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Research Article

Evaluating the efficacy and drawbacks of traceability technology in the quality assurance of the food supply chain

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Abstract

The food industry can significantly benefit from blockchain technology by increasing transparency and visibility throughout the supply chain because it enables end-to-end data traceability in the food retail network. A blockchain does not require a central authority to control all data, reducing organizations' need to disclose their proprietary information. All supply chain participants share only the data essential for a specific record or transaction. In this study, peer-reviewed journal articles were used as secondary data sources for data collection regarding blockchain usage in the food sector. After analyzing the collected data, key findings were organized into relevant themes to address the study's objectives using content analysis. Organizations can adopt a cost-benefit analysis in the food industry when traceability technology is combined with blockchain. Transparency increases revenue and profitability, especially in segments where consumers are willing to pay. However, several risks and challenges must be addressed, including vulnerabilities, piracy, contractual disputes, and hacking. Using smart contracts, blockchain automates production processes and facilitates real-time order settlement. Even the most secure cryptocurrencies on the blockchain can be traced to varying degrees, emphasizing the importance of blockchain transaction reliability. To address privacy concerns and enable data-sharing capabilities, food companies should integrate blockchain with the Internet of Things (IoT). Using blockchain technology in food supply chain and packaging operations can also enhance transparency and traceability by enabling consumers to scan product codes using a mobile app.

Introduction

As evidenced in Wang's [1] study, blockchain technology stands out as a leading force driving digital transformation across various business sectors. This innovative technology offers a decentralized, transparent, and secure environment for businesses and organizations. The globalization of Food Supply Chains (FSCs) and markets has resulted in a substantial surge in the flow of goods and data between nations. Robust vertical integration and close coordination among supply chain partners that enhance efficiency characterize traditional food supply chains [2]. Their goals include reducing trade, operational, and marketing costs while meeting consumers' demands for food quality and safety.

As a result, FSC participants find themselves under increasing pressure to enhance supply chain transparency, facilitate the exchange of trusted information, and improve the tracking and tracing capabilities of agricultural products from farms to retailers. The need for transparency and overall supply chain visibility has become imperative due to various scandals within global FSCs, such as the horsemeat scandal in Europe and the melamine scandal in China [3]. Regulations now require that every aspect of a food product be traceable to its source. Consumer demand has driven the year-round availability of many agricultural products, increasing the pressure on businesses to provide details on specific product attributes, including quality, safety, authenticity, traceability, provenance, and production conditions [4,5].

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The heightened demand for information acts as a catalyst for the introduction of new technologies. For instance, Radio-Frequency Identification (RFID) technology has been deployed in FSCs to enhance visibility and traceability, reduce food waste, facilitate forward tracking, improve operational efficiencies, automate data collection, prevent errors in order picking and transportation, and intelligently manage environmental conditions such as temperature and humidity, as well as supply chain processes.

With stakeholders independently verifying the authenticity of records, blockchain offers the advantage of not requiring a single centralized owner of all data. Consequently, organizations need not divulge their internal systems or proprietary data; they only need to share data relevant to the specific record or transaction, which is openly shared among all participants in the supply chain [6]. Blockchain ensures reliable, accurate data and a single, trusted version of reality that all participants share. It bridges the gaps between stakeholders by providing all parties with the same, real-time, accurate view of the supply chain, a critical factor in ensuring manufacturing and supply chain resilience. As the industry's complexity continues to grow, so does the need for advanced traceability and end-to-end visibility, coupled with regulatory requirements such as the FDA's Drug Supply Chain Security Act (DSCSA), set to be fully enforced by 2023 and the General Data Protection Regulations (GDPR) [7].

Research motivation

The fundamental motivation behind conducting this research is to underscore the increasing imperative of adopting blockchain technology to enhance traceability systems. Within the current body of knowledge, existing publications often lack an in-depth discussion of the application of blockchain technology in the context of traceability, specifically within the food industries. Masudin, et al. [8] have noted that the prevailing literature inadequately addresses blockchain's applications and its substantial, positive impacts on the food sector. This technology has the potential to instill transparency in supply chain processes, bolster business performance, and facilitate digital transformation. However, the influence of blockchain-enabled traceability on business model innovation, supply chain resilience, and the challenges associated with its implementation remains inadequately explored in scholarly studies [9].

Furthermore, a compelling body of evidence delineating blockchain adoption's benefits for enhancing business revenue and performance by elevating supply chain quality is conspicuously absent. The existing research fails to elucidate whether the integration of blockchain technology results in distinct differences in traceability systems when applied in the food sector [10,11]. Although prior publications have highlighted the impact of blockchain on supply chain quality assurance, they have not sufficiently addressed the utilization of traceability systems, as exemplified in the works of Chowdhury, et al. (2022) and Wamba, et al. [12]. Past and current literature has thus far neglected to conduct comprehensive research within this domain to unveil significant implications and ascertain whether enhanced quality can be achieved in supply chain operations. This limitation underscores the necessity for further exploration in this field, aiming to provide timely contributions by addressing challenges and uncovering prospects. In pursuit of this objective, this research investigates how the food sector can harness blockchain technology to augment their business and supply chain operations, ultimately enhancing their competitiveness. This work presents updated and substantiated information to bridge existing gaps in the literature, yielding practical insights while elucidating the advantages of blockchain integration.

Problem statement

The utilization of cloud computing platforms for retrieving data related to food products has become increasingly evident. This information is made accessible to retailers and consumers via websites or barcode scans using mobile devices. Srivastava and Wood (2020) have pointed out that cloud computing facilitates short messaging services within agricultural supply chains, disseminating valuable information regarding weather patterns, appropriate pesticide use, disease outbreak alerts, and government subsidies [13]. While these platforms drive food supply chains toward a digital and data-driven food ecosystem, several critical issues remain unaddressed. Notably, there is a lack of continuous food supply chain visibility and the ability to predict the remaining shelf life of fresh products.

Furthermore, the conventional food oversight system grapples with data fragmentation, a lack of transparency from data disparities and inconsistencies, insufficient interoperability, and a dearth of data traceability [14-16]. To tackle these challenges, experts and researchers in food supply chains envision harnessing blockchain technology to revolutionize the design, development, coordination, and survival of food supply chains. As Wang, et al. [1] highlighted, blockchain has the potential to reshape future supply chain practices and strategies by offering enhanced visibility and traceability. Similarly, it can improve traditional supply chain processes characterized by a dominant entity serving as a central third-party provider imposing its rules, management mechanism, and centralized structures.

In light of these considerations, this study seeks to evaluate the effectiveness and drawbacks of traceability technology in ensuring the quality assurance of the food supply chain industry. While blockchain's potential to address these challenges is evident, its application and impact in this context warrant a comprehensive examination.

Aim and objectives

This research study was designed to comprehensively assess the impact, dependability, and sustainability of traceability technology in enhancing the quality assurance standards and the efficiency of supply chain management within the food industry. The research also delves into the challenges, drawbacks, and benefits associated with the implementation of traceability technology. The main objectives of the research focus were to:

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- Assess the pivotal role of blockchain technology, with a specific focus on traceability, within the context of the food industry;
- Conduct a thorough analysis and evaluation of the effectiveness, dependability, and sustainability of blockchain-based traceability technologies in safeguarding food quality; and
- Identify and scrutinize the challenges and potential risks that accompany the adoption of blockchain technology within the food sector.

Research question

The research question was "What are the efficacy and drawbacks of traceability technology in quality assurance of supply chain in the food via adapting blockchain advancements?" This question delves into the effectiveness and limitations of traceability technology in upholding the quality assurance standards within food industry supply chains, with a specific emphasis on integrating blockchain advancements. This multifaceted inquiry aims to uncover how traceability technology, harnessed through blockchain innovations, enhances product quality and safety while simultaneously evaluating the challenges and drawbacks inherent to its adoption.

Literature review

This section critically examines the existing body of knowledge by scrutinizing the publications and findings presented by scholars and researchers in the field of the subject matter under investigation. To this end, the section delves into recent advancements in blockchain technology within the context of quality assurance processes in supply chains. Furthermore, it assesses the impact of traceability technology on the assurance of quality within supply chains, considering the effectiveness, reliability, and sustainability of blockchain-based traceability solutions. Additionally, the section evaluates the significance of blockchain technology for the food sectors concerning traceability and quality assurance while identifying the disadvantages and risks associated with its application in this sector. The section conducts a comparative analysis of blockchain applications in the food industries to provide a comprehensive perspective, and literature gaps identified during this review are highlighted. The section concludes with a summary encapsulating the critical insights derived from the literature.

Recent blockchain advancements in supply chain quality processes

Blockchain technology has initiated a transformative wave within supply chain operations, promising substantial enhancements to the quality assurance processes [17]. This technology has ushered in notable improvements in business process management and supply chain visibility, laying a robust foundation for substantial investments in this domain. Černý, et al. [18] underscored blockchain's role in fortifying the safety of supply chain quality assurance, particularly in terms of privacy, security, usability, and cost-efficiency. It has effectively bolstered the security and functionality of existing digital platforms linked to supply chains. As Rejeb, et al. [19] observed, blockchain has permeated every supply chain facet, spanning from raw material procurement to end-consumer distribution, spurring a reengineering of supply chain processes and ushering in business process reengineering practices.

The technology enables the restructuring of each transaction, rendering the supply chain path more secure and expeditious. Jabbar, et al. [20] emphasized that blockchain's advancements have ushered in transparency and security within the supply chain by establishing a transparent and secure chain. Dutta, et al. [21] noted that all supply chain transactions that blockchain technology facilitates are more economical, transparent, and efficient, effectively mitigating supply chain risks. These risks encompass vulnerability, piracy, contractual disputes, hacking, and the high costs associated with compliance with governmental regulations. Through automating manufacturing tasks and real-time order settlement via smart contracting, blockchain has enhanced supply chain effectiveness, reduced costs, and streamlined associated business processes.

Impact of traceability technology on supply chain quality assurance

Traceability technology has ushered in sustainability within the realm of quality assurance in supply chains, addressing both social and economic dimensions [22]. This technology has exerted a positive impact on supply chain performance by optimizing value addition across various processes and activities. Razak, et al. [23] highlighted how traceability systems have empowered supply chain stakeholders and engineering tools to comprehensively assess and simulate each facet of the supply chain, from production and manufacturing to doorstep delivery for customers. Notably, traceability enables the tracking of procedures critical to product safety, resulting in reduced overall costs for quality assurance. Furthermore, Zhou and Xu (2021) underscored its capacity to facilitate extensive information sharing among stakeholders, mitigating unforeseen risks within the supply chain process. Traceability technology also contributes to labor cost reduction, allowing businesses to apply cost-benefit models to evaluate performance, ultimately increasing revenue and profitability in areas where customers are willing to invest. Saak [24] concurred that traceability systems enhance supply chain performance in conjunction with risk management, enabling the real-time update, acquisition, and transmission of information with minimal errors and delays. This proactive approach aids in identifying and mitigating disruptions before they escalate, a pivotal dimension of this technology that bolsters confidence in product safety and quality assurance. Song, et al. [25] asserted the growing demand for traceability systems among supply chain participants to minimize distribution and production disruptions while ensuring effective tracing and tracking of potential defective batches and products throughout the supply chain process. Consequently, traceability technology within supply chains yields social, economic, and financial benefits, particularly when conducting quality assurance for the safety, distribution, and delivery of products.

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Efficacy, reliability, and sustainability of blockchain traceability technologies

Blockchain technology possesses the inherent capability to identify counterfeit or fraudulent transactions, thereby inadvertently enhancing the reliability and efficacy of the system. Kumar, et al. [26] evaluated blockchain's efficacy as a traceable technology by scrutinizing external attacks and their impacts on traceability within supply chains. Their study revealed that while vulnerabilities like the origin of funds and the autonomy of data sources persisted, traceability failures were relatively infrequent [26]. Within the food industry realm, Machado, et al. [27] asserted that the mapping of process chains becomes significantly more effective with blockchain, resulting in more efficiently managed and secure operational facilities.

Concerning the reliability of transactions within a blockchain, Khan [28] contended that even the most rigorously functioning cryptocurrencies on the blockchain are still traceable to some extent. This traceability stems from the fundamental principle of blockchain, which entails recording transactional data at each stage, enabling transactions to be traced to their source [28]. The traceability capabilities of blockchain also carry implications for sustainability. As Remme, et al. [29] argued, pollution can be tracked to its source, facilitating more effective pollution management practices.

Significance of blockchain for the food sector in terms of traceability and quality assurance

The paramount significance of blockchain-based traceability in the food industry lies in its capacity to pinpoint the precise source of food items, enabling consumers, suppliers, and buyers to trace their origins from agricultural fields to production and delivery [30,31]. This transparency empowers effective quality management throughout every stage of the process, allowing consumers to detect any deviations in quality readily. In this context, Rejeb, et al. [32] emphasized the example of Kosher and Halal food demands by consumers, highlighting that blockchain-enabled traceability assures quality, thereby allowing consumers to verify the claims made by producers. This verification enhances the credibility of food industry producers and fosters a continuous customer flow, making it possible to distinguish genuine products from counterfeits using blockchain traceability [33]. By ensuring that food originates from reputable suppliers and producers, food supply chain stakeholders and professionals can ensure the quality and authenticity of food.

Drawbacks, challenges, and risks of blockchain for the food sector

In the context of the food industry, Galvez, et al. [34] underscored that blockchain-related risks in traceability predominantly revolve around data acquisition and management. Given that various stakeholders possess access to traceability information, concerns arise regarding the potential compromise of consumer and stakeholder anonymity [34]. However, challenges pertaining to traceability persist. Uddin, et al. [35] elucidated that stakeholders, particularly those involved in product planning and design within the food industry, may be hesitant to adopt blockchain technology due to concerns about trade secrets and internal processes becoming vulnerable to third-party access. The implementation of blockchain traceability inadvertently increases accessibility to information typically restricted to a select few stakeholders. Furthermore, general risks and drawbacks associated with blockchain traceability software encompass the associated costs and the susceptibility to phishing and cyberattacks on the overall system [36]. Consequently, the adoption of blockchain raises critical privacy concerns, as information intended to remain exclusive and anonymous may become susceptible to exposure by irrelevant third parties, potentially leading to the exploitation of such data.

Literature gap

While prior literature has provided valuable insights into recent advancements in blockchain technology within the realm of supply chain quality processes, existing publications have also been effective in addressing the impact of traceability technology on the quality assurance of supply chains. However, there remains a research gap concerning the efficacy, reliability, and sustainability of blockchain-based traceability technologies, particularly within the food sector, where traceability and quality assurance are paramount. Moreover, the challenges and risks associated with blockchain adoption in the food sector have not been thoroughly explored in the existing literature, and there has been limited comparative analysis within this specific sector to assess the full potential of blockchain technology. Recognizing these gaps, this study undertakes a comprehensive research endeavor by employing a secondary qualitative approach to uncover and delve into novel developments, ultimately aiming to identify fresh implications and bridge existing literature gaps.

Research methodology

Research design

The present research employed a qualitative study design that facilitated the exploration of challenges and risks associated with the adoption of blockchain technology in the food sector. The adoption of a qualitative design allowed for a deep understanding of the subject matter and the discovery of trends that had significant implications [37].

Data collection

This study used secondary data, focusing on gathering information from peer-reviewed journal articles, publications, research documents, reports, and scholarly articles. In this research, secondary qualitative data was collected by employing relevant keywords related to the research question, thereby enabling the researcher to assess the findings from previous primary qualitative and quantitative research studies that pertain to the evaluation of traceability technology's efficacy, reliability, sustainability, and associated challenges.

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The comprehensive investigation encompassed a wide array of academic sources, including ScienceDirect, Elsevier, Google Scholar, and other online libraries. Through a meticulous examination of these diverse resources, we have meticulously gathered and synthesized valuable insights, offering a thorough understanding of the dynamics that govern food supply chain quality, the role of traceability technologies, the potential of blockchain, and the challenges and drawbacks that accompany their implementation. The keywords "Food supply chain," "quality," "traceability," "blockchain," and "drawbacks" were instrumental in guiding this search, enabling us to compile a comprehensive and informative manuscript that contributes to the advancement of knowledge in this critical domain.

Flowchart

Using a PRISMA flowchart, 151 articles were initially identified and assessed for duplication. After removing duplicate entries, 139 unique articles remained for screening. Of the 139 articles, 71 were excluded as they did not align with or address the research objectives. Consequently, 68 articles were evaluated for eligibility, and among these, 57 publications were further excluded due to a lack of abstracts, conclusions, or separate findings sections. Ultimately, 11 articles were included in the review, comprising 7 qualitative and 4 quantitative studies as illustrated in Figure 1.

Data analysis

This study applied content analysis to the gathered data to identify and group repetitive words, concepts, and terms under common emergent themes. Content analysis captures specific words, concepts, and theories that help formulate themes used for the analysis and interpretation of data [38]. This approach allowed for examining relationships and diverse meanings within the textual data presented in the selected journal articles. Content analysis was the most suitable method for this study as it facilitated the comparison of similarities and differences in the results related to adopting blockchain-based traceability systems in the food sector. By adopting this method, a comprehensive collection of non-numerical data was organized into a study table, and from there, codes were generated. These codes were then organized into themes, serving as the basis for empirical and content analysis. This approach ensured a thorough examination of innovative blockchain techniques and technologies that enhance supply chain quality in the food industry while maintaining data reliability.

Analysis and discussion

Blockchain technology plays a pivotal role in establishing the accuracy and dependability of shared information within the food supply chain and other sectors like manufacturing. This role is a crucial factor in enhancing the comprehensive visibility of the supply chain through data (Sharma & Sikka, 2021). Consequently, the effectiveness, sustainability, and dependability of blockchain-based traceability technologies are essential for guaranteeing food quality [39]. This technology offers diverse advantages by creating a traceable,

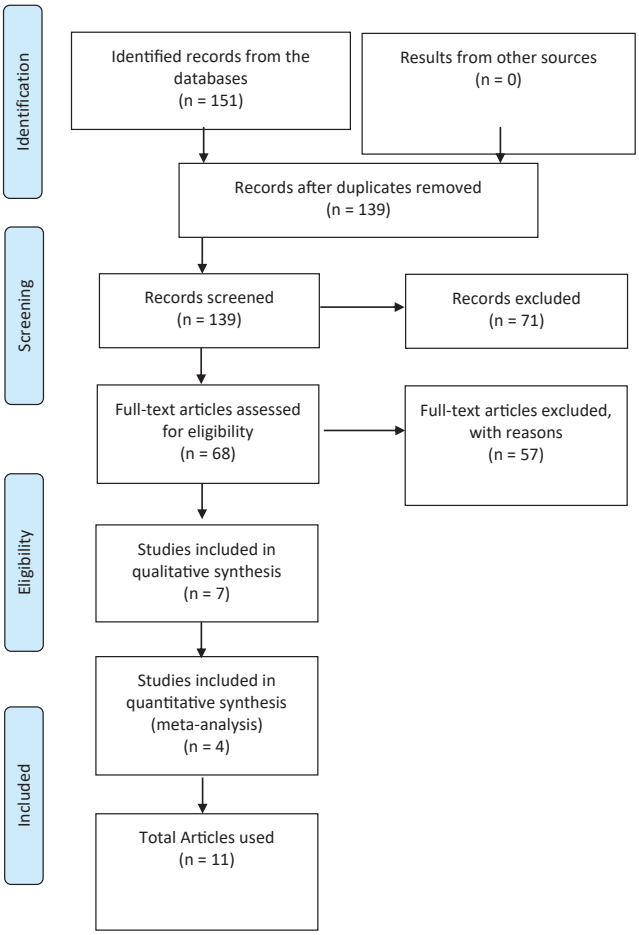

Figure 1: Flowchart of the selection process according to the PRISMA guidelines.

permissioned network that records transactions. Subsequently, a comprehensive discussion was presented through a critical comparison and contrast of the findings with the existing literature.

Critical appraisal of the studies

The critical appraisal of the selected research studies aims to ensure the assessment of their reliability and validity for the secondary analysis. The Critical Appraisal Skills Programme (CASP) tool was employed to accomplish this. This tool comprises ten criteria to assess the reliability and authenticity of research studies, and the chosen articles were scrutinized for their alignment with the research objectives, appropriateness of their methodologies, and the clarity of their findings.

Cooper (2017) and Dutta [21] conducted studies with the primary objective of evaluating the processes, benefits, and challenges arising from the implementation of blockchain traceability technology within the food supply chains. These studies utilized a qualitative design and employed thematic analysis, facilitating an in-depth examination of the key objectives.

Clauson, et al. [40] designed their study to primarily assess the leveraging of blockchain technology and the increased utilization of traceability features within the supply chain.

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This research focused on collecting data through exploratory qualitative analysis, enabling a detailed presentation of findings that elaborated on the opportunities and challenges of adopting blockchain technology in supply chains and the safety of products in the food industries.

Paththinige and Rajapakse [41] and Tönnissen and Teuteberg [42] centered their studies on observing the challenges that the food industries face when utilizing blockchain technology to enhance supply chain efficiency. These studies had a conceptual model and an explanatory design, respectively, which helps mitigate biases and enhance research rigor, enabling a logical and in-depth analysis of the evidence.

Alharthi, et al. [43] performed an exploratory qualitative analysis that assessed the efficacy and reliability of traceability blockchain technology in fostering sustainable and viable supply chain processes within the food industry.

Dai and Zhou [44] investigated various approaches and methodological designs for the reliable development and application of traceability technology, particularly within the food industries. The study's findings provided valuable insights into the opportunities and significance of traceability technology within the food supply chain.

In contrast, Garaus and Treiblmaier [45] utilized a quantitative design with systematic numerical testing using SPSS software. As such, the CASP tool was not applied to evaluate this study. However, it was included due to its alignment with the research objectives and its findings, which highlighted the significance of traceability technology within the food supply chain in terms of reliability.

Dehghani, et al.'s [46] study focused on evaluating the factors and challenges affecting the reliability, efficacy, and sustainability of traceability blockchain technology in the food industry's supply chain.

Additionally, Casino, et al. [47] had a qualitative, in-depth analysis, ensuring a thorough evaluation of the modeling and necessity of food supply chain traceability technology for fostering productive growth in the business and related sectors.

Significance of blockchain technology regarding traceability in the food sector

Garaus and Treiblmaier's [45] study emphasized the advantages of blockchain technology in ensuring product safety, particularly in the context of drug traceability. They highlighted how blockchain provides a unique and transparent solution within the FSC by implementing end-to-end traceability for customer informatics.

They conducted online surveys among Austrian business students, revealing the technology's potential to enhance food safety for retailers. It enables consumers to reduce food fraud and track the flow of food products, addressing issues like dilution, counterfeiting, and adulteration. Importantly, this technology has piqued the interest of policymakers who seek to understand how the traceability of food products can influence consumers' choice of retailers.

Casino, et al. [47] shed light on the significance of blockchain in enhancing transparency when consumers make decisions about their food choices. They developed a distributed functional model to assess various scenarios for food traceability using blockchain technology. The results indicated that extrinsic cues, such as quality labels, brands, and origin, were indirectly related to the food product itself. In contrast, intrinsic cues, representing physical aspects like food safety standards, hold greater importance. Blockchain technology offers additional features that bolster food safety assurance, including provenance and temperature monitoring. These features enable food retailers to build trust by providing certifiability, traceability, verifiability, and trackability.

Dehghani, et al. [46] analyzed the significance of blockchain technology in addressing the benefits and challenges in the production and manufacturing phases of the food sector. They examined 84 organizations within the food industry, highlighting how blockchain facilitates the sharing of information without inherent risks. Factors such as perceived standardization and platform development were found to influence the intention to use blockchain.

In line with this perspective, Garaus and Treiblmaier [45] explained how a blockchain-based decentralized system could effectively integrate the InterPlanetary File System (IPFS) for record-keeping. This approach can also be extended to the drug supply chain, as demonstrated by the "Gcoin" drug lifecycle model, which encompasses each drug's journey from manufacturing to the post-market phase. However, Hyperledger technology plays a crucial role in verifying the authenticity of drugs throughout the supply chain, complemented by the use of barcodes and RFID [45].

Efficacy, reliability, and sustainability of blockchain traceability technologies in ensuring food quality

The study's findings shed light on the existing challenges in managing the food supply chain to ensure both food quality and safety. These challenges emphasize the essential role of blockchain, a digital ledger technology, in addressing supply chain management issues [43].

The results also underscored the significant impact of blockchain technology on the traceability of supply chain records, achieved through the utilization of a Safe, Secure, and Scalable (SSS) data approach in conventional supply chains. This approach aims to manage critical data required for integrating Information Technology (IT) applications like Radio Frequency Identification (RFID), Electronic Data Interchange (EDI), and Enterprise Resource Planning (ERP). This integration contributes to enhancing the reliability and sustainability of blockchain-based traceability technologies, ultimately ensuring food quality [43].

Challenges and risks associated with adopting blockchain technology in the food industry

Cooper's study in 2017 highlighted a primary challenge in adopting blockchain for traceability in the food industry,

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which is the necessity for widespread adoption across various stakeholders. This challenge pertains to the difficulty that the food industry faces in encouraging companies and stakeholders to willingly participate in the adoption and implementation of innovative traceability or blockchain technology to enhance supply chain efficiency and product safety.

Dutta's research in 2020, as mentioned in the MHI annual report, surveyed over 1000 supply chain specialists and found that the adoption rate of blockchain technology in the food industry is merely 10%. This low adoption rate can be attributed to insufficient active participation and collaboration among stakeholders and professionals. Clauson, et al. [40] also emphasized that effective collaboration with individual suppliers to promote the use of traceability technology for ensuring safety and sustainability in the supply chain is essential. Thus, fostering strong partnerships among industry professionals is crucial.

An analysis of existing research studies revealed that managing multiple data sets related to various formulas and ingredients in food product formulation presents a challenge that leads to data integration risks. Paththinige and Rajapakse [41] stressed the importance of ensuring high-quality data protection and collection when utilizing blockchain technology. To maintain data quality, all suppliers and relevant parties must record data and information using blockchain technology. Attention must be given to data integration and protection when employing traceability technology. Furthermore, transferring data from a food company's database to the blockchain traceability system may pose challenges, as different companies in the industry employ various methods of data security and transmission. Additionally, food companies often exchange data in non-uniform formats, presenting a significant obstacle to adopting blockchain systems.

Tönnissen and Teuteberg's [42] study reported another critical challenge: the immature adoption and implementation of blockchain traceability technology in the industry. This immaturity results from low levels of familiarity and awareness of blockchain technology innovations. Lack of understanding and awareness among employees of companies and suppliers in the food industry can hinder the effective application and sustainable use of traceability technology [48-53].

Discussion

This study's first objective was to identify the significance of blockchain in the food industry, considering the importance of the traceability factor. As noted in the literature review, blockchain has transformed each stage of the supply chain, from raw material purchase to consumer distribution, according to Rejeb, et al. [19]. It tackled supply chain reengineering by establishing business process reengineering. As a result, each transaction can be reformed with the use of technology, and the supply chain may be made safer and more efficient [24]. In support of this idea, Garaus and Treiblmaier [45] stated that a blockchain-based decentralized system is beneficial for integrating an InterPlanetary file system for record keeping. Dutta, et al. [21] concurred, adding that all supply chain transactions made possible by technology are more cost-effective, transparent, and efficient, reducing supply chain risks.

The second study objective was to examine the reliability and sustainability of blockchain traceability technologies in ensuring food quality. The literature review showed that Traceability systems, according to Razak, et al. [23], have aided supply chain actors and engineering tools in evaluating and simulating each element of the supply chain, from production and manufacturing through delivery to consumers' doorsteps. Instead of addressing all elements, technology has allowed for tracking operations critical for product safety, resulting in decreased quality assurance costs. Similar findings were denoted in the study findings that the efficacy, long-term viability, and dependability of blockchain traceability systems are critical for maintaining food (Zhou & Xu, 2021).

An analysis of the findings of this research enabled an elaborated evaluation of the results of prevailing research articles associated with the challenges and risks that might serve as an obstacle in the adoption of the traceability blockchain technology within the food industry. The findings suggested that the biggest challenge is the effective collaboration of the suppliers and the stakeholders. The evidence obtained from the literature sources suggests that the lack of consideration of the supplier parties and the companies involved in maintaining effective supply chains for food industries makes it relatively difficult for the reliable and sustainable adoption and progressive implication of blockchain technology [42,43]. With the advancement in the features and the innovations in the technology, an understanding that such blockchain services and technologies cannot be handled without involving experts in the system has been developed [41]. Consequently, a lack of understanding of the strategic methods for operating and handling the traceability blockchain technology within the food industry might result in an uncertain decline in standards. Inefficiencies in handling the supply chains using traceability technology might harm the safety of the food products manufactured within the industry [40].

Another important challenge observed was data integration. The transaction and restoration of the data using blockchain technology are relatively complex as food manufacturing companies usually hold a huge amount of information related to the ingredients within the food manufacturers, commonly stored and organized within a company's databases. The data transactions are maintained manually using different types of databases used within the companies (Cooper, 2017). Such complexities with data integrations and transaction reductions reduce the efficacy and sustainable adoption of the traceability blockchain technology for promoting the safety of the manufacture and the supply chain of the food manufacturing industry [21].

Findings and conclusion

The study's findings underscore the significance of blockchain technology in ensuring product safety, particularly as a valuable tool for food merchants. Blockchain technology

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has the potential to enhance food safety by enabling consumers to track the flow of food products and detect instances of food fraud, which can encompass issues like dilution, forgery, and adulteration. These potentialities have also sparked the interest of policymakers who seek to investigate how food traceability influences consumers' choice of retailer.

While blockchain technology exhibits superiority in terms of efficacy, its traceability aspect imposes limitations on its dependability. Despite these challenges in data protection and reliability, blockchain offers substantial advantages to the food sector. It allows for the assessment and review of supply chain processes, leading to significantly improved product quality. Customers and other stakeholders can monitor each stage of the supply chain, from raw material procurement to processing, packaging, and transportation. However, several challenges persist, including the necessity for widespread adoption (referred to as cluster adoption) and the relatively immature implementation of blockchain technology within the industry.

Recommendations

This work is valuable for the food industry and its supply chain networks in articulating efficient decisions to implement blockchain-based traceability systems for improving the quality assurance process. This articulation can enhance supply chain and logistics operations and improve business performance and productivity. This research can help the food sector to update its information technology systems by investing to achieve desirable outcomes and offer a better customer experience. The research also benefits sectors other than food, such as retail, construction, healthcare, and services industries planning for digital transformation or improving their traceability systems in the supply chain. Thus, this work can enable concerned sectors and industries to form a structure that favors their progressive aspirations since this research can be a learning prototype for them to acquire prospects for business transformation. The study offers trustworthy, reliable, and credible information regarding the subject matter and efficiently works to contribute sufficiently to both practical and conceptual domains.

This study explored the utilization of blockchain technology for traceability, particularly in the food industry. Based on the findings, the following recommendations are proposed for adoption by food sector firms to improve their supply chain operations for food safety and quality:

- Food sector companies should adhere to the requirements set forth by the FDA's DSCSA.
- Implementing blockchain technology can enable effective tracking and tracing of products, thereby ensuring compliance with regulatory standards and meeting the overall safety demands of consumers.

Future implications

The present study employed a qualitative research approach, analyzing secondary data from various journal articles to assess the effectiveness and drawbacks of traceability technology in supply chain quality assurance within the food industry, with a focus on blockchain advancements. Future research could consider a quantitative approach, conducting surveys among blockchain technology specialists in the food sector to gather real-time insights into the role of blockchain in traceability. Additionally, future studies might opt for data collection through semi-structured interviews with industry experts to explore the challenges and risks associated with adopting blockchain technology in the food sector. Last, researchers interested in investigating the sustainability of blockchain traceability technologies for ensuring food quality could draw insights from this study's findings.

Conclusion

Implementing traceability systems has proven beneficial for supply chain stakeholders and engineering tools, facilitating the evaluation and simulation of various supply chain components. These components include everything from production and manufacturing to the final delivery to customers' doorsteps. Rather than encompassing all elements, technology has streamlined the tracking of critical operations essential for product safety, resulting in reduced costs associated with quality assurance. When coupled with effective risk management, traceability solutions have enhanced supply chain performance. Consequently, information can be updated, accessed, and transmitted in real-time with minimal errors and delays. However, the accessibility of traceability data by various parties poses a risk to the confidentiality of customers and other stakeholders. Furthermore, the adoption costs of blockchain and the potential hazards of phishing and cyberattacks on the entire system constitute fundamental risks and drawbacks associated with blockchain traceability software.

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