VAWKUM Transactions on Computer Sciences
http://vfast.org/journals/index.php/VTCS@ 2024, ISSN(e): 2308-8168, ISSN(p): 2411-6335
Volume 12, Number 2, July-December 2024 pp: 205-220

A Blockchain-Based Framework to Make the Citrus Crop Supply Chain Transparent and Reliable in Agriculture

Sawera Kanwal [1*], **Sumaira Nazir** [1], **Syed Muhammad Asadullah Gilani** [2], **Junaid Asghar** [3], **Aasma Aas** [4]

[1*]Department of Computer Science, University of Management and Technology, Lahore 54770, Pakistan; [1]Department of Computer Science, National College of Business Administration and Economics, Lahore, Pakistan; [2]Department of Computer Science, University of Management and Technology, Lahore 54770, Pakistan; [3]Department of Computer Science, University of Lahore 54770, Pakistan; [4]Department of Computer Science, University of Management and Technology, Lahore 54770, Pakistan

Keywords: *Citrus Supply Chain, Blockchain Technology, Traceability, Cryptocurrency (Citrus Coin).*

Journal Info:
Submitted:
October 29, 2024
Accepted:
December 05, 2024
Published:
December 17, 2024

Abstract

Citrus is an important food security crop in the world, and the health benefits or otherwise of the commodity depend on the quality and safety of the grain. It is used in several by-products such as citrus pudding, citrus fritters, and citrus bread. With more and more people paying attention to food safety issues, attention to the safe and stable source of citrus is becoming more important. Problems in this supply chain including those that result in reduced revenue for the farmers and the government, and major losses during off-season arise primarily from lack of trust, dependability, openness, accountability, origin, and safety. To address these difficulties, we present a secure and transparent framework using Blockchain technology to monitor citrus crops from the farm to the consumer's table. We propose a new cryptocurrency token named citrus coin (CC) which will be used in the process of purchasing investors in the citrus n value chain. This system includes an elaborate demonstration, a CC cryptocurrency wallet, and an Initial Coin Offering (ICO). The functioning of the framework is based on smart contracts to manage the transactions which are traceable and transparent through the entire citrus crop supply chain while the CC can be converted into traditional fiat money. Also, we use the decentralized storage system (InterPlanetary File System (IPFS)) to store information about corporations and sellers to improve security, transparency, and access to data. Furthermore, our experimentation and analysis, demonstrate that the proposed framework provides better results compared to the existing solutions for the supply chain in terms of contract verification time, regular gas transaction efficiency, and block generation latency.

***Correspondence author email address:** sawerakanwal233@gmail.com
DOI: 10.21015/vtcs.v12i2.1954

1 Introduction

Citrus is the most important and widely grown commercial fruit crop in the world. In many countries, citrus crops rank high in agricultural economies Brazil China and the USA are among the important producers near the top for this fruit group [1]. Citrus is among the most abundant and beneficial fruits in terms of nutritional aspects (mainly vitamin C), and it is also used in several industrial sectors such as solar, food, and pharmaceutical industries [2]. There are over 10,000 species in the Citrus genus and each has its distinct appearance and function. Commonly cultivated in the warmest regions of temperate and tropical countries, citrus is a key industrial crop for numerous countries throughout both developed and developing regions [3]. Another method that is the basis for successful citrus cultivation is through effective utilization of citrus fruit peel waste being free in every household after consuming the fruit. Citrus peels contain various valuable compounds such as essential oils, flavonoids, and other bioactive substances making them versatile in different industries [4].

The primary purpose of this research is to understand how Blockchain Technology can be implemented in the context of the agri-food supply chain with particular reference to traceability and food safety [5]. Agriculture has long been the backbone of the global economy, securing food supply and providing numerous livelihoods. Citrus types oranges, lemons, and grapefruit are among the most voluminous fruit that grows for sale by commercial interests. The farm-to-fork journey of these vegetables includes growers, distributors aka aggregators/flayers/ consignors' wholesalers such as commission agents and retailers as shown in Figure 1. The size and importance of the (global) citrus industry notwithstanding, its members file innumerable complaints about inefficiency, dishonesty, or opacity leading to financial loss, poor product quality, and ill will between link Maris. Citrus industries now dictate new standards for transparency and predictability in agricultural supply chains. Legacy systems, many of which are based on centralized databases and rely heavily on manual record keeping, suffer from mistakes as well as potential tampering with data [6]. These deficiencies make it difficult to trace the origin and quality of products, raising questions about food safety, fraud as well as unfair pricing practices. To overcome this a credible network of systems must ensure traceability and accountability which in turn ensures smoother the supply chain process. Being a decentralized and irreversible mechanism, blockchain technology potentially provides the right solution to rein in this malfeasance.

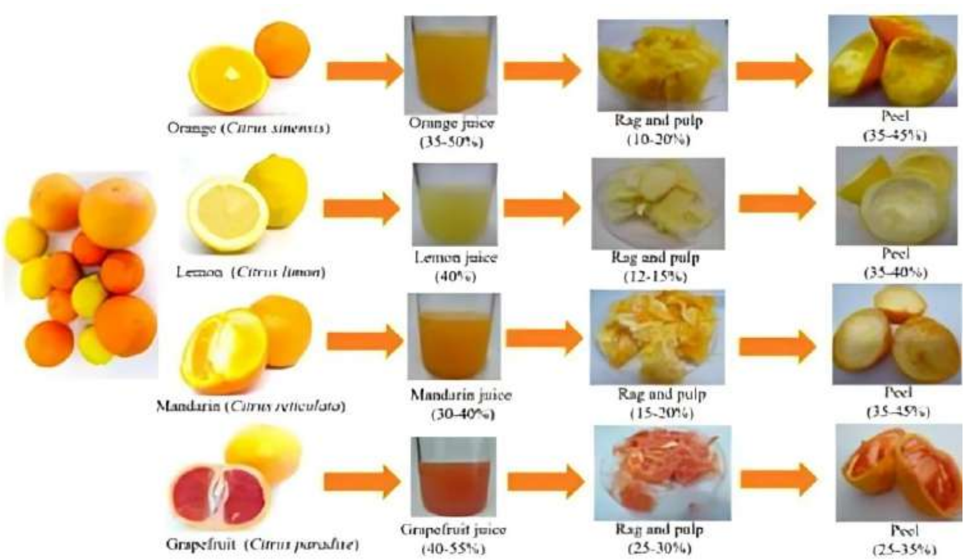

Figure 1. Citrus Product

By developing this recommended blockchain system as shown in Figure 2, the goal is to utilize a distributed ledger that can be used as an unalterable record of each element in their link supply chain from picking through final delivery. High-quality standards and minimization of cheating or errors are ensured by smart contracts integrating slow bureaucratic processes into the Ethereum blockchain. Furthermore, growers and packers are more accountable, this method also allows consumers to examine the origins of their purchased produce–and its quality.

Figure 2. Current Citrus supply chain system

This may improve transparency, reliability, and trust in the sector as a whole as well. While TrustGrid can help address these issues individually, building out a new blockchain-focused system for ensuring citrus fruits are not sourced from unlawful locations or that your glass of orange juice is untainted would also put some minds at ease. The tool can be successfully used by addressing the specific problems faced in the agricultural sector and unfilled gaps in them so that business processes are fine-tuned, and data integrity is delivered as promised to obtain maximum productivity and visibility across the supply chain. The paper will focus on catalyzing the development and deployment of a decentralized solution designed to be globally implementable at low cost for actors spanning small-holder farmers up to large distributors.

The study identifies several perceived enablers that can support Blockchain technology in terms of perceptions and understanding of the technology [7]. Some of these are trust, transparency, better business outcomes, creation of partnerships, consumer education on safe food and ethical farming, branding of fruits, and farmer cooperatives. On the other hand, blockchain technology perceived threats include low digital literacy among the stakeholders, poor organizational culture, expensive traceability-enabled products, and data privacy and security governance issues. The reliability and transparency of supply systems play a vital role in the quality and safety of agricultural products. A specific example of the use of this technology is in the citrus value chain. Blockchain is special for its capacity to deliver secure traceability, control, and immutability while building trust

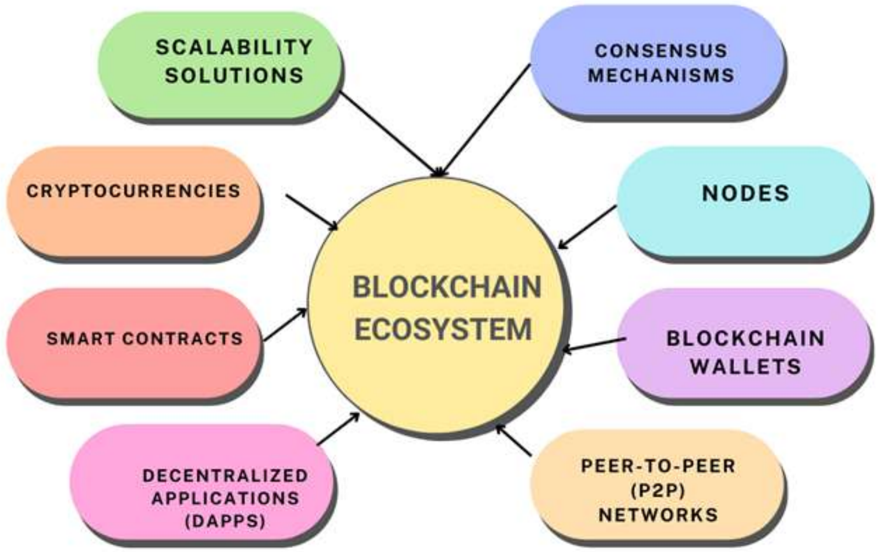

Figure 3. Blockchain Ecosystem

among stakeholders in a cost-efficient IT environment. To try and revolutionize the normal supply chain systems in agriculture, governments have come up with several measures through the formulation of good policies and regulations. However, the current supply chain systems are characterized by some challenges, including limited transparency, poor traceability, and reliability, as shown in Figure 3.

Blockchain technology can revolutionize the agricultural supply chain with a secure and transparent ledger, not to mention an immutable record of transactions. Blockchain enables to development of a decentralized ledger recording all stages of the supply chain guaranteeing data security by reaching network consensus [8]. This method can effectively reduce fraud and increase efficiency, allowing products to be traced from production to consumption. Though blockchain technology has successfully been applied in multiple sectors to improve transparency, applications of this kind have remained limited within agriculture due to some technological and operational challenges. One of the biggest challenges to implementing blockchain in agriculture has been figuring out how cutting-edge technology like this intertwines with conventional approaches. The citrus crop producers are small-scale farmers and do not have the resources or technical know-how to install such advanced technologies [9]. Not to mention the scaling of blockchain networks — and costs associated with deploying on-farm technologies in agriculture. However, the demand for a tailored assurance compliance blockchain system from citrus supply chain players is growing throughout various regions becoming available to all relevant actors.

The citrus supply chain problem proposed in the paper has the potential to solve several challenges by the provided framework. With the help of smart sensors, IoT devices, and data analytics tools the framework provides an opportunity to collect and process data in real-time. Such real-time data can be used to improve the levels of transparency, accountability, and traceability across the supply chain. This in turn can help to develop a trusting relationship between the organization and the users of the information, lessen the number of fraudulent occurrences within the organization, and enhance on effectiveness of activities performed. Further, there is a possibility of the framework being utilized to change the existing practice and implement sustainable practice by identifying the most efficient way to utilize the resources to reduce impacts.

The system that is proposed to be developed based on blockchain technology is expected to improve the issues of traceability, responsibility, and productivity in the chain of supply of citrus fruits. Addressing industry-specific problems, it aims at creating a feasible, scalable, and beneficial solution for all the stakeholders starting from local farmers and ending with large distributors. This research will explore how existing challenges can be overcome and present a blockchain model that ensures transparency and credibility in the agricultural sector. The first section will therefore discuss the citrus fruit supply chain and explain why the market is currently challenged. The second section will also look at the literature and the current technologies in supply chain management to assess the areas that need to be improved. In the third section, the proposed blockchain-based framework will be described in more detail and how smart contracts and distributed ledgers will be implemented in the supply chain will be explained. In the fourth section, the plan to deploy and assess the framework will be outlined about technology and operations. The fifth section of the paper will discuss the implications and limitations of the proposed system, with recommendations for further research and application in the agricultural sector.

2 LITERATURE REVIEW

Blockchain technology is considered one of the most feasible solutions for performing effective traceability services in these networks. However, in the last few years, there has been an increase in interest in the application of blockchain-based traceability in supply chain networks. Several review papers have addressed blockchain traceability in supply chains, including existing implementations, problems, and unresolved areas that require more investigation [10]. This emphasizes the crucial importance of developing and implementing actual, real-world traceability solutions, with a focus on the relevance and cost-effectiveness of supply chain environments.

The study analyses how blockchain traceability systems affect the transparency of various supply chain distribution network architectures [11]. It also explains how IoT and smart contracts improve the possibilities and uses of blockchain technology for traceability. The case study analysis focuses on the different levels of traceability in the supply chain as well as product digitalization and the use of blockchain technology across the supply network [12].

The prototype system underwent testing and validation using realistic settings [13]. Despite these shortcomings, the system provides useful information for ensuring food quality, safety, and process identification. The article also introduces a blockchain-based traceability solution suited for complex supply chains in the textile and clothing industries [14]. An example of a blockchain-enabled organic cotton supply chain with specialized smart contracts and transactional laws is also shown.

Every transaction is recorded and kept in the blockchain's public ledger [15]. Propose a system that uses smart contracts to monitor and track the relationships and activity of citrus chain participants. However, this framework also includes a customer satisfaction feedback mechanism that allows stakeholders to know the quality of a particular product to enable them to make the right decision along the supply chain.

Existing research on supply chain traceability is based on the extended Unified Theory of Acceptance and Use of Technology (UTAUT) and the Technological Innovation Adoption model [16]. However, this paper seeks to understand the role of blockchain in supply chain settings through the use of theory and a literature review to enhance traceability through the use of blockchain solutions. This research aim is therefore to build on previous supply chain research by assessing the effectiveness of blockchain in improving tracking.

SCM can be defined as the administration of the movement of goods and services through supply chains. However typical systems of SCM have some issues like security issues, opaque nature, poor traceability, low level of stakeholder involvement, product imitation, time loss, fraudulent activities, and volatility [17]. Furthermore, this paper reviews the literature to establish the type, characteristics, and business applications of blockchain in different supply chain contexts.

Blockchain is one of the most popular terms in information technology and digital business enablers [18]. Where its application in farming is already well proven, its ability to transform other sectors is emerging. In this study, blocks are defined as groups of farmer records. Two of the most pressing issues of the present are personal information protection and simplification of transaction procedures [19]. Furthermore, a blockchain specialist from Dallas-Fort Worth defines blockchain as the open, shared ledger that is governed jointly to identify assets and document transactions within a business network.

The following is the protocol for service execution in the context of a sharing economy that is aligned with the concepts of this model [20]. It suggests enhancing Shared Manufacturing through cross-chain scalability solutions, which are based on blockchain technology. Furthermore, this paper compares current cross-chain technologies to address the special requirements of Shared Manufacturing and introduces a new approach that uses two kinds of solutions. These implementations are then subjected to real-life tests to determine the cost and time efficiency of the implementations.

The implementation of the framework in this paper has the potential to create trust among the stakeholders, minimize cases of fraud, improve the overall efficiency of the citrus supply chain, and encourage the integration of sustainable practices. Real-time data can be gathered and processed through the integration of data analysis tools and technologies, smart sensors, and IoT gadgets. This research describes an improved blockchain solution that would improve the credibility and efficiency of citrus traceability. This should help to solve the existing traceability problems and decrease the number of improper practices within the modern citrus supply chain. This framework aims to address the challenges of the current farm-to-fork system for citrus products by adopting blockchain technology.

3 MATERIALS AND METHODS

The conceptual model for the design of a traceability system for citrus from farm to consumer as shown in figure 4. The framework seeks to develop a sound, secure, and trustworthy management structure. Integrating a sophisticated blockchain system develops a transparent environment where vendors can track the production process of citrus. The application of blockchain guarantees that the various players such as the retailers and the consumers have confidence in the authenticity of the citrus supply chain. The smart convention is applied to ensure that the payment process is secure. The payment information and all the information of the transaction are saved in the blockchain. After they are stored, the payment records and data cannot be altered, deleted, or manipulated in any way. When the products are moving through the supply chain, the transactions are done securely and in a manner that is fully transparent through smart contracts thus minimizing breakdowns, single points of failure, or centralization. This blockchain system also allows specific documentation of numerous aspects of the citrus supply chain such as seed source, yield date, production farm, citrus mill production, retailer purchase history, distribution network, pricing, and other processes. The kind of tracking offered for citrus gives retailers all the details they need before sourcing from any supplier. Also, the proposed technology enables government authorities to track transactions within the citrus supply chain so that they can easily detect unlawful activities. Figure four shows the improvement introduced by blockchain technology to the existing citrus production system.

3.1 A. Proposed Architecture

This proposed system shown in Figure 5, includes major stakeholders including farmers, citrus growers, seed providers, supermarkets, and wholesaler departments. At the core of this framework is a decentralized application (DApp) with features such as storage and a Private File System (PFS). The citrus crop traceability system on the blockchain network is only interactable through the DApp. To participate, users have to register and enter in-

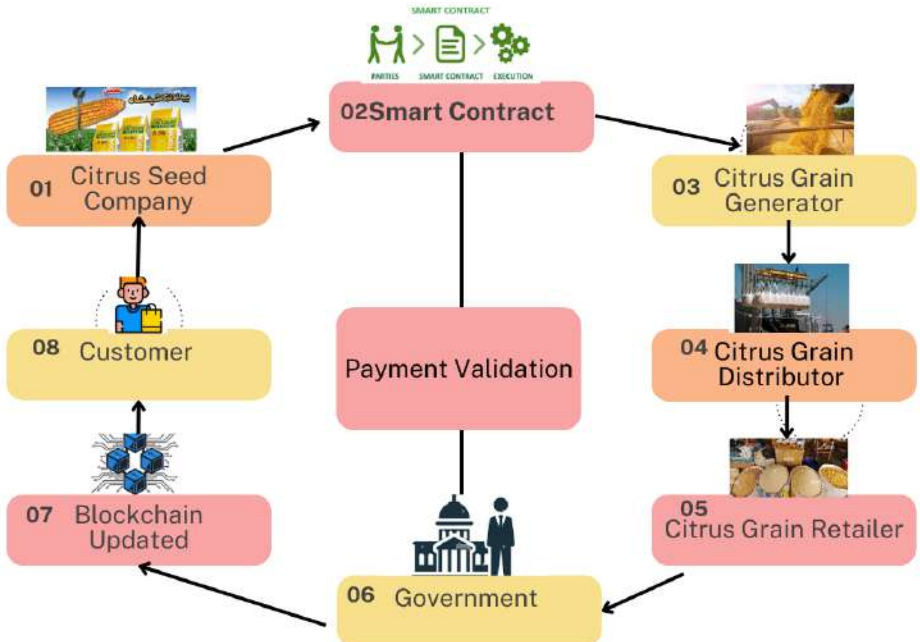

Figure 4. Proposed Framework

formation through the web page or DApp to become a member of the blockchain network and directly involved in the traceability process. The user is given a unique public address that will be used to identify them throughout the network in case they are successful. The data exchange between the storage and DApp components is made possible with the help of the IPFS. The following are participants of the proposed system; Retailers, farmers, and any other organization that is in contact with the Citrus Crop Management System (RCMS) through a mobile or web application developed on blockchain technology. Users can perform, monitor, and approve selective RCMS processes according to their permissions. The RCMS DApp combines a variety of components including an ICO, a coin exchange, and third-party payment processors for different tokens, coins, and digital currencies. Data within the citrus crop management platform is protected and shared through smart contracts within the user records and statistical data by utilizing IPFS technology. It allows users to manage data traffic and data flow over distributed networks and data storage using public addresses. Citrus crops can be bought by buyers or retailers through a mobile DApp that has an incorporated digital wallet, through which they can pay farmers as well as other entities such as retailers and citrus companies. Every purchase creates a new record on the blockchain, and retailers and distributors can obtain information on the price of citrus crops. For those farmers who do not have a digital wallet, then help from a digital wallet team may be needed because some of them may not have any knowledge about digital wallet technology.

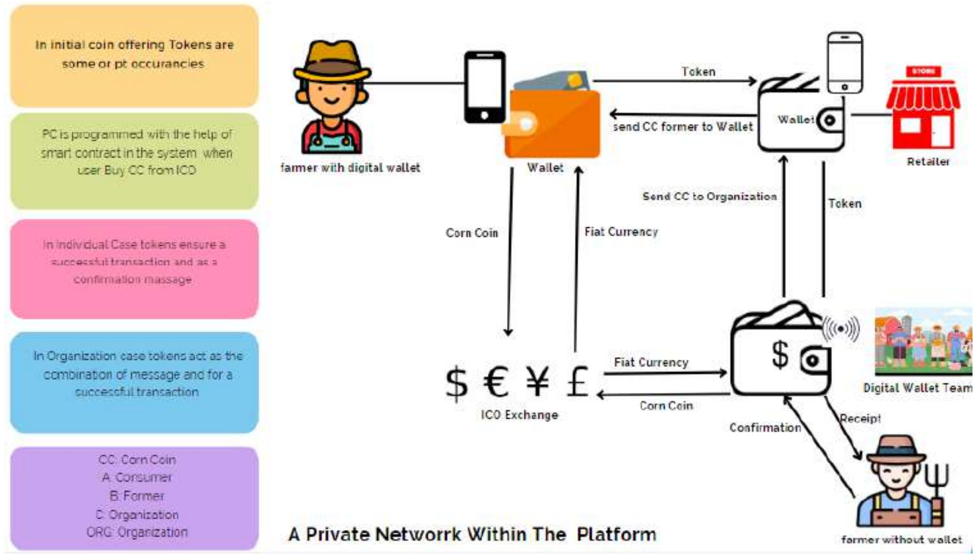

Figure 5. Proposed System Architecture

3.2 B. ECONOMIC MODEL OVERVIEW

Citrus is a new generation of cryptocurrency that is aimed at the creation of a safe and transparent system for tracking citrus crops and their management with the help of all interested parties and state bodies. The model presented in this paper, as illustrated in Figure 6, will serve to safeguard and shield the system from illegality. The maximum amount of Citrus Coin tokens is 500 million, and the price of each token is US$ 100. However, users are not compelled to buy a whole token; they can buy a token in parts depending on their needs. For instance, a user can buy 0.1 Citrus Coin at the price of US$ 10. Citrus Coin is available to be bought with traditional money of the world like EUR, USD, PKR, and digital money like BTC, BNB, and ETH.

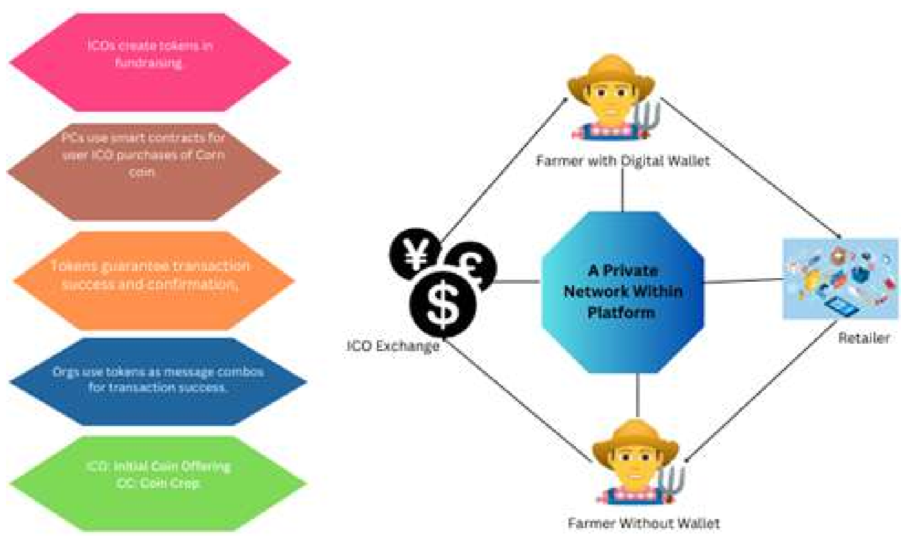

Figure 6. Economy Framework

Citrus Coins (CC) are available for purchase by retailers with no taxes or fees applied to the tokens bought by retailers. When a retailer buys CC, the same amount is transferred to the retailer's wallet balance account. These tokens enable retail outlets to purchase citrus products from distributors without paying for tokens or taxes from the exchange. CC was developed for the maize value chain and is an Ethereum-based token according to the ERC20 standard. It was released through an Initial Coin Offering (ICO) model. Table 1 presents the CC symbol, price, type of token, and maximum supply.

Table 1. SALES VALUES AND TABLE 1 PARAMETERS

Constraint	Principles
Token Symbol	Citrus Coin (CC)
TOKEN TYPE	ERC20 Standard
Total Supply Cap	Total Supply: 500 million
Accepted Currencies	Supported Currencies: PKR, BNB, BTC, ETH, EUR, USD, etc. Token
Price	1 CC = 100 USD

To ensure the privacy of data for the various stakeholders in the proposed system including merchants, farmers, distributors, and maize mills among others, a hybrid blockchain is utilized. Farmers can receive payment through a digital wallet and the CC tokens they receive can be converted to fiat money using an ICO exchange. In the second example, the payment is made through the farmer's digital wallet team which accepts credit card payments and then uses the ICO exchange to change the money to cash. Farmers transfer money to their suppliers, and after the payment has been made, they have to attach a scanned receipt or an image of the receipt to the blockchain.

3.3 C. The Token's Distribution

The first distribution of citrus coins was a decision to allocate 80% for the ICO, allowing various participants such as distributors, farmers, citrus mills, and retailers to buy the coins. It is important to note that there are a total of 50 billion citrus coins in supply, with no new coins created. In addition, 20% was set aside for marketing, trading, key acquisitions, and liquidity.

3.4 D. The Fee for Conversion.

Every transaction costs a particular fee, and this fee depends on the exchange used while converting citrus coins with other cryptocurrencies or digital currencies. The fees charged are standard and are well defined and may differ from one exchange to the other. In addition, the management authority withdraws a set amount for the system. The economic flow generated by the managing authority proves the fact that CC is entirely self-sufficient.

3.5 E. Workflow for the proposed framework

The DApp will help the users of the application to connect with the citrus coin management system. What is more, on the back end, there is the constant running of an ICO and an exchange platform. Citrus coins can be bought by retailers by paying with credit cards or any incorporated bank. The functionalities of the study are shown in Figure 7 below.

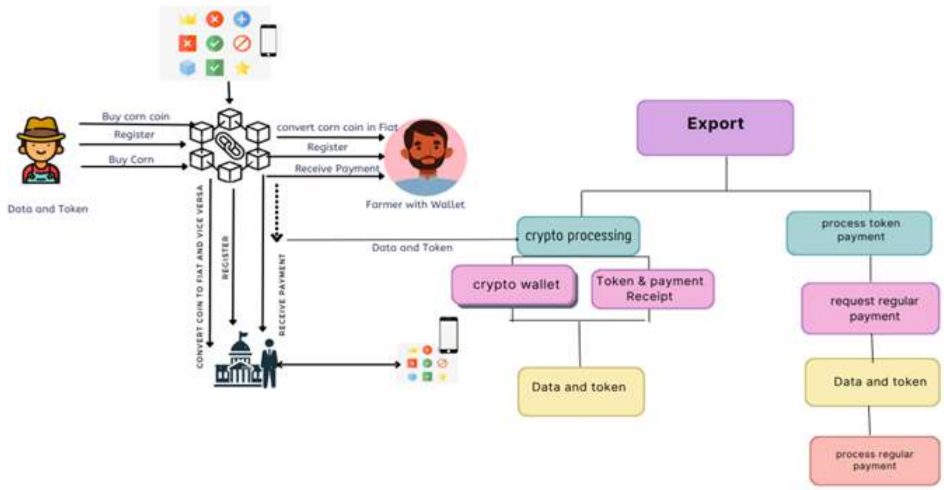

Figure 7. Implementation of The Framework Proposal

This conversion process, organizations are involved in the transactions and pay farmers directly who may not have wallets. Smart contracts are handled by the administration while user authentication, creation of transaction history, and setting of token distribution policies are also the responsibility of the administration. Smart contracts effectively control the ICO and connections with exchanges, and they also define the exchange rates for citrus coins to the various currencies.

4 F. Layered Context Proposed

The next figure 8 illustrates the layers of the proposed framework which is made up of eight layers. In this arrangement, all activities in the layer are logged in the blockchain and all members of the network are notified. However, for a better understanding of each layer technique, it is described in the next part.

4.1 Layer 1:

The Interface Layer enables decentralized applications that connect customers and sellers to the citrus supply chain system. This layer involves the interface of the citrus management system with other parties such as citrus millers, growers, retail shops, and customers. The primary purpose of this site is to help customers start the process of purchasing and selling citrus crops.

4.2 Layer 2:

The second layer monitors transactions, paperwork, payment confirmation, and online account statements. Also, the interface layer and business logic layer are linked through smart contracts.

4.3 Layer 3:

To execute any laws, rules, agreements, and terms, smart contracts have to be enacted through the business layer. Due to its compatibility with all execution, invocation, and communication standards, it is known as the smart contract's active database.

4.4 Layer 4:

Other forms of consensus protocols and other suitable checks such as proof of work and Byzantine algorithms perform security analysis at this level. Further, it employs consensus techniques to all the new transactions and blocks that are added to the system and saves the results at the blockchain stratum.

4.5 Layer 5:
This level involves the management of important details about the ledger, nodes, and blocks. It has also included distributed ledger data, retailers, stakeholders, public and private addresses, and records of Maize mill transactions.

4.6 Layer 6:
This level is used to monitor all transactions that Citrus Coin has with farmers, seed firms, citrus mills, and other players in the Citrus supply chain managing system.

4.7 Layer 7:
In this layer, there is a creation of a P2P network that is used in the exchange and the validation of the information on the Ethereum transactions. After a transaction has been done, it is broadcasted to all the other nodes and a certain predefined set of rules must be met before the transaction is written on the blockchain.

4.8 Layer 8:
This layer is essential to blockchain systems and defends against numerous dangers, including 52% of attacks. To control, protect, and audit the entire process, it has many protocols that operate in parallel with the system. Participants at the interface tier, such as retailers, farmers, seed companies, and maize mills, use web portals and applications to interact with the system. The application layer creates the connection between the user transactions and smart contracts while the trust layer receives the user transactions and applies business rules. The trust layer creates a permanent record of every transaction in the blockchain by using consensus methods like proof-of-work. Public and private keys are used by the blockchain layer to store all transactions.

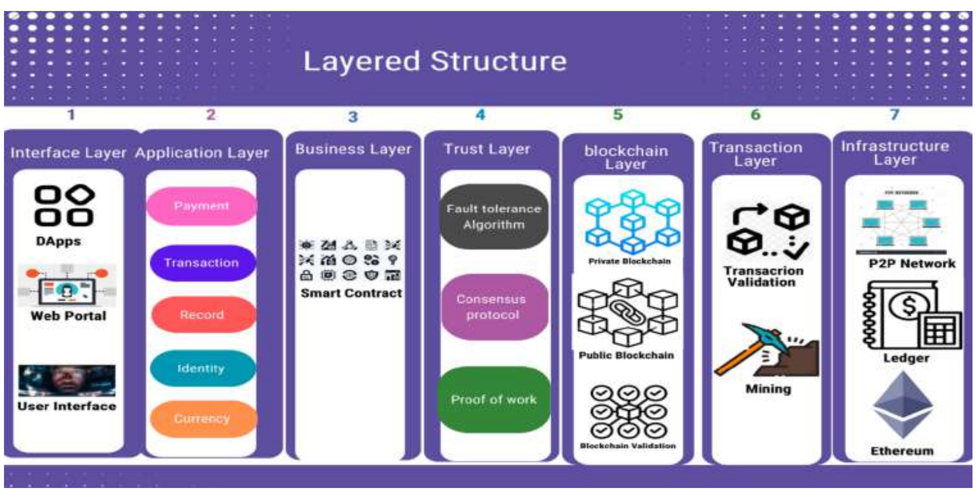

Figure 8. Hierarchical Organization of Proposed Framework

5 EXPERIMENTS AND RESULTS
This section has considered how it is possible to apply suggested frameworks and what results can be achieved in real-world conditions. The following assumptions have been dealt with.

- There are no individual miners or a group of miners with a hash power control exceeding 52% of the total hash power of the system.
- Selling products is allowed only for registered users.

Our framework interacts with the test net smart chain Blockchain through Web 3.0. Smart contracts are written in a remix integrated programming environment (IDE) and all the communication with the Blockchain is done by Postman through HTTP request. As a benchmark for evaluating the proposed Blockchain, we utilize the Access Chain and Validate Block services. In the same way, we use this approach to assess other aspects of performance. Furthermore, we use Web 3.0 to send a customized Python script with 50000 transactions to the network. To test the framework, we developed in the current study, we performed five experiments.

assess the proposed framework, we use the time in nanoseconds which is needed to retrieve data from the longest chain.

- We assess their performance based on the number of transactions and blocks, data-adding time, and block confirmation.
- We associate the delay in block adding in the Blockchain with other pertinent data.
- The costs associated with implementing the suggested framework are discussed about transaction costs.
- We analyze the performance and compare it with other solutions in the same field.
- During the performance evaluation of the proposed framework, we make a comparative analysis of our framework with various Blockchain solutions.

Table 2 shows how the Access Chain, a data retrieval platform applied in several blocks of the Blockchain, has been put into operation.

Table 2. New Block Latency

Blocks	Potential (milliseconds)
1	407
17	380
39	351
55	390
77	277
92	170
999	45
131	708
140	103
177	688
190	99
191	88
218	276
244	323
255	307
270	679
287	899
305	566

The timestamps to get the data and to get data from different blocks using the retrieve Chain function were beneficial in this study. The first block was retrieved with a latency of 91 milliseconds, which is 400 milliseconds lower than at the start of the experiment. But at some point, this latency increased to 940 milliseconds again. Due to the decentralized structure of the Blockchain, there is always a latency issue, which means that data retrieval is slow. It is illustrated in Figure 9 the time needed to retrieve several blocks from the longest chain. We plan

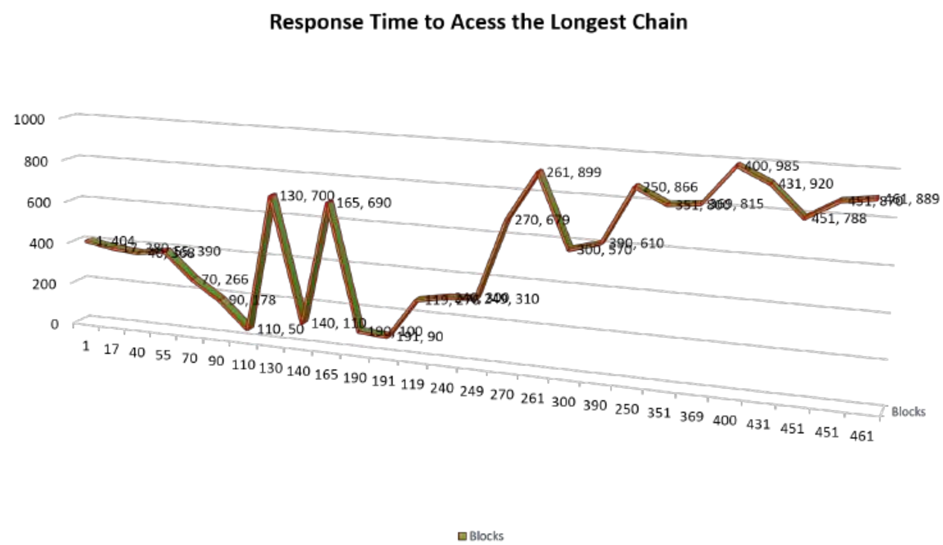

Figure 9. Response Time for Retrieving the Longest Chain

to include new blocks to the Blockchain at a much higher rate than the prior networks have done. In 3 seconds, our research's proposed framework does this, which is much faster than manually adding blocks.

Figure 10 gives the statistical results of the new block incorporation. This first block addition improves system stability and efficiency and also makes it easier to check new transactions within a short time. Our average transaction price in the system is 0.3$, while the price on the Ethereum network can reach 100$ at peak load. In Figure 11 we demonstrate how transaction fees in our system differ from potential blockchain options. In the following table, a comparison of our architecture to different well-known blockchain platforms is provided in more detail in Table 3. Our proposed system can handle, on average, 15.30 million transaction throughputs per day while Ethereum and Bitcoin can handle 0.240 million and 1.130 million, respectively. In addition, figure 11 illustrates the time taken to obtain 14 network clearances, which are essential for verifying financial processes.

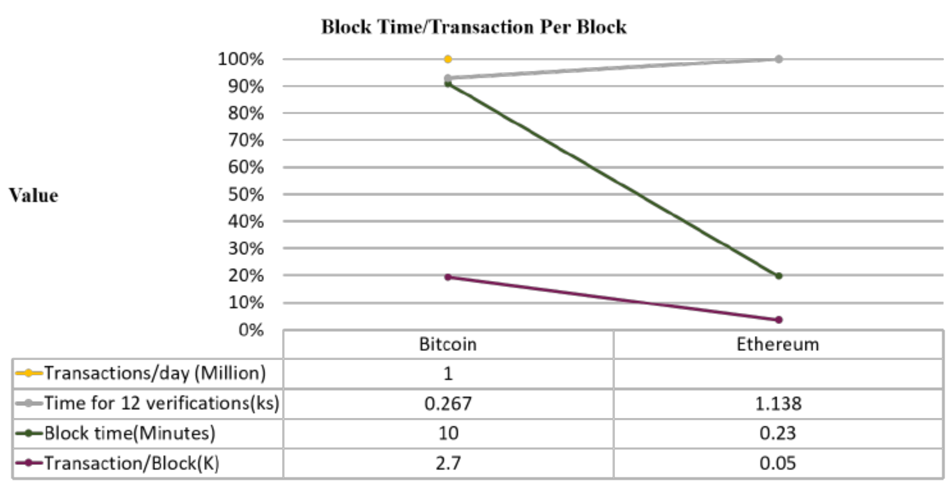

Figure 10. Statistics of New Blocks Addition

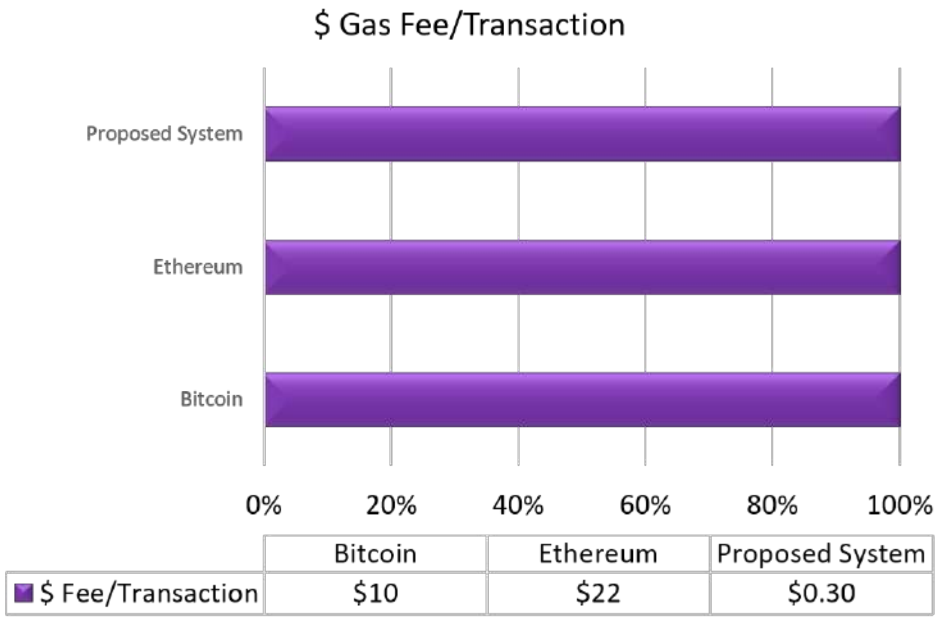

Figure 11. Transaction Costs

Table 3. Comparison of the Proposed Framework with Existing Blockchain Solutions

Blockchain	Block time/minute	Transaction	Transaction with 12 verifications	Time(ks) every day	Fee/transaction
[4]	0.071	0.251	0.183	1.16	$40
[6]	0.267	0.08	0.19	1.138	$20.5
[11]	09	1.8	8.3	0.221	$11.20
Proposed System	0.35	0.8	0.040	16.20	$0.34

Many farmers, stakeholders, and merchants are involved in our suggested framework for maize often has to do with illimitable transactions. Hence, making it scalable for high-volume transactions is quite important. Therefore, this paper has analyzed the test network's thirty days of transactions using Apache Jmeter software.

$$BPD = \left(\frac{\sum_{x=1}^{30} \text{BPD}(x)}{\text{Total Days}} \right) /24 \tag{1}$$

$$BPM = \frac{\text{BPD}}{1540} \tag{2}$$

We calculated the Transaction Per Minute (TPM) by multiplying the average transaction per block by the number of blocks in a minute, resulting in the BPM transaction throughput.

$$\text{TPM} = \text{Number of Transaction in a Block} \times \text{Total Number of Blocks in 1 Minute}$$

$$\text{TMP} = \frac{\text{TSP}}{60}$$

Figure 12 illustrates the hourly data of our recommended maize crop architecture. To find out the daily transaction count, we employed the BPD equation. Based on the TPS equation, we were able to evaluate those 70 transactions that were created. Therefore, the average transaction volume in the architecture we proposed was 60 TPS. Each hour, though, between 800 000 and 1 900 000 transactions took place. The current system can accommodate the maximum number of transactions per hour for maize crops.

6 CONCLUSION

The supply chain industry has gained many advantages as the supply chain shifts to decentralization and the establishment of a reliable environment for all transactions. The proposed study eliminates total traceability and price control. When deployed on the BSC network, it has better throughput, cost-efficiency, and scalability than other blockchains such as Bitcoin (BTC) and Ethereum (ETH), both of which are cryptocurrencies. The solution also makes all transactions secure by adopting the use of digital wallets and smart contracts. It pays farmers and other stakeholders using Citrus Coin (CC) to promote fair payment. In addition, the framework monitors exports of citrus crops and fights against unlawful trade to ensure that costly citrus imports cannot be done during off-seasons. The IPFS system stores encrypted information about farmers, retailers, and businesses so that data is more accessible, safe, and trustworthy. The results obtained from the experiment prove that this architecture offers better TPS, block time, verification time, and average petrol fee than the existing system. Citrus supply chain system today is not secure, reliable, traced, and transparent making sales costly and stock shortages. Public transparency to stakeholders and authorities needs to track the flow of the product from farm to fork.

Author Contributions

Sawera Kanwal: Conceptualization, Methodology, Software **Sumaira Nazir**: Data curation, Writing- Original draft preparation. **Syed Muhammad Asadullah Gilani**: Visualization, Investigation. **Junaid Asghar**: Software, Validation. **Aasma Aas**: Writing- Reviewing and Editing

Compliance with Ethical Standards

It is declare that all authors don't have any conflict of interest. It is also declare that this article does not contain any studies with human participants or animals performed by any of the authors. Furthermore, informed consent was obtained from all individual participants included in the study.

Funding Information

FMS acknowledges the support of NSF grant CHE-1111111.

References

[1] Y. Liu, E. Heying, and S. A. Tanumihardjo, "History, global distribution, and nutritional importance of citrus fruits," *Comprehensive Reviews in Food Science and Food Safety*, vol. 11, no. 6, pp. 530-545, 2012.

[2] L. S. Jyoti *et al.*, "Modification of Cellulose with ZnO Nanoparticles: From Sugarcane Bagasse to Antimicrobial Composite," 2021.

[3] A. K. Singh *et al.*, "Prevalence of co-morbidities and their association with mortality in patients with COVID-19: a systematic review and meta-analysis," *Diabetes, Obesity and Metabolism*, vol. 22, no. 10, pp. 1915-1924, 2020.

[4] E. H. Mattar *et al.*, "Natural resources to control COVID-19: could lactoferrin amend SARS-CoV-2 infectivity?," *PeerJ*, vol. 9, p. e11303, 2021.

[5] Ş. İndap and M. Tanyaş, "Blockchain applications for traceability and food safety in the agri-food supply chain: cherry product application," *Journal of Enterprise Information Management*, 2023.

[6] M. S. Farooq *et al.*, "A blockchain-based framework to make the rice crop supply chain transparent and reliable in agriculture," *Systems*, vol. 11, no. 9, p. 476, 2023.

[7] T. L. Yap *et al.*, "Adopting blockchain-based traceability in the fruit supply chain in a developing economy: facilitators and barriers," *Information Technology & People*, 2023.

[8] Z. Tao and J. Chao, "The impact of a blockchain-based food traceability system on the online purchase intention of organic agricultural products," *Innovative Food Science & Emerging Technologies*, vol. 92, p. 103598, 2024.

[9] D. W. Gitahi, "Evaluation of knowledge and practices of managing citrus pests and diseases and the willingness to pay for an integrated pest management strategy in selected Counties in Kenya," Ph.D. dissertation, Egerton University, 2018.

[10] P. Gonczol *et al.*, "Blockchain implementations and use cases for supply chains—a survey," *IEEE Access*, vol. 8, pp. 11856-11871, 2020.

[11] J. Sunny, N. Undralla, and V. M. Pillai, "Supply chain transparency through blockchain-based traceability: An overview with demonstration," *Computers & Industrial Engineering*, vol. 150, p. 106895, 2020.

[12] F. Casino *et al.*, "Blockchain-based food supply chain traceability: a case study in the dairy sector," *International Journal of Production Research*, vol. 59, no. 19, pp. 5758-5770, 2021.

[13] F. Hueso-González *et al.*, "A full-scale clinical prototype for proton range verification using prompt gamma-ray spectroscopy," *Physics in Medicine & Biology*, vol. 63, no. 18, p. 185019, 2018.

[14] T. K. Agrawal *et al.*, "Blockchain-based framework for supply chain traceability: A case example of textile and clothing industry," *Computers & Industrial Engineering*, vol. 154, p. 107130, 2021.

[15] M. Crosby *et al.*, "Blockchain technology: Beyond bitcoin," *Applied Innovation*, vol. 2, no. 6-10, p. 71, 2016.

[16] M. H. Miraz *et al.*, "The Innovation of blockchain transparency & traceability in logistic food chain," *International Journal of Mechanical and Production Engineering Research and Development*, vol. 10, no. 3, pp. 9155-9170, 2020.

[17] J. T. Mentzer *et al.*, "Defining supply chain management," *Journal of Business Logistics*, vol. 22, no. 2, pp. 1-25, 2001.

[18] F. Della Valle and M. Oliver, "Blockchain enablers for supply chains: How to boost implementation in industry," *IEEE Access*, vol. 8, pp. 209699-209716, 2020.

[19] V. L. Lemieux, "Evaluating the use of blockchain in land transactions: An archival science perspective," *European Property Law Journal*, vol. 6, no. 3, pp. 392-440, 2017.

[20] S. K. Curtis and O. Mont, "Sharing economy business models for sustainability," *Journal of Cleaner Production*, vol. 266, p. 121519, 2020.