Review Based Analysis with Applications of Blockchain in Food Supply Chain management

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***Abstract*—The main aim of food supply chains is to ensure the availability of safe and good quality food the consumers across the world. With the advancement in technology the food supply chains are experiencing significant changes. Block chain technology is attracting interest as its provides benefits of transparency, traceability, smart contracts, decentralization and better sustainability. The ubiquitous technology of block chain has the potential to improve traditional food supply system. It can guide the current food processing towards better food sustainability and efficiency. This paper presents a literature review on the use of block chain technology in food supply systems. We discuss the benefits of blockchain technology. We also discuss the challenges faced by the users of block chain-based food supply systems.**

Keywords—Blockchain, food supply chain, traceability, immutability, decentralization, smart contract

I. INTRODUCTION

The blockchain technology is valued due to its ability to validate transactions publicly, record them and distribute them in an immutable encrypted ledger called blockchain . Cryptographic principles secure the data stored in the blocks in the blockchain decentralized digital ledger[1]. Blockchain Technology ensures integrity and immutability of data by providing a transparent, decentralized system without third party intervention. The main components of blockchain are server, transactions, set of transactions called blocks, ledgers to record the transactions and an algorithmic function known as hash function[1,2]. The potential of blockchain is explored in many fields such as government systems, financial systems, supply chains etc.

The architecture and framework of supply chains is very complex in the industries. The activities included in the supply chain begin from the raw form of goods followed by production and delivery of finished goods[3]. A good supply chain enhances the productivity in business and results in more profit gains. The traceability of the product through all the stages in a supply chain is a challenge faced by the industries. Data transparencies and trust among the supply chain parties are another barriers present at all the levels of the supply chain. Blockchain, due to its potential can be deployed in the supply chain management[3]. With the help of blockchain technology, the information about the product manufacturing, distribution of product can be recorded and made available to all the parties involved, thus ensuring trusted end to end traceability[4].

The requirement of food safety and growing issues on contaminated food risks have attracted researchers to provide efficient ways to track the food through the food supply chain. The blockchain technology could help to maintain a good food supply chain. Blockchain ensures traceability of the food from "farm to fork". The utilization of blockchain technology encourages fraud prevention, good quality food and compliance of regulatory instructions[5]. The functioning of food supply chain is complex It involves multiple parties such as farmers, processors, manufacturers, packers, logistics and consumers[6]. With so many stakeholders it becomes difficult to assure the quality of product and its origin. Currently, the food supply chains are not integrated with technology and mainly dependent on the paper work. Electronic data interchange (EDI), Bar code and Radio-frequency Identification (RFID) tags are some innovations for efficient food traceability already advised by Bosona and Gebresenbet[32] .

This study attempts to review the existing literature to identify the functionalities of blockchain technology. Specifically, this paper focuses on the application of blockchain in food supply chain systems. The researcher attempts to answer the following questions research questions(RQs) in this paper:

RQ1: What are the important characteristics of Blockchain technology?

RQ2: What is the existing study on application of blockchain in food supply system?

RQ3: What is the positive impact of blockchain on food supply chain?

RQ4: What are the barriers and opportunities in adoption of blockchain technology in food supply chain ?

We will review relevant studies and offer a thorough analysis of the literature to help us respond to these issues.

II. LITERATURE REVIEW

A review of relevant existing literature is done to respond to the above mentioned research questions. The main focus is on exploring the feature of blockchain, benefits and challenges of block chain technology in food supply systems.

A. Blockchain Technology

The concept of decentralized peer-to-peer ledger was introduced by Nakamoto in 2008.This technology has gained the attention of researchers for addressing issues in many areas such as finance, voting, supply chains, property etc. This section answers the RQ1 of the study. Blockchain technology has a few significant features: immutability, decentralization, smart contracts, security.

1) Immutability

The immutability feature minimizes the human interference on the records stored in the blocks in the blockchain.. This capability can prohibit any relevant stakeholders from changing the past and abdicating their duties during a food recall, which is extremely helpful. [1,2]. Immutability is a potent indicator of the likelihood of a food catastrophe.

2) Decentralization

Decentralization ensures that every stakeholder have equal power within the network. Unlike the traditional central systems, there is no central governing authority which is responsible for all decisions. The decentralization property gives the benefit of fault tolerance to the blockchain network. The copies of the records are saved by many parties and are accessible at any time. [2]. Users assist one another in maintaining copies of records, validating transactions, and sharing the ability to access history [1,3,4]. Thus, the decentralized feature of blockchain ensures trust building and removes information imbalance.

3) Smart Contracts

Smart contracts are programs that are executed when some predetermined conditions are met. It is an essential component of blockchain, a type of digitalized contract that operates automatically when specific criteria are met. [5].Smart contracts are able to expedite transactions and increase confidence. [6]. For example, once the product reaches the go down the payments is automatically transferred. Smart contracts are based on agreement of all the parties and a single user can not intend to make changes in the contract. The smart contracts enhances speed, efficiency and accuracy.

4) Security

Data Security is attained by the consensus algorithm of blockchain. Algorithms are defined to approve the transactions and to insert the data into the database. Proof of Work (PoW) is a consensus algorithm which requires that all users validate all transactions [6]. The bitcoin blockchain uses the PoW consensus mechanism. Another well-known consensus approach is Proof of Stakeholders (PoS).The decentralization feature of blockchain reduces the risk of hackers as there is no single central authority to be hacked. Hackers need to hack many points in the network, which will require a lot of time and energy [6].. Thus, a large and complex blockchain is secures the data stored in the blocks and reduces the risk of hacking.

5) Traceability

As defined by [3], Traceability is the capacity to trace an entity's history, applications, or documented identifications.. Researches have been done on food traceability and researchers have suggested few benefits of traceability [5], which are improvement of operational efficiencies, ensuring food authenticity increased food safety and meeting legal requirements. Due to frequent food hazards, many governments and non-government organizations have encouraged food manufactured companies to develop their own traceability systems for safe their food. Blockchain is one of the new technologies to guarantee traceability. The structure of a blockchain ensures a traceable and accountable food supply chain in which each stake holders securely shares the vital information.

B. Methodology

In order to answer the research questions this study performs a survey of existing literature on blockchain and food supply chain. This paper reviews the literature to understand the blockchain and also studies the existing literature on practical applications of blockchain on the food supply chain system. We adopted a six stage process to conduct the review: defining research questions, specify the inclusion and exclusion criteria, determine the searching database, apply the criteria, synthesize the literature and discuss the findings. The introduction part of this paper has already discussed the research questions. To review the valuable academic literature, Scopus database was searched to extract the relevant publications. Other resources such as papers from conferences, research reports and book chapters are also studied in order to get knowledge of the updated work on blockchain

The inclusion and exclusion criteria for the consideration of research papers is given in Table I. Some useful papers were finalized for review after applying the inclusion and exclusion criteria. The summary of these papers is presented in a tabular form in Table II. The research papers were read thoroughly. The work done and research gaps are highlighted in the summarized table.

C. Maintaining Benefits of blockchain in FSC

To answer the RQ3, we now discuss the merits of blockchain in food supply systems that we retrieved from the existing literature. Block chain has a great potential in food supply chain management. It benefits all the stakeholders in different contexts. This section covers the valuable impact of blockchain in food supply management system

1) Transparent Transactions

In the traditional food supply chains only partial information about the food is presented to the customers. The customers do not have the detailed information of the product and suppliers. There are many policies published by the government authorities for regular food quality checks but big brands use unfair means to cover up their regulatory violations. The insufficient information impacts the food safety [7]. In a centralized supply chain, it is easy to change or erase the information resulting in low transparency. The decentralization feature of block chain all the stakeholders to access the information without any central authority intervention. All the registered users have the copy of history and can examine the transactions [8]. Thus, block chain increases the transparency along the food supply chain, providing information symmetry among stakeholders.

2) Improved Food Traceability

The block chain plays an important role to trace the food throughout the food supply chain beginning from the farms

to the final consumer. All the records are stored in the blocks in the decentralized distributed ledger which are immutable and irrevocable. Block chain is a potent instrument for preventing food fraud and enhancing traceability effectiveness, including time and cost savings, risks being reduced, and confidence being increased [9]. In order to demonstrate the effectiveness of blockchain in delivering transparency and auditability [32] introduced two traceability systems which were based on a combination of blockchain and Internet of Things. This combination works well on Ethereum and Hyperledger Sawtooth. Block Chain therefore significantly aids in managing traceability and sustainability.

3) Information Security

The block chain technology ensures the security of the information stored. The data is stored in encrypted form in multiple ledgers. This distributed data is difficult to be hacked by the hackers. Once all parties agree on the traceability procedure, the consensus method used by the blockchain ensures that the information won't be altered. [10]. The blockchain's consensus mechanism is the means by which all participants can agree on a record's veracity.

4) Food Safety and Quality assurance

As the food chains are not limited to geographical location and food travels across the world. In this global flow of food, it becomes difficult to assure food safety and food quality. According to the Centers for Disease Control and Prevention (CDC), food contamination results in 48 million illnesses and 3,000 fatalities among Americans each year (CDC 2018) [32].An efficient solution is provided by the blockchain technology to improve the traceability of food which results in food hygiene and safety. The information is recorded at every stage of food supply which allows the identification of food frauds, food contamination and risks at the earliest. Each participant should provide accurate and complete information about the food's origin. In the entire food business, the number of infractions of the code of conduct has decreased.

5) Reduction of waste and Economic loss

The untargeted food recalls are major causes of food waste and financial losses to the food companies. A food recall means removing the food item from sale, distribution or consumption as its usage may be a risk to the consumers. Block chain ensures that the information about the food product is updated in real-time speed and the stakeholders could react to the situation at initial phases of the food supply chain. Data that is traceable and trustworthy at every stage results in a packaged foods having a more precise shelf life, which reduces food scraps and monetary disruption.[31]. The well-known food company Walmart realized that the fresh imported mangoes wait up to four days for checking at the country border [32]. Thus, the companies can accelerate the product checking speed if it follows an efficient traceable system which in turn increases the shelf life of the product.

6) Empowerment of Customers

The block chain technology let the customers take more accurate decisions of buying the food products. Customers want to know whether the food products meet quality standards or not, where the food is produced and processed and how it reaches the store. Due to the block chain technology user can access all this information and the consumer also know that this information is immutable and cannot be modified. Thus, block chain empowers the customers and let them purchase the best food products.

7) Encourage Farmer Investment

The block chain technology benefits the small and medium-size farmers by finding loyal stakeholders. For small farm owners it is challenging to setup operations and it takes few years to establish the business. Initial coin program (ICO) is a funding program which use cryptocurrencies instead of traditional payments method. With the help of ICO, farmers will be able to find investors for the betterment of the business [11]. Cooperatives can also be formed by small farmers to become large firms and block chain can help such firms by providing transparency, trust among the farmers leading to less conflicts of interest [12].

III. CHALLENGES

Block chain is a promising innovation which can revolutionize the food supply chain management system. Being a new technology, it is still in its infancy and still has a ways to go. Many researchers have raised few challenges that are faced in applying the block chain in supply chain. Based on our review, we discuss some of these challenges in brief.

A. Privacy and Security

In a block chain-based food supply system the information is stored in the distributed ledgers available to all the stakeholders, which results in dissemination of personal and sensitive data to all the parties involved in the supply chain. The decentralized nature of block chain makes it vulnerable to digital assault known as 51% attack. Under this concept a particular node dominates over half of the processing power and hashing rate of block chain[13]. Thus, a large portion of the supply chain can be hacked, therefore the block chain based food supply systems require a more powerful and robust solution to enhance security.

B. Scalability

As per the founder of Ethereum it is difficult to attain scalability, security and decentralization in parallel. According to him only two of them can be accomplished in one point of time. He named this concept as “scalability trilemma” . Scalability means how large the capacity of a supply chain could be. In blockchain, the copies of all the transactions are stored in all the nodes[13]. It gives security and a high degree of decentralization. But as the transactions are validated by all the nodes, the validation speed becomes slow and it gets slower as the transactions increases in number. Thus maintaining scalability is a challenge in blockchain as high scalability results in less security and low scalability results in more transaction crowd [14].

C. Infrastructure and cost

There is a lack of public key infrastructure for appeasing all the requirements of block chain-based quality traceability system, such as inter-domain policies and control. The amount of storage capacity and the cost of data storage are another infrastructural barrier in block chain. In the food

processing system, it generates gigabytes of data in real-time, which are complex to process [28].

D. Lack of Laws and Regulations

As block chain is an open data base policies are required to protect the rights of the users. Policies need to be developed in food supply chain systems to protect users. Some countries have shown interest to support the block chain technology, like China has published a Block Chain White book . International organization of standardization (ISO) block chain is working on developing global standards for Block chain [46]. Institute of Electrical and Electronics Engineers (IEEE) and International Telecommunication Union (ITU) collectively attempting to create measures to integrate block chain with other technologies. This requires guidelines, ordinances, laws and legislations[27]. Thus, specialized guidelines and laws are required for efficient deployment of Block chain technology.

E. Raw Data Manipulation

There are possibilities of manipulation of the raw data before it is uploaded to the blocks in the block chain. It is difficult to ensure that the raw data placed in first place is authentic. Governments or some certifications must be involved in the block chain supply networks to ensure the authenticity of initial raw data. The IoT sensors may be tempered to change the specifications of the product. The products are purposely damaged without informing all the stakeholders in block chain [27].

F. Adoption of BCT by all Stakeholders

In the current scenario, all the stakeholders of a food supply chain work on a centralized system for all kinds of information exchange. Thus, stakeholders resist to adopt a new decentralized technology in their daily operations. The business parties involved in the supply chain has to learn new skills or they have to hire new personnel to deploy the latest technology. The block chain infrastructure fee is also a barrier for small enterprises in developing countries. It is also found that most of the companies implementing block chain projects are located in the developed countries [16]. It is also suggested that instead of replacing the whole supply chain system with new block chain, only partial system can be replaced[17] .

G. Limitation of Smart Contracts

The smart contracts are programming codes that benefits the block chain by increasing the area of its application. Nevertheless, there are some disadvantages faced by the users of the block chain-based users. The developers of the smart contracts also face the challenge of developing a cost-efficient cost to minimize the deployment cost. Each function call and transaction that is started in the smart contract has a fee associated with it. The user-set gas limit must be taken into account while creating a smart contract to prevent excessive gas use. According to each client's gas cost, which is defined by Ethereum, calling methods cost different amounts for different clients. Finally, smart contracts must be programmed keeping low complexity and cost effectiveness in mind.

IV. Literature Review Table

Table I presents the inclusion and exclusion criteria for the consideration of research papers. The papers published from 2016 to 2022 were focused. Mainly the papers which focused on Block chain and block chain food supply chain were shortlistde for the literature review. The Table I summarizes basis of selecting the papers for review pupose.

TABLE I. TABLE I INCLUSION AND EXCLUSION CRITERIA

Inclusion Criteria	• Papers published in English language • Paper published since 2016 to 2022 • Papers focus on blockchain technology • Papers focus on blockchain for food supply chain
Exclusion Criteria	• Papers published in languages other than English • Papers published before 2016 • Papers focus on other technologies • Papers focus for food supply chain Technologies

Table II summarizes the findings of the research papers studied during this literature survey. A total of 16 papers were considered for review after applying the criteria given in Table I. We have presented the recent researches performed on block chain and its benefits in food industry

TABLE II. FINDINGS OF LITERATURE REVIEW

Sr. No.	Name of the Author	Year of Publication	Findings
1	Tanwar et al. [10]	2022	Reviewed many previous studies of the security of the food supply chain, discussed a full overview of the food sector, its security concerns, and the integration of BT. Proposed a safe, decentralized architecture based on BT.
2	Alobid M., Abujudeh S., Szűcs I. [11]	2022	79 research papers were reviewed, with an emphasis on the state of blockchain technology in agriculture and its future significance.
3	Wang L., He Y., Wu Z.[12]	2022	Constructed a framework for a supply chain traceability system based on Radio Frequently Identification (RFID) and blockchain technology. The system is comprised of an RFID system at the package level for data collecting and storage, as well as a decentralised blockchain-enabled data storage system for data administration.
4	Chang, A., El-Rayes, N., Shi, J. [13]	2022	A thorough analysis of the functionalities, and deployments of Blockchain Technology (BCT). Traceability is the primary factor driving BCT's implementation in supply chain management (SCM), among other BCT qualities .
5	Wünsche, J.F., Fernqvist, F.[14]	2022	To assess the current state of BCT and put it into perspective by outlining the benefits, drawbacks, rewards, objectives, and expectations related to its deployment in international food systems, qualitative interviews with eight main BCT providers

			were undertaken.
6	Lorenzo et al. [15]	2022	Explore how blockchain technology (BCT) can be interspersed into the food supply Chains. Also described a BCT solution designed to improve traceability and analyze its implementation in two small companies.
7	Arokiaraj David, C. Ganesh Kumar, P. Victer Paul[16]	2022	The original data were used to conduct this empirical investigation. The supply chain activities such purchasing, pre-processing, transportation, warehousing, stock management, marketing, processing, and other marketing initiatives were taken into consideration when creating the questionnaire.
8	Damoska Sekuloska, J., Erceg [17]	2022	The goal of the study is to determine how blockchain technology might help address the food supply chain's (FSC) growing productivity, accessibility, integrity, traceability, and safety concerns. Local food supply chains will receive special consideration in the study (LFSC).
9	Peng et al. [18]	2022	A supervisory cross-chain model appropriate for the complex data of the rice supply chain was constructed using parallel blockchain theory and smart contract technology to improve the ability of the rice supply chain to be supervised in an epidemic condition.
10	Echegaray et al. [19]	2022	The role of Meat 4.0 enablers in meat processing, preservation, and assessments of quality, safety, and authenticity was discussed.
11	Khanna et al. [20]	2022	Research focuses on preserving the nutritional benefits of dairy products, spotting malpractices and contaminants in dairy products, improving the financial sustainability of operating a dairy farm, and raising the dairy company's revenue.
12	Zhang, X., Li, Y., Peng, X., Zhao, Z., Han, J., Xu, J[21]	2022	Builds an information tracing model for the supply chain of whole grains and oils, and it explains how contracts are implemented and example contracts are verified. developed using the open-source Hyperledger Fabric framework, and the system is tested using a case study.
13	Shoufeng Cao , Marcus Foth , Warwick Powell , Thomas Miller , Ming Li [22]	2022	Designed a multi signature strategy based on blockchains to digitally alter supply chain administration in food supply chains for beef that is globally scattered.
14	Tsoukas, V., Gkogkidis, A., Kampa, A., Spathoulas, G., Kakarountas, A [23]	2022	A self-sovereign identity strategy for all supply chain actors ensures the minimising of single points of failure. A security mechanism, which is based on the application of TinyML's emerging technology, is integrated in monitoring devices
			to minimise a sizable fraction of hostile behaviour from supply chain actors.
15	Kayikci Y, Durak Usar D, Aylak BL. .[25]	2021	A single use-case analysis is conducted after performing literature survey to investigate the potential of blockchain to achieve excellence in operations for the Perishable Food Supply Chain (PFSC) during pandemics by implementing Context, Interventions, Method, and outcomes (CIMO-logic).
16	Younes Abbassi, Habib Benlahmer [26]	2021	This paper explains the overview of combining blockchain and IOT.
17	Dhruman Gohil and Shivangi Viral Thakker[24]	2021	This article intends to demonstrate how blockchain technology may improve supply chain operations' flexibility and agility.

V. Conclusion

In this research paper, we systematically reviewed the blockchain enabled food supply chain in detail. Many papers that we reviewed concluded that the potential of block chain technology can bring promising benefits to the food supply chain management. Block chain technology improves the working of food supply systems by providing transparency, traceability, reduction in food waste and food safety. The consumers in today's world wants to know each and every details of the food products like its source, where it was grown and in which conditions. Thus, adopting block chain technology for food supply chain gives the consumer more information about food and enables to take more accurate buying decisions.

VI. Futurescope And Limitations

In our upcoming work, we will try to create a block chain-based solution for a specific class of food goods based on the findings of this review. However, research papers under consideration are based on supply chain of different food items. Thus, to use BCT for a specific food item we need to review the research carried out for that specific food product.

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