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An Approach for Risk Traceability Using Blockchain Technology for Tracking, Tracing, and Authenticating Food Products

Urvashi Sugandh [1], Swati Nigam [1], Manju Khari [2] and Sanjay Misra [3,*]

[1] Department of Computer Science, Faculty of Mathematics and Computing, Banasthali Vidyapith, Banasthali 304022, India; urvashi5sugandh@hotmail.com (U.S.); swatinigam.au@gmail.com (S.N.)
[2] School of Computer and Systems Sciences, Jawaharlal Nehru University, New Delhi 110067, India; manjukhari@yahoo.co.in
[3] Department of Applied Data Science, Institute for Energy Technology, 1777 Halden, Norway
* Correspondence: sanjay.misra@ife.no

Abstract: Regulatory authorities, consumers, and producers alike are alarmed by the issue of food safety, which is a matter of international concern. The conventional approaches utilized in food quality management demonstrate deficiencies in their capacity to sufficiently address issues related to traceability, transparency, and accountability. The emergence of blockchain technology (BCT) has provided a feasible approach to tackle the challenge of regulating food safety. This research paper presents a methodology for implementing blockchain technology to establish risk traceability in the context of monitoring, tracing, and authenticating agricultural products. The proposed system underwent a comprehensive evaluation, which placed significant emphasis on simulation parameters and assessment standards. The aim of the study was to demonstrate the effectiveness of the system through the assessment of various quantitative metrics, including throughput, latency, and resource utilization. The Hyperledger Fabric and Hyperledger Caliper were employed in the formulation and assessment of algorithms intended for agricultural supply chain management. The configuration comprising two entities and two peers achieved the highest write throughput (205.87 transactions per second; TPS), thereby demonstrating the network's effective transaction processing capability. In a two-organization, two-peer system, the mean latency for read operations exhibited variability spanning from 0.037 to 0.061 s, contingent upon the transaction rates and accounting for the duration needed for network processing and validation. The results were visually depicted, offering a distinct demonstration of the system's efficacy under various conditions. This study presents a quantitative analysis that illustrates the efficacy of the blockchain system in enhancing the traceability of agricultural products across the entire supply chain. The results of this research suggest that the implementation of blockchain technology could potentially enhance both the security and efficacy of food supply management.

Keywords: blockchain technology; smart farming; agriculture; food safety

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1. Introduction

As the food sector changes so quickly, it is now crucial to ensure food safety. In order to properly manage food safety, novel solutions are desperately required given the expanding complexity of supply networks and rising consumer expectations. This study proposes a novel method to monitor, trace, and authenticate food goods using blockchain technology, therefore revolutionizing food safety management.

Food safety affects public health, economic development, and international commerce worldwide. The WHO estimates that 600 million people globally get foodborne diseases each year, resulting in 420 thousand deaths [1]. Food quality and safety are threatened by inadequate transparency and traceability and the complexity of the food distribution supply chain. Traditional food safety management requires tedious and costly manual record-keeping and inspections. These procedures are error-prone. The food sector of today is not without its difficulties. Due to the complexity of supply chains, the wide range of regulations, and the need for real-time information sharing, conventional approaches to guaranteeing food safety are no longer enough. With unmatched transparency, security, and efficiency, the incorporation of blockchain technology appears as a disruptive force in this environment.

The food business is going through an extraordinary period of change worldwide. The dynamics of food production, distribution, and consumption have changed dramatically as supply networks have become more complex and international. In the meantime, food safety continues to be a major worry. The increasing number of contamination events and foodborne disease cases highlights the critical need for creative solutions. With an emphasis on monitoring, tracing, and authenticating food goods, our study investigates a unique method that uses blockchain technology for risk traceability in this context. This article examines the present state of the food business to highlight critical issues that need urgent attention. It also sets the stage for a discussion of how our proposed approach may revolutionize the way food safety and transparency are ensured.

Decentralized, transparent, and secure record-keeping and transaction processing are possible with BCT. Every block of the chain contains a unique cryptographic hash that links it to the previous block, ensuring transaction immutability and integrity [2]. BCT-based food safety pilot programs have proliferated internationally in recent years. BCT may improve food safety by increasing food supply chain transparency, traceability, and authenticity [3]. A shared ledger that keeps food product data up-to-date is accessible to food supply chain stakeholders using BCT. This intervention can help identify and segregate food items that pose a risk to public health, reducing foodborne illness rates [4]. However, there are still challenges to overcome. Interoperability, scalability, and privacy are major issues [5]. Distributed ledger systems need significant infrastructure, human resources, and instructional initiatives. This research compares BCT's pros and cons in food safety management. This research examines BCT-based food product monitoring, tracking, verification, and smart contract management to assure food safety [6,7]. This study's results may improve food safety management systems and community health.

In light of the urgency of the issue, it is critical to investigate creative solutions that surpass customer expectations while adhering to regulatory requirements. The decentralized and unchangeable ledger of blockchain technology has made it seem like a game-changer. By giving end-to-end insight into the food supply chain, it tackles the essential challenges of traceability and authenticity, which are at the foundation of food safety management [8,9].

Our method is unique in the field of blockchain applications, which makes it stand out. Our approach, in contrast to general blockchain implementations, is specifically designed for the complexities involved in managing food safety. Our goal is to close the gap between theoretical blockchain principles and real-world, industry-specific solutions by concentrating on the subtleties of this area. This distinction, which offers a specialized answer to a specific issue, increases the relevance of our study.

The stated issue statement, which is the inadequacy of current food safety management systems in handling the complexity of the contemporary food sector, lies at the heart of our study. We understand that just digitizing is insufficient; rather, a thorough, blockchain-driven revolution that completely rethinks how we see and guarantee food safety is needed. Therefore, we have two research goals. First, in the context of food safety management, we conduct a thorough literature review to assess current approaches and their shortcomings. Second, we use simulation methods to evaluate our blockchain-based solution's scalability and practical viability. Our study attempts to provide a comprehensive viewpoint by merging theoretical understanding with actual data by integrating these two elements.

1.1. Purpose and Objectives of the Study

The objective of this investigation is to analyze the benefits and drawbacks associated with the implementation of BCT as a means of controlling food safety. The objective of this research is to conduct an extensive review of the existing literature on the implementation of blockchain technology in food safety management to gain deeper insight into its capabilities and constraints. The present paper presents findings from a comprehensive investigation into the utilization of smart contracts for the purposes of food safety management as well as the monitoring, tracking, and authentication of food products through the implementation of blockchain technology. This analysis will:

- Perform an exhaustive literature review to assess the benefits and drawbacks of implementing BCT in food safety management.
- Assess the efficacy of BCT in augmenting transparency and accountability in the food supply chain, with a specific emphasis on the execution of mechanisms for monitoring, tracing, and authenticating food products.
- Specify and acknowledge the constraints and challenges associated with BCT in the management of food safety, including data privacy, scalability, and interoperability.

The outcomes of this study will enhance our comprehension of the potential applications of BCT in guaranteeing the safety of food distribution. This study aims to provide insights into the benefits and drawbacks of utilizing blockchain technology for food safety management, with the goal of facilitating the creation of more streamlined and impactful food safety management systems. The results of this study could be employed by governmental entities, producers, and individuals to enhance the safeguarding of public health.

1.2. Paper Organization

The rest of the article is organized as follows. Section 2: Literature Review, provides an overview of food safety management, blockchain technology, and previous studies on blockchain-based food safety management. The proposed method in Section 3 presents the different stakeholders involved in the proposed system. The simulation setup and performance analysis are described in Section 4, which describes the methodology used to test and analyze the proposed system's performance. The discussion in Section 5 presents the implications of the findings, compares the proposed system with traditional food safety management methods, and addresses the limitations and challenges of blockchain-based food safety management. Finally, Section 6: Conclusions, summarizes the main findings of the research and presents future directions for research in the field.

2. Literature Review

2.1. Overview of Food Safety Management and BCT

The safety of food products is of great concern to various stakeholders, including consumers, government agencies, and the food industry. The globalization of food production and supply systems has led to heightened complexity and challenges in ensuring food safety. The traditional methods for ensuring food safety, such as manual tracking and paper-based documentation, are deemed insufficient in terms of their precision, efficacy, and ability to maintain a clear record of the process. An imperative requirement for managing food safety is implementing a novel strategy, particularly in light of the escalating occurrences and outbreaks associated with this concern.

BCT offers a novel approach to food safety management through its transparent and secure platform designed to monitor, trace, and authenticate food products. Blockchain, a distributed ledger technology, enables the maintenance of an unalterable record of all historical transactions. This innovation can revolutionize the food industry by enhancing transparency, responsibility, and effectiveness in food safety management.

The implementation of BCT has the potential to improve food safety management by enabling the monitoring of every stage of the supply chain, from the farm to the table. This entails monitoring the origin and transportation of our food to its destination on our tables. The authentication of food quality, safety, and sustainability can be achieved through the utilization of BCT. The provision of this data to consumers, regulatory bodies, and other stakeholders has the potential to enhance transparency and credibility within the food industry.

Collaboration among producers, processors, distributors, retailers, and regulatory bodies is essential for the successful implementation of BCT in food safety monitoring. The integration of BCT into pre-existing food safety management systems and guidelines is also a prerequisite for its deployment. In order to ensure the interoperability and scalability of food safety management systems based on blockchain technology, it is imperative to establish standards and protocols.

2.2. BCT and Its Applications

Secure, transparent, and decentralized transactions are made possible by BCT, which is a distributed ledger system. There are nodes in this network whose only purpose is to verify and permanently record transactions. The blockchain is a distributed ledger in which each "block" is a collection of related transactions connected to each other through cryptography. A block on the blockchain cannot be changed or removed after it has been created, protecting the data it contains.

Use Cases for Blockchain in Food Safety:

- Tracing and Tracking: With BCT, food items can be traced and tracked from the farm to the table. Information about the food's production, preparation, and delivery may all be recorded on the distributed ledger system (blockchain). In the event of an epidemic, this will allow relevant parties to quickly pinpoint the origin of the contamination and implement appropriate countermeasures. In addition, it lets buyers know exactly where their food came from, boosting confidence in the item's legitimacy and quality.
- Food fraud and adulteration may be avoided by using BCT to verify the authenticity of food items. A digital fingerprint may be registered on the blockchain for each individual food item. At any stage in the distribution process, this identity may be used to confirm the legitimacy of the food item. As a bonus, BCT may be used to spot and stop counterfeiting by letting stakeholders monitor the product's journey and verify that it has not been tampered with along the way.

2.3. Methodology: Systematic Literature Review

When we were performing our systematic literature review, we made sure to follow the detailed and exact technique that is specified in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. This ensured that our findings are accurate and reliable. Our investigation started with a specific research topic, which served as the basis for our methodical investigation. The first step in the approach consisted of conducting exhaustive searches across a variety of recognized academic databases, such as PubMed, IEEE Xplore, and Google Scholar. We painstakingly constructed a list of search phrases that included essential components of our study, such as "Blockchain Technology", "Food Safety", and "Traceability". This allowed us to guarantee that our approach was thorough.

After the first search of the available literature, the discovered articles were put through a rigorous screening procedure. The titles and abstracts of the articles were carefully examined to see whether or not they were relevant to the goals of our study. The entire texts of the papers were carefully evaluated further only after they had been determined to have passed the first screening. To determine whether or not each manuscript met the requirements, we first used a set of inclusion and exclusion criteria that had been previously established. The chosen databases were shown as rectangles, and the direction of the arrows indicated which search phrases were used. The screening procedure, shown in a diamond-shaped diagram, presented the decision pathways for determining the inclusion or exclusion of an article. During the screening process, which is represented by a diamond shape, decision routes, which are shown in Figure 1, determined whether a paper was included or eliminated.

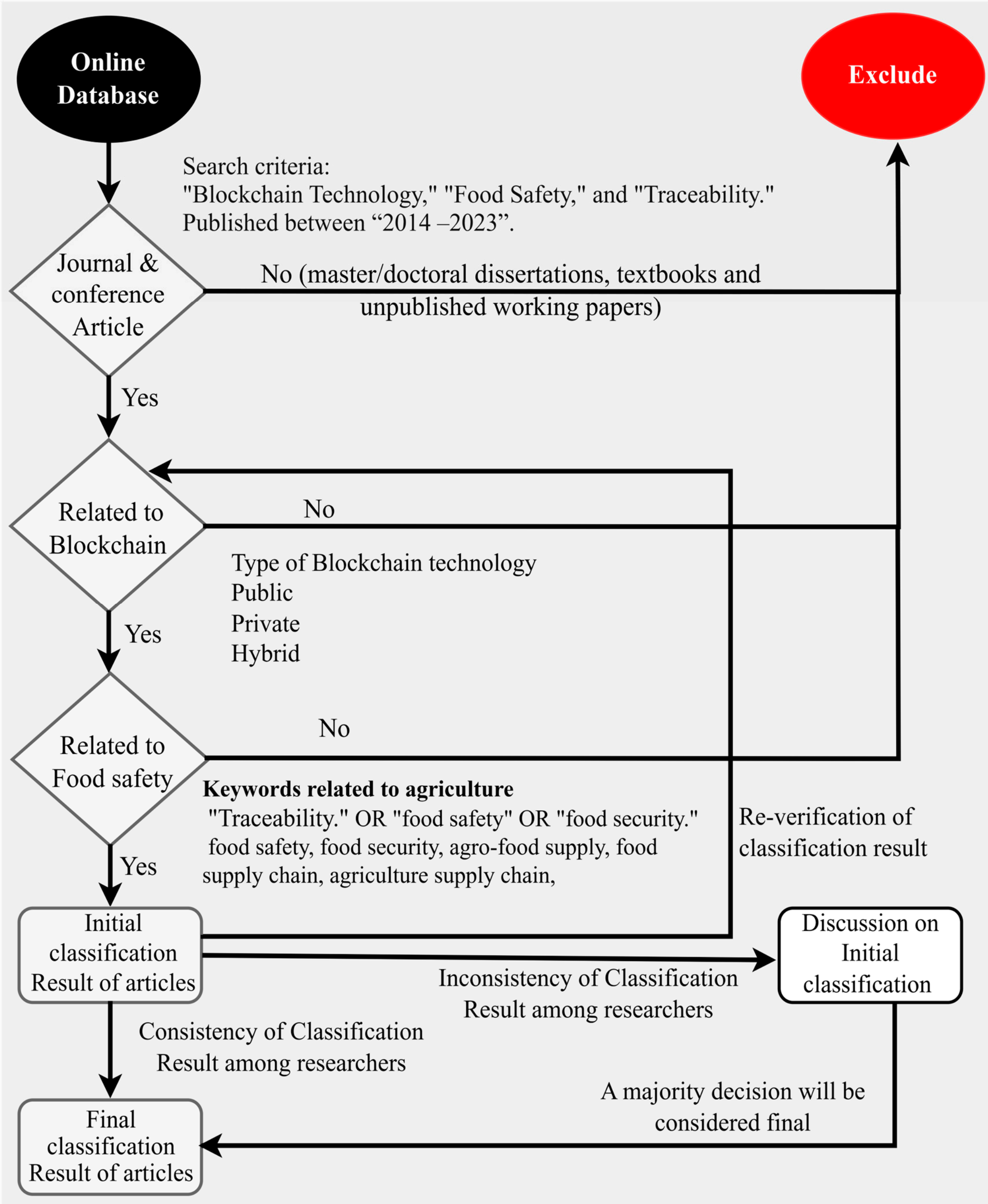

Figure 1. Article selection criteria.

Following the completion of the screening procedure, the selected articles were subjected to a phase consisting of painstaking data extraction and analysis, if relevant. This gave us the ability to make important conclusions. The final selection, which is represented by a decision diamond, brought attention to the papers that were able to fulfill our severe requirements. The stage of synthesis and review, which is depicted by a rectangle, consisted of conducting an in-depth investigation of the selected body of literature, identifying the most important results, and organizing those findings into cohesive themes. The integrity and dependability of our systematic literature review are protected by this all-encompassing process, which adheres to the PRISMA principles. Our research study on the methodology for risk traceability with blockchain technology in monitoring, tracing, and authenticating food goods is built on a solid basis provided by the insights that were generated as a consequence of this stringent method, which serves as the paper's foundation.

2.4. Previous Studies on Blockchain-Based Food Safety Management

In order to establish a distributed ledger that is available to all supply chain participants, the authors present the Harvest Network, a hypothetical end-to-end application [9]. The objective is to deal with problems including information asymmetry, inconsistent data formats, and antiquated information systems. The article offers a basic framework that may be used to create a simulation or prototype using current protocols and technology. According to the authors, the next stage is for academics and practitioners in the industry to use AGILE techniques to develop cutting-edge projects and functional prototypes that promote transparency [9].

In order to create a visible and impenetrable food supply chain, the authors of [10] suggest a traceable food safety solution using blockchain technology and smart contracts. The goal of this solution is to build enduring trust with stakeholders and customers by guaranteeing dependability and traceability from the fields to the kitchen. According to the report, this strategy may lessen the likelihood of major health hazards and advance our understanding of the production, distribution, and retail of food items.

A food traceability system based on blockchain and Internet of Things (IoT) technology is proposed in the study in [11]. With the help of this system, which is built for a smart agricultural ecosystem, food safety concerns should be addressed by tracking and monitoring food production throughout its whole lifecycle. All participants in the ecosystem are involved in an open, self-organizing, and ecological system. This study advances the technological side of food safety.

Issues with the conventional food supervision system include data fragmentation and a lack of industry chain, which result in incoherent field regulations and a slow reaction time [12]. As a solution, the authors suggest a secondary-check method and a hierarchical multi-domain blockchain (HMDBC) network topology [12]. This system may facilitate arbitration of superior regions, auxiliary verification of supervision nodes, and prompt rectification and replacement of malicious supervision nodes by regional nodes co-governance. In order to fairly and objectively assess each node's overall reputation in that area, the authors additionally suggest a fuzzy comprehensive assessment model of credibility that takes into account a variety of node performance indicator-influencing aspects. When smart contracts are used in conjunction with food industry norms, the system may automatically identify food quality and alert users to subpar food along the whole industrial chain.

The authors' goal is to determine how blockchain technology could enhance the coffee supply chain's ecological embeddedness [13]. They use a qualitative case study approach to examine the first blockchain-enabled coffee company in the United States. The results show that the scenario under study does not have an environmentally integrated blockchain implementation. The authors come to the conclusion that a coffee supply chain with an incorporated circular economy would benefit from the extension of blockchain technology to take into account the production byproducts and vaporizable trash as assets [13].

In order to ascertain the effects of blockchain technology on the tourist industry and its sustainability, the writers examine research patterns pertaining to this application of technology [14]. The findings point to an increasing pattern of scholarly inquiry on supply chain efficiency and sustainable management. Marketing, logistics, and intelligent business models are the tourist industry operations that are using this technology more than others. Solutions that anticipate and encourage visitor behavior based on sustainable consumption patterns and behavior are already made possible by this technology, benefiting a variety of stakeholders [14].

In order to account for possible self-selection biases and confounding variables, the authors used propensity score matching (PSM), ordered logit model (Ologit), and ordinary least square (OLS) techniques using online survey data of 1058 fresh fruit customers [15]. The findings indicate that customers' information-seeking behavior about fresh fruits is considerably impacted by their risk attitude. The likelihood of customers seeking information decreases with increasing risk preference. In addition to offering several recommendations for policy and practice to achieve a wider trajectory in agri-food information disclosure, the research gives fresh insights into the relationship between the food control risk mindset and traceability of agri-food information [15].

The integration of Internet of Things (IoT) devices that generate and consume digital data throughout the chain is covered in the [16] study. The authors created and implemented a use-case for the from-farm-to-fork vertical domain, defining a use-case inside it. They achieved traceability by using Ethereum and Hyperledger Sawtooth, two distinct blockchain implementations. We assessed and contrasted the latency, CPU, and network use of the two implementations. The study emphasizes how blockchain technology may be used to solve problems with existing IoT-based traceability and provenance systems for agri-food supply chains, including data integrity, manipulation, and single points of failure.

The authors examine the state-of-the-art blockchain technology, its applicability in the agri-food value chain, and related difficulties using a comprehensive literature network analysis [17]. The results indicate that four key areas of agri-food value chain management—manufacturing, information security, traceability, and sustainable water management—have benefited from the adoption of blockchain technology, advanced information and communication technology, and the Internet of Things (IoT). Six obstacles are listed in the paper: scalability and storage capacity; privacy leakage; high cost and regulatory issues; throughput and latency issues; and insufficient skills. By emphasizing how blockchain technology might enhance agri-food value chain performance in areas like food safety, food quality, and food traceability, the research adds to the body of knowledge.

A food safety traceability system using blockchain technology and the EPC Information Services (EPCIS) is proposed in the study [18]. The system's objective is to effectively identify and avert food safety issues by precisely documenting, exchanging, and tracking information throughout the whole logistics chain. This covers the procedures involved in manufacturing, processing, warehousing, shipping, and retail. Additionally, the authors create a working prototype system and suggest an on-chain and off-chain data management architecture to address the blockchain's data explosion problem for the Internet of Things. Ethereum was used to create the prototype system.

The authors create a multimode storage mechanism that integrates chain storage and suggest a novel system architecture based on blockchain technology [19]. Real-world instances and application scenarios were used in the testing and verification of this prototype system. The suggested system differs from conventional ones in that it offers real-time sharing of information about hazardous materials, data security and dependability, information connectivity and intercommunication, and dynamic and reliable whole-process tracking [19]. This method is very important and serves as a benchmark for ensuring food safety and quality via process traceability.

The research in [20] examines blockchain usage in the food supply chain using a content analysis-based literature review. According to the authors, blockchain has four advantages: it may improve food traceability, increase information transparency, improve recall efficiency, and work better when paired with the Internet of Things (IoT) [20]. They also list five possible obstacles, including a lack of a thorough grasp of blockchain, problems with technology, the manipulation of raw data, the difficulty of gaining the support of all parties, and the absence of legislation. According to the research, blockchain technology may improve the efficiency of managing food recalls and alleviate food poverty.

Because of its distribution and tamper-resistance properties, the information storage infrastructure the authors have built using Hyperledger ensures the legitimacy and authenticity of data [21]. The study provides a strategy for assessing the risk to food safety and tracks unqualified goods using visual aids including force-directed graphs, heat maps, and migration maps. Using a case study that used aquatic goods as an example, the approach was evaluated using food sample data from 2016. The outcomes provided a foundation for developing a regulatory plan for risky locations by demonstrating the risks in an understandable and effective manner and analyzing the causes and traceability procedures.

Table 1 shows the summary of previous studies for blockchain-based food safety management.

Table 1. Previous studies on blockchain-based food safety management.

Authors	Summary	Year	Citations	Main Findings
M. P. Caro et al. [16]	Existing agri-food supply chain traceability and provenance systems are based on consolidated backends. The Internet of Things is the foundation of these setups.	2018	376	AgriBlockIoT is a traceability solution that utilizes blockchain technology to manage the supply chain of Agri-Food. It establishes a connection between IoT devices that generate and utilize digital data in a decentralized manner, without a centralized authority. The evaluation was carried out during the development and deployment of a conventional use-case in the vertical domain, specifically "from farm to fork".
G. Zhao et al. [17]	BCT has improved the management of the agri-food chain in four key areas, namely traceability, data security, production, and sustainable water management.	2019	175	There are six issues to consider: scalability and storage capacity, privacy concerns, cost, delay, and expertise. Further activities and research are needed to address the uses of BCT in the management of the agri-food chain.
Q. Lin, et al. [18]	Traceability may be the answer to the issue of too much data being created by the blockchain for the Internet of Things.	2019	175	Food safety traceability is improved by using blockchain and EPCIS. Data tampering and leaking of private information are both avoided by enterprise-level smart contracts.
X. Zhang, et al. [19]	When it comes to guaranteeing the quality and traceability of food safety procedures, the proposed system is crucial and has reference value.	2020	52	A BCT-based structure for the wheat supply chain incorporated multimode chain storage. The proposed system encompasses several key features, including data security and reliability, interconnectivity, real-time exchange of hazardous-material information, and comprehensive tracking capabilities throughout the entire process. The proposed approach is essential for tracing the production process of safe and high-quality food.
J. Duan, et al. [20]	The distributed ledger technology might improve food recalls, data transparency, and chain of custody.	2020	129	Blockchain enhances the efficiency of food recalls, information traceability, and transparency of food goods. The blockchain and the Internet of Things make everything better. It is possible that there will be problems with blockchain due to a lack of knowledge, technical difficulties, raw data manipulation, lack of stakeholder buy-in, or holes in regulations.
Z. Hao, et al. [21]	A proposed method may serve as the cornerstone of a regulatory strategy for high-threat areas.	2020	28	Blockchain and data visualization tools have been utilized to analyze potential food safety risks safely and efficiently. Data modeling and risk analysis techniques are used to quantify and analyze food safety problems. It is possible to keep tabs on subpar goods and flag potential trouble spots using tools like heat maps, migration maps, and force-directed graphs.

Table 1. *Cont.*

Authors	Summary	Year	Citations	Main Findings
K. Behnke, et al. [22]	To fully deploy BCT, supply chain procedures must be modified.	2020	194	Eighteen limits on business, regulation, quality, and traceability were highlighted in the four cases. Independent governance, a shared platform, and standardized auditable processes are necessary for the widespread use of BCT. Before blockchain can be implemented, supply chain systems and organizational procedures need to be adapted to work within the boundaries imposed on them.
Y. Wang, et al. [23]	The blockchain-based food safety monitoring system has the potential to save expenses, boost productivity, and make regulation and public scrutiny easier for all parties involved.	2020	2	While BCT has many potential advantages—including lower costs, improved efficiency, and easier public or regulatory agency oversight—it also faces challenges, including a dearth of relevant laws and regulations, an inadequate infrastructure, and increased risks of information and data leakage. The blockchain is a new technology that is still in its infancy.
Y. Wang et al. [24]	Deploying several nodes and performing functional testing helps achieve the goal of food safety traceability.	2020	8	BCT might improve food safety tracking. A need assessment and guidelines for milk safety traceability led to the development of the system architecture for milk tracking. The blockchain platform Hyperledger Fabric was selected, and the Go programming language was utilized to create and implement the tracing method.
A. Rejeb, et al. [25]	The main benefits of BCT in food supply chains include increased food traceability, increased collaboration, operational efficiencies, and accelerated food trade processes.	2020	76	BCT can improve food traceability, encourage collaboration, and speed up trade processes. Potential stumbling blocks include things like tech, org, and reg worries. The practical ramifications of BCT in FSCs should be the primary focus of future research.
R. Kamath [26]	Walmart's usage of BCT has reduced the time it takes to determine where mangoes were grown from seven days to 2.2 s.	2018	231	The implementation of two blockchain projects by Walmart involving the sale of pork and mangoes in China and the Americas was made possible through the utilization of IBM's Hyperledger Fabric BCT. The employment of BCT by Walmart resulted in a significant reduction in the time required to trace a mango from seven days to 2.2 s, while also enhancing the transparency of the company's food supply chain.
S. Pearson et al. [27]	Distributed ledgers might significantly improve how food is transported and stored.	2019	78	Food waste and spoilage might be reduced with the use of BCT. To fully realize DLT's promise, worldwide data standards and governance must be implemented to protect the food supply. Data structures, privacy, and scalability are all issues that need fixing.

2.5. Key Takeaway of the Literature Review

Blockchain technology has the capacity to significantly transform the food supply chain through its ability to enhance traceability, transparency, and safety [22].

A distributed ledger technology, blockchain enables the creation of a tamper-proof and secure ledger of transactions. This feature renders it optimal for monitoring the succession of food items from cultivation to consumption along the supply chain [23].

By utilizing blockchain technology, consumers can purchase food with the knowledge that it is genuine and secure to eat. Additionally, they are able to trace the origin of their food, enabling them to make more informed decisions regarding their dietary selections [24].

Despite being in its nascent phases of development, blockchain possesses the capacity to revolutionize the food supply chain. The authors of the papers used in the literature review are optimistic regarding the prospects of blockchain technology and assert that it possesses the capacity to foster a more sustainable and equitable agricultural system.

In particular, we discovered that blockchain technology can be employed to:

- Blockchain technology can be utilized to monitor the passage of food products from farm to fork along the supply chain. This can aid in the identification and mitigation of food safety hazards, while also empowering consumers to make more informed decisions regarding their dietary choices [25].
- Blockchain technology has the potential to facilitate the establishment of a more transparent food supply chain. This can facilitate the development of consumer confidence in food manufacturers [26].
- Food safety can be enhanced through the use of blockchain technology, which generates a tamper-proof and secure ledger of all transactions. This can aid in the prevention of food contamination and fraud [27].

Additionally, some of the obstacles that must be surmounted prior to the widespread implementation of blockchain technology in the food supply chain were addressed by the authors. The following are some of these challenges:

- Blockchain implementation can be costly due to the fact that it is a relatively new technology.
- Utilizing and comprehending blockchain technology can be challenging due to its complexity.
- The regulatory environment pertaining to blockchain technology is continuously developing.

The authors maintain that the potential advantages of blockchain surpass the associated dangers, notwithstanding these obstacles. They are certain that blockchain is anticipated to have a significant impact on the food supply chain in the future.

We also discovered that a growing corpus of research is devoted to the application of blockchain technology in the food supply chain, in addition to the aforementioned advantages and difficulties. A diverse range of stakeholders, including academia, industry, and government, are collectively undertaking this research.

3. The Proposed Method

In this part, we provide a full exposition of our pioneering food safety management system that is built on blockchain technology. In the proposed methodology, crucial transactional data are securely maintained on the blockchain, including significant information such as the source of the product, various stages of processing, evaluations of quality, and records of distribution. The use of a hierarchical data model facilitates the maintenance of standardized formats, hence maintaining a high level of consistency and compatibility across the supply chain. The use of a structured approach facilitates the optimization of querying and retrieval processes, hence improving the overall usability of the system.

The core of our technique is the use of smart contracts, which are sophisticated self-executing programs that are implemented on the blockchain. The contracts provide the automation of several procedures within the food supply chain, carrying out predetermined norms and conditions. Automated processes include many activities such as quality evaluations, financial reconciliations, and communication alerts, therefore optimizing operational efficiency, guaranteeing precision, and mitigating human mistakes. By using encryption methods, both inside and outside of the blockchain network, the protection of sensitive data is ensured, hence guaranteeing the confidentiality and accuracy of information. Off-chain storage is used to store sensitive information, such as secret recipes or supplier contracts, in order to enhance security measures and comply with regulatory standards.

Figure 2 illustrates the food safety and traceability system architecture currently being considered for implementation. Participating in this specific system are a wide variety of organizations and people, including those involved in food production, distribution, retail, and regulation, as well as consumer advocacy organizations and groups of individual consumers.

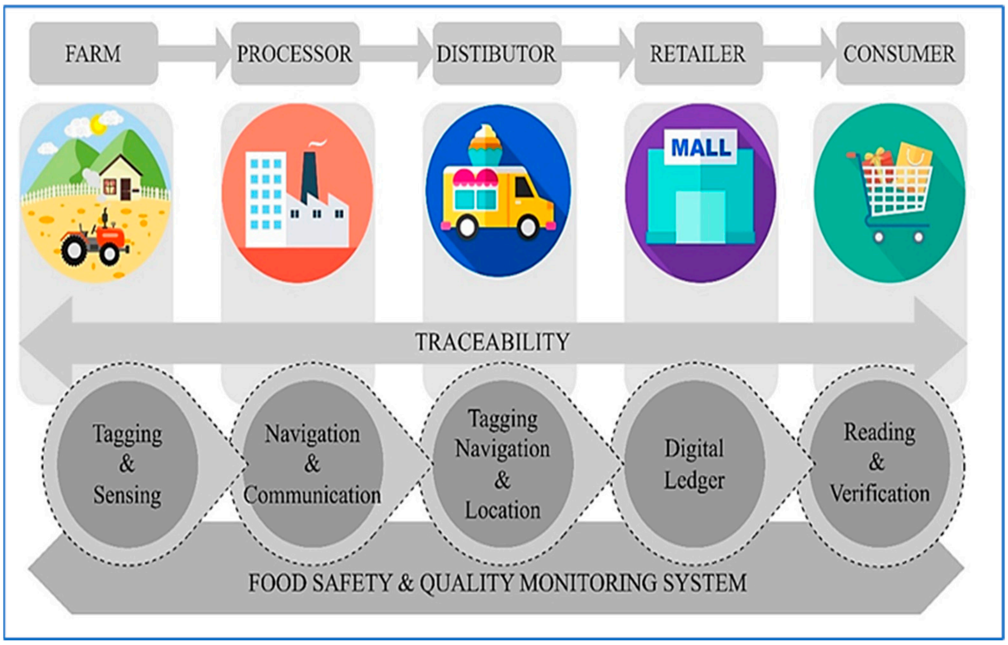

Figure 2. Food safety and traceability system.

The network that comprises the blockchain operates as a decentralized ledger for the purpose of recording and confirming a multitude of transactions and occurrences that take place across the whole of the food supply chain, beginning with the preliminary phases of production and ending with the phase of consumption at the end of the chain. This function of the blockchain network is intended to help ensure the safety of the food supply chain. Utilizing blockchain technology for the purpose of storing production data, inspection reports, and test results in a transparent and irreversible way might offer a dependable method for assuring the quality and safety of food items. This is because blockchain technology cannot be altered once it has been created. The safety and security of the food supply chain are things that must be ensured, and the transmission of this information to all important parties is meant to do just that. In order to supervise and guarantee that food safety norms and standards are adhered to, regulatory bodies and consumer protection groups may choose to use this technique. Consumers can have access to the information they need in order to make educated choices about the foods they put into their bodies thanks to the use of blockchain technology. The suggested workflow for the system to ensure the safety of food and track its origin is shown in Figure 3.

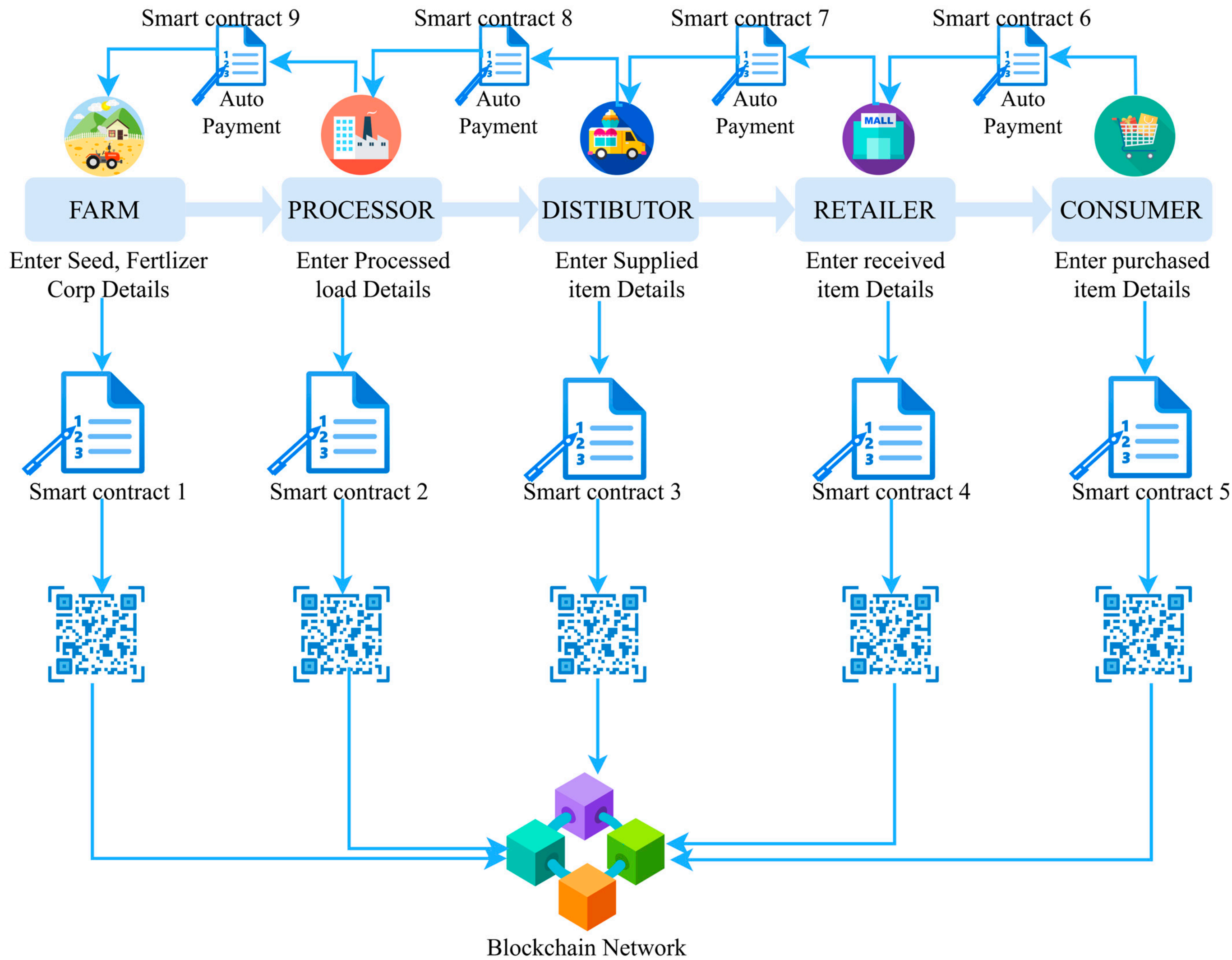

Figure 3. Workflow of proposed food safety and traceability system.

3.1. Different Stakeholders in the Proposed System

In the realm of utilizing BCT for the purpose of food safety management, a multitude of stakeholders can be discerned. The primary stakeholders in the food industry include food producers, retailers, distributors, processors, and consumers. The stakeholders who are involved in the making, circulation, and consumption of food goods have a significant influence on the safety and purity of food. Additional stakeholders encompass governmental entities accountable for food safety regulations and policies, third-party logistics and certification entities, and food safety auditors and inspectors.

- Food producers and farmers: The individuals or entities responsible for the production and cultivation of agricultural products are commonly referred to as producers and cultivators of food. The implementation of BCT enables the monitoring and recording of the entire supply chain of food products, from their origin at the farm to their destination on the table. This ensures the safety, freshness, and high quality of the food. Table 2 presents the algorithm and pseudo code employed by food producers and farmers.

Table 2. Algorithm and pseudo code: food producers and farmers.

Algorithm	Pseudo Code
Input Variables: Food product, source, destination, timestamp, blockchain network Output: Traceability and transparency of food product movement Steps: 1. Assign a unique ID to each food product at the source. 2. Record the product data, including the unique ID, source, destination, and timestamp, on the blockchain network. 3. Transport the food product to the destination and record each stage of the transportation process on the blockchain network. 4. At the destination, verify the product data against the data logged on the network. 5. If the data match, the food product is considered safe and authentic, and the transaction is considered complete. 6. If the data do not match, investigate the source of the discrepancy. 7. If-else loop: If the product data are verified and match the data logged on the network, the product is considered safe and authentic. If the data do not match, the product is flagged, and the source of the discrepancy is investigated.	1. Function farmer_food_producer(food_product, source, destination, timestamp, blockchain_network) 2. unique_id = generate_unique_id(food_product) 3. blockchain_network.record(product_info = {unique_id, source, destination, timestamp}) 4. transport_food_product(destination, blockchain_network) 5. if verify_product_info(destination, blockchain_network) == true then 6. return "Safe and authentic food product" 7. else 8. investigate_discrepancy() 9. end if 10. end function

- Food processors and manufacturers: Food processors and manufacturers are responsible for the processing and production of food. BCT can be utilized to oversee and verify the legitimacy of the fundamental components employed in the production procedure, thereby guaranteeing the integrity and cleanliness of the product. Table 3 displays the algorithm and pseudo code utilized by food processors and manufacturers.

Table 3. Algorithm and pseudo code: food processors and manufacturers.

Algorithm	Pseudo Code
Input Variables: Food product, certification, blockchain network Output: Verification of the authenticity of food product certifications Steps: 1. Issue and record a food product certification on the blockchain network. 2. Record the certification data, including the certification ID, issuer, and timestamp, on the blockchain network. 3. Verify the food product against the certification data logged on the network. 4. If the data match, the food product is considered certified and authentic. 5. If the data do not match, the certification is considered invalid. 6. If-else loop: If the food product is verified against the certification data logged on the network and the data match, the food product is considered certified and authentic. If the data do not match, the certification is considered invalid.	1. Function food_processor_manufacturer(food_product, certification, blockchain_network) 2. certification_id = generate_certification_id(food_product, certification) 3. blockchain_network.record(certification_info = {certification_id, issuer, timestamp}) 4. if verify_certification_info(certification_id, blockchain_network) == true then 5. return "Certified and authentic food product" 6. else 7. return "Invalid certification" 8. end if 9. end function

- Distributors and supply chain partners are integral components of the business ecosystem. The stakeholders bear the responsibility of conveying and disseminating food products. BCT can be employed to monitor and trace the transportation of food items across the supply chain, guaranteeing the secure and effective delivery of said products. Table 4 presents the algorithm and pseudo code utilized by the distributors and supply chain partners in their operations.

Table 4. Algorithm and pseudo code: distributors and supply chain partners.

Algorithm	Pseudo Code
Input Variables: Food product, source, destination, timestamp, blockchain network Output: Traceability and transparency of food product movement Steps: 1. Record the food product data, including the unique ID, source, destination, and timestamp, on the blockchain network. 2. Transport the food product to the destination and record each stage of the transportation process on the blockchain network. 3. At the destination, verify the food product data against the data logged on the network. 4. If the data match, the food product is considered safe and authentic, and the transaction is considered complete. 5. If the data do not match, investigate the source of the discrepancy. 6. If-else loop: If the food product data are verified and match the data logged on the network, the food product is considered safe and authentic. If the data do not match, the food product is flagged, and the source of the discrepancy is investigated.	1. Function distributors_supply_chain_partners(food_product, source, destination, timestamp, blockchain_network) 2. blockchain_network.record(product_info = {unique_id, source, destination, timestamp}) 3. transport_food_product(destination, blockchain_network) 4. if verify_product_info(destination, blockchain_network) == true then 5. return "Safe and authentic food product" 6. else 7. investigate_discrepancy() 8. end if 9. end function

- Retailers and food service providers: The stakeholders in question bear the responsibility of vending and dispensing food items to end-users. Businesses can employ BCT to authenticate and ensure the standard of their food products, thereby ensuring a secure and gratifying customer experience. Table 5 presents the algorithm and pseudo code utilized by retailers and food service providers.

Table 5. Algorithm and pseudo code: retailers and food service providers.

Algorithm	Pseudo Code
Input Variables: Food product, certification, blockchain network Output: Verification of the authenticity and quality of food products Steps: 1. Verify the food product against the certification data logged on the network. 2. If the data match, the food product is considered certified and authentic. 3. If the data do not match, the certification is considered invalid. 4. If-else loop: If the food product is verified against the certification data logged on the network and the data match, the food product is considered certified and authentic. If the data do not match, the certification is considered invalid.	1. Function retailers_food_service_providers(food_product, certification, blockchain_network) 2. if verify_certification_info(certification_id, blockchain_network) == true then 3. return "Certified and authentic food product" 4. else 5. return "Invalid certification" 6. end if 7. end function

- Consumers: The end-users of the food products are considered as stakeholders. BCT can be employed to monitor and record the transportation and distribution of food items, thereby guaranteeing the safety and superior quality of the food products consumed. Table 6 presents the algorithm and pseudo code pertaining to the functioning of the consumers.

Table 6. Algorithm and pseudo code: Consumers.

Algorithm	Pseudo Code
Input Variables: Food product, source, destination, timestamp, blockchain network Output: Traceability and transparency of food product movement Steps: 1. Verify the food product data against the data logged on the network. 2. If the data match, the food product is considered safe and authentic. 3. If the data do not match, do not consume the food product, and report the discrepancy. 4. If-else loop: If the food product data are verified and match the data logged on the network, the food product is considered safe and authentic. If the data do not match, the consumer should not consume the food product and report the discrepancy to the relevant authorities.	1. Function consumers(food_product, source, destination, timestamp, blockchain_network) 2. if verify_product_info(destination, blockchain_network) == true then 3. return "Safe and authentic food product" 4. else 5. do_not_consume() 6. report_discrepancy() 7. end if 8. end function

The responsibility of guaranteeing adherence to food safety regulations and policies by all participants in the food supply chain rests with food safety auditors and inspectors. Food production, processing, distribution, and retailing facilities are subject to inspections and audits to verify compliance with regulations and policies. Certification services are offered by third-party logistics and certification organizations to stakeholders in the food supply chain, signifying that they have fulfilled standards for food safety and quality.

3.2. Data Model for Hyperledger Fabric Implementation

The crucial factor in the endeavor to improve food safety via blockchain technology is the incorporation of a precisely defined data model. Within the framework of this study, we suggest the implementation of a structured data model in Hyperledger Fabric, a permissioned blockchain system renowned for its appropriateness in supply chain implementations. The data model comprises critical elements, namely Smart Contracts, Assets, Participants, and Transactions, all of which fulfill distinct functions in enabling the monitoring and evaluation of food product risk and traceability.

- The Asset category is primarily occupied by information pertaining to products. Meticulously preserved product attributes include the following: Product ID, Product Name, Description, Manufacturer Details, Production Date, Expiration Date, Batch Number, Ingredients, and Allergen Information. In addition to ensuring that each product is uniquely identifiable, these characteristics also furnish an exhaustive synopsis of its composition and history.
- The Participant segment comprises the various stakeholders engaged in the food supply chain, including but not limited to regulatory bodies, processors, retailers, consumers, and farmers. A unique identifier is assigned to each participant in order to facilitate identification and allow for accurate monitoring of their progress throughout the product's lifecycle.
- The foundation of both traceability and authentication lies in transactions. Transaction IDs and timestamps are documented in order to track the progress of individual

products. This includes location and jurisdiction alterations in addition to transfers of ownership. Critically, transaction details comprise quality control reports, certificates of authenticity, and any modifications to the ownership or condition of the product.
- Smart contracts play a crucial role in the operation of the blockchain network as they are self-governing programs that verify the validity of transactions, establish the process of traceability, and ensure authenticity. These contracts establish regulations that facilitate the evaluation and reduction of hazards linked to the food supply chain.

Here is an example of how the data model could be used:

```
# Asset
asset_id: "1234567890"
asset_type: "fresh produce"
asset_name: "apples"
asset_description: "A crate of red apples"
asset_owner: "Farmer Arvind"
asset_location: "Farmer Arvind Land"
asset_risk_level: 2
asset_risk_score: 10
# Transaction
transaction_id: "9876543210"
asset_id: "1234567890"
transaction_type: "produce"
transaction_date: "2023-11-02 12:00:00"
transaction_location: "Farmer Arvind Land"
transaction_participant: "Farmer Arvind"
```

3.3. Data Stored on the Blockchain

The information contained within the blockchain is an extensive repository that is of the utmost importance for the administration of food safety. It comprises risk assessment data, timestamps, transaction IDs, quality and authenticity documents, ownership and location information, and the complete lifecycle of food products. As a whole, these data provide an all-encompassing perspective on the product's trajectory, authenticate its quality and genuineness, monitor its whereabouts throughout the supply chain, and assess possible hazards. The storage of relevant information and the utilization of this data model are fundamental to the implementation of a food safety risk traceability system that is efficient and effective using blockchain technology.

4. Simulation Setup and Performance Analysis

This section provides a comprehensive account of the evaluation of the proposed system, including the meticulous selection of simulation parameters and assessment criteria. The results that were acquired have been comprehensively analyzed, with consideration given to the fluctuations of significant parameters such as the duration of block creation and the dimensions of the block, among other factors. The research showcases findings that demonstrate the efficacy of the system in relation to metrics such as throughput, latency, resource utilization, and network capturing. Graph plots are utilized to visually represent diverse scenarios with varying configurations in order to enhance the engagement of the findings. The objective of these findings is to furnish the audience with a lucid comprehension of the capabilities and constraints of the suggested system, along with possible avenues for enhancement.

4.1. Simulation Setup

The simulation environment necessitates specific hardware and software requirements, which have been defined for the purpose of conducting our experiment. The minimum hardware specifications comprise an Intel i5 central processing unit, 8 gigabytes of random-access memory, 100 gigabytes of storage capacity, and either Ethernet or Wi-Fi connectivity.

Regarding software requirements, it is recommended that the operating system used be Ubuntu 18.04 LTS or a more recent version. Additionally, the installation of Docker version 19.03, Docker Compose version 1.25, Go Programming Language version 1.13, Node.js version 10.x, and Java Development Kit (JDK) version 11 is necessary. Furthermore, our blockchain-based experiment will employ Hyperledger Fabric version 2.2 and Hyperledger Calliper version 0.4.2. An integrated development environment (IDE) such as Visual Studio Code is used for development purposes. The establishment of a simulation environment guarantees the availability of essential resources and software tools required for the experiment while also ensuring that the experiment is conducted in a controlled and replicable manner.

The development and evaluation of food supply chain management algorithms can be facilitated using Hyperledger Fabric and Hyperledger Calliper. The frameworks provide the essential resources and systems to guarantee the security, scalability, and efficiency of the blockchain network, facilitating the effective monitoring, tracing, and authentication of food items [28]. Hyperledger Fabric is a blockchain application development platform that is designed for enterprise use. It offers a modular and permissioned blockchain foundation. The system exhibits interoperability with smart contracts that are composed in diverse programming languages, such as Golang, Node.js, and Java. Hyperledger Fabric employs the Practical Byzantine Fault-Tolerance (PBFT) consensus algorithm to safeguard the integrity and permanence of blockchain networks. Hyperledger Calliper is a software utility designed to assess the efficiency and effectiveness of distributed ledger technology networks. The modular architecture of the system facilitates the integration of various blockchain frameworks, such as Hyperledger Fabric, Ethereum, and Corda.

Additionally, we rationalize our implementation choice of Hyperledger Fabric, a blockchain technology that operates under permissioned conditions. The decision process was influenced significantly by Hyperledger Fabric's modular design, its ability to handle smart contracts, its strong data privacy features, and its scalability. Through an explanation of these many factors, we provide a rationale for our choice, clarifying the seamless alignment between Hyperledger Fabric and the unique needs of our food safety management system. The aforementioned justification highlights the strength and durability of our implementation, thereby confirming the appropriateness of the framework for practical applications in real-world scenarios and its potential to scale at an enterprise level.

4.2. Performance Analysis

Hyperledger Fabric blockchain network design and deployment need performance studies. They measure the network's transaction capacity and identify any bottlenecks or performance concerns. Performance measurements for a planned Hyperledger Fabric blockchain network include:

- Transaction throughput: The network's transaction processing speed. Ensure the network can handle enough transactions for the anticipated use-case.
- Latency: Network processing and validation time. Transaction processing is quicker with lower latency.
- CPU and memory usage: Measures network resources used during transaction processing. The network must have enough CPU and memory to handle predicted transaction volume.
- Scalability: How well the network handles more nodes and users. To satisfy shifting demand, the network must be scalable [29].
- Execution Time: The time it takes a database or blockchain network to perform a transaction is called execution time. A transaction's validation and blockchain writing time is Hyperledger Fabric's execution time. The network must obtain consensus, execute smart contracts, and post transaction data to the ledger [30–32].
- Commit Time: Nevertheless, commit time is the blockchain's transaction commit time. After being confirmed and published to the blockchain, a transaction must

be committed to make its modifications permanent and irreversible. Commit time comprises transaction data writing to disc and durability.

In Figure 4B, we see how and when the number of transactions per second in a certain Hyperledger Fabric network changes from 50 to 250 at 50-intervals, the average latency, measured in seconds, for read operations changes as well. All four possible pairings—a single company with two peers, two companies with one peer each, and two companies with two peers each—were put to the test. The average delay rises for all four setups as the number of transactions per second grows. Nonetheless, the data reveal that the two-organization, two-peer setup is the most economical for read operations due to its low average latency across all transaction rates. Nonetheless, the average latency is higher for the one-organization-one-peer setup, suggesting that it is the least effective setup for read activities.

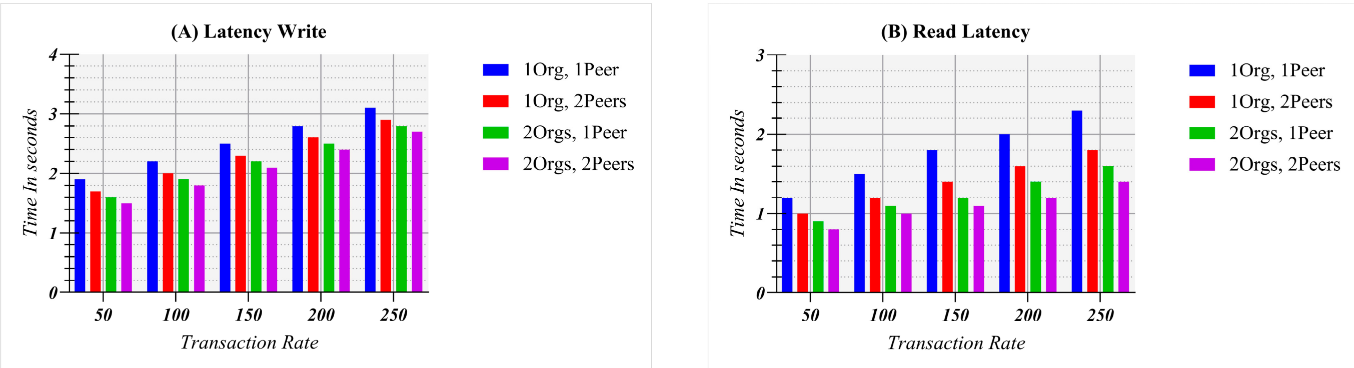

Figure 4. (**A**) Average latency for write operation at different transaction rates; (**B**) average latency for read operation at different transaction rates.

Figure 4A is a bar chart that depicts the same four configurations as Figure 4B: a single company paired with two peers, two companies paired with one peer each, and two companies paired with two peers each. This table, however, only shows comparisons of average latency for writes, since the transaction rate is in a range of 50–250 with a 50–interval. The average delay rises for all four setups as the number of transactions per second grows. The table demonstrates that the two-organization, two-peer setup is the most efficient for write operations since it has the lowest average latency across all transaction rates. The one-organization, one-peer setup is the least efficient since it has the largest average latency for writing operations.

Figure 5A compares the execution time in seconds for write operations across the same four tested configurations: a single organization with one peer, a single organization with two peers, a pair of organizations with one peer each, and a pair of organizations with two peers each, as the transaction rate varies from 50 to 250 with a 50-interval. In all four setups, the execution time grows according to the number of transactions per unit of time. The chart also reveals that the two-organization, two-peer arrangement has the fastest execution time for all transaction rates, making it the optimal setup for writing data. When comparing write operations, the one-organization, one-peer arrangement is the least efficient since it takes the longest to execute. Figure 5B compares the execution time in seconds for read operation and shows that two-organization, two-peer is the most efficient arrangement.

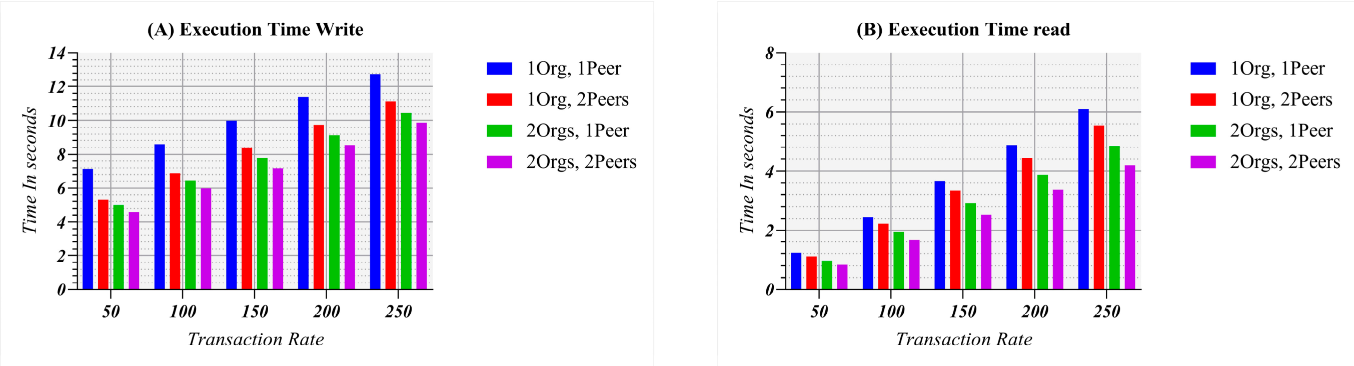

Figure 5. (**A**) Average execution time for write operation at different transaction rates; (**B**) average execution time for read operation at different transaction rates.

Figure 6A demonstrates write operation average throughput at various transaction rates and network settings. As the preceding tables, the transaction rate ranges from 50 to 250 with a 50-interval. The table compares outcomes for several network configurations: one-organization, one-peer; one-organization, two-peers; two-organizations, one-peer, and two-organizations, two-peers. The arrangement of two-organizations and two-peers yields the greatest throughput, 205.87 TPS at 250 TPS. One-company and two-peers have the second-highest throughput, 202.99 TPS at 250 TPS. When peers and organizations expand, throughput rises. The greatest and lowest transaction rate throughputs vary by just a few TPS. The network setup may not affect write operation throughput.

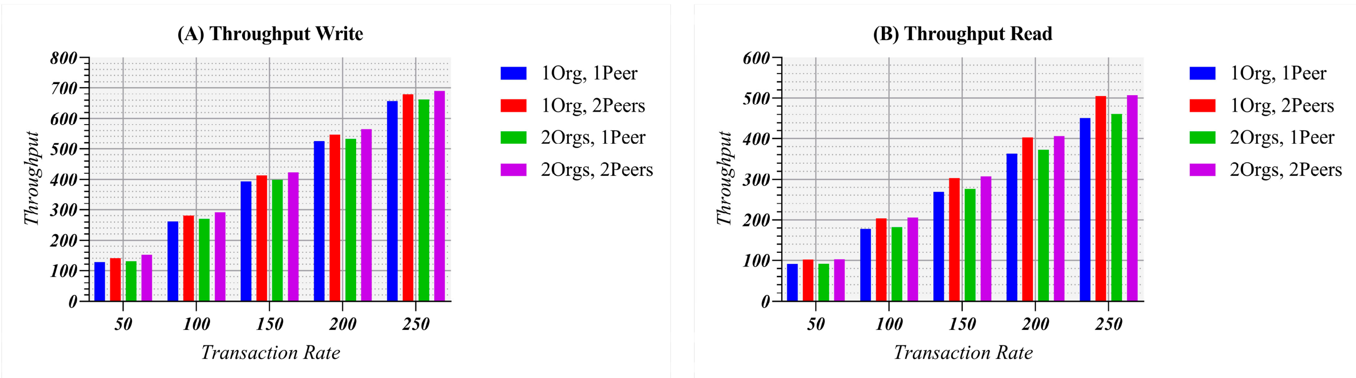

Figure 6. (**A**) Average throughput for write operation at different transaction rates; (**B**) average throughput for read operation at different transaction rates.

Figure 6B displays the average read operation throughput (transactions per second) for various Hyperledger Fabric network topologies. The transaction rate is 50–250. With one organization and one peer, throughput varies from 192 to 200 transactions per second for varied transaction rates. One-organization and two-peers have a throughput of 321–337 transactions per second at varied transaction rates. Two-organizations and one-peer have a throughput of 211–220 transactions per second at varying transaction rates. Two-organizations and two-peers have a throughput of 363–380 transactions per second at varying transaction rates. These findings indicate that distributed networks may outperform centralized networks since configurations with more peers and organizations have greater throughput. Blockchain-based applications that need high transaction processing capacity benefit from higher transaction rates and throughput.

Commit times for read and write operations on a Hyperledger Fabric network, in seconds, for a variety of network topologies, transaction counts, and elapsed times are shown in Figure 7A. In the case of read operations, the commit time is mostly unaffected by changes in the number of transactions or the length of time between them. This would indicate that read operations are more efficient and take less time to commit transactions than write activities. Figure 7B demonstrates, on the other hand, that the commit time for write operations grows with the number of transactions and the intervals between them. The longer commit durations seen in setups with more peers and organizations suggest that they need more capacity to process the greater number of transactions. These findings point to the fact that the number of peers and organizations involved, as well as the kind and number of transactions, may affect the scalability and performance of a Hyperledger Fabric network. While planning the design and implementation of a Hyperledger Fabric network, these considerations must be given great attention to guarantee the best possible performance and scalability.

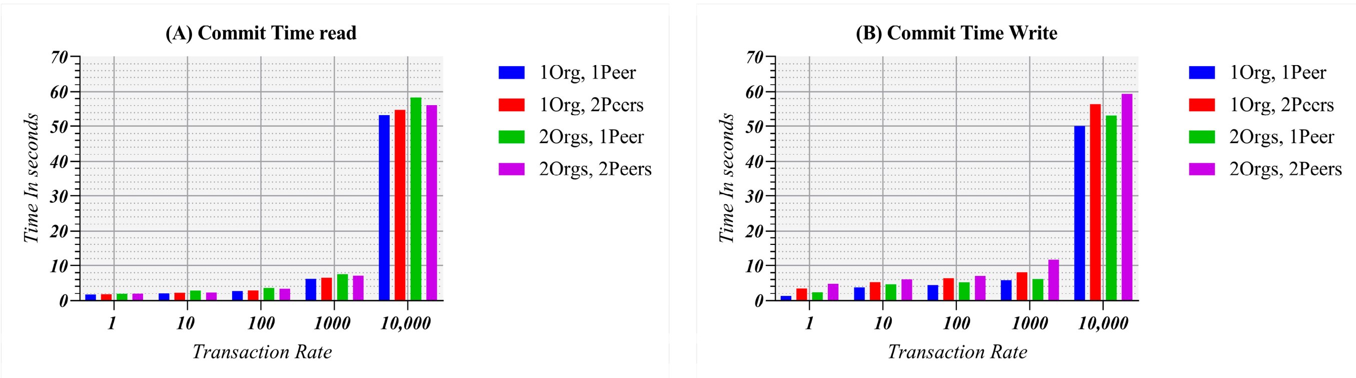

Figure 7. (**A**) Average commit time for read operation at different transaction rates; (**B**) average commit time for write operation at different transaction rates.

With a constant block duration of 250 ms and 2 s for both read and write operations, Figure 8 displays the average delay (in seconds) for various transaction rates (50, 100, 150, 200, and 250). Figure 8A shows that the average delay for the read operation rises for both block periods as the transaction rate increases. The rise is noticeable for both block times, but it is much larger for the 2 s block duration than the 250 ms block period. This is because more transactions will pile up before being committed to the blockchain if the block duration is increased, leading to longer wait times. Figure 8B shows that the average write latency is often longer than the average read latency. The average delay for both block periods grows as the transaction rate does, mirroring the behavior seen for the read operation. The average latency for a write operation, at 250 ms, is far larger than that for a read operation, at 2 s. This is because writes need more complicated calculations and network traffic, resulting in longer wait times despite reduced block durations.

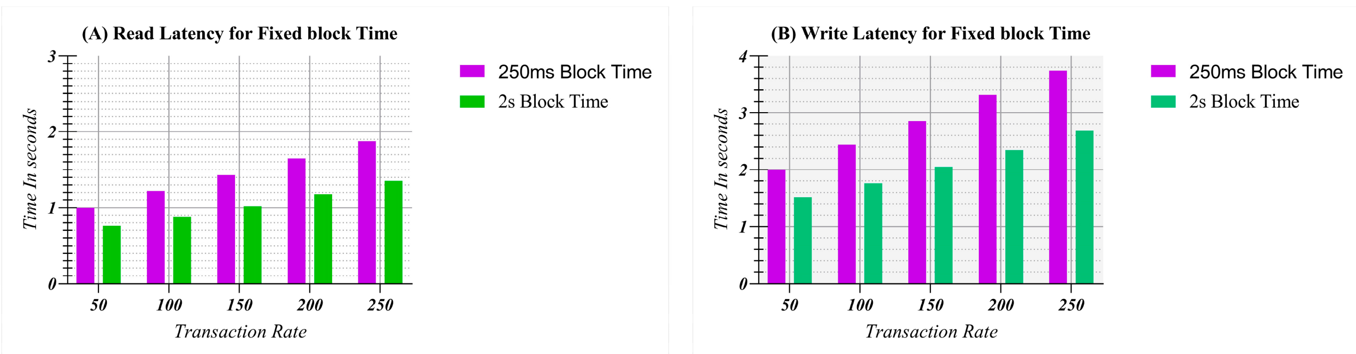

Figure 8. (**A**) Average latency for read operation for fixed block time; (**B**) average latency for write operation for fixed block time.

The average throughput in TPS for several Hyperledger Fabric network topologies with changing transaction rates and fixed block periods of 250 ms and 2 s is shown in Figure 9. The outcomes for both reading and writing are provided independently. Figure 9B, which depicts write operations, demonstrates how throughput grows in tandem with transaction rate across the board. The configuration with two organizations and two peers has the best throughput, followed by the configurations with two organizations and one peer, one organization and two peers, and lastly the configuration with one organization and one peer. With the exception of a single enterprise and a single peer, for which the maximum throughput is reached at a transaction rate of 200 TPS, the maximum throughput for the fixed block time of 250 ms is 250 TPS. Although the maximum throughput for a fixed block time of 2 s is 200 TPS for all configurations except for a single organization and a single peer, where it is only 150 TPS, the block time is set at 2 s. Figure 9A displays similar trends for read operations. The configuration with two organizations and two peers yielded the highest throughput, followed by the configurations with two organizations and one peer, one organization and two peers, and finally the configuration with one organization and one peer. As read operations require less processing than write operations, it stands to reason that the throughput for read operations would be lower.

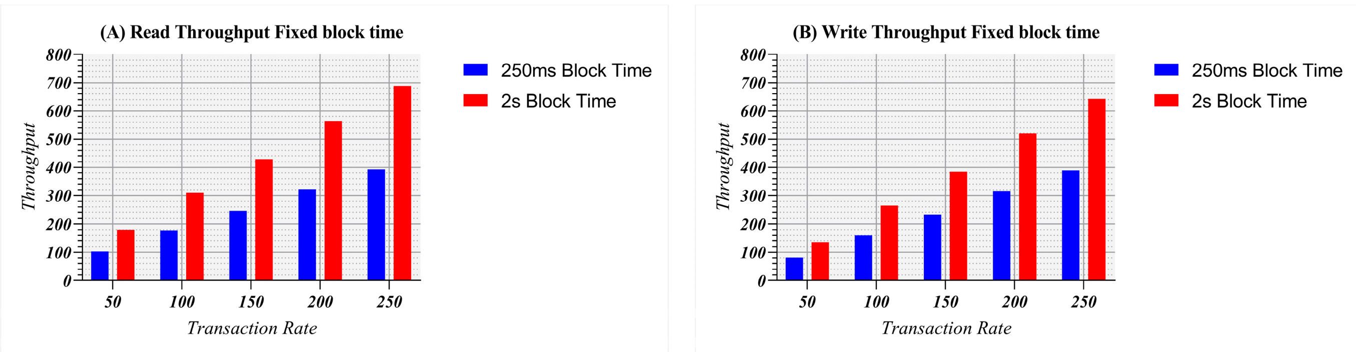

Figure 9. (**A**) Average throughput for read operation for fixed block time. (**B**) Average throughput for write operation for fixed block time.

With a variety of transaction speeds and fixed block sizes for read and write operations, Figure 10 displays the average delay in seconds. The number of transactions per second ranges from 50 to 250 with a 50-point spread, and the block sizes utilized are always either 10 or 5. As the system can handle more transactions in the same amount of time, it stands to reason that the average latency for read operations would decrease as the transaction rate increased, as shown in Figure 10A. The latency for read operations is significantly greater for a fixed block size of 10 compared to a fixed block size of 5. This may be because validation and network propagation of bigger blocks take more time, as shown in Figure 10B. Compared to read operations, the average delay for writing is much larger. This is because achieving network agreement during a write transaction is more time-consuming than during a read operation. Along with read operations, write operations benefit from lower latency since more transactions occur per unit of time. A fixed block size of 10 results in less delay than a fixed block size of 5, although this is not the case for read operations. One possible explanation is that bigger blocks can handle more transactions at once, lowering the average latency for each individual transaction.

Figure 11 illustrates the average throughput in TPS for read and write operations in a Hyperledger Fabric network at various transaction rates and fixed block sizes. Block sizes are permanently set at 10 and 5, while the transaction rates range from 50 to 250 with a 50-point interval. The findings demonstrate that throughput grows in tandem with the number of transactions, both for reading and writing. More so, when comparing fixed block sizes of 10 and 5, the throughput is greater for the former. A maximum read throughput of 771.30 TPS was obtained with a transaction rate of 250 and a block size of

10. At a transaction rate of 250 and a constant block size of 10, the maximum throughput for write operations was 783.66 TPS. Throughput for both read and write operations in a Hyperledger Fabric network seems to be greatly enhanced by raising the transaction rate and adopting a bigger fixed block size.

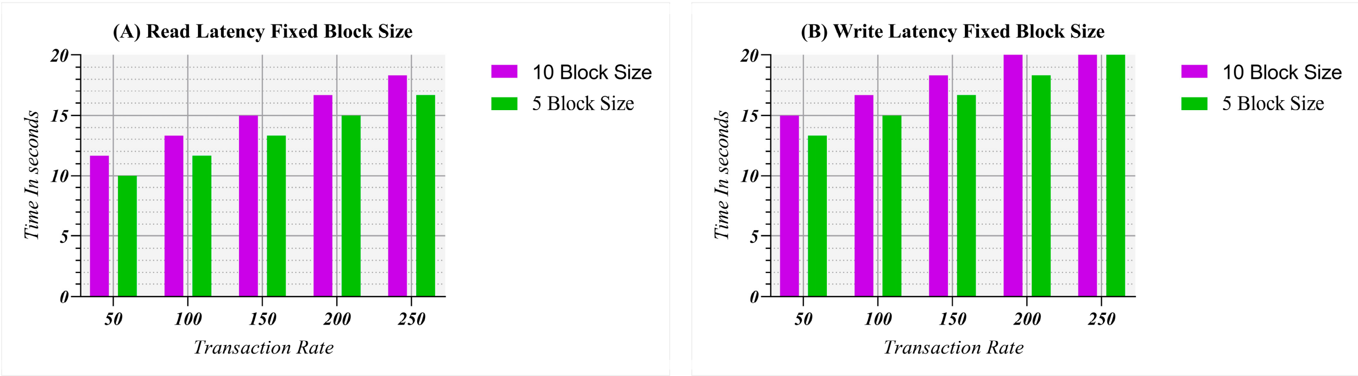

Figure 10. (**A**) Average latency for read operation for fixed block size. (**B**) Average latency for write operation for fixed block size.

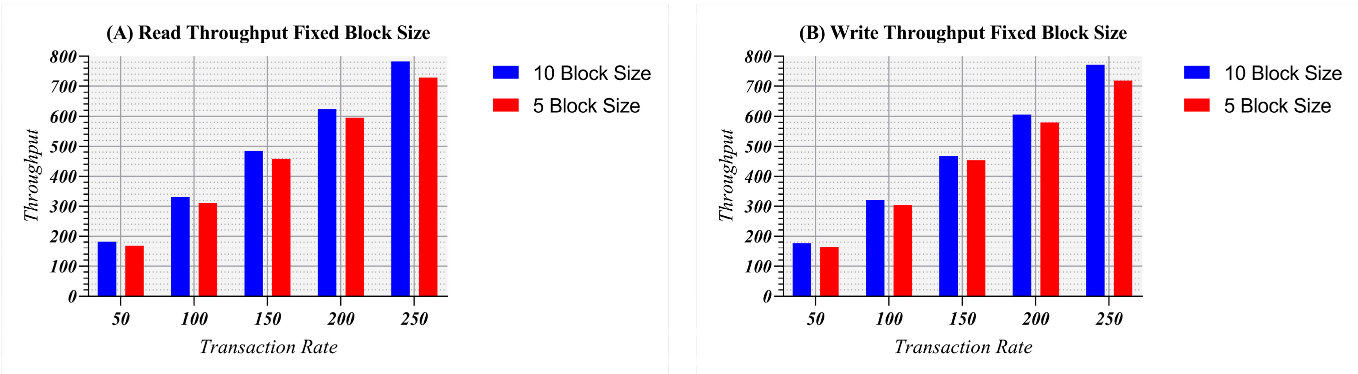

Figure 11. (**A**) Average throughput for read operation for fixed block size. (**B**) Average throughput for write operation for fixed block size.

In Table 7, you can see how much memory, CPU, incoming and outgoing traffic, and disc writes different Docker image configurations use on the Hyperledger Fabric network. One organization with two peers, two organizations with one peer, two organizations with two peers, and an orderer are the configurations available. The findings demonstrate that the consumption of resources rises with the number of peers and organizations involved. Deployments with more than a few peers and organizations result in increased memory and CPU utilization. It stands to reason that as the number of nodes grows, so does the need for network maintenance costs. As the number of people with whom we have connections and the number of institutions we belong to grows, so does the volume of our incoming and outgoing traffic. This is because an increase in the number of nodes always leads to more data being sent over the network. Since more nodes mean more data are being written to disc, it follows that the disc write consumption is likewise larger for setups with more peers and organizations. When compared to numerous organizations and peers, these findings highlight the need for careful attention to the network's resource needs throughout design and deployment.

Table 7. Resource utilization.

Configuration	Type	Memory (avg)	CPU (avg) %	Traffic In (MB)	Traffic Out (MB)	Disk Write (MB)
1Org, 1Peer	Docker	51.2 MB	17.32	5.6 MB	4.25 MB	7.10 MB
1Org, 2Peers	Docker	102.4 MB	23.93	8.65 MB	7.50 MB	8.20 MB
2Orgs, 1Peer	Docker	76.8 MB	28.25	7.82 MB	7.35 MB	8.15 MB
2Orgs, 2Peers	Docker	153.6 MB	26.76	7.23 MB	8.70 MB	9.30 MB
Orderer	Docker	70.24 MB	7.10	3.8 MB	6.50 MB	8.20 MB
1Org, 1Peer	Docker	51.2 MB	17.32	5.6 MB	4.25 MB	7.10 MB

5. Discussion

5.1. How the Food System Will Be Impacted Using BCT Methods

In this paper, we have introduced a novel method for risk traceability in the context of monitoring, tracing, and authenticating food goods by using blockchain technology. This strategy has significant potential ramifications, and thus a thorough examination of how it could affect the food chain is necessary. Beyond its technological applications, blockchain technology has the potential to completely transform the food chain. This makes it an important tool for food traceability. We can significantly improve the food supply chain's integrity by using blockchain's decentralization, immutability, and transparency. This may thus result in better food safety, a more efficient supply chain, greater customer trust, and more successful regulatory compliance. As the need for secure and open food supply networks continues to rise, our strategy is well-positioned to support the development of a robust and reliable food system.

5.2. Implications of the Findings

The outcomes of this research hold significant implications for individuals engaged in the sectors of food production and distribution. The utilization of BCT has the potential to address various concerns related to food safety, such as food fraud, contamination, and supply chain inefficiencies. This is achieved by providing a secure and transparent platform for monitoring, tracing, and authenticating food products. The enhancement of public trust in the food supply chain holds significant promise for the long-term sustainability of the sector. The use of BCT is expected to provide significant benefits for several parties involved in the agricultural supply chain, including producers, processors, distributors, retailers, regulators, and consumers. This is due to its potential to enhance communication and transparency among these parties. Effective communication, informed decision-making, and a collective dedication to food safety are essential in ensuring the quality and safety of food products.

5.3. Comparison with Traditional Food Safety Management Methods

To begin, the time, effort, and lack of trustworthiness inherent in old systems' reliance on paper records and manual procedures are major drawbacks. On the other side, BCT can automate data gathering and enable real-time access to information throughout the supply chain, both of which improve efficiency and lessen the likelihood of mistakes.

Second, it is sometimes impossible to determine the origin of food safety concerns using conventional approaches because of a lack of transparency and traceability. With the use of BCT, food producers, distributors, retailers, and consumers will have access to an immutable and tamper-proof record of product data from farm to fork, allowing for faster detection of tainted or hazardous goods.

The third issue with conventional methods is that various parties typically keep information in separate silos. With the help of BCT, it may be possible to establish a centralized hub where many parties can safely exchange information and work together in real time. Although conventional approaches have been useful to the food sector for quite some time, the use of BCT offers a fresh take on food safety management, with benefits including improved productivity, openness, traceability, and teamwork [33].

5.4. Addressing the Limitations and Challenges of Blockchain-Based Food Safety Management

The potential utility of BCT in the realm of food safety warrants further investigation, as there are notable limitations and issues that require additional scrutiny. Small and medium-sized enterprises (SMEs) in the food industry may encounter an initial barrier to entry as a result of the significant expenses associated with the adoption of BCT [34]. The extensive adoption of blockchain technology is reliant on the willingness of its participants to engage in collaborative efforts and information sharing, which may be impeded by competitive attitudes and concerns regarding the disclosure of personal data. As a tertiary aspect, it is imperative to note that BCT is incapable of independently resolving all food safety concerns [35]. Instead, it must collaborate with supplementary tools and techniques such as the Internet of Things and machine learning algorithms.

5.5. Scope and Limitations of the Study

The objective of this study is to assess the viability of employing BCT to oversee food safety through tracking and validating food products at each juncture of the supply chain. The present study aims to provide a comprehensive overview of the current knowledge regarding blockchain-based food safety management. It will investigate the utilization of BCT in the food supply chain and evaluate its effectiveness in enhancing transparency, traceability, and authenticity in food safety management. The study will assess the viability of smart contracts in food safety management and ascertain the hindrances and constraints of blockchain-based food safety management, including but not limited to data privacy, scalability, and interoperability.

The research encounters difficulties due to the volume and caliber of the extant literature on blockchain-based food safety management. Due to the limitation of the search to solely English-language papers, pertinent studies were authored in other languages. Furthermore, the study will solely focus on the implementation of BCT in the food supply chain and not delve into other aspects of food safety management.

The implementation of blockchain-based food safety management systems may face challenges in certain nations or food supply chains due to the absence of the requisite infrastructure and technological expertise. The study will also omit the potential financial ramifications associated with the implementation of blockchain-based food safety monitoring systems.

We acknowledge in this research the importance of resolving any issues and constraints related to our suggested blockchain-based food safety management system. Scalability is an important issue, especially in large-scale food supply chains where a significant amount of data exchanges may occur. It is crucial to make sure the system can manage growing data volumes without losing effectiveness. Another important component is interoperability, which highlights how well the system integrates with current platforms and technologies used in the food business. Suitability for a range of systems is necessary for broad acceptance and efficiency. Furthermore, we recognize the critical relevance of protecting data privacy and emphasize the need for strong encryption techniques and strict access restrictions. Our suggested approach seeks to handle real-world complications by recognizing these difficulties and actively looking for answers, guaranteeing its viability, realism, and use in realistic food safety management situations. This proactive method fortifies the basis of our study by highlighting the new solution's practical feasibility in the intricate food business context.

Despite the limitations, the study will contribute to the existing body of knowledge on the management of food safety through blockchain technology. Furthermore, it will offer valuable perspectives on the capacity of blockchain technology to regulate food safety. The outcomes of this investigation possess the capability to influence forthcoming research endeavors and facilitate the development of more sophisticated food safety administration frameworks.

6. Conclusions

In order to solve food safety management, this study uses blockchain technology to monitor, verify, and oversee food goods across the supply chain. This research has shown the benefits and drawbacks of using BCT for food safety, offering insightful information on the practical implementation of blockchain-based systems in the food sector. One of the primary contributions of this work is the quantitative analysis of the suggested blockchain technology. The results suggest that by improving traceability and transparency across the food supply chain, the system may improve food safety.

The use of quantitative analysis to evaluate the proposed blockchain technology is a key component of this study. The results suggest that the strategy might improve food safety by making the food supply chain more transparent and traceable. Two firms and two peers had 205.87 TPS for write operations, according to the research. The quantitative data demonstrate the system's multitasking capability, which is essential for managing the food supply. The quantitative data revealed that, depending on transaction rates, read operations in the systems of two corporations and two peers took, on average, 0.037 to 0.061 s. Real-time meal monitoring depends on the system's ability to quickly analyze and assess network data, which is made possible by its low latency. According to a study, resource management is essential for network design and deployment. According to the study, involvement in groups and organizations was associated with higher memory and CPU use. Research demonstrates that effective resource allocation is necessary for blockchain-based food safety systems. The absence of empirical evidence and the need for further research on BCT's practical impacts on the food sector are two of this study's weaknesses, despite its magnitude.

This study offers a strong basis for enhancing food safety via the use of blockchain technology. To expand on this profitable endeavor, future research may look at the use of blockchain-based technologies in the food business. Real research may be required to demonstrate that these systems function in practical environments. Improved food traceability may result from the integration of cutting-edge technology into block-chain ecosystems, such as AI for data processing and IoT devices for data collecting. Cooperation between producers, regulators, and consumers is necessary to establish data sharing protocols. This will facilitate the adoption of blockchain technology throughout the whole food supply chain.

Author Contributions: The authors engaged in a collaborative effort to create an extensive research paper that presents an innovative methodology for augmenting the management of food safety via the utilization of blockchain technology. The authors' respective efforts in conducting a literature study, designing the methodology, performing quantitative analysis, and overseeing the entire project have jointly enhanced the comprehension of how blockchain technology might enhance traceability and transparency inside the food supply chain. The following are the major individual contributions by the authors of this work: U.S.: U.S. was instrumental in conceptualizing and planning the study, with a particular emphasis on the use of blockchain technology for the management of food safety. U.S. contributed significantly to the literature study by sharing her knowledge of blockchain technology and food safety management. She also actively contributed to the quantitative examination of the suggested system, particularly when assessing variables like throughput and latency. Her efforts were essential in showing how blockchain technology may potentially improve traceability and transparency in the food supply chain. S.N.: S.N. made a substantial contribution to the review of the literature by exploring the complexities of food safety management, blockchain technology, and earlier work on blockchain-based food safety management. The backdrop for the investigation was greatly enhanced by S.N.'s knowledge of the topic. She was crucial in laying out the system's stakeholders as well as the recommended approach. Swati also contributed to the discussion section, discussing the results' ramifications and contrasting the suggested system with conventional approaches to food safety management. M.K.: The simulation setup and performance study of the proposed blockchain-based food safety system relied heavily on M.K.'s expertise. She carefully outlined the evaluation

criteria and simulation parameters, which were crucial for assessing the system's performance. M.K.'s aptitude for quantitative analysis was especially useful for evaluating crucial metrics like throughput, latency, and resource use. Her contributions made it possible to show, in measurable terms, how well the system handled many transactions while providing low latency for real-time monitoring. S.M.: S.M. oversaw the whole study procedure from its conception to its completion. His advice and knowledge played a critical role in developing the study approach and analysis. S.M. was instrumental in choosing the suitable blockchain frameworks for the creation and assessment of algorithms in the food supply chain, including Hyperledger Fabric and Hyperledger Caliper. He was also in charge of the quantitative analysis, which offered proof of the system's efficiency. S.M. also made a substantial contribution to the discussion session, underlining the relevance of the study results and stressing the significance of resource management in the design and implementation of blockchain networks. All authors have read and agreed to the published version of the manuscript.

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