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Research Article

FARMER TO CONSUMER – AN ONLINE SUPPLY CHAIN PROCESS SYSTEM USING BLOCKCHAIN TECHNOLOGY

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Abstract

Globally, the mango industry is one of the largest industrial sectors – also considered the backbone industry of the country's agriculture sector. This sector mobilizes key industrial activities of many economies, such as agriculture, production, handling, storage, logistics, certification, and packing of a variety of mangoes (e.g., with over 1,500 varieties, of which at least 30 are grown commercially in Pakistan). From local, regional, and national, to international levels, many businesses in this sector are involved in extensive mango supply networks fulfilling the demands of many consumers and markets (e.g., B2B, B2C, etc.) locally worldwide. Currently, 43% of total farmers in Pakistan are smallholder farmers, as they possess less than 2.6 hectares of land. Intermediaries dominate the entire supply chain in Pakistan, due to which small to average farmers face several challenges. This can be avoided by developing a user-friendly system to link farmers directly to the market or consumers. The proposed system identifies the gaps in the process model of Pakistan's mango supply chain system. It creates a platform to link farmers directly to the market or consumers through a seamless online system using blockchain technology for performing reliable transactions using smart contracts. The proposed system is implemented through Ethereum, a permissioned blockchain network using Smart Contracts. It is a distributed ledger accessible to participants of the supply chain with permission to ensure the trust and authenticity of the information. By using this system, the farmers will attain increased profit through direct access to retailers, consumers, and the international market.

Keywords: *Farmer intermediary, blockchain, supply chain, Ethereum, Smart Contracts*
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1. INTRODUCTION

Mango (Mangifera Indica) is among the most significant commercial fruit crops in Pakistan. Punjab and Sindh provinces of Pakistan are the two major Mango production regions, which contribute 63% and 37% to total production respectively (Hasan, 2020). Mango is a perishable fruit and supply chain management of perishable products is a major issue for participants involved along the supply chain. Around 30-35% of perishable produce is wasted at several levels of the supply chain which results in a great amount of post-harvest losses(Chauhan et al., 2021). It results in a loss of revenue for the farmers and adds up the costs in the supply chain which ultimately burdens the consumers and retailers. It negatively impacts food security and financial sustainability of the farmer, exporters, retailers, and the consumers.

Food insecurity is becoming a critical issue globally. The major reasons include climate change, growing population, urbanization, reduction of water resources leading to low productivity and quality. To ensure food security, there is a need to utilize available resources effectively to optimize production and reduce the loss of produce after harvest. An efficient supply chain system can result in optimization of resources and the reduction of post-harvest losses.

The existing mango supply chain in Pakistan consists of various stakeholders as shown in Figure 1. It's a common practice

for farmers to sell their standing crops to pre-harvest contractors at the flowering stage. The contractors then auction the fruits to the whole sellers who further sell to the retailers or exporters (Mehdi et al., 2016). Most of the farmers do not have direct access to the market and export opportunities. This can be improved in two ways: first, by educating farmers and linking them directly to the retailers or the export market; second, by improving traceability of supply chain for all stakeholders to avoid exploitation at any stage.

The existing system is not efficient as there are multiple intermediaries involved and performing different functions along the supply chain. In many instances, the fruit gets overripe along the chain and there is no record of when the fruit was harvested, packed, transported, and treated for ripening. Similarly, there are different levels of stocks maintained at wholesale and retail levels which mix fruit from various sources and result in traceability issues in the supply chain system.

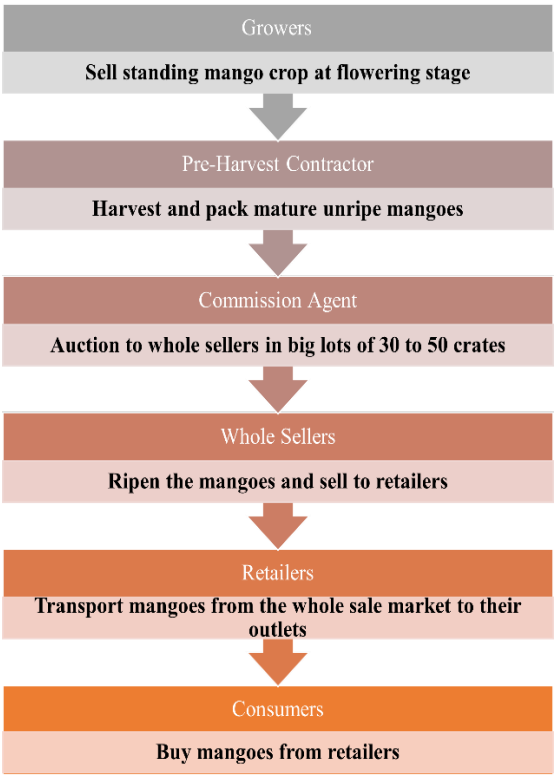


Figure 1: Current mango supply chain system (Source: Shafique et al., 2022)

Traceability can be defined as having access to information of the complete lifecycle of a product from raw material to reaching the final consumer. Supply chain traceability can improve transparency in operations and tracking of supply chain processes. It helps to achieve operational and organizational level visibility (Agrawal *et al.*, 2021).

Blockchain technology is an emerging technology that can provide a feasible solution to improve supply chain traceability. It is designed in such a way to ensure secure and immutable information along the supply chain. Blockchain technology is a database that has a cryptographic distributed ledger. It can help in performing transactions between participants of the network. Transactions are validated using a consensus mechanism eliminating the need for intermediaries for transaction validation (Mougayar and Buterin, 2016). A blockchain-based system can be implemented for tracking and tracing mango produce starting from the seedling stage until reaching the retail store and then to the consumer. Blockchain technology ensures data accessibility to all participants within the network in a secure way. This ensures consistent information is shared with all participants of the network. Blockchain is trusted, tamper-proof, secure, and traceable, thus it can be effectively being adopted in agriculture and supply chain management systems (Salah et al., 2019. Blockchain technology is getting huge popularity, as the capability of providing transparency of transactions enhances trust among participating stakeholders. Blockchain deployment in any system ensures that the information shared by the system is authentic. In a centralized system, the decision power is in the hands of a specific group of entities, they act as a central authority and enforce rules for all entities of the system. Whereas blockchain is a decentralized system, which promotes transparency and integrity of the system. The consensus mechanism ensures that each transaction performed is validated

and cannot be tampered with or altered (Tan et al., 2022).

Blockchain technology is versatile and can be applied to various industries, including circular supply chain, food supply chain, cold chain management, retail, healthcare, manufacturing, logistics, and transportation. Notable recent applications of blockchain technology in supply chain management include vaccine distribution, food traceability, supply chain transparency, container logistics through trade lens, trusted supplier management, recycling, and waste and emissions control (Chang et al., 2022). Although the formation of blockchain technology networks and stakeholder coordination has yet to receive significant attention in existing research (Liu et al., 2020; Saurabh and Dey, 2021).

2. Related Work

Blockchain technology is getting huge popularity, as the capability of providing transparency of transactions enhances trust among participating stakeholders. Researchers and food firms have recently started exploring the implementation of Blockchain for supply chain traceability. Blockchain technology has numerous potential applications in supply chain traceability, which involves the tracking of goods and services from their origin to their destination. Blockchain implementation for improving different supply chain operations has been evaluated by several research studies. The result of a studies conducted by (Agrawal et al., 2022) depicted that blockchain is a viable technology for supply chain traceability and transparency which can assist in recording and tracking every step of the supply chain process transparently. This makes it easier to identify the source of any issues, such as contamination or fraud, and take corrective action.

Smart contracts are self-executing agreements that can be programmed to trigger based on certain conditions. In supply chain management, smart contracts have been used to automate and enforce agreements between different parties, such as suppliers and customers. Smart contracts were implemented for developing product traceability solutions in several studies (Salah et al., 2019; Wang et al., 2019; Moosavi et al., 2021) by programming smart contracts to enable product transactions between multiple supply chain partners. By streamlining the supply chain process using smart contracts, the time and costs associated with tracking and verifying the movement of goods can be reduced. This can also help to reduce the risk of errors and delays and eventually improve efficiency (Saberi et al., 2019).

The researchers (Damoska Sekuloska and Erceg, 2022) performed a review and concluded that blockchain technology has a huge potential for removing unnecessary intermediaries from the supply chain for transaction validation and many industries are exploring its potential for improving business processes and strategies. A framework was proposed by (Agrawal et al., 2022), using blockchain technology for creating partner interactions consisting of a procurement unit and a distribution unit. This study provided a network architecture to depict stakeholder interactions and rules for interactions between network participants. Smart contract network verification and validation were described using algorithms and a UML diagram defining interaction sequences for smart contracts. Smart contracts were tested by deploying on the Ethereum blockchain. The framework proposed in the study ensured the quality and authenticity of data in supply chain networks.

The work of (Salah et al., 2019) proposed blockchain-based soybean traceability in the agricultural supply chain. The authors proposed a generic framework using the Ethereum blockchain and smart contracts for tracing, tracking, and performing business transactions in a soybean supply chain. Globally blockchain is being used by some food firms for developing track and trace solutions to ensure food safety to reduce foodborne illnesses.

A popular retail store Walmart Inc. initiated a pilot project to test blockchain for mango and meat traceability (Yiannas, 2018). The findings of this project stated that blockchain-based food traceability systems will ensure several benefits including transparency, data availability, and reduction in food waste.

A study by (Tan et al., 2022) proposed a blockchain framework for tracing Halal food chains by performing real-life implementations in three different halal supply chains. This work illustrated the implementation of an integrated blockchain framework for halal food traceability by capturing information at each stage of the supply chain using a QR code. Authors proposed that blockchain ensures that halal compliance is met as information obtained using blockchain is transparent and traceable. Another review in a study by (Damoska Sekuloska and Erceg, 2022) analyzed the potential of blockchain technology in the local food supply chain to tackle the issues of improving efficiency, transparency and traceability, security, and audit.

The primary focus of supply chain management is to ensure that information is preserved and easily searchable in the long term, while also allowing for the tracking of transaction histories. However, traditional supply chain systems rely on a centralized ledger that is recorded by each enterprise locally. This approach can lead to the falsification of information when it is not beneficial to the enterprise, which can increase communication costs and create mistrust between enterprises. Furthermore, inconsistencies in data recorded within individual enterprises can disrupt the product traceability process between nodes in the supply chain (Wang et al., 2019).

The absence of a direct link between farmers and consumers poses a significant hurdle in the efficiency of the mango supply chain. This disconnect results in challenges such as delayed information flow, limited market access for farmers, and increased chances of price manipulation by intermediaries. Addressing this issue is crucial for establishing a more transparent system that benefits both farmers and consumers.

Secondly, the absence of an easy-to-use online system exacerbates the challenges faced by small to average farmers. A modernized and user-friendly online platform can streamline processes, enhance communication, and facilitate transactions between various stakeholders in the supply chain. This, in turn, empowers farmers to engage with a broader market and potentially increase their income through fair and direct transactions.

The food supply chain faces the issue of perishability as fresh food products have a short lifespan and can spoil quickly if not handled properly. Perishability creates a challenge for the food supply chain, requiring careful management to prevent food from going bad and ensuring it reaches consumers while still fresh. Since fruits and vegetables pass through several hands before reaching the end consumer, there is a higher probability of mishandling and delays, leading to fruit ripening before reaching the desired stage. Overripe fruits and vegetables have reduced shelf life and result in financial losses for all parties involved.

With multiple entities involved, there is often no standardized system for documenting important information such as the date of harvest, packing, transportation, or the specific treatments applied to the fresh fruits and vegetables for ripening. This absence of accurate and transparent data makes it challenging to trace the food's origin and identify potential bottlenecks or quality issues along the supply chain.

3. Methodology

In this section, we describe our proposed solution for developing an online system utilizing Ethereum blockchain and smart contracts to perform transactions in mango supply chains. Our solution aims to improve traceability of supply chain for all stakeholders by recording their data transactions. It will also provide an online

system to farmers to directly access markets and customers.

3.1. General System Overview/Proposed Framework

The proposed online supply chain process system utilizes blockchain technology to revolutionize the traditional farmer-to-consumer journey by deploying Ethereum smart contracts. Smart contracts are intelligent self-executing contracts, equipped with predefined rules governing data transactions between farmers and consumers. These smart contracts create a robust data structure that not only facilitates seamless transactions but also ensures the immutability and tamper-proof nature of recorded data. . Smart contracts are lines of code that are executed when certain conditions are met, these contracts receive transactions in form of function calls (Salah et al., 2019). Smart contracts functions and codes are executed when agreed upon by globally distributed mining nodes. A mining node will collect, validate and execute transactions, and store the data and results of these transactions on a distributed ledger. In the blockchain, smart contracts execute transactions as function calls and allow participating entities to monitor violations(Caro et al., 2018)

In blockchain networks, a write operation, which involves adding or modifying data on the blockchain, requires token of the blockchain network. We used tokens to perform transactions by executing smart contracts and each transaction occurrence was recorded as a block of data. These data blocks record information about each phase of the supply chain by executing smart contract functions. Each data block is connected to the block occurring before and after it, thus blocks are securely linked together in sequence and cannot be altered or ppended. This results in a tamper-proof blockchain-based supply chain traceability, building a reliable ledger of transactions that all network members can trust.

For product traceability purposes, in this study we developed Smart contract consisting of attributes and functions to interact with the system. Function calls were integrated into the smart contracts, enabling a smooth flow of data transactions across the supply chain. Standardization of these function calls is prioritized to enhance interoperability, making it easier for diverse participants to engage with the system. Structs data structure was used to design the

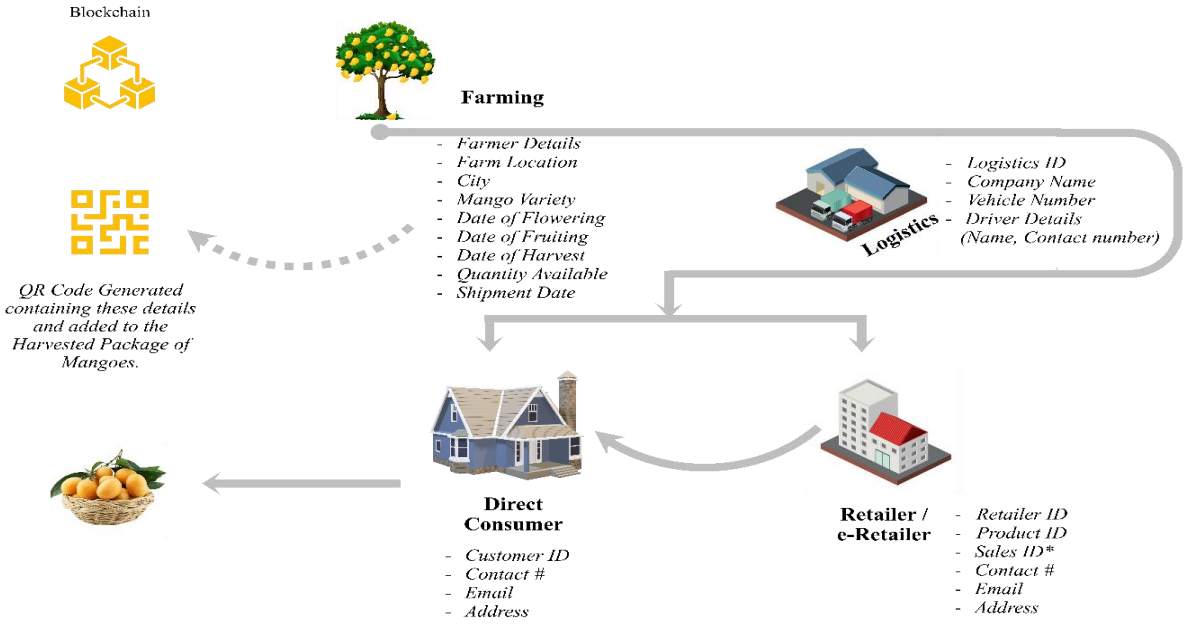


Figure 2: The proposed supply chain system.

smart contract for storing details of participating entities and product details.

This study implements the supply chain framework, as presented in Figure 2, using block chain system. This is an extended version of the framework that we proposed in (Shafique *et al.*, 2022). Figure depicts an overview of the system architecture for the proposed food supply chain management solution. with main entities Farm, logistics, retailer and consumer.

Each participant is assigned an Ethereum account complete with a distinctive Ethereum Address (EA) serving as a unique identifier for each entity. This Ethereum account comprises the Ethereum Address or Wallet ID, along with both public and private keys. These keys play a crucial role in cryptographically and digitally signing transactions, ensuring the integrity of the data in each transaction.

Table 2: Logistics Data

Company Name
Vehicle Number
Driver Details (Name, Contact number)

Table 3: Retailer Data

Retailer Details (name, contact number, address)
Product ID
Sales ID

Table 4: Customer Data
Customer ID
Contact #
Email
Address

Data for Logistics, retailer and customer were collected as depicted in tables 3, 4 &5.

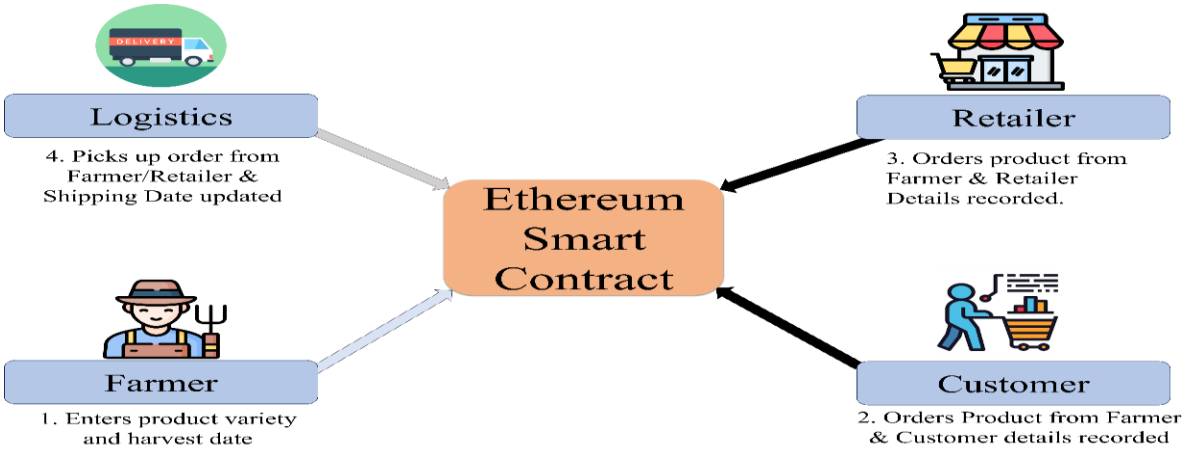


Figure 3: Each level of the supply chain participant is linked with a smart contract

We collected data from three mango clusters (Rahimyar Khan, Multan, Mir Pur Khas) using purposive sampling. The structured data as listed in Table 1 was collected using survey based techniques from selected farmers.

Table 1: Farm Level Data

Farmer Details (name, contact number, address)
Farm Detail (Address , City)
Mango Variety
Harvest Date
HWT Treatment
Quantity Available
Shipment Date

3.2. System Design

We have linked all participating entities that have a role in the proposed supply chain system with a smart contract. Each participant is assigned a distinct level of access to the data using public-private keys based on pre-defined set of rules.

The following section describes the interactions between all participating entities and the smart contract as illustrated in figure 3 and further described in the following section.

Farmer: It describes the entity which is responsible for the production phase of

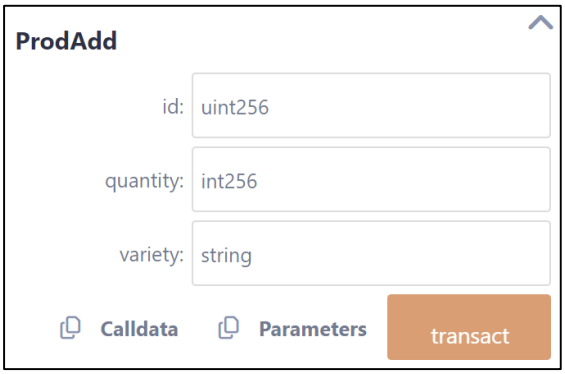
the supply chain. Farmer can add products on harvest day by entering product ID, quantity and Variety of Mango batch in the online system. The smart contract automatically stores harvest date using *block.timestamp()* method of Ethereum. Each product ID is linked to Farmers Wallet which is unique for each participating entity. At this phase, the bulk mangoes are treated (hot water treatment) and packed into boxes. Treatment details are also added to the system at this stage. A QR code is added to the package of mangoes containing these details for tracking purposes.

Logistics: Logistics is responsible for picking up orders from the store anddelivering them to the retailer, exporters, or directly to the consumers. Once the mango packages were collected by the logistic vehicle for shipment, the QR code was scanned and the shipping date was entered into the system.

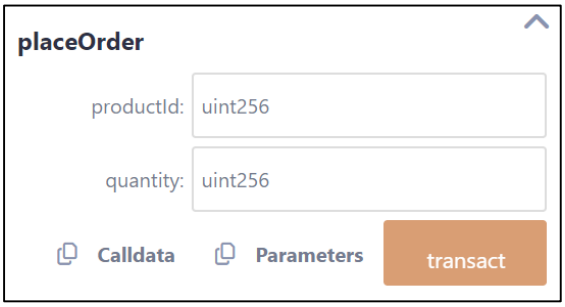
Retailer: The retailer can order mangoes in bulk from the farm entity and further sell them to consumers. Retailer can also trace back all details of product traceability journey from farm to the retailer. This traceability information will provide details of all supply chain participants through which the product reached the final consumer.

Consumer: The cosumer is the end user who can buy the package of mangoes from the retailer or directly from the farmer. Consumers can access the traceability information by scanning the QR code stamped on the box of mangoes.

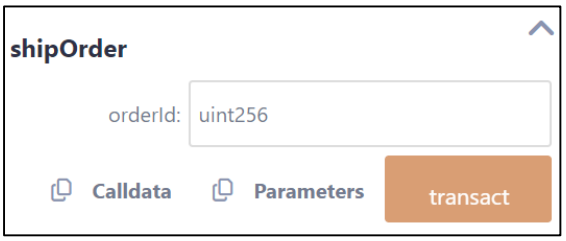
Figure 4a. illustrates the transaction interface of deployed smart contract to perform product add transactions. Only farmer is allowed access to this function to ensure that no unauthorized entity can add product in the system. Farmer can add products on harvest day by entering product ID, quantity and variety of mango batch by interacting with the add product interface. When this transaction is performed the smart contract automatically stores harvest date of this harvest batch using *block.timestamp()* method of Ethereum. Each product ID is linked to Farmers Wallet which is unique for each participating entity. These rules ensure that authentic information is entered into the system.



a) Product Add Transaction Interface and attributes.



b) Product Order transaction Interface and attributes.



c) Ship Order transaction Interface and attributes.

Figure 4: Smart Contract deployment transaction interface.

Consumers and Retailers can order products from farmer by entering product ID and quantity in the order interface as depicted in Figure 4b. Logistics entity enters the shipping date of each order by using the ship order interfae as illustrated in figure 4c.

Each entity interacts with the system using their Ethereum wallet IDs , this links each transaction to particular entity ensuring data authenticity. All the dates are entered in the system using block.timestamp() method of Ethereum , which automatically stores the current date. This maintains a synchronized and secure timeline for events within the blockchain, contributing to the trust and integrity of records and smart contracts.

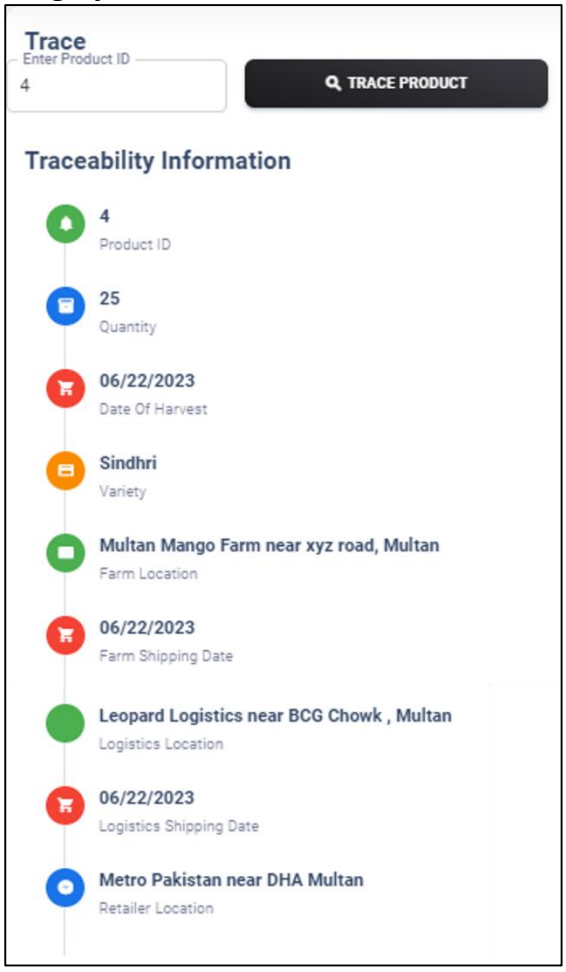


Figure 5: Interface to access product traceability information.

Online supply chain process system is implemented using defined smart contract. When the product is sent from farm level product traceability information including quantity, date of harvest, variety, farm location and shipping dates are recorded in the blockchain ledger. When products are sent to further participants of the supply chain, the product ID is linked to their corresponding wallet addresses and shipping date is added to the system. The product details, shipping dates and locations of all levels of supply chain through which the product passed, can be accessed from an immutable record stored on blockchain based decentralized application as illustrated in Figure 5.

4. Discussion

The mango supply chain of Pakistan consists of multiple intermediaries that perform specific functions along the supply chain. Traditional supply chain management systems lack integration of all entities due to being centralized and disconnected from each other. This causes a lack of communication and trust between participating entities that is a major hurdle in achieving traceability and authentication along the supply chain. The purpose of this study was to design and develop a blockchain-based food supply chain traceability system, which aimed to enhance transparency, efficiency, and trustworthiness in the food industry.

One of the major findings of this study is that blockchain technology offers significant advantages for enhancing food supply chain traceability. By utilizing a decentralized and immutable ledger, the system ensures that all transactions and events related to the food supply chain are recorded and cannot be tampered with. This feature increases transparency and trust among the stakeholders, including producers, distributors, retailers, and consumers. The use of blockchain also enables real-time tracking of food products, facilitating the rapid identification and resolution of issues such as contamination, fraud, and recalls.

Supply chain traceability aims to develop trust between participating entities. Distributed ledgers and smart contracts assist in establishing authentic and valid information flow among supply chain entities. The decentralized nature of the proposed blockchain based supply chain system ensures that all participants of the system have access to the secure and authentic record of transactions. The records added in the blockchain cannot be easily changed that improves end-to-end

traceability and develops trust between participating entities of the supply chain.

As each transaction in the supply chain is being recorded in the system using QR codes and smart contracts, it is easy to detect bottlenecks in the system. Smart contracts automate and streamline various supply chain processes, eliminating the need for intermediaries and manual intervention (Shrivas, 2019). This results in faster transaction times, reduced paperwork, and improved overall efficiency. Smart contracts are an efficient tool as they are customized as per the business logic. In our case supply chain management functions are programmed to automate product traceability and supply chain data management such as harvest date, shipment date and farm location of each package of mangoes.

Using smart contracts, we have a transparent and auditable record of every transaction and event within our supply chain system. All participants can access and verify the information, ensuring trust and accountability. This transparency also enables better traceability of products, allowing all participants of the system to track items at every stage of the supply chain, from sourcing to delivery. By eliminating intermediaries, paperwork, and manual processes, smart contracts significantly reduce operational costs in the supply chain. Automation minimizes errors and delays, leading to cost savings and increased productivity. Complete testing of smart contract is essential before deploying it on mainnet blockchain as in case of any changes, smart contracts need to be deployed again. Smart contracts are coded using programming languages, and any bugs or vulnerabilities in the code can lead to unintended consequences. Once deployed on the blockchain, these contracts are immutable and cannot be easily modified, making it crucial to ensure that the code is error-free before deployment.

Smart contracts, while promising, come with their share of challenges. Programming errors in the code can have unintended consequences, and legal enforceability may be lacking in some jurisdictions.

The system results in efficient and trustable supply chain management system. The data collected along the supply chain based on the proposed system can provide trustable information to assist in decision making for the participating entities.

5. Conclusion

Blockchain technology has the potential to develop a secure system to improve traceability of transactions along the supply chain. It has the potential to detect the bottlenecks and improve resource utilization, so the produce may reach the retailers and export market in time. By offering training to the farmers, they may be linked directly to the market to improve their profitability. Reliable transactions are performed using smart contracts and the distributed ledger that is accessible to all participants of the supply chain according to the pre-defined rules. By replacing the traditional supply chain system with the transparent blockchain based system can assist in gaining licenses that is a requirement for export to the high-end international market.

A recent study was conducted by(Boye et al., 2023) with the aim of evaluating the level of knowledge among mango growers regarding food traceability. The study also sought to identify the factors that influence their intention to participate in a scientific traceable value chain and explored the perceived challenges associated with implementing a traceable value chain within the mango industry. The findings of this study revealed there is a lack of awareness among farmers about importance of traceability and if growers are educated about the advantages of traceability, they will be inclined to adopt it in their production practices and will hold a favorable attitude towards it. The results also depicted that the growers identified inadequate resources and limited support services as obstacles hindering the adoption of a traceable value chain.

Despite these challenges, there are initiatives aiming to address these issues and bring technological interventions to traditional supply chain systems. For example, mobile applications and SMS-based platforms have been developed to provide farmers with access to market information and to bypass intermediaries. Additionally, the development of decentralized and blockchain-based systems holds promise for increasing transparency and reducing the influence of middlemen.

While this research has made contribution in the development of a blockchain-based food supply chain traceability system, there are several avenues for future exploration. Firstly, further research is needed to address scalability and interoperability challenges associated with blockchain technology. As the system expands to include a larger number of participants and transactions, the scalability of the blockchain network needs to be ensured. Additionally, interoperability standards should be developed to facilitate seamless integration with existing supply chain management systems.

To overcome these challenges effectively, a holistic approach is needed, considering factors such as infrastructure development, digital literacy programs, financial support, and policy interventions. By addressing these issues, it is possible to bring about positive change and create a more equitable and efficient supply chain system that benefits all stakeholders, particularly the farmers who have historically been exploited.

Furthermore, exploring the potential of emerging technologies such as artificial intelligence and machine learning in conjunction with blockchain can unlock new possibilities for predictive analytics, anomaly detection, and risk management in the food supply chain. These technologies can enhance the system's ability to proactively identify and mitigate potential risks and improve decision-making processes.

Overall, this study contributes to the field of supply chain management by demonstrating the potential of blockchain technology to revolutionize the mango supply chain. By providing an enhanced level of transparency, authenticity, and traceability, the adoption of blockchain can foster sustainability, efficiency, and accountability in the mango industry, ultimately benefiting all participants involved, from farmers to consumers.

6. REFERENCES

Agrawal, T.K., J. Angelis, W.A. Khilji, R. Kalaiarasan and M. Wiktorsson. 2022. Demonstration of a blockchain-based framework using smart contracts for supply chain collaboration. Int. J. Prod. Res. 61.

Boye, M., A. Ghafoor, M.T. Tahir and S. Ilyas. 2023. Food Traceability inAgriculture Value Chain: EvidencefromPakistani Mango Growers. Adv. Econ. Manag. Polit. Sci. 6:295–303.

Caro, M.P., M.S. Ali, M. Vecchio and R. Giaffreda. 2018. Blockchain-based traceability in Agri-Food supply chain management: A practical implementation. 2018 IoT Vertical and Topical Summit on Agriculture - Tuscany, IOT Tuscany 2018. Institute of Electrical and Electronics Engineers Inc. pp.1–4.

Chang, A. (Jasmine), N. El-Rayes and J. Shi. 2022. Blockchain Technology for Supply Chain Management: A Comprehensive Review. FinTech 1:191–205.

Chauhan, C., A. Dhir, M.U. Akram and J. Salo. 2021. Food loss and waste in food supply chains. A systematic literature review and framework development approach. J. Clean. Prod. 295.

Damoska Sekuloska, J. and A. Erceg. 2022. Blockchain Technology toward Creating a Smart Local Food Supply Chain. Computers 11:95.

Hasan, Z. 2020. Report of Planning Commission of Pakistan, Ministry

of Planning, Development & Special Initiatives February 2020. Knowl. Life 1–96.

Liu, P., Y. Long, H.C. Song and Y.D. He. 2020. Investment decision and coordination of green agri-food supply chain considering information service based on blockchain and big data. J. Clean. Prod. 277:123646.

Mehdi, M., B. Ahmad, A. Yaseen, A. Adeel and N. Sayyed. 2016. A comparative study of traditional versus best practices mango value chain. Pakistan J. Agric. Sci. 53:733–742.

Moosavi, J., L.M. Naeni, A.M. Fathollahi-Fard and U. Fiore. 2021. Blockchain in supply chain management: a review, bibliometric, and network analysis.

Mougayar, W. and V. Buterin. 2016. The business blockchain : promise, practice, and application of the next internet technology. Hoboken, New Jersey John Wiley et Sons, Inc. [2016], New Jersey.

Saberi, S., M. Kouhizadeh, J. Sarkis and L. Shen. 2019. Blockchain technology and its relationships to sustainable supply chain management. Int. J. Prod. Res. 57:2117–2135.

Salah, K., N. Nizamuddin, R. Jayaraman and M. Omar. 2019. Blockchain-Based Soybean Traceability in Agricultural Supply Chain. IEEE Access 7:73295–73305.

Saurabh, S. and K. Dey. 2021. Blockchain technology adoption, architecture, and sustainable agri-food supply chains. J. Clean. Prod. 284:124731.

Shrivas, M.K. 2019. The Disruptive Blockchain: Types, Platforms and Applications. Texila Int. J. Acad. Res. 17–39.

Tan, A., D. Gligor and A. Ngah. 2022. Applying Blockchain for Halal food traceability. Int. J. Logist. Res. Appl. 25:947–964.

Wang, S., D. Li, Y. Zhang and J. Chen. 2019. Smart contract-based product traceability system in the supply chain scenario. IEEE Access 7:115122–115133.

Yiannas, F. 2018. A New Era of Food Transparency Powered by Blockchain. Innov. Technol. Governance, Glob. 12:46–56.