on technological aspects, 45% explore their application in food traceability. However, industry adoption remains limited, partly due to a lack of stakeholder involvement and disruptions caused by the pandemic.

Blockchain offers significant advantages across the supply chain: brands can enhance trust and sales, distributors benefit from transparent and tamper-proof supply chain management, and consumers gain product traceability through technologies like QR codes. The integration of IoT further strengthens traceability by enabling real-time access to detailed product information, including chemical composition and provenance, via smartphones. To promote wider adoption and bridge the gap between research and practice, this review recommends the following actionable strategies:

- Develop open-source, lightweight Blockchain toolkits tailored for small-scale farmers and cooperatives, enabling cost-effective adoption without requiring deep technical expertise.
- Establish industry-wide interoperability standards, as emphasized by Casino et al. (2021) [27], to facilitate seamless integration of Blockchain with existing ERP and supply chain systems, thereby reducing deployment complexity and vendor lock-in.
- Encourage the exploration and deployment of hybrid Blockchain architectures—combining public and private ledgers—to strike a balance between transparency and data privacy, particularly when handling sensitive production or trade data.
- Design capacity-building initiatives and training programs in collaboration with agricultural extension services and rural ICT centers to educate businesses and farmers on Blockchain's operational and economic benefits.
- Foster collaborative efforts between academia, industry, and government agencies to develop scalable frameworks integrating Blockchain with Big Data and Edge Computing, ensuring efficient real-time traceability across diverse agro-ecosystems.

These steps are critical not only for scaling Blockchain adoption in agri-food traceability but also for ensuring equitable participation, regulatory compliance, and long-term sustainability of digital agriculture systems.

Acknowledgement

We thank all who have helped us directly and indirectly.

References

[1]. M. Garaus and H. Treiblmaier, ''The influence of blockchain-based food traceability on retailer choice: The mediating role of trust,'' Food Control, vol. 129, Nov.2021, Art. no. 108082.

[2]. K. Petersen, R. Feldt, S. Mujtaba, and M. Mattsson, ''Systematic mapping studies in software engineering,'' in 12th International Conference on Evaluation and Assessment in Software Engineering., University of Bari, Italy, Jun. 2008, pp. 1–10.

[3]. M. M. Aung and Y. S. Chang, ''Traceability in a food supply chain: Safety and quality perspectives,'' Food Control, vol. 39, pp. 172–184, May 2014.

[4]. T. Bosona and G. Gebresenbet, ''Food traceability as an integral part of logistics management in food and agricultural supply chain,'' Food Control, vol. 33, no. 1, pp. 32–48, Sep. 2013.

[5]. B. M. Yakubu, R. Latif, A. Yakubu, M. I. Khan, and A. I. Magashi, ''RiceChain: Secure and traceable Rice supply chain framework using blockchain technology,'' PeerJ Computer Science, vol. 8, pp. e801, Jan. 2022.

A. Tan, D. Gligor, and A. Ngah, ''Applying blockchain for halal food traceability,'' International Journal of Logistics Research and Applications, vol. 25, no. 6, pp. 947–964, Jun. 2022.

[6]. K. Kampan, T. W. Tsusaka, and A. K. Anal, ''Adoption of blockchain technology for enhanced traceability of livestock-based products,'' Sustainability, vol. 14, no. 20, pp. 13148, Oct. 2022.

A. Shahid, A. Almogren, N. Javaid, F. A. Al-Zahrani, M. Zuair, and M. Alam, ''Blockchain-based agri-food supply chain: A complete solution,'' IEEE Access, vol. 8, pp. 69230–69243, 2020.

[7]. N. Niknejad, W. Ismail, M. Bahari, R. Hendradi, and A. Z. Salleh, ''Mapping the research trends on blockchain technology in food and agriculture industry: A bibliometric analysis,'' Environmental Technology & Innovation, vol. 21, Feb. 2021, Art. no. 101272.

[8]. S. A. Bhat, N.-F. Huang, I. B. Sofi, and M. Sultan, ''Agriculture-food supply chain management based on blockchain and IoT: A narrative on enterprise blockchain interoperability,'' Agriculture, vol. 12, no. 1, pp. 40, Dec. 2021.

[9]. T. K. Dasaklis et al., ''A systematic literature review of blockchain-enabled supply chain traceability implementations,'' Sustainability, vol. 14, no. 4, pp. 2439, Feb. 2022.

[10]. D. T. Bhatia, ''Digitalization of agri-food supply chain with blockchain technology: A review, taxonomy and open research issues,'' Tech. Rep.

[11]. G. P. Agnusdei and B. Coluccia, ''Sustainable agrifood supply chains: Bibliometric, network and content analyses,'' Science of the Total Environment, vol. 824, Jun. 2022, Art. no. 704.

[12]. M. Alobid, S. Abujudeh, and I. Szűcs, ‘‘The role of blockchain in revolutionizing the agricultural sector,’’ Sustainability, vol. 14, no. 7, pp. 4313, Apr. 2022.
[13]. S. Tanwar, A. Parmar, A. Kumari, N. K. Jadav, W.-C. Hong, and R. Sharma, ‘‘Blockchain adoption to secure the food industry: Opportunities and challenges,’’ Sustainability, vol. 14, no. 12, pp. 7036, Jun. 2022.
[14]. U. Marfuah et al., ‘‘Blockchain traceability for agroindustry— A literature review and future agenda,’’ in IOP Conference Series: Earth and Environmental Science, vol. 1063, no. 1, Jul. 2022, Art. no. 012056.
[15]. B. Kitchenham and S. Charters, ‘‘Guidelines for performing systematic literature reviews in software engineering,’’ Technical reports, 2007.
[16]. R. B. Ayed, M. Hanana, S. Ercisli, R. Karunakaran, A. Rebai, and F. Moreau, ‘‘Integration of innovative technologies in the agri-food sector: The fundamentals and practical case of DNA-based traceability of olives from fruit to oil,’’ Plants, vol. 11, no. 9, pp. 1230, May 2022.
[17]. Y. Kayikci, N. Subramanian, M. Dora, and M. S. Bhatia, ‘‘Food supply chain in the era of industry 4.0: Blockchain technology implementation opportunities and impediments from the perspective of people, process, performance, and technology,’’ Production Planning & Control, vol. 33, nos., pp. 301–321, 2020.
[18]. L. Cocco, R. Tonelli, and M. Marchesi, ‘‘Blockchain and self-sovereign identity to support quality in the food supply chain,’’ Future Internet, vol. 13, no. 12, p. 301, Nov. 2021.
[19]. M. P. Kramer, L. Bitsch, and J. H. Hanf, ‘‘The impact of instrumental stakeholder management on blockchain technology adoption behavior in agri-food supply chains,’’ Journal of Risk and Financial Management, vol. 14, no. 12, p. 598, Dec. 2021.
[20]. J. P. Domínguez and P. Roseiro, ‘‘Blockchain: A brief review of agrifood supply chain solutions and opportunities, ’Advances in Distributed Computing and Artificial Intelligence Journal, vol. 9, no. 4, pp. 95–106, Dec. 2020.
[21]. G. Zhao, S. Liu, and C. Lopez, ‘‘A literature review on risk sources and resilience factors in agri-food supply chains,’’ in 18th Working Conference on Virtual Enterprises, Vicenza, Italy, Sep 2017,. pp.739-752.
[22]. J. F. Galvez, J. C. Mejuto, and J. Simal-Gandara, ‘‘Future challenges on the use of blockchain for food traceability analysis,’’ TrAC, Trends in Analytical Chemistry, vol. 107, pp. 222–232, Oct. 2018.
[23]. H. Feng, X. Wang, Y. Duan, J. Zhang, and X. Zhang, ‘‘Applying blockchain technology to improve agri-food traceability: A review of development methods, benefits and challenges,’’ Journal of Cleaner Production, vol. 260, Jul. 2020, Art. no. 121031.
[24]. L. Marchesi, K. Mannaro, and R. Porcu, ‘‘Automatic generation of blockchain agri-food traceability systems,’’ in IEEE/ACM 4th International Workshop on Emerging Trends in Software Engineering for Blockchain, Madrid, Spain, May 2021, pp. 41–48.
[25]. F. Casino, V. Kanakaris, T. K. Dasaklis, S. Moschuris, S. Stachtiaris, M. Pagoni, and N. P. Rachaniotis, ‘‘Blockchain-based food supply chain traceability: A case study in the dairy sector,’’ international journal of production research, vol. 59, no. 19, pp. 5758–5770, Oct. 2021.
[26]. X. Lin, S.-C. Chang, T.-H. Chou, S.-C. Chen, and A. Ruangkanjanases, ‘‘Consumers’ intention to adopt blockchain food traceability technology towards organic food products, ’International Journal of Environmental Research and Public Health, vol. 18, no. 3, pp. 912, Jan. 2021.
A. Scuderi, V. Foti, and G. Timpanaro, ‘‘The supply chain value of POD and PGI food products through the application of blockchain,’’ Calitatea, vol. 20, no. S2, pp. 580–587, 2019.
[27]. D. Syromyatnikov, A. Geiko, S. Kuashbay, and A. Sadikbekova, ‘‘Agile supply chain management in agricultural business, ’International Journal of Supply Chain Management, vol. 9, no. 3, p. 377, 2020.
[28]. J. D. Borrero, ‘‘Agri-food supply chain traceability for fruit and vegetable cooperatives using blockchain technology,’’ Revista de Economía Pública, Social y Cooperativa, vol. 95, pp. 71–94, Jan. 2019.
[29]. M. P. Kramer, L. Bitsch, and J. Hanf, ‘‘Blockchain and its impacts on agrifood supply chain network management,’’ Sustainability, vol. 13, no. 4, p. 2168, Feb. 2021.
[30]. N. Amarfii-Railean, ‘‘Streamlining management in the agri-food sector through blockchain technology, ’Eastern European Journal for Regional Studies, vol. 6, no. 2, pp. 92–107, 2020.
[31]. U. Sengupta and H. M. Kim, ‘‘Meeting changing customer requirements in food and agriculture through the application of blockchain technology,’’ Frontiers Blockchain, vol. 4, p. 5, Feb. 2021.
[32]. H. Fu, C. Zhao, C. Cheng, and H. Ma, ‘‘Blockchain-based agri-food supply chain management: Case study in China,’’ International journal of Food Agribusiness Management Review, vol. 23, no. 5, pp. 667–679, Dec. 2020.
[33]. F. Casino, V. Kanakaris, T. K. Dasaklis, S. Moschuris, and N. P. Rachaniotis, ‘‘Modeling food supply chain traceability based on blockchain technology,’’ IFAC-PapersOnLine, vol. 52, no. 13, pp. 2728–2733, 2019.
[34]. R. B. dos Santos, N. M. Torrisi, and R. P. Pantoni, ‘‘Third party certification of agri-food supply chain using smart contracts and blockchain tokens,’’ Sensors, vol. 21, no. 16, pp. 5307, Aug. 2021.
A. B. Abdulhussein, A. K. Hadi, and M. Ilyas, ‘‘Design a tracing system for a seed supply chain based on blockchain,’’ in 2020 3rd International Conference on Engineering Technology and its Applications, AL-Najaf, Iraq, Sep. 2020, pp. 209–214.
[35]. Arena, A. Bianchini, P. Perazzo, C. Vallati, and G. Dini, ‘‘BRUSCHETTA: An IoT blockchain-based framework for certifying extra virgin olive oil supply chain,’’ in IEEE International Conference on Smart Computing, Jun. 2019, pp. 173–179.
[36]. J. Astill, R. A. Dara, M. Campbell, J. M. Farber, E. D. G. Fraser, S. Sharif, and R. Y. Yada, ‘‘Transparency in food supply chains: A review of enabling technology solutions,’’ Trends in Food Science and Technology, vol. 91, pp. 240–247, Sep. 2019.
[37]. G. Baralla, A. Pinna, and G. Corrias, ‘‘Ensure traceability in European food supply chain by using a blockchain system,’’ in IEEE International Conference on Smart Computing, Washington, DC, USA, 2019, pp. 381-386.
[38]. D. Bumblauskas, A. Mann, B. Dugan, and J. Rittmer, ‘‘A blockchain use case in food distribution: Do you know where your food has been?,” International Journal of Information Management, 52, Jun. 2020, Art. no. 102008.
[39]. Yu, Y. Zhan, and Z. Li, ‘‘Using blockchain and smart contract for traceability in agricultural products supply chain,’’ in Proc. Int. Conf. Internet Things Intell. Appl. (ITIA), Nov. 2020, pp. 1–5.
[40]. M. P. Caro, M. S. Ali, M. Vecchio, and R. Giaffreda, ‘‘Blockchainbased traceability in agri-food supply chain management: A practical implementation,’’ in IoT Vertical and Topical Summit on Agriculture – Tuscany, Tuscany, Italy, May 2018, pp. 1–4.
[41]. H. Chen, Z. Chen, F. Lin, and P. Zhuang, ‘‘Effective management for blockchain-based agri-food supply chains using deep reinforcement learning,’’ IEEE Access, vol. 9, pp. 36008–36018, 2021.
[42]. P. Chun-Ting, L. Meng-Ju, H. Nen-Fu, L. Jhong-Ting, and S. Jia-Jung, ‘‘Agriculture blockchain service platform for farm-to-fork traceability with IoT sensors,’’ in International Conference on Information Networking. Barcelona, Spain, Jan. 2020, pp. 158–163.
[43]. M. Creydt and M. Fischer, ‘‘Blockchain and more–Algorithm driven food traceability,’’ Food Control, vol. 105, pp. 45–51, Nov. 2019.
[44]. X. Dong, X. Zheng, X. Lu, and X. Lin, ‘‘A traceability method based on blockchain and Internet of Things,’’ in Intl Conf on Parallel & Distributed Processing with Applications, Big Data & Cloud Computing, Sustainable Computing & Communications, Social Computing & Networking, Xiamen, China, Dec. 2019, pp. 1511–1518.
[45]. F. Tian, ‘‘An agri-food supply chain traceability system for China based on RFID & blockchain technology,’’ in 13th International Conference on Service Systems and Service Management, Kunming, China, Jun. 2016, pp. 1–6.
[46]. F. Tian, ‘‘A supply chain traceability system for food safety based on HACCP, blockchain & Internet of Things,’’ in International Conference on Service Systems and Service Management, Dalian, China, 2017, pp. 1–6.
[47]. R. George, H. Harsh, P. Ray, and A. Babu, ‘‘Food quality traceability prototype for restaurants using blockchain and food quality data index, “Journal of Cleaner Production, vol. 240, Dec. 2019, Art. no. 118021.
A. Haroon, M. Basharat, A. M. Khattak, and W. Ejaz, ‘‘Internet of Things platform for transparency and traceability of food supply chain,’’ in IEEE 10th Annual Information Technology, Electronics and Mobile Communication Conference, Vancouver, BC, Canada, 2019, pp. 13–19.
[48]. H. Hayati and I. G. B. B. Nugraha, ‘‘Blockchain based traceability system in food supply chain,’’ in International Seminar on Research of Information Technology and Intelligent Systems, Yogyakarta, Indonesia, 2018, pp. 378-383.

[49]. W. Hong, Y. Cai, Z. Yu, and X. Yu, ‘‘An agri-product traceability system based on IoT and blockchain technology,’’ in IEEE International Conference on Hot Information-Centric Networking, Zhenzhen, China, Aug. 2018, pp. 254–255.
[50]. J. Jaiyen, S. Pongnumkul, and P. Chaovalit, ‘‘A proof-of-concept of farmer-to-consumer food traceability on blockchain for local communities,’’ in International Conference on Computer Science and Its Application in Agriculture, Bogor, Indonesia, Sep. 2020, pp. 1–5.
[51]. S. S. Kamble, A. Gunasekaran, and R. Sharma, ‘‘Modeling the blockchain enabled traceability in agriculture supply chain,’’ International Journal of Information Management, vol. 52, Jun. 2020, Art. no. 101967.
[52]. M. Kim, B. Hilton, Z. Burks, and J. Reyes, ‘‘Integrating blockchain, smart contract-tokens, and IoT to design a food traceability solution,’’ in IEEE 9th Annual Information Technology, Electronics and Mobile Communication Conference, Vancouver, British Columbia, Canada, Nov. 2018, pp. 335–340.
[53]. S. Köhler and M. Pizzol, ‘‘Technology assessment of blockchain-based technologies in the food supply chain,’’ Journal of Cleaner Production, vol. 269, Oct. 2020, Art. no. 122193.
[54]. M.-J. Lee, J.-T. Luo, J.-J. Shao, and N.-F. Huang, ‘‘A trustworthy food resume traceability system based on blockchain technology,’’ in International Conference on Information Networking, Jeju Island, Korea (South), Jan 2021, pp. 546-552.
[55]. J. Li and X. Wang, ‘‘Research on the application of blockchain in the traceability system of agricultural products,’’ in 2nd IEEE Advanced Information Management, Communicates, Electronic and Automation Control Conference, Xi'an, China, May 2018, pp. 2637–2640.
[56]. Q. Lin, H. Wang, X. Pei, and J. Wang, ‘‘Food safety traceability system based on blockchain and EPCIS,’’ IEEE Access, vol. 7, pp. 20698–20707, 2019.
[57]. W. Lin, X. Huang, H. Fang, V. Wang, Y. Hua, J. Wang, H. Yin, D. Yi, and L. Yau, ‘‘Blockchain technology in current agricultural systems: From techniques to applications,’’ IEEE Access, vol. 8, pp. 143920–143937, 2020.
[58]. K. S. Loke and O. C. Ann, ‘‘Food traceability and prevention of location fraud using blockchain,’’ 8th IEEE Region 10 Humanitarian Technology Conference, Kuching, Malaysia, Dec. 2020, pp. 1–5.
[59]. S. Madumidha, P. S. Ranjani, U. Vandhana, and B. Venmuhilan, ‘‘A theoretical implementation: Agriculture-food supply chain management using blockchain technology,’’ in TEQIP III Sponsored International Conference on Microwave Integrated Circuits, Photonics and Wireless Networks, Tiruchirappalli, India, May 2019, pp. 174–178.
[60]. D.-H. Nguyen, N. H. Tuong, and H.-A. Pham, ‘‘Blockchain-based farming activities tracker for enhancing trust in the community supported agriculture model,’’ in International Conference on Information and Communication Technology Convergence, Jeju, Korea (South), Oct 2020, pp. 737–740.
[61]. P. S, Meeradevi, and M. R. Mundada, ‘‘Analysis of agricultural supply chain management for traceability of food products using blockchain Ethereum technology,’’ in IEEE International Conference on Distributed Computing, VLSI, Electrical Circuits and Robotics, Udupi, India, Oct. 2020, pp. 127–132.
[62]. Pérez, R. Risco, and L. Casaverde, ‘‘Analysis of the implementation of blockchain as a mechanism for digital and transparent food traceability in Peruvian social programs,’’ in IEEE XXVII International Conference on Electronics, Electrical Engineering and Computing, Lima, Peru, Sep. 2020, pp. 1–4.
[63]. G. M. T. Pradana, T. Djatna, and I. Hermadi, ‘‘Blockchain modeling for traceability information system in supply chain of coffee agroindustry,’’ in International Conference on Advanced Computer Science and Information Systems, Depok, Indonesia, pp. 217–224.
[64]. Qian, W. Wu, Q. Yu, L. Ruiz-Garcia, Y. Xiang, L. Jiang, Y. Shi, Y. Duan, and P. Yang, ‘‘Filling the trust gap of food safety in food trade between the EU and China: An interconnected conceptual traceability framework based on blockchain,’’ Food and Energy Security, vol. 9, no. 4, Nov. 2020, Art. no. e249.
[65]. M. A. S. Rünzel, E. E. Hassler, R. E. L. Rogers, G. Formato, and J. A. Cazier, ‘‘Designing a smart honey supply chain for sustainable development,’’ IEEE Consumer Electronics Magazine, vol. 10, no. 4, pp. 69–78, Jul. 2021.
[66]. Salah, N. Nizamuddin, R. Jayaraman, and M. Omar, ‘‘Blockchain based soybean traceability in agricultural supply chain,’’ IEEE Access, vol. 7, pp. 73295–73305, 2019.
[67]. S. Saurabh and K. Dey, ‘‘Blockchain technology adoption, architecture, and sustainable agri-food supply chains,’’ Journal of Cleaner Production, vol. 284, Feb. 2021, Art. no. 124731.
[68]. S. Shaikh, M. Butala, R. Butala, and M. Creado, ‘‘AgroVita using blockchain,’’ in IEEE 5th International Conference for Convergence in Technology, Bombay, India, March 2019, pp. 1-5.
[69]. S. Stranieri, F. Riccardi, M. P. M. Meuwissen, and C. Soregaroli, ‘‘Exploring the impact of blockchain on the performance of agri-food supply chains,’’ Food Control, vol. 119, Jan. 2021, Art. no. 107495.
[70]. Y. P. Tsang, K. L. Choy, C. H. Wu, G. T. S. Ho, and H. Y. Lam, ‘‘Blockchain-driven IoT for food traceability with an integrated consensus mechanism,’’ IEEE Access, vol. 7, pp. 129000–129017, 2019.
[71]. Tse, B. Zhang, Y. Yang, C. Cheng, and H. Mu,‘‘Blockchain application in food supply information security,’’ in Proc. IEEE Int. Conf. Ind. Eng. Eng. Manage., Dec. 2017, pp. 1357–1361.
A. Vangala, A. K. Das, N. Kumar, and M. Alazab, ‘‘Smart secure sensing for IoT-based agriculture: Blockchain perspective,’’IEEE Sensors Journal., vol. 21, no. 16, pp. 17591–17607, Aug. 2021.
[72]. Vangala, A. K. Sutrala, A. K. Das, and M. Jo, ‘‘Smart contract based blockchain-envisioned authentication scheme for smart farming,’’ IEEE Internet of Things Journal., vol. 8, no. 13, pp. 10792–10806, Jul. 2021.
[73]. S. Voulgaris, N. Fotiou, V. A. Siris, G. C. Polyzos, A. Tomaras, and S. Karachontzitis, ‘‘Hierarchical blockchain topologies for quality control in food supply chains,’’ in Proc. Eur. Conf. Netw. Commun., Jun. 2020, pp. 139–143.
[74]. Wang, L. Xu, Z. Zheng, S. Liu, X. Li, L. Cao, J. Li, and C. Sun, ‘‘Smart contract-based agricultural food supply chain traceability,’’ IEEE Access, vol. 9, pp. 9296–9307, 2021.
[75]. W. Xie, X. Zheng, X. Lu, X. Lin, and X. Fan, ‘‘Agricultural product traceability system based on blockchain technology,’’ in Proc. IEEE Int. Conf Parallel Distrib. Process. With Appl., Big Data Cloud Comput., Sustain. Comput. Commun., Social Comput. Netw., Dec. 2019, pp. 1266–1270.
[76]. X. Yang, M. Li, H. Yu, M. Wang, D. Xu, and C. Sun, ‘‘A trusted blockchain-based traceability system for fruit and vegetable agricultural products,’’ IEEE Access, vol. 9, pp. 36282–36293, 2021.
[77]. J.-Y. Yeh, S.-C. Liao, Y.-T. Wang, and Y.-J. Chen, ‘‘Understanding consumer purchase intention in a blockchain technology for food traceability and transparency context,’’ in Proc. IEEE Social Implications Technol. (SIT) Inf. Manage., Nov. 2019, pp. 1–6.
[78]. W. Yu and S. Huang, ‘‘Traceability of food safety based on block chain and RFID technology,’’ in Proc. 11th Int. Symp. Comput. Intell. Design, vol. 1, Dec. 2018, pp. 339–342.
[79]. X. Zhang, P. Sun, J. Xu, X. Wang, J. Yu, Z. Zhao, and Y. Dong, ‘‘Blockchain-based safety management system for the grain supply chain,’’ IEEE Access, vol. 8, pp. 36398–36410, 2020.
[80]. G. Baralla, S. Ibba, M. Marchesi, R. Tonelli, and S. Missineo, ‘‘A blockchain based system to ensure transparency and reliability in food supply chain,’’ in. Europian Conference on Parallel Processing. Cham, Switzerland, 2018, pp. 379–391.
[81]. M. A. L. Basnayake and C. Rajapakse, ‘‘A blockchain-based decentralized system to ensure the transparency of organic food supply chain,’’ in International Research Conference on Smart Computing and Systems Engineering (SCSE), Colombo, Sri Lanka, Mar. 2019, pp. 103–107.
[82]. Shakhbulatov, A. Arora, Z. Dong, and R. Rojas-Cessa, ‘‘Blockchain implementation for analysis of carbon footprint across food supply chain,’’ in International Conference on Smart Blockchain. Cham, Switzerland, Jul. 2019, pp. 546–551.
[83]. S. Mondal, K. P. Wijewardena, S. Karuppuswami, N. Kriti, D. Kumar, and P. Chahal, ‘‘Blockchain inspired RFID-based information architecture for food supply chain,’’ IEEE Internet of Things Journal., vol. 6, no. 3, pp. 5803–5813, Jun. 2019.

[84]. R. M. A. Latif, S. Iqbal, O. Rizwan, S. U. A. Shah, M. Farhan, and F. Ijaz, ‘‘Blockchain transforms the retail level by using a supply chain rules and regulation,’’ in 2nd International Conference on Communication, Computing and Digital systems (C-CODE), Islamabad, Pakistan, Mar. 2019, pp. 264–269.
[85]. Q. Tao, X. Cui, X. Huang, A. M. Leigh, and H. Gu, ‘‘Food safety supervision system based on hierarchical multi-domain blockchain network,’’ IEEE Access, vol. 7, pp. 51817–51826, 2019.
[86]. H. Huang, X. Zhou, and J. Liu, ‘‘Food supply chain traceability scheme based on blockchain and EPC technology,’’ in International Conference on Smart Blockchain. Cham, Switzerland, Jul 2019, pp. 32–42.
[87]. Markovic, P. Edwards, and N. Jacobs, ‘‘Recording provenance of food delivery using IoT, semantics and business blockchain networks,’’ in Sixth International Conference on Internet of Things: Systems, Management and Security (IOTSMS), Granada, Spain, Oct. 2019, pp. 116–118.
A. Kamilaris, A. Fonts, and F. X. Prenafeta-Boldú, ‘‘The rise of blockchain technology in agriculture and food supply chains,’’ Trends in Food Science and Technology, vol. 91, pp. 640–652, Sep. 2019.
[88]. S. Madumidha, P. S. Ranjani, S. S. Varsinee, and P. S. Sundari, ‘‘Transparency and traceability: In food supply chain system using blockchain technology with Internet of Things,’’ in 3rd International Conference on Trends in Electronics and Informatics, Tirunelveli, india, Apr. 2019, pp. 983–987.
[89]. S. H. Awan, A. Nawaz, S. Ahmed, H. A. Khattak, K. Zaman, and Z. Najam, ‘‘Blockchain based smart model for agricultural food supply chain,’’ in International Conference on UK-China Emerging Technologies, Glasgow, UK, Aug. 2020, pp. 1–5.
[90]. R. Miron, M. Hulea, and S. Folea, ‘‘Food allergens monitoring system backed-up by blockchain technology,’’ in IEEE International Conference on Automation, Quality and Testing, Robotics (AQTR), Cluj-Napoca, Romania, May 2020, pp. 1–4.
[91]. B. Yu, P. Zhan, M. Lei, F. Zhou, and P. Wang, ‘‘Food quality monitoring system based on smart contracts and evaluation models,’’ IEEE Access, vol. 8, pp. 12479–12490, 2020.
A. Biscotti, C. Giannelli, C. F. N. Keyi, R. Lazzarini, A. Sardone, C. Stefanelli, and G. Virgilli, ‘‘Internet of Things and blockchain technologies for food safety systems, ’in IEEE International Conference on Smart Computing, Bologna, Italy, Sep. 2020, pp. 440–445.
[92]. L. Hou, R. Liao, and Q. Luo, ‘‘IoT and blockchain-based smart agri-food supply chains,’’ Handbook Smart Cities, 2020, pp. 1–22.
[93]. Kshetri and J. DeFranco, ‘‘The economics behind food supply blockchains,’’ Computer, vol. 53, no. 12, pp. 106–110, Dec. 2020.
[94]. M. Enescu and V. M. Ionescu, ‘‘Using blockchain in the agri-food sector following SARS-CoV-2 pandemic,’’ in 12th International Conference on Electronics, Computers and Artificial Intelligence (ECAI), Bucharest, Romania, Jun. 2020, pp. 1–6.
[95]. V. Sudha, R. Kalaiselvi, and P. Shanmughasundaram, ‘‘Blockchain based solution to improve the supply chain management in Indian agriculture,’’ in nternational Conference on Artificial Intelligence and Smart Systems (ICAIS), Coimbatore, India, Mar. 2021, pp. 1289–1292.
[96]. S. Yasmin, M. F. A. A. Sohan, M. N. B. Anwar, M. Hasan, and G. M. F. Hossain, ‘‘SFC: A lightweight blockchain model for smart food industry,’’ in 2nd International Conference on Robotics, Electrical and Signal Processing Techniques (ICREST), DHAKA, Bangladesh, Jan. 2021, pp. 699–703.
A. Marchese and O. Tomarchio, ‘‘A blockchain-based system for agrifood supply chain traceability management,’’ SN Computer Science, vol. 3, no. 4, pp. 1–21, May 2022.
[97]. Ehsan, M. I. Khalid, L. Ricci, J. Iqbal, A. Alabrah, S. S. Ullah, and T. M. Alfakih, ‘‘A conceptual model for blockchain-based agriculture food supply chain system,’’ Scientific Programming, vol. 2022, pp. 1–15, Feb. 2022.
[98]. Y. Lu, P. Li, and H. Xu, ‘‘A food anti-counterfeiting traceability system based on blockchain and Internet of Things, Proceedia Computer Scence, vol.199, pp. 629–636, Jan. 2022.
[99]. B. Bigliardi, E. Bottani, and S. Filippelli, ‘‘A study on IoT application in the food industry using keywords analysis,’’ Proceedia Computer Scence, vol. 200, pp. 1826–1835, Jan. 2022.
[100]. Q. Tao, Z. Cai, and X. Cui, ‘‘A technological quality control system for Rice supply chain,’’ Food and Energy Security, vol. 12, no. 2, Mar. 2023, Art. no. e382.
[101]. M. E. Latino, M. Menegoli, and A. Corallo, ‘‘Agriculture digitalization: A global examination based on bibliometric analysis,’’ IEEE Transactions on Engineering Management, Mar. 30, 2022.
[102]. X. Cui and Z. Gao, ‘‘Application of Internet of Things and traceability technology in the whole industrial chain in mountainous areas by blockchain,’’ in 2022 IEEE 2nd International Conference on Power, Electronics and Computer Applications , Shenyang, China, Jan. 2022, pp. 720–723.
[103]. L. Marchesi, K. Mannaro, M. Marchesi, and R. Tonelli, ‘‘Automatic generation of Ethereum-based smart contracts for agri-food traceability system,’’ IEEE Access, vol. 10, pp. 50363–50383, 2022.
[104]. Y. Zhang, L. Chen, M. Battino, M. A. Farag, J. Xiao, J. Simal-Gandara, H. Gao, and W. Jiang, ‘‘Blockchain: An emerging novel technology to upgrade the current fresh fruit supply chain,’’ Trends in Food Science and Technology, vol. 124, pp. 1–12, Jun. 2022.
[105]. Burgess, F. Sunmola, and S. Wertheim-Heck, ‘‘Blockchain enabled quality management in short food supply chains,’’ Proceedia Computer Science, vol. 200, pp. 904–913, Jan. 2022.
[106]. S. L. Bager, C. Singh, and U. M. Persson, ‘‘Blockchain is not a silver bullet for agro-food supply chain sustainability: Insights from a coffee case study,’’ Current Research in Environmental Sustainability, vol. 4, Jan. 2022, Art. no. 100163.
[107]. H. H. Khan, M. N. Malik, Z. Konečná, A. G. Chofreh, F. A. Goni, and J. J. Klemeš, ‘‘Blockchain technology for agricultural supply chains during the COVID-19 pandemic: Benefits and cleaner solutions,’’ Journal of Cleaner Production, vol. 347, May 2022, Art. no. 131268.
[108]. Luo, R. Liao, J. Li, X. Ye, and S. Chen, ‘‘Blockchain enabled credibility applications: Extant issues, frameworks and cases,’’ IEEE Access, vol. 10, pp. 45759–45771, 2022.
[109]. S. Bökle, D. S. Paraforos, D. Reiser, and H. W. Griepentrog, ‘‘Conceptual framework of a decentral digital farming system for resilient and safe data management,’’ Smart Agriculture Technology, vol. 2, Dec. 2022, Art. no. 100039.
[110]. B. Subashini and D. Hemavathi, ‘‘Detecting the traceability issues in supply chain industries using blockchain technology,’’ in International Conference on Advances in Computing, Communication and Applied Informatics, Chennai, India, Jan. 2022, pp. 1–8.
A. Ferrari, M. Bacco, K. Gaber, A. Jedlitschka, S. Hess, J. Kaipainen, P. Koltsida, E. Toli, and G. Brunori, ‘‘Drivers, barriers and impacts of digitalisation in rural areas from the viewpoint of experts,’’ Information and Software Technology, vol. 145, May 2022, Art. no. 106816.
[111]. Moretto and L. Macchion, ‘‘Drivers, barriers and supply chain variables influencing the adoption of the blockchain to support traceability along fashion supply chains,’’ Operations Management Research, vol. 15, pp. 1470–1489, Mar. 2022.
[112]. Kowalska and L. Manning, ‘‘Food safety governance and guardianship: The role of the private sector in addressing the EU ethylene oxide incident,’’ Foods, vol. 11, no. 2, p. 204, Jan. 2022.
[113]. S. Rao, S. Shukla, and Rizwana, ‘‘Food traceability system in India,’’ Meas., Food, vol. 5, Feb. 2022, Art. no. 100019.
[114]. S. Jin, W. Li, Y. Cao, G. Jones, J. Chen, Z. Li, Q. Chang, G. Yang, and L. J. Frewer, ‘‘Identifying barriers to sustainable apple production: A stakeholder perspective,’’ Journal of Environmental Management, vol. 302, Jan. 2022, Art. no. 114082.
[115]. P. Agnusdei, B. Coluccia, V. Elia, and P. P. Miglietta, ‘‘IoT technologies for wine supply chain traceability: Potential application in the Southern Apulia Region (Italy),’’ Procedia Computer Science, vol. 200, pp. 1125–1134, Jan. 2022.
[116]. Chauhan, V. Parida, and A. Dhir, ‘‘Linking circular economy and digitalisation technologies: A systematic literature review of past achievements and future promises,’’Technological Forecasting and Social Change, vol. 177, Apr. 2022, Art. no. 121508.
[117]. Kannan, M. Pattnaik, G. Karthikeyan, E. Balamurugan, P.J. Augustine, and J. J. Lohith, ‘‘Managing the supply chain for the crops directed from agricultural fields using blockchains, ’in International Conference on Electronics and Renewable Systems (ICEARS), Tuticorin, India, 2022, pp. 908-913.
[118]. Ravi, S. Ramachandran, R. Vignesh, V. R. Falmari, and M. Brindha, ‘‘Privacy preserving transparent supply chain management through hyperledger fabric,’’Blockchain Research and Applications, vol. 3, no. 2, Jun. 2022, Art. no. 100072.

[119]. N. Singh and P. Bagade, ‘‘Quality, food safety and role of technology in food industry,’’ in Thermal Food Engineering Operations, 2022, pp. 415–454.
[120]. F. Anastasiadis, I. Manikas, I. Apostolidou, and S. Wahbeh, ‘‘The role of traceability in end-to-end circular agri-food supply chains,’’ Industrial Marketing Management, vol. 104, pp. 196–211, Jul. 2022.
[121]. Bala and P. D. Kaur, ‘‘Transparent subsidized agri-product distribution during pandemics with reputation based PoA blockchain,’’ Concurrency and Computation: Practice and Experience, vol. 34, no. 22, Oct. 2022, Art. no. e6863
[122]. V. S. Narwane, A. Gunasekaran, and B. B. Gardas, ‘‘Unlocking adoption challenges of IoT in Indian agricultural and food supply chain,’’Smart Agricultural Technology, vol. 2, Dec. 2022, Art. no. 100035.
[123]. Treiblmaier and M. Garaus, ‘‘Using blockchain to signal quality in the food supply chain: The impact on consumer purchase intentions and the moderating effect of brand familiarity,’’International Journal of Information Management, vol. 68, Feb. 2023, Art. no. 102514.
[124]. M. E. Latino, M. Menegoli, M. Lazoi, and A. Corallo, ‘‘Voluntary traceability in food supply chain: A framework leading its implementation in agriculture 4.0,’’ Technological Forecasting and Social Change, vol. 178, May 2022, Art. no. 121564.
[125]. Compagnucci, D. Lepore, F. Spigarelli, E. Frontoni, M. Baldi, and L. D. Berardino, ‘‘Uncovering the potential of blockchain in the agri-food supply chain: An interdisciplinary case study,’’ Journal of Engineering and Technology Management, vol. 65, Jul. 2022, Art. no. 101700.
A. H. Adow, M. K. Shrivas, H. F. Mahdi, M. M. A. Zahra, D. Verma, N. V. Doohan, and A. Jalali, ‘‘Analysis of agriculture and food supply chain through blockchain and IoT with light weight cluster head,’’ Computational Intelligence and Neuroscience, vol. 2022, pp. 1–11, Aug. 2022.
[126]. S. Cao, M. Foth, W. Powell, T. Miller, and M. Li, ‘‘A blockchain-based multi signature approach for supply chain governance: A use case from the Australian beef industry,’’Blockchain Research and Applications, vol. 3, no. 4, Dec. 2022, Art. no. 100091.
[127]. D. Sekuloska and A. Erceg, ‘‘Blockchain technology toward creating a smart local food supply chain,’’ Computers, vol. 11, no. 6, p. 95, Jun. 2022.
[128]. Zhai, A. Sher, and Q. Li, ‘‘The impact of health risk perception on blockchain traceable fresh fruits purchase intention in China,’’ International Journal of Environmental Research and Public Health, vol. 19, no. 13, p. 7917, Jun. 2022.
[129]. Lei, S. Liu, N. Luo, X. Yang, and C. Sun, ‘‘Trusted-auditing chain: A security blockchain prototype used in agriculture traceability,’’ Heliyon, vol. 8, no. 11, Nov. 2022, Art. no. e11477.
[130]. O. Okorie, J. Russell, Y. Jin, C. Turner, Y. Wang, and F. Charnley, ‘‘Removing barriers to blockchain use in circular food supply chains: Practitioner views on achieving operational effectiveness,’’ Cleaner Logistics Supply Chain, vol. 5, Dec. 2022, Art. no. 100087.
[131]. Bettín-Díaz, A. E. Rojas, and C. Mejía-Moncayo, ‘‘Colombian origin coffee supply chain traceability by a blockchain implementation,’’ Operations Research Forum, vol. 3, p. 64, Nov. 2022.
A. Pakseresht, A. Yavari, S. A. Kaliji, and K. Hakelius, ‘‘The intersection of blockchain technology and circular economy in the agri-food sector,’’ Sustainable production and consumption, vol. 35, pp. 260–274, Jan. 2023.
[132]. Singh, A. Gutub, A. Nayyar, and M. K. Khan, ‘‘Redefining food safety traceability system through blockchain: Findings, challenges and open issues,’’ Multimedia Tools Appllications, vol. 82, pp. 21243–21277, Oct. 2022.
[133]. Ktari, T. Frikha, F. Chaabane, M. Hamdi, and H. Hamam, ‘‘Agricultural lightweight embedded blockchain system: A case study in olive oil,’’ Electronics, vol. 11, no. 20, p. 3394, Oct. 2022.
[134]. Parvathi, M. Girish, M. G. Sandeep, and K. Abhiram, ‘‘Secured blockchain technology for agriculture food supply chain,’’ Journal of pharmaceutical negative results, pp. 357–361, Sep. 2022.
[135]. Tharatipyakul, S. Pongnumkul, N. Riansumrit, S. Kingchan, and S. Pongnumkul, ‘‘Blockchain-based traceability system from the users’ perspective: A case study of Thai coffee supply chain,’’ IEEE Access, vol. 10, pp. 98783–98802, 2022.
[136]. P. Liu, Z. Zhang, and Y. Li, ‘‘Investment decision of blockchain-based traceability service input for a competitive agri-food supply chain,’’ Foods, vol. 11, no. 19, p. 2981, Sep. 2022.
[137]. F.-J. Ferrández-Pastor, J. Mora-Pascual, and D. Díaz-Lajara, ‘‘Agricultural traceability model based on IoT and blockchain: Application in industrial hemp production,’’ Journal of Industrial Information Integration, vol. 29, Sep. 2022, Art. no. 100381.
[138]. Bosona and G. Gebresenbet, “The role of blockchain technology in promoting traceability systems in Agri-food production and supply chains,” Sensors, vol. 23, no. 11, p. 5342, Jun. 2023, doi: 10.3390/s23142.
[139]. Md. N. Mowla, N. Mowla, A. F. M. S. Shah, K. M. Rabie, and T. Shongwe, “Internet of Things and Wireless sensor networks for smart agriculture Applications: a survey,” IEEE Access, vol. 11, pp. 145813–145852, Jan. 2023, doi: 10.1109/access.2023.3346299.
[140]. S. Menon and K. Jain, “Blockchain Technology for Transparency in Agri-food Supply Chain: use cases, limitations, and future directions,” IEEE Transactions on Engineering Management, vol. 71, pp. 106–120, Oct. 2021, doi: 10.1109/tem.2021.3110903.
[141]. K. Tsolakis, C. A. Keramydas, A. K. Toka, D. A. Aidonis, and E. T. Iakovou, “Agrifood supply chain management: A comprehensive hierarchical decision-making framework and a critical taxonomy,” Biosystems Engineering, vol. 120, pp. 47–64, Nov. 2023, doi: 10.1016/j.biosystemseng.2013.10.014.
[142]. Hamulczuk, K. Pawlak, J. Stefańczyk, and J. Gołębiewski, “Agri-food Supply and Retail Food Prices during the Russia–Ukraine Conflict’s Early Stage: Implications for Food Security,” Agriculture, vol. 13, no. 11, p. 2154, Nov. 2023, doi: 10.3390/agriculture13112154.
[143]. J. Kuizinaitė, M. Morkūnas, and A. Volkov, “Assessment of the most appropriate measures for mitigation of risks in the Agri-food supply chain,” Sustainability, vol. 15, no. 12, p. 9378, Jun. 2023, doi: 10.3390/su15129378.
[144]. R. Granillo-Macías, I. J. G. Hernández, and E. Olivares-Benítez, “Logistics 4.0 in the agri-food supply chain with blockchain: a case study,” International Journal of Logistics Research and Applications, vol. 27, no. 10, pp. 1766–1786, Feb. 2023, doi: 10.1080/13675567.2023.2184467.
[145]. Ş. İndap and M. Tanyaş, “Blockchain applications for traceability and food safety in agri-food supply chain: cherry product application,” Journal of Enterprise Information Management, Jul. 2023, doi: 10.1108/jeim-03-2023-0165.
A. Sharma, A. Sharma, R. K. Singh, and T. Bhatia, “Blockchain adoption in agri-food supply chain management: an empirical study of the main drivers using extended UTAUT,” Business Process Management Journal, vol. 29, no. 3, pp. 737–756, Mar. 2023, doi: 10.1108/bpmj-10-2022-0543.
[146]. Fiore and M. Mongiello, “Blockchain Technology to Support Agri-food Supply Chains: A Comprehensive review,” IEEE Access, vol. 11, pp. 75311–75324, Jan. 2023, doi: 10.1109/access.2023.3296849.
[147]. Q. Zhang, S. Khan, S. U. Khan, and I. U. Khan, “Understanding blockchain Technology adoption in operation and supply chain management of Pakistan: extending UTAUT model with technology readiness, technology affinity and trust,” SAGE Open, vol. 13, no. 4, Oct. 2023, doi: 10.1177/21582440231199320.
A. Al-Ashmori, G. Thangarasu, P. D. D. Dominic, and A.-B. A. Al-Mekhlafi, “A readiness model and factors influencing blockchain adoption in Malaysia’s software sector: a survey study,” Sustainability, vol. 15, no. 16, p. 12139, Aug. 2023, doi: 10.3390/su151612139.
[148]. W. A. Khan and Z. U. Abideen, “Effects of behavioural intention on usage behaviour of digital wallet: the mediating role of perceived risk and moderating role of perceived service quality and perceived trust,” Future Business Journal, vol. 9, no. 1, Sep. 2023, doi: 10.1186/s43093-023-00242-z.
[149]. Vu, A. Ghadge, and M. Bourlakis, “Blockchain adoption in food supply chains: a review and implementation framework,” Production Planning & Control, vol. 34, no. 6, pp. 506–523, Jun. 2021, doi: 10.1080/09537287.2021.1939902.
[150]. S. P. S. Ibrahim, S. M. Sumetha, P. L. Indumalini, and B. S. Gupta, “Agri food supply chain using blockchain,” Applied and Computational Engineering, vol. 8, no. 1, pp. 387–393, Jul. 2023, doi: 10.54254/2755-2721/8/20230194.
[151]. Jiang et al., “Blockchain technology applications in waste management: Overview, challenges and opportunities,” Journal of Cleaner Production, vol. 421, p. 138466, Aug. 2023, doi: 10.1016/j.jclepro.2023.138466.
[152]. J. Gong, Y. Sun, H. Du, and X. Jiang, “Research on safety risk control of prepared foods from the perspective of supply chain,” Heliyon, vol. 10, no. 3, p. e25012, Jan. 2024, doi: 10.1016/j.heliyon.2024.e25012.

[153]. Pal, V. Bommisetti, P. Suvarnakanti, S. S. Dudala, S. Asha, and V. Jaiswal, “The revolutionary role of blockchain technology in the Agri-food sector focusing on the food supply chain,” Food Reviews International, pp. 1–32, Oct. 2024, doi: 10.1080/87559129.2024.2418464.
[154]. F. Mokgomola, A. Telukdarie, I. Munien, U. Onkonkwo, and A. Vermeulen, “Blockchain and smart contracts based agricultural supply chain,” Procedia Computer Science, vol. 237, pp. 637–644, Jan. 2024, doi: 10.1016/j.procs.2024.05.149.
[155]. G. Chiaraluce, D. Bentivoglio, A. Finco, M. Fiore, F. Contò, and A. Galati, “Exploring the role of blockchain technology in modern high-value food supply chains: global trends and future research directions,” Agricultural and Food Economics, vol. 12, no. 1, 2024, doi: 10.1186/s40100-024-00301-1.
[156]. R. W. Ahmad, K.-M. Ko, A. Rashid, and J. J. P. C. Rodrigues, “Blockchain for food industry: opportunities, requirements, case studies, and research challenges,” IEEE Access, vol. 12, pp. 117363–117378, Jan. 2024, doi: 10.1109/access.2024.3447918.
[157]. D.-C. Toader, C. M. Rădulescu, and C. Toader, “Investigating the adoption of blockchain technology in Agri-food supply chains: Analysis of an Extended UTAUT model,” Agriculture, vol. 14, no. 4, p. 614, Apr. 2024, doi: 10.3390/agriculture14040614.
[158]. Casati, C. Soregaroli, G. L. Frizzi, and S. Stranieri, “Impacts of blockchain technology in agrifood: exploring the interplay between transactions and firms’ strategic resources,” Supply Chain Management an International Journal, vol. 29, no. 7, pp. 51–70, Jul. 2024, doi: 10.1108/scm-09-2023-0443.
[159]. Sharma, A. Palakshappa, and S. A. Naqvi, “Enhancing traceability in agricultural supply chain using blockchain technology,” International Journal of Information Engineering and Electronic Business, vol. 16, no. 3, pp. 11–21, Jun. 2024, doi: 10.5815/ijieeb.2024.03.02.
[160]. Guidani, M. Ronzoni, and R. Accorsi, “Virtual agri-food supply chains: A holistic digital twin for sustainable food ecosystem design, control and transparency,” Sustainable Production and Consumption, vol. 46, pp. 161–179, Feb. 2024, doi: 10.1016/j.spc.2024.01.016.