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Blockchain Adoption to Secure the Food Industry: Opportunities and Challenges

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Abstract: With the growth in food products' usage, ensuring their quality and safety has become progressively difficult. Specifically, food traceability turns out to be a very critical task for retailers, sellers, consumers, surveillance authorities, and other stakeholders in the food supply chain system. There are requirements for food authenticity verification (correct declaration of cultivation, origin, and variety), quality checks (e.g., justification for higher prices), and preventing food products from fraudsters in the food industry. The ubiquitous and promising technology of blockchain ensures the traceability of food trade networks with high potential and handles the aforementioned issues. Blockchain makes the food industry more transparent at all levels by storing data immutably and enabling quick tracking across the stages of the food supply chain. Hence, commodities, stakeholders, and semi-finished food items can be recognized significantly faster. Motivated by these facts, in this paper, we present an in-depth survey of state-of-the-art approaches to the food industry's security, food traceability, and food supply chain management. Further, we propose a blockchain-based secure and decentralized food industry architecture to alleviate security and privacy aspects and present a comprehensive solution taxonomy for a blockchain-based food industry. Then, a comparative analysis of existing approaches with respect to various parameters, i.e., scalability, latency, and food quality, is presented, which facilitates the end-user in selecting approaches based on the merits over other approaches. Finally, we provide insights into the open issues and research challenges with concluding remarks.

Keywords: blockchain; food industry; food supply chain; traceability; food data security

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1. Introduction

The growing food industry is increasingly confronted with new challenges related to food protection, food safety, and food quality with respect to industry, politics, and science. The food and beverage market is growing at a 36.34% compounded annual growth rate, and it will reach USD 142 billion by 2020 in India [1]. Moreover, the foodservice market has grown significantly since 2014. Figure 1 shows the growth of the foodservice market in India, which is expected to reach USD 110 billion in 2025 [2]. The rapid opening of food franchises and releasing of food and beverage products make it essential to serve healthy and fresh food. This is precisely in line with the World Health Organization (WHO) report, where is shown that, every year, more than 23 million European people suffer and around 5000 people die due to consuming contaminated food and water, which lead to foodborne diseases such as norovirus, listeria, salmonella, and many more [3,4]. Therefore, there is a need for a traceability mechanism that can track the backward and forward movement of food products and their ingredients in the supply chain and turn the food industry into a highly sustainable system [5–8]. Unfortunately, food traceability is a challenging task due to various reasons such as dynamic consumer preferences, traceability varying by industry, and the lack of standardization.

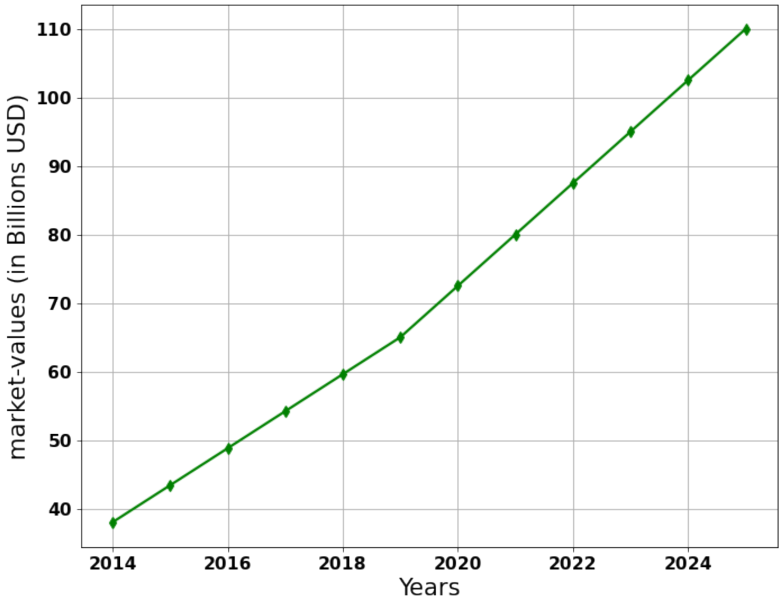


Figure 1. Food and beverage market growth in India (in USD).

The prevailing technologies such as cloud computing systems and the Internet of Things (IoT) provide the monitoring and effective storage of particular data at different levels of the supply chain, for instance, food production, processing, dissemination, and consumption. Nevertheless, they operate on a centralized system, where all stakeholders have to depend on a single data source to store food data, resulting in severe issues such as a single point of failure, security and privacy issues, inflexible decision-making, etc. [9,10]. Consequently, most consumers face difficulty in gaining full transaction information related to the Food Product Life Cycle (FPLC), tracking the origins of products, and contamination [11]. In addition, the existing food systems are not effective at building customer's trust due to third party involvement, degraded Quality of Service (QoS), traceability issues, and security issues (such as session hijacking, timing attacks, data breaches, and many more) in the food supply chain [7,9,12]. Moreover, food data security, privacy, and immutability are paramount issues in the food industry, which hinder the economic growth of governments, producers, farmers, consumers, and cold storage managers [13,14]. Therefore, there is a requirement for a promising technology, i.e., Blockchain Technology (BT), that can handle the aforementioned issues and offer effective and reliable food supply chain management [12].

Blockchain is an immutable and decentralized ledger that facilitates secure storage and transparency in business operations. It is a plausible solution that can address various food supply chain issues, such as food quality, production, distribution, and processing, to improve the security, durability, traceability, and integrity of the food industry [12,15–17]. It consists of blocks linked by cryptographic hashes and their associated timestamps to solve the privacy and security issues. Furthermore, it provides real-time transaction settlement without involving any third party. It has been widely accepted in various industries such as finance and smart cities as a viable solution to trust and security issues. BT with the IoT offers valuable information related to quality monitoring and food traceability using Wireless Sensor Networks (WSNs), short-range wireless technology, sensor tracking systems, and many more. BT can help provide adequate information regarding the authentication and tracking of contamination sources through the entire food supply chain in the food industry.

1.1. Scope of This Study

Most researchers across the globe have published surveys on the food industry. However, these surveys have not investigated traceability and security threats such as information data integrity, spoofing, denial-of-service, and injection attacks to the fullest extent. For example, Bumblauskasa et al. [18] proposed a technique to deploy BT in food distribution, mainly focusing on the egg supply chain. They provided a literature review on BT concepts and their applications. With this, George et al. [19] examined the famous existing methods for food traceability and proposed a blockchain-based restaurant prototype to collect data from all stakeholders and generate a food quality index. Then, Johng et al. [20] presented a framework, i.e., Fides, which is a business process for the retail food supply chain. Wu et al. in [21] conducted a comprehensive survey and proposed blockchain frameworks, and they bifurcated the entire framework into four layers, starting from the data layer and ending with the application layer for analytics and decision-making: (i) data layer, (ii) consensus layer, (iii) network layer, and (iv) application layer. Then, Noor et al. [22] presented a short review of the food processing sector with nine advancements in technology that drive Industry 4.0. Hence, the proposed survey covers the food industry issues along with countermeasures and presents a blockchain-based secure food supply chain architecture.

Further, Wu et al. in [21] presented a comprehensive survey on the adoption of BT in different applications, especially for IoT-based applications. They classified their proposed survey into four layers, i.e., data, consensus, network, and application. Each layer is associated with the blockchain network. The authors mentioned the essential characteristics of each layer with the severe challenges that hinder the performance of the blockchain-based application. However, the proposed survey was meant in particular for IoT-based applications and lacked a discussion on the food industry. Then, the authors of [23] introduced the benefits of BT in trade supply chains. They explored different scenarios where they could replace the conventional system and integrate the indispensable characteristics of BT. Additionally, they discovered several challenges if the blockchain is integrated with the international trade supply chain systems. The proposed survey was exhaustive; however, it did not explore the IPFS-based blockchain solutions. Further, in [24], the authors presented a comprehensive survey on Agri-food 4.0 inline with the usage of BT. To optimize the complex network and performance of the agriculture sector, they explored and analyzed more than a hundred new technologies. However, the proposed survey was not analyzed and compared with the baseline approaches. Recently, the authors of [25] studied the spacious scope of BT in the food industry. They explored the challenges, such as scalability and interoperability in the food supply chain, along with their countermeasures using blockchain. However, they did not highlight the influence of blockchain from the perspective of security. To clarify the major difference between existing survey papers and the proposed survey paper, a comparative analysis is given in Table 1. The comparison parameters comprise the objectives, pros, and cons of existing surveys and the proposed study.

Summary: The proposed survey explores the security challenges in the food industry and involves BT in confronting them. It investigates several parameters, such as architectures, open issues, attack types, scalability, security, applications, and taxonomies, that differentiate it from the existing works. The parameters that we consider in Table 1 are merely used to compare the proposed survey with the existing survey. Based on these parameters, we remark that there is a requirement for a survey highlighting the security perspective and intervention of BT in the food industry. Although we covered most of the parameters, i.e., architectures, open issues, scalability, taxonomies, security, applications, and attack types, in the proposed survey, there is still a broad scope available to explore these parameters to their fullest extent. For instance, the proposed survey explored the security implications in the food industry; however, it did not consider modern-day attacks that severely affect the operations of the food industry. This is the limitation of the proposed survey. Nevertheless, the survey sets the stage on which we develop a novel solution that alleviates modern-day attacks on the food industry.

Table 1. Comparison of the proposed survey with existing state-of-the-art surveys.

Authors	Year	Objective	Pros	Cons	1	2	3	4	5	6	7
The proposed survey	2022	Empowers the food industry using BT	An exhaustive and systematic survey of the blockchain-based food industry with a proposed architecture along with a solution taxonomy.	Implementation of the proposed architecture in real-life applications is included as future work.	Y	Y	Y	Y	Y	Y	Y
Pandey et al. [25]	2022	Review and bibiliometric analysis of blockchain in the food industry.	Showed potential benefits and challenges of blockchain in the food supply chain	Did not consider security and privacy aspects in the food supply chain.	N	Y	N	N	N	N	Y
Ali et al. [26]	2021	Blockchain framework for the halal food supply chain.	Proposed a novel blockchain-based framework for the halal food supply chain	Security and privacy aspects were not explored.	Y	Y	Y	N	N	N	N
Lezoche et al. [24]	2020	Supply chains and technologies for future agriculture.	Showed the integration of the latest technologies in the food industry. They focused on IoT, blockchain, and Artificial Intelligence (AI).	Resource management needs to emphasize better safety, quality, food quantity, and the waste of food products, as well as all resources more.	N	Y	Y	Y	Y	N	N
Juma et al. [23]	2019	Introduced a comprehensive survey using BT in food supply chain solutions.	To monitor transportation and detect counterfeit goods in the food industry environment.	BT prioritizes security over performance. Need to discuss scalability issues of blockchain-based systems.	N	Y	Y	Y	Y	N	N
Liu et al. [27]	2019	Surveyed blockchain regarding the theoretical perspective.	They reviewed game models to address the security issues, blockchain economic and energy trading, and mining management issues.	They checked the potential of the proposed framework, and the mathematical tools of game theory can be applied for further investigation, which is a challenging task.	Y	Y	Y	Y	Y	Y	N
Wu et al. [21]	2019	Presented a survey to manage data in the food supply chain using blockchain.	Highlighted four crucial challenges. throughput, scalability, data retrieval, and access control, and reviewed the promising solutions.	Few proofs-of-concept were discussed, and surveys on blockchain-based supply chain system from the logistics perspective and the underlying challenges need to be identified more precisely	Y	Y	Y	Y	Y	Y	N
Noor et al. [22]	2019	Presented a short review on Industry 4.0 technologies in the sector of food processing.	This study discussed the nine technological advancements in Industry 4.0	Discussed the small-scale and medium-scale food processors only; need to include large-scale food processors also	N	Y	Y	N	Y	N	N

Parameters: 1: architecture, 2: application, 3: open issues and challenges, 4: taxonomy, 5: security, 6: attack type, 7: scalability. Notations: Y: considered, N: not considered.

1.2. Research Contributions

This paper emphasizes the security and privacy concerns and their consequences in the food industry. The primary focus of the paper is data security while featuring a system with complete traceability and transparency. We also re-explored BT to secure and improve the safety of the food industry with the features of immutability, transparency, etc., using smart contracts and a consensus algorithm. The contributions of this paper are as follows:

- We present a comprehensive survey on the food industry along with BT and discuss potential applications of BT in detail. This paper systematically discusses the precarious supply chain of the food industry and its security challenges.
- Then, this paper presents a taxonomical representation of each component of the food industry and its security implications, along with their relevant solutions for blockchain-enabled food supply chain systems.
- A secure and reliable blockchain-based architecture is proposed to enhance the food supply chain system and bridge the gap between the performance metrics, such as latency, scalability, and food quality.
- Lastly, we highlight several open issues and research challenges that hinder the performance of the food industry.

1.3. Organization

The remaining part of the paper is arranged as follows. Section 2 emphasizes the background and history of the food industry, BT, and its integration in the food industry. Section 3 presents the survey methodology utilized for this systematic survey. In Section 4, we introduce the solution taxonomy for the food industry. Section 5 investigates the proposed architecture of the food industry based on BT. Section 6 describes the experimental setup and performance evaluation of the proposed architecture. Section 7 explores the open issues and future research challenges, and finally, the paper is concluded in Section 8.

2. Background

This section describes the background of blockchain and its intervention in the food industry. First, it specifies each stage of the food supply chain consisting of agriculture, processing of food, manufacturing, distribution, regulation, and marketing of food products. Then, the influence of security issues in the food industry is discussed, followed by the incorporation of BT, which alleviates the security concerns of the food industry.

2.1. Food Industry

The food industry is a complex business that drives the supply, processing, and storage of food consumed. In addition, the food industry collaborated with other sectors such as agriculture, manufacturing, marketing, and distribution to enhance the food supply chain. A summary of each sector is described as follows:

- *Agriculture:* Formally, the food and agriculture industries are closely associated with each other. Moreover, the food industry is heavily dependent on the agricultural sector because it is the primary source of raw materials for the food industry. It is a practice related to farming, which includes cultivating crops, nurturing animals and husbandry, fish cultivation, and many more. Furthermore, it involves fertilizers, farm equipment, hybrid seeds, and farm machinery to encourage horticultural production. All the factors mentioned above improve the performance and smoothen the operation of the food industry.
- *Processing of food:* The conversion from a raw product into a fresh food product is known as the processing of food. This comprises washing, chopping, cooking, freezing, pasteurizing (in the case of dairy products), and many other complex methods to process convenient food.
- *Manufacturing:* Once the food is processed, it has to be transformed into an edible food product. Furthermore, market research is used, which facilitates the suggestions of

food consumers to improvethe food product. An effective manufacturing process can control food contamination and ensure food quality standards.

- *Distribution:* The main aim of this sector is to efficiently distribute food products to manufacturers, retail stores, government storage facilities, grocery stores, warehouses, etc. This consists of food storing, food transporting, and food delivery to consumers. Therefore, the food industry needs an efficient transportation system to connect/reach different parts of the world for efficient food delivery.
- *Regulation:* Before the distribution of food to the consumers, it needs to be assessed for its quality, safety, and hygiene. Hence, several standard regulatory bodies, such as the Food and Drug Administration (FDA) and the Food Safety and Standards Authority of India (FSSAI), enforce rules and regulations for food production and distribution to ensure food product quality and safety. Government authorities impose these rules and regulations to ensure that the correct amount of nutrients gets to the country's consumers.
- *Marketing of food products:* This plays an essential role in the food industry in terms of economic growth. The food product that satisfies the food quality, regulations, and safety has to increase its demand in the food market. Toward this goal, there is a need for a strategic business plan and marketing that can increase the demand for that particular food product. Moreover, this involves advertisements, promotions, campaigns, etc., to promote the consumption and purchase of a food or beverage. Therefore, marketing is one of the primary driving forces for promoting information about food products.
- Other bodies participate in food delivery to the consumer; these are catering systems, wholesalers and retailers, grocery stores, farmers, public markets, etc.

Further, the modern food industry uses advanced technologies such as agriculture machinery and robotics, reducing human labor and effort and boosting food processing, packaging, food serving, and production. All entities (for instance, retailer and consumer) are linked together in the food supply chain system, as shown in Figure 2 [28]. The existing system in the food industry needs to be more transparent and responsive with regard to food disaster traceability and food system security [29].

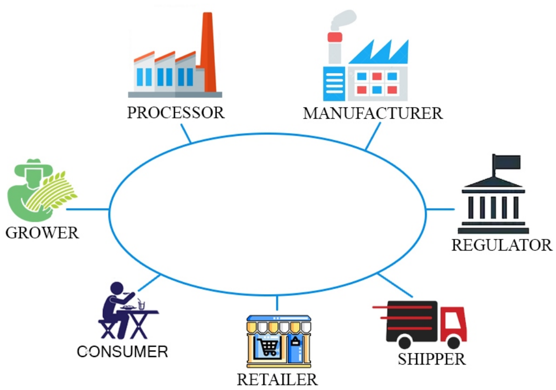


Figure 2. Various entities in the food industry.

Technological advancements and high computing capabilities, such as the IoT and cloud and fog computing, influence the attackers to jeopardize the performance of the food security systems. The attackers passively collect the data from the food industry database and modify them; for example, they change the food expiry date, manufacturing date, and food price to manipulate the food supply chain. Several attacks, such as the Stuxnet Worm Trojan, Flame Worm, DDoS attack, etc., have been detected, which necessitate the analysis of the attacks' impact and prevention mechanisms. Therefore, to tackle such active attacks on the food industry, there is a need for a technology, i.e., blockchain, that not only securely stores the data, but also preserves user privacy. Large organizations such as Unilever and

Nestle are considering BT for that reason, i.e., to make the food industry more secure and reliable against security threats.

2.2. Blockchain

Blockchain is a tamper-proof, transparent, decentralized, and immutable technology that stores each transaction using cryptographic hashes. It is primarily a revolutionary and pivotal technology as it diminishes security threats, prevents fraud, and brings transparency to the system. In principle, it is a chain of blocks, where each block encompasses several immutable transactions inside the blockchain network [30]. A block consists of various information in two sections: one is the header (store block index, Merkle root, timestamp, block hash of the previous block, and the data Themselves) [31]; the other one is a body to store the transaction details. In BT, the first block is referred to as the genesis block or zero block, which reserves the ownership of the transactions. BT transactions necessitate a public–private key pair for the validation of the data. The participant's private key validates each BT transaction block. Moreover, there are three types of blockchains, namely public (permissionless), private (permissioned controlled by the specific enterprise), and consortium (federated blockchain, similar to a private blockchain).

BT manages transactions using smart contracts (a set of computer programs) under concrete terms and conditions to make the system distributed. Like conventional legal contracts, smart contracts bundle the logical rules and ensure their application through BT automation in the network [23,32]. In addition, BT encompasses several consensus algorithms, for instance Proof-of-Work (PoW), Proof-of-Activity (PoA), Proof-of-State (PoS), Practical Byzantine Fault Tolerance (PBFT), Delegated PoS (DPoS), Proof of-Burn (PoB), Federated BFT (FBFT), and Proof-of-Elapsed Time (PoET), to ensure reliability within the network [33,34].

2.3. Integration of Blockchain in the Food Industry

BT can be used in the food industry as it is all about managing the food system efficiently with a set of linked chains. There are several actors in that chain; for instance, suppliers provide the food, retailers, and aggregators to retail food, and consumers purchase the food ultimately; however, this is all about the supply chain. BT is very much designed to manage consequential transactions and a chain of actions. However, BT is exceptionally secure and lends itself to the food system. The benefits of integrating BT in the food industry are as follows [35]:

- *Food traceability and information continuity:* The immutable and irrevocable properties of BT help to share the food data amongst the stakeholders to ensure food products are traceable without any intrinsic risk. BT plays an essential role in farm to fork service (from food production to food consumption) because all data and records are immutable and decentralized on the distributed ledger.
- *Food data accessibility and security:* The massive food data are generated through different IoT devices such as sensors, actuators, etc. Sensor-enabled smart devices can be accessed and secured using BT in the food supply chain system.
- *Material and information flow:* The IoT provides the connection between material and information flow at various levels of the food supply chain, such as production, processing, storage, and distribution to improve the effectiveness of the food industry.
- *Reduction in fraud and code of conduct violation:* The auditable and transparent features of BT help detect fraud at each level of the food supply chain. Moreover, code of conduct violations are reduced throughout the food industry.

Apart from these, BT adoption is extensive in the food industry due to food safety, regulatory compliance, social issues, sustainability, and consumer information privacy features [36]. BT can be used as a Blockchain-as-a-Service (BaaS) platform for the food supply chain, which requires an Internet browser for a user (can be a farmer, supply chain manager, or operator at a production site) to connect his/her food data and access information on a digital ledger [37].

3. Survey Methodology

This section discusses the detailed procedure to investigate this topic, for instance keywords and the composition of search strings, then inclusion and exclusion parameters to assimilate recent and relevant literature. Based on the collected literature, we propose a taxonomical representation of existing work for a different component of the food industry that is influenced by security attacks.

Accomplished Survey

The proposed survey focused on identifying and classifying the existing research works on the food industry using BT. The identified research questions are listed in Table 2. A broader perspective is always important for the comprehensiveness of every survey paper. To find relevant literature, the inclusion of a wider range of standard electronic sources is recommended by Kitchenham et al. [38–40]. Hence, digital libraries such as IEEE eXplore, Springer, and Wiley were explored online.

Table 2. Research questions and their objectives.

Research Questions	Research Objectives
What are the issues and challenges in the food industry?	This aims to explore the various problems and challenges in the food industry, such as food traceability and security issues.
What are the existing solutions to handle this and how?	It is expected to explore issues and address the problems using the miscellaneous existent techniques in the literature to guarantee a secure food supply chain.
Which studies underline the usage of BT in the food industry?	This aims to explore existing literature that presents the theoretical, prototypical, or practical approaches for the use of BT in the food industry.
What are the different parameters to evaluate the effectiveness of BT in the food industry?	It is expected to explore parameters that can be used to evaluate the performance and effectiveness of BT in the food industry.

In this survey, we utilized keywords such as "Blockchain" or "Food Industry" and other associated keywords mentioned for the search criteria, as shown in Figure 3, on online digital repositories. Next, we manually started searching based on the distinct sections of the paper, for instance the relevant title, abstract, and conclusion, due to the massive literature collection. Finally, the manual search process selects the paper where the title or abstract of the paper contains the keyword or search string.

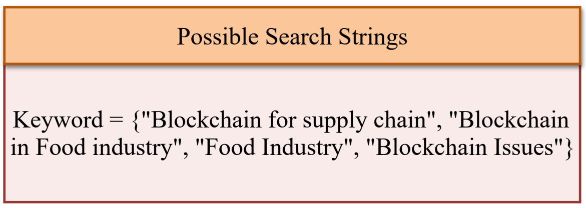


Figure 3. Search string for blockchain-based food industry.

The supply chain, traceability, and security issues are the essential aspects and important research topics in the food industry, so the search string *"Blockchain for the food industry"* provided many papers; however, this was not appropriate for our proposed survey because there are only a few papers that cover all the aspects of the integration of blockchain in the food industry. For instance, a few papers mention a robust blockchain architecture, but do not discuss any security implications; a few papers discuss the food industry's blockchain taxonomy, but do not present any open issues and security challenges. Hence, the search criteria process needs to follow strict filtration to obtain relevant papers. Therefore, the suitable and current papers until 2022 were included (including the early access articles) to make this systematic survey impactful. Figure 4 shows the filtration of the gathered literature for the proposed survey's theme. Finally, we performed a quality evaluation of the 72 relevant identified research papers.

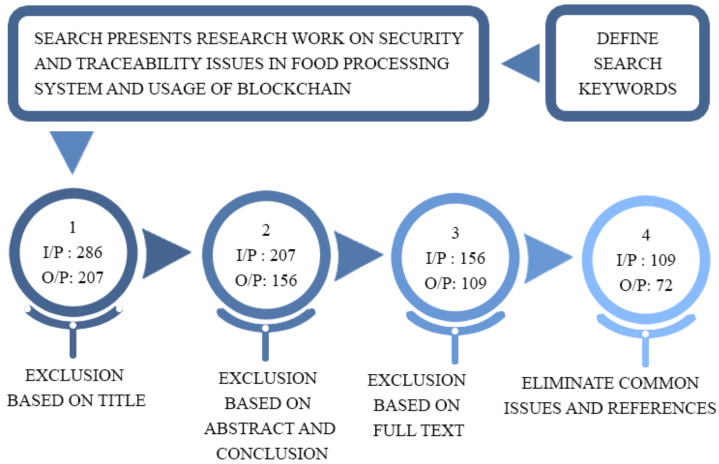


Figure 4. Inclusion and exclusion criteria.

The quality screening questions are listed in Table 3, which shows the inclusion and exclusion criteria. With the help of that, we sorted the relevant papers, articles, or literature.

Table 3. Quality evaluation.

Question Description	Answer
Does the research paper cover blockchain in the food industry? The papers include scholarly coverage of the food industry using BT.	Yes
The articles/papers containing the word "Blockchain" are removed from the accumulated literature.	No
Does the paper title, abstract, and full text of the research paper discuss the food industry's blockchain?	Yes
Does the research paper (collected for a survey) discuss the food industry's sub-areas in a different section such as the abstract, title, or full text?	Yes

4. The Proposed Taxonomy

This section highlights the various component of the food industry, such as the food supply chain, the IoT, and others, as shown in Figure 5. The food supply chain is divided into three distinct categories as food processing, storage, and distribution. The component the IoT comprise the elements and entities involved in the entire process, from food production to consumption. It is essential to include IoT technology because most modern food supply chains employ IoT sensors for food traceability. The sensors are at constant risk of being manipulated by the attackers because they use the Internet to share their data among each other. Therefore, it is important to include this in the taxonomy to understand what modern security solutions the researchers propose and how BT can assist IoT technology in protecting it from security and privacy issues. Further, the remaining section involves various other factors such as logistics and cold storage management, economic loss, product waste reduction, standardization, and many more. Next, we discuss the apparent traceability and security issues in the food supply chain with the objective of an effective food industry system. The existing food industry system is disrupted by various security threats such as component jamming, data manipulation, intrusion attacks, etc.

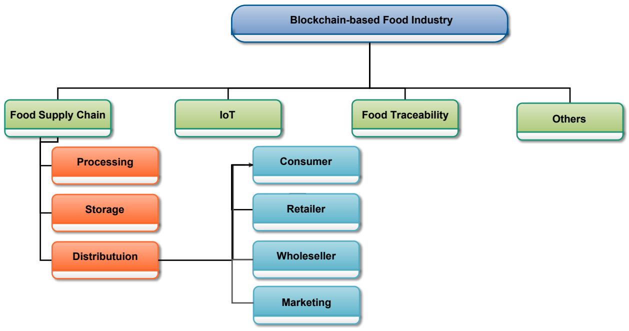


Figure 5. The proposed taxonomy: blockchain for food industry.

4.1. Food Supply-Chain

The food supply chain is a process in which food moves from farm to fork. It is divided into three categories: food processing, food distribution, and food storage. The security attacks can leverage these categories, and therefore, there is a need for BT to secure them. A detailed comparison of the existing BT-based approaches for the food supply chain is shown in Table 4, and the detailed description of each category is explained as follows.

4.1.1. Food Processing

Food processing specifies the transformation of raw food items into a form that can be used for consumption. This transformation utilizes various processes such as chemical and physical, which transform the raw food items into a food product. The source of raw food items can either be an animal, plant, or a combination thereof. It comprises primary and secondary food processing, wherein the primary raw food items are processed by milling, threshing, and shelling, for instance, grains and nuts. Poultry, fish and meat are processed by cutting, freezing, drying, and, often, extracting their oils. On the other hand, secondary food processing includes the food ingredients that are used as ready-to-use foods, such as baked goods and alcoholic products. Both forms of processing need a system that checks the quality of the food products. This is because processed food requires predefined conditions such as an adequate room temperature to keep the food fresh, keep the food away from light, and many more. Therefore, tracking the food quality in the food supply chain necessitates much research work, and therefore, the research community has provided various solutions for this.

For example, Basnayake et al. [41] proposed a system and implemented it to verify the quality of the food supply chain by using blockchain. Here, a Quick Response (QR) code related to the product is used to map the virtual product with the physical one. In addition, a unique token-based mechanism was proposed to connect farmers with their product and build a reputation; farmers could place a certification for the product and gain reputation tokens. Then, Arena et al. [42] proposed an IoT- and blockchain-based application called BRUSCHETTA. It is used to detect and certify Extra Virgin Olive Oil (EVOO). It also helps track the origin and the information related to EVOO by exploring the entire food supply chain. Further, Burgess et al. in [43] presented a blockchain-based architecture to enhance the quality management of a short food supply chain. They primarily focused on food relocalization, i.e., initiating an ancient process where more emphasis is given to local food instead of the dominant food-provision system. Their architecture comprises IoT devices, a network interface (4G/5G), blockchain, data analysis, and trust management, along with the integration of smart contracts to improve the usability and reliability of the proposed work.

4.1.2. Food Storage

This subsection comprises food storage to keep it fresh and usable for the long term; this can be handled using cold storage, light-reducing containers for oils, air-tight containers, and dry storage for food grains. Further, storing the food in a suitable and safe place preserves the quality of the food and its essential nutrients. For that, Fang et al. [44]

designed an Intelligent Detection System (IDS) for food spoilage, which is based on an embedded arm that detects food spoilage and its safety. They mainly emphasized hardware platforms and software design along with their collaboration. The embedded arm shows that the system can effectively detect food spoilage. Furthermore, AI models have shown better detection capabilities with higher accuracies. This approach has good application value in food spoilage detection and safety monitoring. Then, Moudoud et al. [45] presented a BT-based architecture dedicated to the food supply chain that consists of different distributed IoT entities, called LC4IoT. It reduces energy consumption and increases storage capacities and latency. Additionally, the proposed architecture uses smart contracts and an Oracle network, which ensures system openness and food traceability.

Then, Garaus et al. in [46] introduced a blockchain-based food traceability system wherein the consumer can track the flow of the food supply chain to reduce food scandals. Furthermore, they established trust between consumers and retailers by employing BT, where consumers can track the essential details of the food products, such as the origin of the product, expiration date, food ingredients, and many more. This improves the communication and trust between retailers and consumers because the food details stored in the blockchain are immutable and transparent to all authenticated blockchain members, i.e., consumers and retailers. In addition, Feng et al. in [47] introduced the usage of BT for live fish waterless transportation. The main concern for waterless transport is the dynamic change in the environment and oxygen levels where the survival rate of the fish is diminished. Therefore, constant monitoring and supervision are necessary to find the changes in the fish's oxygen, carbon dioxide, glucose, and blood levels and temperature. This is formally done using wireless sensors, but the data that are collected from the sensors are at significant risk of being manipulated. Therefore, they adopted immutable BT, which enhances the security and reliability of waterless transportation.

4.1.3. Food Distribution

This subsection comprises food distribution, which is the dissemination of food to the general population, including consumers, retailers, wholesalers, and government agencies. Food distribution is severely affected by risk factors such as the nation's economic failure, natural disasters, and political conflicts, due to which the food is wasted and there is a total collapse in the food distribution. Moreover, there are food scandals where forged intermediaries stole a massive amount of food ingredients such as grains, dairy products, and fuel, which makes the food supply chain unreliable and insecure. To resolve the aforementioned issues and increase the efficiency of food distribution, several researchers across the globe have proposed various architectures. For example, Salah et al. [48] proposed an approach for a soybean tracking system, which used Ethereum blockchain and smart contracts to maintain the trust among all the stakeholders. The solution highlights the utilization of smart contracts to handle and control the supply chain. Tian et al. [49] showed the usage and development of RFID and blockchain to trace the food distribution in the supply chain. It also included a demonstration of the building process. Then, Bumblauskas et al. [18] proposed a food distribution system for eggs from farm to consumer to track egg-based food products from farm to fork using the IoT and blockchain. This helps the consumer obtain food information as per their need.

Then, in [50], the authors proposed a blockchain-based model for an agricultural food distribution system. The raw food items are mainly accumulated from the farmlands and sold to the stakeholders, who then process these raw food items and distribute them as edible food products. However, the current food supply chain has many discrepancies in terms of trust and security. For instance, the consumers are not fully aware of the origin of the food product; the intermediaries modify the travel history, food ingredients, expiry date, etc. Therefore, the authors adopted a decentralized technology, i.e., blockchain, which enables adequate transparency and traceability in the current food supply chain. Further, Chen et al. in [51] presented an AI- and blockchain-based framework for the agricultural food supply chain, which faces many challenges, such as centralized management and ineffective traceability. To overcome the aforementioned issues, the authors combined blockchain and AI technology, wherein the blockchain ensures food product traceability and offers reliable security solutions. On the contrary, the AI model was used for profit optimization by offering effective decision-making and storage of food products.

4.2. Internet of Things

The above-mentioned literature shows that blockchain provides security, reliability, and transparency in the food industry. However, the stringent requirement of monitoring and constant supervision of food processing, distribution, and storage still thwarts the flawless operation of the food industry. Therefore, a collaborative integration of blockchain and IoT devices is required, where the IoT plays a crucial role in data collection from several origins, such as storage facilities, sources of raw food items, and distribution centers. To do so, Asare et al. [52] gave a novel authentication method for the IoT, which helps BT to ensure the security and integrity of the data. Then, Aich et al. [35] reviewed the benefits of BT integrated with IoT-based food supply chain management. They highlighted the difference between the traditional supply chain and IoT-empowered BT in the seafood industry. Then, Lagutin [53] presented a federated solution for the existing IoT environment using BT. This work showed flexible cooperation between different parties, for example smart grid load balancing and food supply chain. The proposed solution also enables cross-pilot interactions and was tested in four real-life pilots.

Then, Caro et al. [14] proposed a fully decentralized blockchain-based method for food supply chain management, referred to as AgriBlockIoT. Here, the proposed system was deployed in Ethereum- and hyperledger-based blockchain, then they evaluated the performance of the proposed system based on various parameters such as latency, memory, and network usage. Moreover, Mondal et al. [54] proposed a blockchain-inspired IoT architecture to create a transparent food supply chain. An IoT-based food monitoring architecture tracks the food and performs a quality check of packaged food. Here, the real-time sensor data (collected using the single sensor) are updated in a BT while scanning the food packages at different places such as the retailer, logistics, or storage within the supply chain. Many sensors are integrated depending on the packaged food and sensing parameters of interest, for instance light, moisture, and temperature. Then, the authors of [55] discussed the shortcomings of IoT technology deployed for monitoring food products. For example, the collected data are not fully transparent to the consumers, and there is a risk of data tampering attacks on the collected food data. Therefore, they involved BT, which securely stores the food data collected by the IoT sensors. The proposed framework shows improvement while protecting the food data against data integrity attacks.

Further, Lu et al. in [56] introduced the unification of blockchain and the IoT for a food anti-counterfeiting traceability system. The main concern of the food industry is that they still operate their businesses on a centralized system, which lacks trust and security. The authors presented an anti-counterfeiting system based on a decentralized and immutable ledger that provides data integrity solutions, and IoT technology offers authenticity and reliability to the data stored inside the blockchain. Further, in [57], the authors discussed the importance of IoT devices for tracing and monitoring essential environments through which the food is processed and distributed; as a result, the quality of the food product significantly increases. They also pointed out the IoT challenges in the food industry, such as quick accessibility of data, trust issues with third party services, and complex security issues. For that, they proposed a traceability framework for the food industry in a Raspberry PI and deployed it on a cloud environment. The proposed framework outperformed other frameworks in terms of traceability, transparency, and security. Then, Cocco et al. in [58] introduced the combinatorial framework based on blockchain and the IoT, which enhances the operations of the food supply chain, in particular for Italian bread. They utilized an Interplanetary File System (IPFS) and ethereum-based blockchain that assists by providing conformity to food quality and hygienic conditions. Additionally, IoT sensors are used to monitor and trace the food products throughout the entire journey of the food product. A detailed comparison between existing approaches for the IoT in the food industry is shown in Table 5.

Table 4. A comparative analysis of existing approaches for food supply chain.

Author	Year	Description	Benefits	1	2	3	4	5	6	7
Burgess et al. [43]	2022	Incorporation of blockchain to enhance the quality management of the short food supply chain	Enables trust, traceability, authenticity, and reliability	Private	Yes	Yes	Yes	Short food supply chain	Yes	-
Feng et al. [47]	2022	Blockchain and IoT technology to increase the survival rate of live fish	Enhances the security and reliability of the waterless transportation	Public	Yes	Yes	Yes	Waterless transportation	Yes	-
Ehsan et al. [50]	2022	Blockchain-based traceability model for food supply chain	Optimized the supply chain, security, and efficiency	Public	Yes	Yes	Yes	Agricultural food supply chain	Yes	-
Chen et al. [51]	2021	AI and blockchain-based effective management framework for food supply chain	The proposed framework is highly effective, reliable, and cost effective	Public	Yes	Yes	Yes	Agricultural food supply chain	Yes	ASC
Garaus et al. [46]	2021	Blockchain-based conceptual model for food traceability	Building trust in the retailer	Public	Yes	-	Yes	Food retailers	Yes	
Asare et al. [52]	2019	An IoT-data-based authentication mechanism using blockchain	The nodal authentication approach integrating blockchain and the IoT provides data integrity and security through the nodes in the blockchain network	Public	Yes	Yes	No	-	Yes	-
Yadav A. et al. [59]	2018	A blockchain-based online food court payment system	It is a cellular-based app and web application designed for beverage enterprises and consumers. It supports the owner to make changes and manage the shop as per his/her requirements	Private	Yes	Yes	Yes	Web-based food court payment	Yes	Ethereum

1: Blockchain type, 2: customer privacy, 3: proposed architecture, 4: fully traceable, 5: application area 6: food data security, 7: framework used.

Table 5. A comparative analysis of existing approaches that highlight the role of the IoT in food industry.

Author	Year	Description	Benefits	1	2	3	4	5
Lu et al. [56]	2022	Blockchain and IoT-based food anti-counterfeiting traceability system	Decentralized storage and improved authenticity and reliability of the food data	Private	Yes	Yes	Yes	-
Al-Rakhami et al. [57]	2022	Traceability framework to track the origin of the food product	The proposed framework is deployed and assessed over the cloud and local environment	Public	Yes	Yes	Yes	ProChain
Cocco et al. [58]	2021	Blockchain-based traceability system for an Italian bread	Improves the transparency of the proposed system	Public	Yes	Yes	Yes	-
Stach et al. [55]	2020	Blockchain and IoT-based trustworthy framework for food monitoring	Build trust in the food monitoring system and protect the food data from data integrity attacks	Public	Yes	Yes	Yes	Sheepdog
Lagutin D. et al. [53]	2019	SOFIE, a secure and open federation of IoT devices using inter-ledger technologies	SOFIE provides open and secure federation between the existing IoT platforms (without making any change to the IoT platforms) using BT	Private	Yes	Yes	Yes	Sofie
Fang S. et al. [44]	2018	Detection system for food spoilage	The system is based on an embedded arm and integrated detection system development platform	-	Yes	-	No	-
Kim M et al. [60]	2018	An IoT-based food traceability system using IoT, blockchain, and smart contract tokens	A farm-to-fork traceability application (theoretical) integrated with IoT devices and Ethereum to exchange messages; uses IoT devices and Ethereum blockchain to transfer messages between IoT devices	Public	Yes	Yes	Yes	Ethereum
Wan X. [61]	2017	Application of the Internet of Things, blockchain, and asset securitization	Financial firms can provide financial services to consumers such as asset fidelity, reducing financing costs, and many more, using this blockchain-based application; also ensures asset management with the authenticity of the underlying asset quality	Private	No	Yes	Yes	-

1: Blockchain type, 2: proposed architecture, 3: food data security, 4: authenticity, 5: framework used.

4.3. Food Traceability

Food traceability is the most important criterion to improve QoS and customer confidence of different stakeholders, such as consumers and retailers. It adroitly enables tracing the activity of the food supply chain from its initial stage, i.e., raw food items, to food distribution. It also helps in medical outbreak situations such as Ebola, COVID-19, etc., and disaster-prone areas where there is an emergent need for food products for the people affected by the above-mentioned crisis. With effective food traceability, government agencies can trace the best suitable source from which they can accommodate food supplies for the population affected by the disaster or medical outbreaks. Not only that, it also aids in quickly removing contaminated food products from the marketplace, thereby reducing foodborne illnesses. The scientific community across the globe has provided many food traceability solutions, such as Kim [60], who proposed an end-to-end, farm-to-fork food traceability application (theoretical) integrated with IoT devices and Ethereum-based BT for message exchange. This enterprise solution facilitates the public health safety, traceability, and efficiency of the food industry. Then, Tian et al. [49] created a real-time tracking system for food traceability using BT, the IoT, and Hazard Analysis and Critical Control Points (HACCP). This system delivers the real-time safety status of food products to all food supply chain members, remarkably decreases the risk of single-point-failure issues, and presents a highly secure, distributed, and collaborative system. It significantly improves the food supply chain's transparency and efficiency to rebuild the consumer's confidence in the food industry. Further, in [62], the authors highlighted several limitations in the food supply chain, such as forged products, damage to food commodities, security, and damage to consumer rights. Therefore, the authors employed blockchain- and AI-based models to enhance food traceability, scalability, and monitoring. Then, Conti et al. in [63] proposed a lost cost and highly feasible food (olive oil) traceability system using Near-Field Communication (NFC). The authors mentioned that the food supply chain is complex and unmanageable because of various stakeholders and intermediaries. As a result, it incurs a high cost of the traceability system, which would not be affordable to a normal consumer or small enterprises. Therefore, the authors utilized smartphone and NFC technology at every stage of the food supply, allowing direct bidirectional communication between consumers and stakeholders. This is advantageous because it is easy to use and inexpensive and involves various food products. A detailed comparison of the existing approaches for food traceability is shown in Table 6.

Table 6. A comparative analysis of the existing approaches for food traceability.

Author	Year	Description	Benefits	1	2	3	4	5
Conti et al. [63]	2022	Olive oil traceability using cost-effective communication	The proposed system is easy to use and inexpensive	-	No	No	Yes	EVO-NFC
Ling et al. [62]	2021	Blockchain- and AI-based food traceability system	Integrated system enhances the traceability, security, and monitoring of the food supply chain	Public	No	Yes	Yes	-
Mirabelli et al. [64]	2020	Blockchain and agricultural supply chain traceability	The paper shows the benefits of BT as it is reliable and in its early stage; efforts are required to reach the maturation stage	Public	No	Yes	Y	-
Salah et al. [48]	2019	A soybean traceability system using blockchain in agricultural supply chain	Ethereum blockchain and smart contracts used for soybean tracking and traceability	Public	Yes	Yes	Yes	Ethereum
Baralla et al. [65]	2019	A European food supply chain system to ensure traceability using BT	This model shows the traceability from farm to fork in the European Union	Public	No	Yes	Yes	-
Caro et al. [14]	2018	A practical implementation of food traceability based on blockchain in food industry	The proposed traceability solution for the supply chain system ensures seamless integration of IoT devices, which consume and produce digital data along with the blockchain data	Public	Yes	Yes	Yes	Ethereum

1: Blockchain type, 2: authenticity, 3: data security, 4: support traceability, 5: framework used.

4.4. Others

This section comprises the other research work (which has not been included in the above sections) in the food industry, such as cellular-based application development, donation systems, food security systems, recommendation systems, and many more. For example, Yadav et al. [59] developed a web- and cellular-based application focusing on the food industry. First, it helped the restaurant staff keep track of all the orders placed and manage their online menu. Here, the customer could order food from anywhere and received it instantly. Then, Wan et al. [61] proposed an approach for a consumer credit line and asset securitization for a specific transaction process. Next, Junfithrana et al. [66] presented an IoT-based rice donation system for orphanages, where each orphanage has a heavy sensor and uses Raspberry-pi devices to establish a connection. These orphanages are connected to the BT network, monitored, and accessed by the mobile application. Here, donors can monitor an orphanage that lacks rice, which can be reserved for donation through an application. This system establishes a smart contract between donors and providers using a BT network, monitoring each transaction and making it more secure. Then, Huang et al. [67] studied a food safety system to track food based on BT to check the health status of chickens. It helps rebuild consumers' trust in the food industry by making food traceable, ensuring food quality, and enhancing product competitiveness.

5. Blockchain-Based Architecture for Food Industry

The world is facing an acute shortage of food and its supply because of several reasons, such as the recent COVID-19 outbreak, political corruption, and high food prices due to the Russian–Ukraine war, high inflation, etc. Hence, the food industry is on the brink of a complete collapse. However, modern advancements and collaborative unification of technologies can assist the food industry in terms of food traceability, bring transparency, enhance food product innovation cycles, label forged food products, etc. Blockchain is one such robust and promising technology that can be embedded in the food industry to tackle the aforementioned concerns. In addition, the food industry can be automated with minimal human interference if multiple IoT sensors are attached to the sophisticated machinery to assure the stakeholders for the effective food supply chain. Sensors gather an enormous amount of data from the surrounding environments and share them with cloud servers for faster processing and effective decision-making. Further, using blockchain, one can store IoT sensors' collected data in a distributed, secure, immutable ledger.

From the security viewpoint, an adversary can perform different attacks (e.g., Sybil attack, data unavailability attacks, data integrity attacks) in the food supply chain to gain benefits. Additionally, the food data are transferred from one edge server to another edge server via a wireless network interface, which is at high risk of being manipulated by attackers [68]. An adversary can perform an impersonation attack to disrupt the standard functionality of the food supply chain system. As shown in Figure 2, the traditional food supply chain system is not viable in terms of security and reliability. Attackers can target any component of the food supply chain and make it hazardous for people. Here, traceability in the traditional system is quite challenging. To secure communication between various stakeholders, we proposed a blockchain-based secure and decentralized architecture for the food industry, as shown in Figure 6. A blockchain is a feasible solution to make the food industry secure and safe. It manages to store each transaction generated by the IoT in an encrypted hash format. One block is immutably linked with the previous block and creates a chain of data [30].

The proposed architecture is divided into three layers: The first layer consists of all the stakeholders such as the food grower, processor, manufacturer, and regulator; it is referred to as the physical layer. The second layer is the blockchain, which connects the physical and user layers to make the food system secure and safe against security threats. The last layer is the user layer; it can be a consumer or an authorized person from the stakeholders. The physical layer communicates with the blockchain and user layer either with a wired connection (e.g., LAN/WAN) or wireless connection (e.g., Bluetooth/Zigbee) through a computer system, smartphones, or any other IoT devices. BT provides immutable, transparent, reliable, and secure functionalities using a smart contract to the food supply chain system. It can be developed in any programming language such as solidity or javascript.

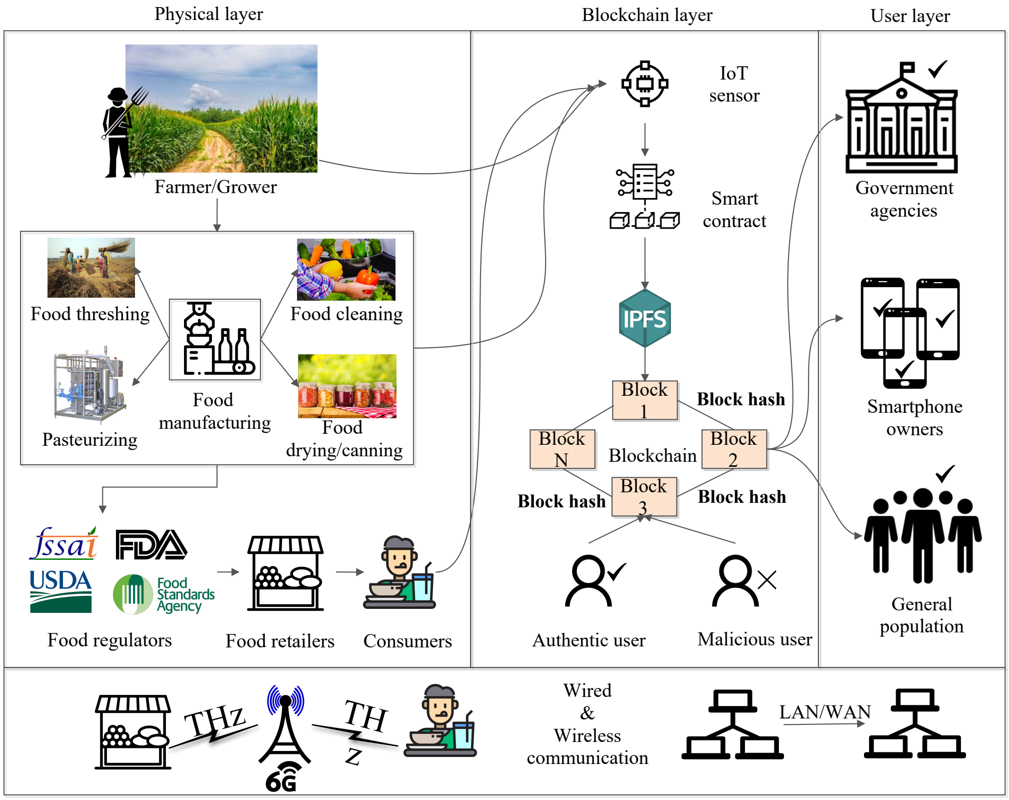


Figure 6. The proposed Blockchain-based architecture for food industry.

The regulatory authorities authenticate stakeholders such as farmers, manufacturers, and food procedures in the blockchain [69]. The food process starts with the grower, who farms the food. The grower can create a block of food items and store details about their states in a blockchain. The grower/farmer stores details about the farming conditions in the immutable blockchain. He/she store the respective phase's details in his/her particular block. With the help of timestamps, other blockchain participants can know when this process happens. The grower sends food to the processor to process the food by canning, freezing, etc. The details about the processing will be linked to the grower's block and stored as the respective data in his/her block. If the processing includes more than one stage or phase, each phase's details should be recorded in the blockchain. Likewise, all the phases receive information from the previous block, and detail about the respective phase is added. In the end, the final food product goes to the consumer. With the help of the proposed architecture, one can trace back the food's origin by tracing the blockchain node.

The proposed architecture provides various benefits. For example, it enhances security as food data are sensitive and crucial. Blockchain could significantly change the view of critical information by creating an unaltered record (once data are captured that cannot be altered), which is encrypted end-to-end. This helps prevent fraud and unauthorized activity in the food supply chain system. It furnishes greater transparency as the proposed architecture uses a distributed ledger, where food data and transactions are captured identically (data are dated and timestamped) in multiple locations. Next, it provides instant traceability of food from the audit trail. Then, it increases efficiency, speed, and automation in the food supply chain system using smart contracts. With the help of a smart contract, a transaction or process is triggered automatically when it meets pre-specified conditions.

6. Result Analysis of the Proposed Architecture

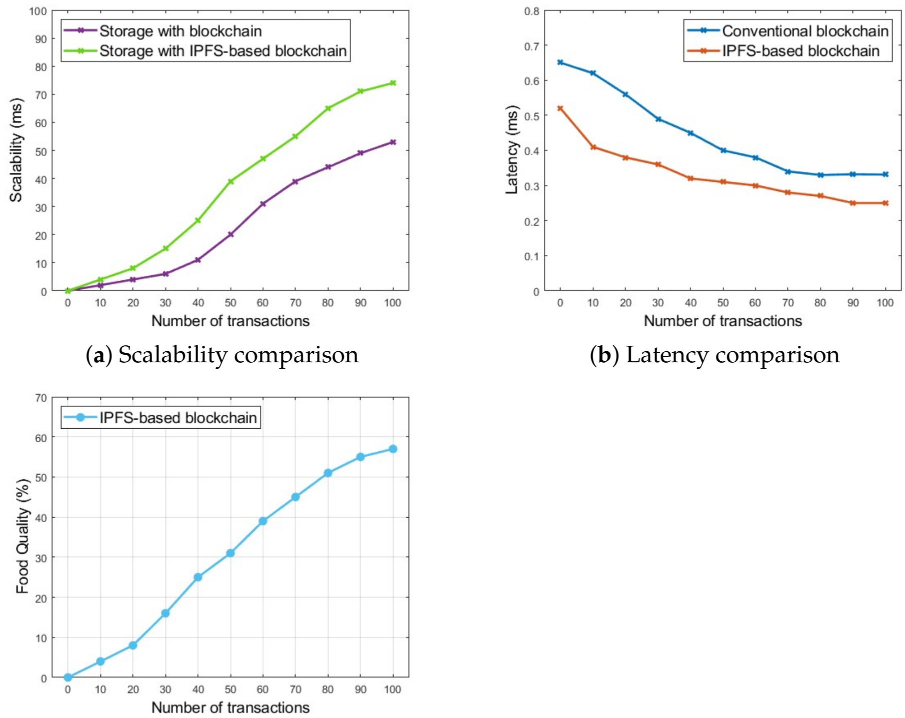
This section describes the experimental setup, tools, and performance of the proposed architecture in terms of scalability, latency, and food quality.

6.1. Experimental Setup and Tools

The proposed architecture was developed by including different tools and frameworks, such as NodeJS, Truffle, Metamask, and Ganache network. These tools help in formulating the application and blockchain layer of the proposed architecture. On the other hand, we assumed that the communication between each entity of the blockchain and the application layer is performed using the conventional cellular network. For the blockchain layer, a smart contract is implemented with the solidity programming language with different user-defined functions for farmers, manufacturers, and stakeholders. A few of the implemented functions are *getFarmer()* to fetch the farmers' Identity (ID), *addRawProduct()* to add the product to the ledger, *getRole()* to assign a particular role to the farmers, manufacturer, and stakeholders, a few functions associated with the raw products, such as *addItem()*, *getItemIds()*, *getProductsCount()*, *getTransactionsCount()*, *getReviewsCount()*, and many more. The smart contracts are compiled using truffle, which is a development and testing environment for blockchain applications. Once the contract is compiled, it can be tested on Ganache's network. If the smart contract validates the information of farmers, manufacturers, and stakeholders, the data are stored inside the IPFS-based blockchain. The IPFS converts the raw food data into the hashed data, which improves the scalability and latency of the proposed architecture. The subsequent subsection describes the performance of the proposed architecture in terms of latency, scalability, and food quality.

6.2. Performance Analysis

Figure 7a illustrates the scalability parameter of the proposed IPFS-based blockchain architecture for the food industry. The scalability is greatly increased by employing the IPFS in the blockchain; this is because the IPFS converts the raw food data into the hashed data, which are faster to fetch from the IPFS-based blockchain than the conventional blockchain. In addition, this reduces the computational overhead of the proposed architecture because hashed data are small in size compared to the plain data; hence, it is effortless to fetch them with a minuscule computational overhead. Figure 7b depicts the latency comparison with the conventional blockchain and the IPFS-based blockchain. Latency is an important parameter to quickly obtain the data from the system and act accordingly; if the system has high latency, then there is a delay in the action response, which will deteriorate the performance of the food supply chain system. Therefore, it is necessary to have a low-latency communication system that provides the data on time. From the graph, we can see that as the number of transactions increases, the latency of the IPFS-based blockchain decreases. This is again because the IPFS is faster than the conventional blockchain. Lastly, Figure 7c shows the improvement in food quality as the number of transactions increases. The reason behind this is that every member of the blockchain is connected to the immutable and distributed ledger, implying that if someone tries to forge the food data, for example ripened food is forged as fresh food, the blockchain members automatically see it and discard such maliciousness from the ledger. Consequently, this will increase the transparency in the blockchain. It is evident that if only the correct data are stored inside the blockchain, one can improve the food quality of the food industry.



(**a**) Scalability comparison

(**b**) Latency comparison

(**c**) Improved food quality

Figure 7. Performance analysis of the proposed architecture.

7. Open Issues and Future Research Directions

This section provides the insight of our survey on BT's usage in the food industry to address a wide range of issues in the food industry. Although BT benefits the food industry with various functions such as reliability, immutability, and many more, plenty of issues remain open for additional examinations, which require a considerable amount of future research work, as shown in Figure 8. The following are the open issues and challenges for integrating the blockchain in the food industry.

- *Privacy*: The pervasive use of the sensing systems of IoT devices means continually gathering data from their surrounding environment, and the food supply chain compels invasions of privacy. For example, in the blockchain-based food supply chain system, each node has its copy of the distributed ledger, which results in sensitive or personal data being disseminated to all participating nodes [70,71].
- *Scalability*: The scalability of the system is an essential feature in the food industry. If the nodes are fewer, the BT is appropriate to use for the transactions, and the required speed can be enforced. On the other hand, it can be preferable to have an adequate number of nodes and phases connected. Blockchain platforms such as Ethereum and Bitcoin can handle 12 transactions every second. Many other blockchain platforms are being developed to reduce transaction execution times and improve consensus algorithms [72,73].
- *Security*: The decentralized nature of blockchain has its benefits and its shortcomings. Blockchain is robust against an assortment of safety dangers, yet its nature itself makes it vulnerable to a digital assault referred to as 51% attack (usually on bitcoins). For this, a prospector node dominates over half of the blockchain processing power and hash rate. In food processing, this circumstance happens if a large portion of the frameworkis hacked. Therefore, a powerful, robust solution is needed to extend the security of the whole blockchain-based food processing network [74].
- *Smart contracts*: This is a programming code that can be vulnerable to various security assaults because of the absence of proper programming modes. Testing smart contract methods can be a route forward [75,76].

- *Lack of standardization and regulations*: Numerous associations such as IEEE and ITU are currently attempting to create current blockchain innovation measures, which help blockchain integration with different technologies. IEEE has various ventures in blockchain benchmarks to make the blockchain executions future-proof; however, this requires legitimate guidelines, laws, legislation, ordinances, and procedures. Along these lines, advanced blockchain executions will remain cooperative with the modern ones. Thus, part of the research should be performed right now to create appropriate specialized principles, strategies, and guidelines for BT's effective deployment in the food industry [77,78].
- *Data storage capacity*: Blockchain still has the hurdle of storage capacity, which is a significant issue that needs to be studied. However, in the food processing system, it generates gigabytes of data in real-time, which are complex to process [79]. Hence, it is challenging to make a compatible implementation of a food processing system with blockchain. This could be a limitation of the proposed secure and decentralized system.
- *Data storage cost*: Blockchain in the food processing industry improves data protection and increases the data storage expense. Storing a single word (32 bytes, i.e., 256 bits) in the Ethereum blockchain requires 20 K Gas. The modern Gas cost is $\approx$ 6 gwei, and the modern value of Ethereum cryptocurrency (Ether) is USD 131. Hence, the ultimate value to store 1 MB in Ethereum is $\approx$USD 57.
- *Throughput improvement*: BT has been accepted in various scenarios of the food industry. However the throughput, which is the capacity of processed transactions in BT networks, can limit BT's scope of usage in the food industry. The foremost concern for this issue is the limited block size and long block creation time [80]. Conversely, block size and block creation time cannot be easily changed to improve throughput. The analyses in [81] showed that miners intend to build a federation in the case of an unlimited or huge block size. This is destructive to preserving the decentralized network of BT-based food industry systems. Thus, to improve the throughput, further development is required of blockchain protocols for the proper block size and efficient block creation.

Figure 8. Future research issues and challenges.

8. Conclusions

The current development of BT has made it a disruptive and robust technology. The DLT in the blockchain acts as the backbone of several IoT-based applications such as smart cities, smart grids, and the food industry. The integration of high-potential BT, combined with the IoT, is revolutionizing the food industry. Companies working in the food supply chain domain are aware of BT's potential, and they are demanding their suppliers to enable greater food security and a more transparent supply chain. This paper discussed a detailed description of the food industry, its security issues, and the integration of BT, which benefits the food industry. Next, we discussed and compared different existing surveys of the food supply chain in terms of security with our proposed survey. Then, we presented a solution taxonomy for the food industry with a comparative analysis of available approaches and methodologies in each dimension. Further, we proposed a BT-based secure and decentralized architecture that canbe deployed in the food industry for an effective food supply chain. The proposed architecture was evaluated against different performance metrics, such as scalability, latency, and food quality, to enhance the operation of the food supply chain. Finally, we listed several BT-based open research issues and challenges that can help other researchers working in the same research area.

In the future work, based on the proposed survey, we will attempt to develop a unique solution to confront modern security attacks in the food industry.

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