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Research Article

Rigorous review of "Is blockchain a reliable technology in the agricultural supply chain?"

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ABSTRACT- The blockchain mechanism offers a promising and versatile solution with the potential to benefit various fields of knowledge and industry. Currently, blockchain technology is advancing in sectors such as agriculture, medicine, tourism, and education. However, while its design and implementation provide notable advantages, they also come with certain weaknesses, as well as unique opportunities and challenges. This research aims to identify key blockchain indicators within the agricultural supply chain and to assess its strengths and limitations in this context. To achieve these objectives, we conducted a comprehensive review of scientific articles on blockchain applications in the agricultural supply chain. From a broad collection of articles published between 2012 and 2024, 130 were selected through the Meta-synthesis method. Within these articles, we identified and categorized 124 relevant blockchain indicators affecting the agricultural supply chain. Given the specific challenges and limitations blockchain faces in this sector, we also sought to identify the barriers to its adoption in agricultural supply chains. Our review highlighted various issues and opportunities associated with blockchain implementation in this context. The collected information was then analyzed using the SWOT method, revealing 8 strengths, 4 weaknesses, 4 opportunities, and 3 significant threats in implementing blockchain within the agricultural supply chain.

INTRODUCTION

With the growing population, ensuring access to water, energy, and food has become a major challenge for both Iran and the global community. Projections indicate that Iran and other nations may face significant crises in these areas in the future (Loni and Sharifzadeh, 2022). The introduction of blockchain technology in agriculture has rendered traditional methods for tracking and authenticating organic agricultural supply chains (OASC) outdated. A blockchain certificate tracking model (BTM) now offers an ideal solution for offline businesses, allowing consumers to verify product information easily by scanning a barcode. Additionally, consumers can confirm and reserve products while browsing online (Hu et al., 2022). Agriculture remains fundamental to human civilization, fulfilling essential daily needs (Alobid et al., 2022). To drive growth and modernization, agriculture increasingly relies on innovative technologies that create a more transparent, responsive environment. One promising tool is blockchain technology, which has gained substantial attention in agriculture due to its reliability, transparency, and immutability (Lin et al., 2020; Mirabelli and Solina, 2020). Blockchain addresses crucial issues in the agricultural ecosystem, including food safety, transparency, quality control based on the Internet of Things (IoT), origin tracing, and improved efficiency in contractual exchanges and trading. With diverse, sometimes unreliable participants, such as small-scale farmers, producers, logistics companies, distributors, and retailers, in the agricultural supply chain, balancing efficiency with data integrity is essential (Lin et al., 2020). Blockchain serves as a foundational technology, acting as a decentralized ledger that aligns well with the distributed economic structure. The distributed scheduling model for agribusiness resources, built on a public service platform, offers a comprehensive response to current agricultural challenges often described as "dispersed, small, disorganized, and weak". This model plays a crucial role in integrating decentralized resources (Leng et al., 2018). Blockchain technology is already driving growth across multiple sectors, including agriculture. Many agricultural companies are leveraging blockchain to improve traceability within the food supply chain. For example, Farmers Edge, a global leader, has revolutionized traditional agriculture through digitalization, providing advanced AI-powered solutions and creating new opportunities for an advanced agricultural future. Blockchain networks efficiently collect and upload data from various smart devices, expanding the scope of information available for sharing.

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This technology addresses issues such as asymmetric information, unreliable institutions, third-party involvement, and insufficient traceability of organic food. This innovative model embodies a significant step toward the "digital democratization of agriculture" (Alobid et al., 2022). In recent years, the agricultural sector has shown significant interest in the application of blockchain technology, largely in response to various systemic concerns. Key issues include food contamination and fraud, data security challenges for smart agriculture and precision farming based on the IoT, and problems related to trust, efficiency, data transparency, and overall system integrity in financial auctions. These governance challenges have led to an increase in blockchain-based innovations designed to enhance transparency and accountability through flexible, cost-effective, and sustainable solutions. Integrating blockchain into the agricultural supply chain allows all stakeholders, from farmers to distributors and buyers, to secure the integrity of their data within blockchain-based systems for agricultural production and auctions, thereby strengthening user trust in the agricultural supply chain system (Lin et al., 2020). Unlike centralized agricultural management systems, blockchain offers a decentralized data structure for securely storing and retrieving information, effectively addressing several critical issues inherent in centralized systems, including the following: (1) centralized systems are vulnerable to hacker attacks that can compromise data integrity, (2) internal manipulation of centralized databases poses a threat to data accuracy, (3) supply chain management systems dependent on a centralized database are at risk of single points of failure, and (4) high costs arise from the need for third-party verification and auction monitoring. To address these challenges, distributed databases utilizing advanced cryptography have been proposed over the past few decades. In this context, blockchain has emerged as a leading solution to trust issues, with its origins dating back to the invention of Bitcoin in 2008 (Lin et al., 2020). From a research standpoint, only a few countries are actively investing in this technology, with China and the United States being the most engaged, followed by Italy, which also plays a significant role in the trend. While blockchain technology shows considerable promise, substantial efforts are still needed to mature the technology (Mirabelli and Solina, 2020). Undoubtedly, blockchain represents the next generation of information infrastructure, attracting increasing interest from countries involved in both industrial and research initiatives. When integrated into a food quality monitoring system with smart contracts in the food industry, blockchain enhances the reliability of processes, such as juice production (Lin et al., 2020). The traditional agricultural supply chain, however, currently faces many challenges, including a lack of transparency, delays in product delivery from farmers to consumers, price fluctuations, the prevalence of fake and low-quality products, low profits for farmers, high profits for intermediaries, inconsistent production, and the possibility of overproduction by multiple farmers, which leads to reduced prices. Blockchain offers a solution to these issues by enabling accurate and reliable systems, providing farmers with annual plans and detailed schedules. This system allows farmers to plant and harvest with confidence, ensuring they can deliver products to consumers at fair prices. This research aims to propose a support model for the agricultural supply chain based on modern blockchain technology, creating a reliable platform that helps farmers and ranchers increase production capacity, while ensuring the integrity of the supply chain.

Blockchain

Blockchain systems are classified into three types based on their level of access and security: public blockchain, consortium blockchain, and private blockchain. Any node can access a public blockchain with internet connectivity, making it open and transparent. This type of digital ledger is highly secure, as it is difficult to alter the data. However, the decentralized nature of public blockchains leads to significant redundancy, making it less efficient for handling large amounts of information.

Therefore, public blockchains like Bitcoin and Ethereum are better suited for applications with relatively few transactions or data to store. In contrast, a private blockchain is managed by a single entity. While still decentralized, it offers advantages over public blockchains, particularly in terms of efficiency and control. Private blockchains retain many of the features of public blockchains but are optimized for specific use cases with a different architecture. They are often seen as a viable alternative to traditional centralized systems, especially in situations where there is a need to prevent insider attacks. The third type, consortium blockchain, is a hybrid model that combines the benefits of public and private blockchains. It involves multiple parties in data storage and is ideal for applications where data privacy and high transaction speeds are critical. Consortium blockchains are particularly useful in sectors such as agriculture, where they can offer tailored solutions for managing farm inputs. Various blockchain platforms, including Hyperledger Fabric, Multichain, Quorum, and Corda, can be used to implement either consortium or private blockchain systems (Lin et al., 2020). Fig. 1 illustrates the structure of blockchain blocks.

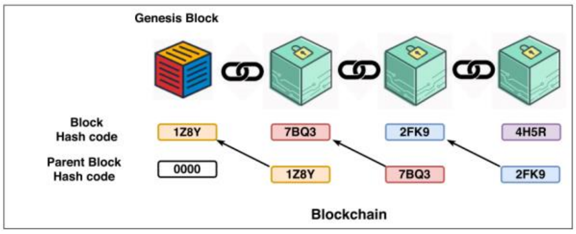

Fig. 1. Blockchain as a sequence of hashed blocks (Torky & Hassanein, 2020).

Blockchain technology was first introduced through the digital currency Bitcoin in 2008 and has since been successfully implemented across various industries. It has revolutionized the way data is stored in databases, offering a secure and decentralized system for data management. By utilizing blockchain, users can protect their data from cyber-attacks related to storage, access, and monitoring. Since its inception, blockchain has been widely adopted in numerous sectors to ensure data protection and high reliability. The technology employs encrypted hash functions that prevent hash collisions, allowing for the verification of block validity. If an attempt is made to alter a block, the changes will propagate throughout the subsequent blocks in the chain, making blockchain resistant to manipulation. Blockchain offers several advantages, including secure data management, distributed access, and control over data for end-users. It functions as a shared ledger distributed across multiple locations and participants. To add new data to the blockchain, it is first converted into a block, which contains a collection of records. This block is then cryptographically linked to the previous block via a hash key before being appended to the chain. As the hash key connects the current block to the previous one, each new block is linked to all its ancestors in the chain, hence the term "blockchain". As a decentralized ledger technology, blockchain ensures secure data storage and retrieval while guaranteeing immutability. This feature is a result of its distributed nature, which eliminates the need for a centralized system and allows participants to exchange data directly with their peers. The first block in the blockchain is known as the "genesis block", which does not contain any transactions. Subsequent blocks contain sets of valid transactions and are cryptographically linked to the preceding block. Blockchain's cryptographic techniques and distributed network environment ensure the secure distribution of data, providing visible digital fingerprints and auditable trails for enhanced transparency and reliability.

Types of supply chain risk

Shekarian and Mellat Parast (2021) discussed various risks facing supply chains in their research. The supply chain is the comprehensive process that transforms raw materials into finished products and delivers them to customers. At its highest level, the supply chain consisted of two fundamental and integrated processes: the production planning and inventory control process, and the distribution and logistics procedure. Several types of risks were associated with supply chains, including demand risk, supply risk, process risk, control risk, and environmental risk. Demand risk arose from uncertainties in customer demand. Examples included unpredictable or unstable demand, incomplete or inaccurate customer data, unexpected delays in customer payments, sectoral developments, forecasting errors, and the actions of innovative competitors. Supply risk involved deviations in the quality, quantity, or timing of received resources and disruptions in the flow of products and information within the supply chain, particularly upstream from the focal companies. The goal of supply chain managers was to minimize the costs associated with managing multiple suppliers and to foster stronger, more reliable supplier relationships. Sources of supply risks included poor supplier performance, such as unreliable delivery or failure to meet orders, supplier quality issues, sudden supplier failures due to insolvency, ineffective coordination with logistics providers, variability in material exchanges or lack of competence in handling materials, subcontracting issues, global concerns, supplier commitment levels, and variability in replacement times. Process risk involved the potential for abnormalities in producing the desired quality and quantity of products on time. It included quality, time, and capacity risks that affected both internal and external operations. Sources of process risks included process variability, operational disturbances, disruptions in internal resources such as equipment failures or inefficiencies in the supporting transmission or delivery systems, technical failures like machinery malfunctions or long startup times, failures in IT infrastructure, external IT disruptions, product quality issues, and local disturbances such as labor strikes, fires, or explosions. Control risk, or network risk, referred to the assumptions, regulations, systems, and procedures that guided how an organization managed its operations. Examples of sources of this risk included trade and batch sizes, security and storage procedures, and asset management and delivery processes. Control risks also occurred when vertically integrated suppliers or competitors disrupted the supply chain relationship, forcing a company to sever ties. Other sources of control risks included imbalanced power dynamics, loss of collaborative planning, and a lack of internal visibility across the supply chain. Environmental risks were external threats that could disrupt any part of the supply chain, such as product contamination or the failure of any link in the chain due to unexpected events like extreme weather or natural disasters. Sources of environmental risk included political instability, terrorism, war, disease outbreaks or epidemics, natural disasters, social and governmental unrest, economic downturns, and technological changes.

Blockchain and supply chain management

The integrated production process that transforms raw materials into finished products and delivers them to the customer is known as the supply chain. At its highest level, the supply chain consists of two basic and integrated processes: the production planning and inventory control process, and the distribution and logistics process (Beamon, 1998). In essence, the supply chain encompasses a set of related activities that involve the planning, coordination, and control of materials, components, and finished goods from the supplier to the customer. Traditionally, material flow was considered only at the operational level. However, the potential of supply chain integration is now recognized as a critical factor. Companies that adopt the right tools and techniques to meet market demands and manage the supply chain of agricultural products as a unified entity will have a competitive advantage in the fight for survival (Stevens, 1989). Supply chain management (SCM) involves the systematic and strategic cooperation of these processes within and between companies, aiming to reduce costs, improve customer satisfaction, and gain competitive advantages for both individual companies and the entire supply chain (Serdarasan, 2013).

Blockchain technology in agricultural supply chain

The agricultural food products supply chain encompasses the entire series of operations, from production on the farm to processing, distribution, and marketing of products. According to Chen, Shepherd, and da Silva (2005), the terms supply chain, value chain, commodity chain, and agri-food system are sometimes used interchangeably. Traditionally managed agri-food supply chains have evolved into a globally interconnected network of complex relationships that influence how food is produced, processed, and delivered to market (Burch and Lawrence, 2005). These changes present significant challenges for organizations involved in the agricultural food supply chain. There is growing concern among businesses and governments to focus on the environmental impact and origins of agri-foods, especially in light of the evolving state of the sector. There are also concerns about the sustainability of agricultural supply chains, particularly with the ongoing challenges of population growth and resource depletion (Global Footprint Network, 2012).

MATERIALS AND METHODS

Review protocol

This research was conducted in two stages: Meta-synthesis and SWOT analysis. In the first stage, the Meta-synthesis method was used to identify blockchain technology indicators in the supply chain of agricultural crops. For this purpose, the seven-step method outlined by Sandelowski and Barso (2006) was employed. The steps of this method are illustrated in the fig. 2. This method provides a clear framework for conducting the meta-synthesis process. As shown in fig. 2, the first step involves defining the research questions. The second step is a systematic review of relevant texts, where related keywords, databases, and time periods are determined. In the third step, appropriate texts are selected from scientific databases. The fourth step involves extracting data from the reviewed texts. In the next step, the qualitative findings are analyzed and synthesized. The sixth step focuses on quality control, and the final research findings are presented at the end. Following this stage, the blockchain technology indicators, including its benefits, were extracted and categorized. All steps of the meta-synthesis process are summarized in Fig. 2.

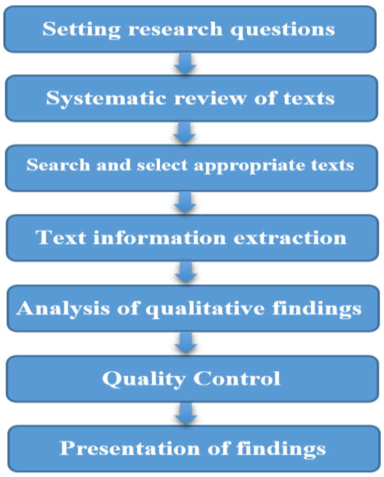

Fig. 2. Sandelowski and Barso's seven steps of Meta-synthesis (2006).

In addition, from the extracted articles, the strengths, weaknesses, opportunities, and threats associated with the implementation of blockchain technology in the supply chain of agricultural products were identified and presented using a SWOT analysis. SWOT stands for Strengths, Weaknesses, Opportunities, and Threats. A strategic planning tool involves assessing these four aspects within an organization, project, or business. A SWOT analysis can be conducted for a company, product, location, industry, or individual. This process helps distinguish investment goals for a business or project and identifies internal and external factors that are either favorable or unfavorable for achieving the desired objectives. SWOT analysis is a strategic methodology that assists businesses in recognizing their strengths, weaknesses, opportunities, and threats. The abbreviations for each component are as follows:

S refers to the strengths, which are the positive attributes of a business that make it superior to its competitors.

W: What are the weaknesses in the SWOT matrix: the negative characteristics of a business are named, which causes it to be at a disadvantage compared to its competitors.

O: What are opportunities in the SWOT matrix? External factors that a business can use to improve its performance and growth.

T: What are threats in the SWOT matrix? External factors that can negatively affect the performance and growth of a business?

Research questions

This study aims to achieve a deep understanding of the blockchain technology parameter, predicting research in the agricultural chain from the three research questions defined below:

RQ1- What are the effective indicators in the use of blockchain technology in the agricultural supply chain?

RQ2- What are the limitations of blockchain in the agricultural supply chain?

RQ3- In terms of SWOT analysis: is blockchain technology a useful technology in the agricultural supply chain?

Search strategy

With a systematic approach to standardizing the search process, from the beginning, the following keywords were used in retrieving articles:

((‘‘Blockchain + Agricultural”) OR (‘‘Blockchain + dietary)” OR (‘‘Blockchain + food supply chain”) AND (‘‘Blockchain + Agricultural”)). After conducting the search, 130 articles were retrieved.

Selection criteria

The literature was examined using exclusion criteria to eliminate studies that were not pertinent to the defined research topic. The exclusion criteria (EC) are outlined as follows:

EC.1: The article does not contain indicators related to the use of blockchain technology in the agricultural supply chain.

EC.2: It is a survey article.

EC.3: The full text of the study cannot be viewed.

EC.4: Articles not before 2012.

After applying all the criteria associated with the meta-synthesis method, 130 articles remained. As shown in Table 1, the articles were sourced from Google Scholar, Web of Science, Taylor and Francis, Science Direct, and Emerald databases. Of the total 16,882 documents initially found, 12,092 were eliminated during the title review stage, leaving 4,790 documents.

Following the abstract review, 3,951 documents were excluded as they were not relevant to the research topic. Additionally, 455 documents were removed after a full-text reading, resulting in a final count of 130 documents that were relevant to the research. These articles were published between 2012 and 2024. Fig. 3 illustrates these steps.

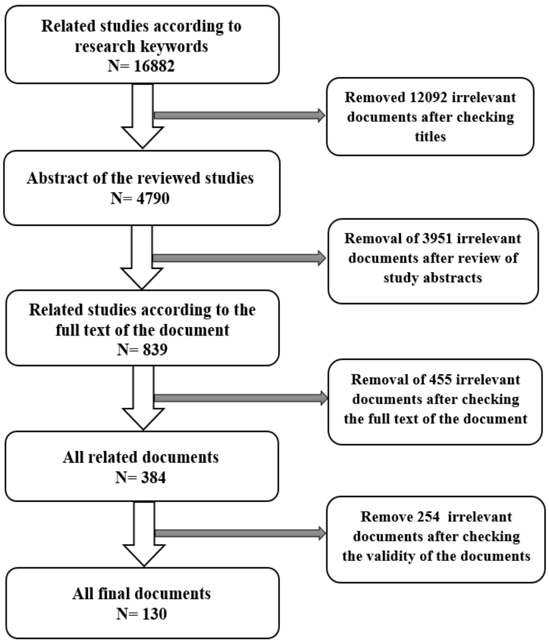

Fig. 3. The process of search results and selecting the appropriate document in the current research.

Among the 130 selected articles, 21 articles are related to 2024, 13 articles for 2023, 19 articles for 2022, 25 articles for 2021, 35 articles for 2020, 8 articles for 2019, 6 articles for 2018, and 3 articles for 2017, whose diagram is displayed in Fig. 4.

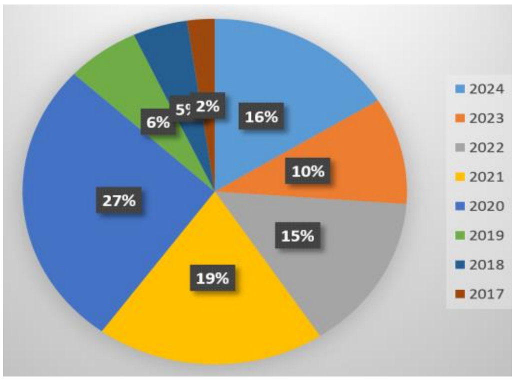

Fig. 4. Graph of the percentage of articles by year.

RESULTS AND DISCUSSION

In this section, we discuss the results by answering the questions in order. The first research question (RQ1) addresses the effective indicators for utilizing blockchain technology in the agricultural supply chain. During the meta-synthesis stage, relevant articles were retrieved from various databases, and the reliability and validity of each article were assessed using Glynn's method. The titles of the articles, along with their publication years, are displayed in the table 1.

According to Glynn's checklist, the reliability and validity of each article was measured in the meta-synthesis stage.

Validation of Glynn's method:

After completing Glynn's table, validation was calculated according to the formula (Y + N + U = T).

Y + N + U = T = 5810

N + U = 678

If Y/T is 75% or if N + U/T is 25%, it can be safely concluded that the study is valid.

N + U/T = 678/5810 = 0.116 = 12%

According to the answer of 13%, we conclude that Glynn's table is valid.

A total of 124 indicators were extracted from 130 articles. These indicators include high security, safe and permanent storage of data, reliability, trustworthiness, maintaining ownership of auctions, protecting privacy, safeguarding intellectual property, identity verification, electronic voting systems, digital signatures, existence of time stamps, asymmetric key systems, affordability, reduction of transaction costs, reduction of settlement time, lowering the overall price of food products, fair pricing, prevention of hoarding, helping the disadvantaged, reduction of global poverty, tracking and payment of subsidies, high income, impact on the global economy, annual savings in the logistics industry, reduction of financial risks, reduction of administrative costs, lower transaction fees, auditability, simplified accounting systems, elimination of paper, improvement of soil quality, insect management, increased productivity, growth and production, reducing backorders and lost sales, managing farm and food waste, enhancing food quality, improving customer satisfaction and productivity, ensuring customer health, respecting human rights, developing rural businesses, increasing finance, promoting solidarity with the circular economy, communicating with all stakeholders in the supply chain, boosting competitiveness, blocking non-core assets, accountability, facilitating the local economy, economic feasibility, supply and demand relationships, reducing commercial friction, simplifying complex sales, reducing irregularities and fraud, preventing theft, reducing losses from fake and gray markets, preventing forgery and fraud, non-manipulation and elimination, improving financial management, improving exchanges, assisting in solving the food crisis, management commitment, scalability, traceability, immutability, data integrity, transparency, risk reduction, smart contracts, decentralized databases, shared databases, targeting intermediaries, resolving disputes between stakeholders, anti-corruption efforts, reducing bureaucracy, democratizing agriculture, accountability, verifiability, time-saving, irreversibility, flexibility, sustainability, interoperability, heterogeneity, originality, the potential to transform the entire sector, distributed ledger technology, high accuracy, incentive structures, promoting environmentally friendly behavior, real-time accessibility, logistics improvement, asymmetric encryption, multi-point data sharing, multilateral consensus, neutrality, authenticity, open-source technology, data anonymity, fault detection, backup troubleshooting, increased transaction capacity, automating contract processes, independence, standardization, synchronization of data, predictability, error-free systems, fluidity of auctions in multi-stakeholder systems, interactivity, immunity to potential cyber-attacks, good coordination, automation, visibility promotion, innovation, social responsibility, controllability, preventing physical injuries, reducing physical meetings, increasing government initiatives, desired value, improving supply chain management, enhancing supply chain performance, adaptability, and planning.

All the extracted indicators are displayed in Fig. 5.

Table 1. Information on selected texts

Row	Selected document	Author	Year
1	Blockchain technology for pay-for-outcome sustainable agriculture financing: implications for governance and transaction costs	Chung & Adriaens	2024
2	Blockchain adoption in supply chains: implications for sustainability	Zhang et al.	2024
3	A Framework for Agricultural Food Supply Chain using Blockchain	Sudarssan	2024
4	Agriculture in Society 5.0	Aggarwal et al.	2024
5	Evaluation of blockchain implementation solutions in the sustainable supply chain: A novel hybrid decision approach based on Z-numbers	Dehshiri & Amiri	2024
6	Enhancing Supply Chain Traceability through Blockchain and IoT Integration: A Comprehensive Review	Wong et al.	2024
7	Mapping smart farming: Addressing agricultural challenges in data-driven era	Huo et al.	2024
8	Pengembangan Waralaba Pertanian Berbasis Blockchain Di Koperasi Yarumori	Dwi et al.	2024
9	Leveraging the Power of Blockchain in Industry 4.0 and Intelligent Real-Time Systems for Achieving the SDGs	Fowdur et al.	2024
10	Blockchain technology as a strategic weapon to bring procurement 4.0 truly alive: Literature review and future research agenda	Govindan et al.	2024
11	Green Agri-Food Blockchain Technology for Investment Decision-Making under Cost Data Constraints	Gao & Li	2024
12	Climate smart agriculture for sustainable productivity and healthy landscapes	Vishnoi & Goel	2024
13	Symmetry in Blockchain-Powered Secure Decentralized Data Storage: Mitigating Risks and Ensuring Confidentiality	Lin et al.	2024
14	ABE-Based Postquantum Cross-Blockchain Data Exchange Approach for Smart Agriculture	Yu & Mu	2024
15	An intelligent blockchain technology for securing an IoT-based agriculture monitoring system	Mahalingam & Sharma	2024
16	Transforming agricultural supply chains: Leveraging blockchain-enabled java smart contracts and IoT integration	El Mane et al.	2024
17	Blockchain and agricultural sustainability in South America: a systematic review	Ordoñez et al.	2024
18	Blockchain technology in agriculture: digitizing the Iraqi agricultural environment	Albaaji & Chandra	2024
19	Evaluation of the effective drivers in the use of blockchain technology in the rice supply chain	Yahyayi & Kavoosi-Kalashami	2024
20	Optimized Data Fusion with Scheduled Rest Periods for Enhanced Smart Agriculture via Blockchain Integration	Ahmed et al.	2024
21	Implementations and Rationale for Blockchain Technique in Agriculture	Bansal et al.	2024
22	Integrated Agri-Food Supply Chain Model: An Application of IoT and Blockchain	Hasan et al.	2023
23	Exploration of barriers and enablers of blockchain adoption for sustainable performance: implications for e-enabled agriculture supply chains	Zkik et al.	2023
24	AgriOnBlock: Secured data harvesting for agriculture sector using blockchain technology	Patel & Shrimali	2021
25	Blockchain technology and its applications in agriculture and supply chain management: a retrospective overview and analysis	Srivastava et al.	2023
26	Blockchain-Based Traceability for Agricultural Products: A Systematic Literature Review	Lv et al.	2023
27	Agricultural IoT Data Storage Optimization and Information Security Method Based on Blockchain	Zhao et al.	2023
28	A Systematic Review of Blockchain Technology Adoption Barriers and Enablers for Smart and Sustainable Agriculture	Akella et al.	2023
29	The impact of blockchain technology on the online purchase behavior of green agricultural products	Liu et al.	2023
30	A blockchain-enabled security framework for smart agriculture	Chatterjee & Singh	2023
31	Antecedents for blockchain technology-enabled sustainable agriculture supply chain	Nayal et al.	2023
32	Blockchain Traceability Adoption in Agricultural Supply Chain Coordination: An Evolutionary Game Analysis	Zheng et al.	2023
33	Towards applicability of blockchain in agriculture sector.	Sajja et al.	2023
34	The intersection of blockchain technology and circular economy in the agri-food sector	Pakseresht et al.	2022
35	The role of blockchain in revolutionizing the agricultural sector	Alobid et al.	2022
36	Blockchain for agricultural sector: The case of South Africa	Mavilia et al.	2022

Table 1. Continue

Row	Selected document	Author	Year
37	Blockchain technology for agricultural supply chains during the COVID-19 pandemic: Benefits and cleaner solutions	Khan et al.	2022b
38	A Blockchain and Metaheuristic-Enabled Distributed Architecture for Smart Agricultural Analysis and Ledger Preservation Solution: A Collaborative Approach	Khan et al.	2022a
39	Dual-Chain Blockchain in Agricultural E-Commerce Data Traceability Considering the Viniar Algorithm	Xie et al.	2022
40	Smart Agricultural Futures Market: Blockchain Technology as a Trust Enabler between Smallholder Farmers and Buyers	Kumarathunga et al.	2022
41	Blockchain Adoption in Agricultural Supply Chain for Better Sustainability: A Game Theory Perspective	Song et al.	2022
42	Survey on the Applications of Blockchain in Agriculture	L.B	2022
43	An analysis on the role of blockchain-based platforms in agricultural supply chains	Cao et al.	2022
44	Ranking of Important Indicators of Blockchain Technology for the Vegetable Oil Supply Chain	Ranjbar et al.	2022
45	Trusted-auditing chain: A security blockchain prototype used in agriculture traceability	Lei et al.	2022
46	Removing barriers to Blockchain use in circular food supply chains: Practitioner views on achieving operational effectiveness	Okorie et al.	2022
47	Blockchain technology in food supply chains: Review and bibliometric analysis	Pandey et al.	2022
48	Blockchain: An emerging novel technology to upgrade the current fresh fruit supply chain	Zhang et al.	2022
49	Blockchain Enabled Quality Management in Short Food Supply Chains	Burgess et al.	2022
50	Blockchain is not a silver bullet for agro-food supply chain sustainability: Insights from a coffee case study	Bager et al.	2022
51	Blockchain applications in agriculture: A scoping review	Sendros et al.	2022
52	Proposing an interpretive structural model of barriers to using blockchain technology in the food supply	Rahimi et al.	2022
53	The Scope of Blockchain Technology: A Meta-Synthesis Study of Applications, Benefits, Challenges, and Related Technologies	Mohammadi Fateh & Salarnejad	2022
54	A blockchain maturity model in agricultural supply chain	Ronaghi	2021
55	Application of blockchain technology for sustainability development in agricultural supply chain: justification framework	Mukherjee et al.	2022
56	How can channel data strategy promote sales by combining ICT and blockchain?	Dong et al.	2021
57	A trusted blockchain-based traceability system for fruit and vegetable agricultural products	Yang et al.	2021a
58	Blockchain technology for sustainable supply chains of agri-food in Vietnam: a SWOT analysis	Vu & Trinh	2021
59	E-agricultural supply chain management coupled with blockchain effect and cooperative strategies	Alkahtani et al.	2021
60	The value of blockchain and agricultural supply chain parties' participation confronting random bacteria pollution	Niu et al.	2021
61	Implications for Agricultural Producers of Using Blockchain for Food Transparency, Study of 4 Food Chains by Cumulative Approach	Commandré et al.	2021
62	Blockchain-based trust management for agricultural green supply: A game theoretical approach	Bai et al.	2021
63	A decision algorithm for selecting the design scheme for blockchain-based agricultural product traceability system in q-rung orthopair fuzzy environment	Yang et al.	2021b
64	Enabling financing in agricultural supply chains through blockchain	Pufahl et al.	2021
65	Research on Traceability Technology of Agricultural Products Supply Chain Based on Blockchain and IPFS	Zhang et al.	2021
66	Blockchain-based approach to achieve credible traceability of agricultural product transactions	Yi et al.	2021
67	Agriculture-food supply chain management based on blockchain and IoT: a narrative on enterprise blockchain interoperability	Bhat et al.	2021
68	A double-blockchain solution for agricultural sampled data security in IoT network	Ren et al.	2021
69	Blockchain and its impact on agri-food supply chain network management	Kramer et al.	2021
70	A systematic literature review on applications of information and communication technologies and blockchain technologies for precision agriculture development	Liu et al.	2021
71	Smart contract model for trust based agriculture using blockchain technology	Verma	2021
72	User interface of blockchain-based agri-food traceability applications: A review	Tharatipyakul & Pongnumkul	2021
73	Blockchain in agricultural supply chain management	Bingzhang & Zirianov	2021
74	Exploring the impact of blockchain on the performance of agri-food supply chains	Stranieri et al.	2021
75	Blockchain technology adoption, architecture, and sustainable agri-food supply chains	Saurabh & Dey	2021

Table 1. Continue

Row	Selected document	Author	Year
76	Effective management for blockchain-based agri-food supply chains using deep reinforcement learning	Chen et al.	2021
77	Blockchain-enabled government efficiency and impartiality: using blockchain for targeted poverty alleviation in a city in China	Ning et al.	2021
78	Third party certification of agri-food supply chain using smart contracts and blockchain tokens	Dos Santos et al.	2021
79	Blockchain technology in current agricultural systems: from techniques to applications	Lin et al.	2020
80	Blockchain and agricultural supply chains traceability: Research trends and future challenges	Mirabelli & Solina	2020
81	Electronic agriculture, blockchain and digital agricultural democratization: Origin, theory and application	Chen et al.	2020
82	The blockchain as a sustainable business model innovation	Tiscini et al.	2020
83	Blockchain technology adoption barriers in the Indian agricultural supply chain: an integrated approach	Yadav et al.	2020
84	Blockchain-based traceability and visibility for agricultural products: A decentralized way of ensuring food safety in India	Prashar et al.	2020
85	Safe farming as a service of blockchain-based supply chain management for improved transparency	Iqbal & Butt	2020
86	Agricultural supply chain management using blockchain technology	Hegde et al.	2020
87	Blockchain smart contract for scalable data sharing in IoT: A case study of smart agriculture	Rahman et al.	2020
88	Research on value integration mode of agricultural E-commerce industry chain based on IoT and blockchain technology	Li & Huang	2020
89	An effective yield estimation system based on blockchain technology	Osmanoglu et al.	2020
90	A consortium blockchain-based agricultural machinery scheduling system	Yang et al.	2020
91	Research on risk management of agricultural products supply chain based on blockchain technology	Wang et al.	2020
92	A big data mining and blockchain-enabled security approach for agricultural based on IoT	Zhang & Zhang	2020
93	Blockchain brings confidence to facilitate the flow of data in the agricultural field	Topart et al.	2020
94	Blockchain technology for agriculture: Applications and rationale	Xiong et al.	2020
95	Perspectives of blockchain technology in the development of the agricultural sector	Bunchuk et al.	2020
96	Business financing and blockchain technology adoption in agroindustry	Rijanto	2020
97	A robust security framework based on blockchain and SDN for fog computing enabled agricultural IoT	Friha et al.	2020
98	Analysis of agricultural supply chain management for traceability of food products using blockchain-Ethereum technology	Pooja & Mundada	2020
99	Blockchain based Smart model for agricultural food supply chain	Awan et al.	2020
100	Using blockchain and smart contract for traceability in agricultural products supply chain	Chuntang et al.	2020
101	Blockchain: A new safeguard for agri-foods	Xu et al.	2020
102	Integrating blockchain and the IoT in precision agriculture: Analysis, opportunities, and challenges	Torky & Hassanein	2020
103	Research on blockchain for sustainable e-agriculture	Song et al.	2020
104	Blockchain in agriculture traceability systems: A review	Demestichas et al.	2020
105	Security and privacy for green IoT-based agriculture: Review, blockchain solutions, and challenges	Ferrag et al.	2020
106	Blockchain applications in the agri-food domain: the first wave	Motta et al.	2020
107	Smart agriculture using supply chain management based on Hyperledger blockchain	Putri et al.	2020
108	Blockchain in agriculture by using decentralized peer to peer networks	Thejaswini & Ranjitha	2020
109	Supply chain management in agriculture using blockchain and IoT	Borah et al.	2020
110	Blockchain-based agri-food supply chain management: case study in China	Fu et al.	2020
111	Blockchain with IoT, an emergent routing scheme for smart agriculture	Awan et al.	2020
112	Blockchain based producer-consumer model for farmers	Revathy & Priya	2020
113	Investigating the relationships between the influencing indicators of blockchain in the food industry	Rezaee & Babazadeh	2020
114	A survey on blockchain technology and its proposed solutions	Dave et al.	2019
115	A Review on blockchain applications in the agri-food sector	Antonucci et al.	2019
116	Thai agriculture products traceability system using blockchain and IoT	Surasak et al.	2019
117	Application of blockchain technology in agricultural product traceability system	Wang & Liu	2019
118	A theoretical implementation: Agriculture-food supply chain management using blockchain technology	Madumidha et al.	2019
119	The supply chain value of pod and pgi food products through the application of blockchain	Scuderi et al.	2019
120	Blockchain-based soybean traceability in agricultural supply chain	Salah et al.	2019
121	A systematic literature review of blockchain technology in agriculture	Yadav & Singh	2019

Table 1. Continue

Row	Selected document	Author	Year
122	Research on agricultural supply chain system with double chain architecture based on blockchain technology	Leng et al.	2018
123	Blockchain and IoT based food traceability for smart agriculture	Lin et al.	2018
124	Blockchain based provenance for agricultural products: A distributed platform with duplicated and shared bookkeeping	Hua et al.	2018
125	Advances in Automation, Signal Processing, Instrumentation, and Control	Komanapalli et al.	2021
126	A safe and efficient storage scheme based on blockchain and IPFS for agricultural products tracking	Hao et al.	2018
127	Blockchain in agriculture: A systematic literature review	Bermeo-Almeida et al.	2018
128	Use of blockchain technology in agribusiness: Transparency and monitoring in agricultural trade	Papa	2017
129	Blockchain: The evolutionary next step for ICT e-agriculture	Lin et al.	2017
130	Secured data storage scheme based on block chain for agricultural products tracking	Xie et al.	2017

RQ2-Related (accuracy and reliability assessment) discussion: What are the limitations of blockchain in the agricultural supply chain?

Limitations of blockchain in agricultural supply chain:

1. Technical limitations:

- Limitations in transaction processing capacity: Current blockchains may be limited in processing many auctions in the agricultural supply chain.
- Data volume limitation: due to the high volume of data related to agricultural products, storing this volume of data in the blockchain may be a challenge.

2. Economic restrictions:

-Implementation and deployment costs: Using blockchain in the agricultural supply chain may require high initial investments that are not affordable for many farmers and small businesses.

- Operational costs: The costs of energy consumption and blockchain transaction costs may not be cost-effective for agricultural supply chain actors in the long run.

3. Legal and regulatory restrictions:

- Lack of specific legal frameworks: Many countries currently lack the necessary legal frameworks and regulations to support the adoption and utilization of blockchain in the agricultural supply chain.
- Security and privacy concerns: The implementation of blockchain may be accompanied by certain data security and confidentiality issues.

These limitations can generate challenges in the implementation and deployment of blockchain in the agricultural supply chain, necessitating careful consideration and mitigation.

Results of the SWOT stage

In SWOT analysis, strengths, weaknesses, opportunities, and threats are examined and extracted. Regarding RQ3—“From a SWOT analysis perspective, is blockchain technology a useful tool for the agricultural supply chain?”—the SWOT analysis conducted revealed both the potential advantages and challenges associated with implementing blockchain in the agricultural supply chain. The strengths of this technology suggest that blockchain can significantly enhance supply chain efficiency, transparency, and security. Additionally, the identified opportunities highlight the potential for blockchain to improve various aspects of the agricultural sector, including traceability, data management, and cost reduction. However, the analysis also uncovered certain threats, which need to be addressed. Researchers and implementers of blockchain technology should remain vigilant about these threats and work proactively to mitigate them. Overall, the strengths and opportunities provided by blockchain technology make it a promising tool for the agricultural supply chain, contributing to its increasing acceptance and interest among researchers and industry professionals.

Strengths

Based on the reviewed articles, the implementation of blockchain technology in the agricultural supply chain can encourage consumers to confidently purchase more agricultural and food products for their families, while also ensuring job security for farmers and distributors. Furthermore, blockchain technology can enhance the development of agricultural systems by improving supply chain processes through data security, transparency, traceability, data integrity, smart contracts, and authentication and certification. Additionally, it fosters better stakeholder behaviors, such as interoperability, reliability, accountability, and scalability. However, there are some contradictions regarding scalability found in the literature. Earlier studies identified scalability as a significant barrier to blockchain adoption, with researchers arguing that blockchain is not well suited for IoT models. Khan and Salah (2018) suggested that while positive developments could occur with the integration of IoT into blockchain systems, the challenge lies in the fact that IoT nodes transmit large volumes of data in real time, potentially overwhelming blockchain’s ability to process transactions. Given that, blockchain platforms can handle only a limited number of transactions per second; this could create a bottleneck in IoT systems. They also argued that blockchain's design is not optimal for storing large amounts of data, and scaling blockchain to accommodate numerous heterogeneous devices presents significant technical challenges (Torky & Hassanein, 2020). In contrast, studies that are more recent indicate that researchers are now viewing blockchain as a potential solution to these scalability issues, recognizing it as one of the technology's key advantages.

Weaknesses

Although blockchain-based supply chains have many strengths, it must be noted that in the agricultural sector, the presence of small-scale agricultural producers presents challenges, including the high cost of developing blockchain infrastructure and platforms. The high hardware and software costs associated with implementing blockchain make it difficult for small-scale farmers to adopt the technology initially (Vu & Trinh, 2021). Additionally, blockchain technology is still a relatively new innovation that is in the early stages of development. Many farmers have yet to fully recognize the benefits of blockchain implementation in the agricultural supply chain. This situation highlights the need for governments to invest resources in educating and preparing the supply chain members for blockchain adoption. In addition to these challenges, issues such as blockchain forking, the 51% attack, high energy consumption, and scalability can be regarded as weaknesses of blockchain technology. One such issue is blockchain forking, which occurs when two miners simultaneously add two valid blocks to the chain, creating a situation known as "blockchain pressure". While blockchain protocols typically address this with a simple rule, that the longest blockchain is considered correct, forking can still lead to complications such as confusion, fraudulent auctions, technical difficulties, and economic instability within the system. To mitigate these risks, it is generally recommended to wait for six blocks to confirm a transaction. However, some newer blockchain platforms, such as Tezos, propose alternative design structures aimed at reducing the likelihood of blockchain forks (Torky & Hassanein, 2020). Another threat is the 51% attack, which occurs when more than half of the network's computers begin sending false data, causing the false data to be accepted as true. This leads to the occurrence of a 51% attack, as explained by Kuo et al. (2017) (Fig. 6).
High energy consumption: One of the biggest problems of implementing blockchain technology in all branches is the very high energy consumption. Moreover, it needs sufficient infrastructure, which itself requires the existence of initial capital (Yadav et al., 2020).

Opportunities

Blockchain technology in agricultural supply chains offers numerous opportunities for optimization and improvement. These opportunities include enhanced supply chain efficiency in terms of time, cost, and revenue generation, as well as improved quality control and a positive impact on overall supply chain management, both regionally and globally. As technology advances and blockchain becomes more widely adopted in agricultural supply chains around the world, we can expect significant improvements in the speed of exchange and the quality of food products moving through these chains. Additionally, the traceability enabled by blockchain technology will facilitate the export of agricultural and food products to domestic and international markets, ensuring compliance with the strictest quality and food safety standards.

Threats

At the global level, countries are actively pursuing research and implementation of blockchain technology within their borders, with one of the most prominent areas of focus being the agricultural product and food supply chain. As we witness the adverse effects of climate change, urbanization, and industrialization on agriculture globally, finding a suitable solution to address these challenges has become increasingly urgent. Additionally, the existence of fraud and the volatile market prices of agricultural products has caused farmers to experience job insecurity. Some researchers suggest that blockchain technology could provide a solution to the problems facing agriculture, despite the fact that blockchain itself also has limitations that could pose serious threats to the agricultural supply chain if not carefully addressed. These limitations include technical constraints, economic barriers, and legal and regulatory challenges. A summary of the points discussed by researchers in their articles, as outlined in the SWOT analysis is presented in Table 2.

CONCLUSION

The implementation of blockchain technology in the agricultural supply chain enables both consumers and producers of agricultural products to engage in transactions with greater confidence. This study analyzed 130 scientific articles to extract the advantages and disadvantages of blockchain in the agricultural crop supply chain. From the review of these articles, 124 effective blockchain indicators were identified and categorized for use in the agricultural supply chain. These indicators were organized into 12 groups: Impact on Supply Chain Management, Supply Chain Efficiency, Traceability, Supply Chain Transparency, Quality Control, Data Security in the Supply Chain, Smart Contracts, Data Integrity, Authentication and Certification, Scalability, Interoperability, and Regional and Global Impact. Each of these groups was further divided into subgroups. The "Impact on Supply Chain Management" group includes improving supply chain management, management commitment, resolving disputes between stakeholders, communication with all stakeholders in the supply chain, reducing the number of back orders and lost sales, increasing competitiveness, responsiveness, predictability, simplifying complex transactions, and the potential for sector-wide transformation. The "Supply Chain Efficiency" group covers improvements in supply chain performance, reduced settlement time, time savings, reduced administrative costs, lower transaction fees, affordability, reduced cost of transactions, fair pricing, tracking and payment of subsidies, higher income, annual savings in the logistics industry, improved financial management, reduced financial risks, greater financial inclusion, improved exchanges, and reduction of losses caused by fake and gray markets. The "Traceability" group includes the traceability of origin, anti-corruption measures, and diagnosing malfunctions, while the "Supply Chain Transparency" group includes transparency, multilateral consensus, reliability, risk reduction, reducing irregularities and fraud, open-source technology, information sharing and synchronization, accessibility, and auditability. In the "Quality Control" group, the focus is on improving soil quality, increasing food quality, insect management, and reducing farm and food waste.

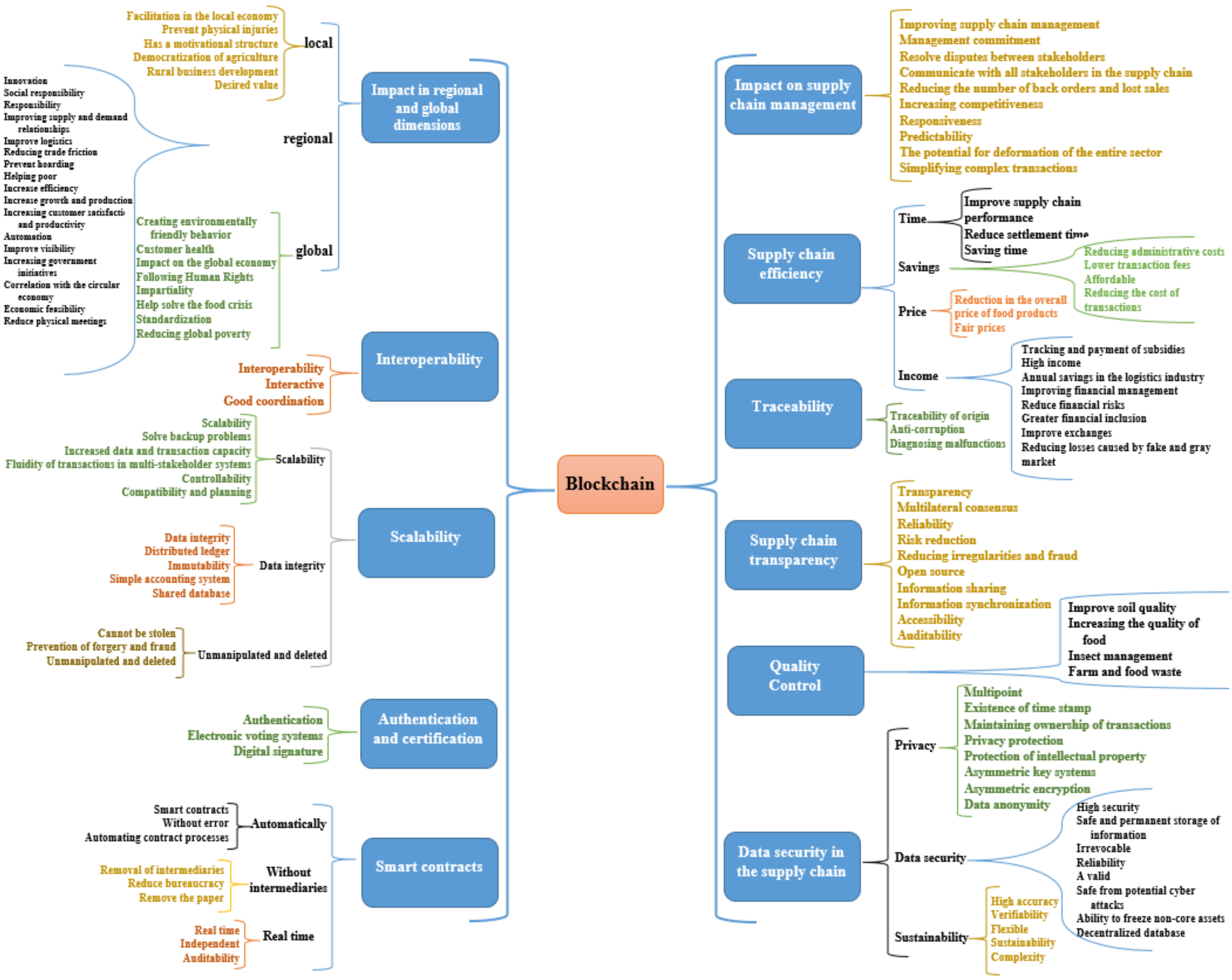

Fig. 5. The extracted indicators of blockchain technology in the agricultural supply chain.

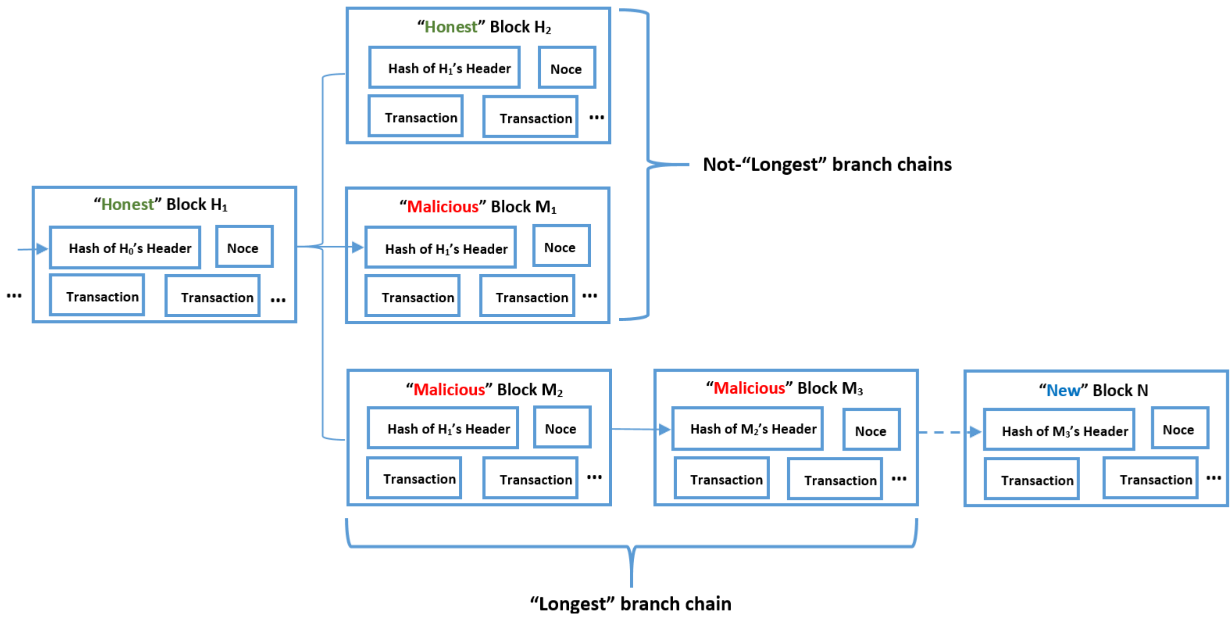

Fig. 6. An example of a 51% attack (Kuo et al., 2017)

Table 2. The SWOT analysis of blockchain-based supply chains in agriculture sector

Strengths	**Weaknesses**
Data security in the supply chain	Blockchain forking
Traceability	51% attack threat
Supply chain transparency	High energy consumption
Interoperability	Blockchain infrastructure development cost
Data integrity	
Smart contracts	
Authentication and certification	
Scalability	
Opportunities	**Threats**
Supply chain efficiency (time, price, and revenue)	Technical limitations
Quality Control	Economic constraints
Positive impact on supply chain management	Legal and regulatory restrictions
Impact in regional and global dimensions	

The "Data Security in the Supply Chain" group includes multipoint systems, timestamps, maintaining ownership of transactions, privacy protection, intellectual property protection, asymmetric key systems, asymmetric encryption, data anonymity, high security, safe and permanent data storage, irrevocability, reliability, cyber-attack prevention, the ability to freeze non-core assets, decentralized databases, high accuracy, verifiability, flexibility, sustainability, and complexity management. The "Smart Contracts" group emphasizes smart contracts, error-free processes, automation of contract processes, elimination of intermediaries, reduced bureaucracy, removal of paper, real-time transactions, independence, and auditability. The "Data Integrity" group focuses on data integrity, distributed ledgers, immutability, simple accounting systems, shared databases, prevention of data theft, prevention of forgery and fraud, and ensuring data is not manipulated or deleted. The "Authentication and Certification" group includes authentication, electronic voting systems, and digital signatures. The "Scalability" group includes scalability, solutions for backup problems, increased data and transaction capacity, fluidity of transactions in multi-stakeholder systems, good coordination, controllability, and compatibility with planning. The "Interoperability" group emphasizes interoperability and interactivity. Finally, the "Regional and Global Impact" group includes facilitating the local economy, preventing physical injuries, providing a motivational structure, democratizing agriculture, rural business development, desired value, innovation, social responsibility, improving supply and demand relationships, enhancing logistics, reducing trade friction, preventing hoarding, helping the poor, increasing efficiency, boosting growth and production, improving customer satisfaction, automating processes, improving visibility, increasing government initiatives, correlating with the circular economy, economic feasibility, reducing physical meetings, promoting environmentally friendly behavior, enhancing customer health, improving global economic impact, respecting human rights, impartiality, solving the food crisis, standardization, and reducing global poverty. Using the SWOT method, the strengths, weaknesses, opportunities, and threats associated with the implementation of blockchain technology were also identified. According to the SWOT analysis, eight strengths include data security in the supply chain, traceability, supply chain transparency, interoperability, data integrity, smart contracts, authentication and certification, and scalability. Four weaknesses were identified: blockchain forking, the threat of a 51% attack, high energy consumption, and the high cost of blockchain infrastructure development. Four opportunities were identified: improvements in supply chain efficiency (time, price, and income), quality control, a positive impact on supply chain management, and regional and global impact. Three important threats include the challenges of blockchain implementation in the agricultural supply chain. Overall, blockchain technology is an emerging innovation with numerous advantages that can be beneficial in the agricultural product supply chain. By adopting this technology, many issues within the agricultural supply chain can be resolved. With blockchain-based programming in the agricultural system, farmers can cultivate crops more safely, mitigate challenges related to mass cultivation, eliminate intermediaries, and ultimately achieve higher profits.

Limitations

This research primarily focused on identifying effective indicators for utilizing blockchain technology within the agricultural supply chain. In summary, while the implementation of blockchain in the agricultural supply chain held significant potential to enhance transparency, increase trust, and improve data management, it also presented challenges that required careful consideration and mitigation.

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This article is part of a doctoral dissertation and all authors contributed to the conception and design of the study. All authors read and approved the final version.

DECLARATION OF COMPETING INTEREST

The authors of this research article declare that they have no competing financial interests or known personal relationships that could have influenced the work reported in this study.

ETHICAL STATEMENT

This study is extracted from a doctoral thesis.

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