A FRAMEWORK FOR IMPROVING AGRI-FOOD SUPPLY CHAIN WITH BLOCKCHAIN TECHNOLOGY

A thesis submitted in the fulfillment of the requirements

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DOCTOR OF PHILOSOPHY

By

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Dedicated To

The Almighty and My parents

Declaration

I, Anandika Sharma hereby declare that the thesis entitled, "A Framework for Improving Agri-Food Supply Chain with Blockchain Technology" submitted to Thapar Institute of Engineering & Technology (Deemed to be University), Patiala, in fulfilment of the requirements for the award of the degree of DOCTOR OF PHILOSOPHY in Management, is a record of the original work carried out by me under the supervision of Dr. Anupam Sharma, Assistant Professor, School of Humanities and Social Sciences and Dr. Tarunpreet Bhatia, Associate Professor, Computer Science and Engineering Department, Thapar Institute of Engineering & Technology. I also declare that this thesis or any other part of it has not been submitted before for the award of any degree, diploma, title or recognition.

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Abstract

The increasingly complex supply chain in today's era faces significant challenges regarding traceability and transparency. Food safety, quality, susceptibility to fraud and adulteration, and the discrepancy between the farmers' selling price and actual price, etc. are major challenges around the globe today, there are variety of food products are available in the market, and becomes difficult for people to recognize authenticated product and their cost. Therefore, it is very important to track and trace the entire product history from production to consumer. This concern can be alleviated by using blockchain technology. Blockchain technology is a revolutionary decentralized ledger technology that plays a pivotal role in transforming traditional processes, particularly in industries like supply chain, food supply chain and agri-food supply chain. Blockchain technology is interconnected with a series of blocks, each containing a secure record of transactions. Within the realm of agri-food supply chain, blockchain addresses inherent challenges by providing an immutable and transparent ledger, enhancing visibility and traceability, and allowing stakeholders to track the journey of food products from source to destination. The decentralized and tamper-resistant nature of blockchain mitigates risks related to fraud, adulteration, and unauthorized alterations to critical information. Moreover, by reducing reliance on intermediaries, blockchain fosters a more efficient and equitable distribution of profits, benefiting primary producers. It is a transformative force that empowers the agri-food supply chain with tools to overcome challenges, fostering a more resilient, transparent, and sustainable ecosystem. This thesis primarily focused on a comprehensive analysis of the challenges, such as economic, marketing and technological, that are inherent in the conventional agri-food supply chain. The study uses advanced CB-SEM (Covariance-Based Structural Equation Modeling) technique through Smart PLS 4 by gathering opinions, perceptions, and experiences from stakeholders within the agri-food supply chain, to provide a nuanced understanding of the issues faced by the agri-food supply chain sector.

In spite of these challenges, this thesis is dedicated to bridging the gap in blockchain adoption, a technology that is still in its nascent stage in India. Before delving into adoption strategies, it is imperative to thoroughly analyze the capabilities of blockchain technology and the relationships that underpin its potential impact. Therefore, this study adopted a mixed-method approach encompassing qualitative and quantitative study. Initially, the opinions of blockchain experts is collected using interview-based techniques, and thematic analysis is used to finalize

the five capabilities namely traceability, transparency, transaction, information security, and trust and quality of blockchain-enabled agri-food supply chain. The finalized five capabilities are modeled using Total Interpretive Structural Modelling (TISM) to provide the contextual relationship.

Following a thorough examination of blockchain capabilities within expert domains, it becomes crucial to gauge the perspectives of stakeholders regarding the adoption of this technology in agri-food supply chains. A conceptual model of extended Unified Theory of Acceptance and Use of Technology (UTAUT) is crafted to explore the sentiments of stakeholders, including farmers and government officials, towards the prospective adoption of blockchain technology. The study rigorously assesses the proposed model using Structural Equation Modelling (SEM) and leveraging the analytical capabilities of Smart PLS 4 software The findings reveal a positive inclination among stakeholders towards embracing blockchain technology in the agri-food supply chain sector. This empirical validation underscores the potential acceptance and endorsement of blockchain solutions by those integral to the industry, paving the way for informed decision-making and strategic implementations.

At last, secure and traceable blockchain-based framework has been proposed using Ethereum platform. Smart contracts have been developed to provide traceability and transparency of food products across the agri-food supply chain. All the transactions are recorded in the immutable nature of blockchain ledgers with links to a decentralized file system. The proposed framework eliminates the need for a third party, creates trust among stakeholders, provides transaction records, and enhances safety and efficiency with high integrity, reliability, and security. Additionally, a security analysis is conducted, which further reinforces the robustness and reliability of the proposed framework. The proposed framework is immune to potential security vulnerabilities such as Integer Underflow, Integer Overflow, Parity Multisig Bug 2, Callstack Depth Attack Vulnerability, Transaction-Ordering Dependence (TOD), Timestamp dependency and Re-Entrancy Vulnerability.

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Abbrevations

AI	Artificial Intelligence
AFSC	Agri-food supply chain
API	Application Programming Interface
AVE	Average Variances Extracted
BI	Behavioural Intention
BSC	Blockchain Enabled Agri-food Supply Chain
CB-SEM	Covariance-Based Structural Equation Modeling
CFA	Confirmatory Factor Analysis
CFI	Comparitive Fit Index
CR	Composite Reliability
DApp	Decentralized Application
DC	Dynamic Capability
EBC	Enterprise Blockchain
EC	Economic Challenges
EE	Effort Expectancy
FC	Facilitating Conditions
FDA	Food and Drug Administration
FTSCON	Food Trading System with Consortium Blockchain
GFI	Goodness of Fit Index
GPS	Global Positioning System
HM	Hedonic Motivation
IDT	Innovation Diffusion Theory
IIT	Indian Institute of Technology
IoT	Internet of Things
IPFS	Interplanetary File Storage System
IS	Information Security
ISM	Interpretive Structural Modelling
IT	Interfirm Trust

MC	Marketing Challenges
MPCU	Model of PC utilization
NITI	National Institution for Transforming India
PAU	Punjab Agricultural University
PBFT	Practical Byzantine Fault Tolerance
PDS	Public Distribution System
PE	Performance Expectancy
PEOU	Perceived Ease Of Use
PLS-SEM	Partial Least Square Structural Equation Modelling
POA	Proof of Authority
POB	Proof of Burn
PoS	Proof of Stake
POW	Proof of Work
PU	Perceived Usefulness
PV	Price Value
RMSEA	Root Mean Square Error of Approximation
SI	Social Influence
TAM	Technology Adoption Model
TC	Technological Challenges
TISM	Total Interpretive Structural Modeling
TNQ	Trust and Quality
TPB	Theory of Planned behavior
TRA	Theory of Reasoned Actions
TRC	Traceability
TRN	Transparency
TRS	Transaction
UTAUT	Unified Theory of Acceptance and Technology
VIF	Value Inflation Factor
VOL	Voluntariness of Use

List of publications

International journals

1. Sharma, A., Sharma, A., Singh, R. K., & Bhatia, T. (2023). Blockchain adoption in agri-food supply chain management: an empirical study of the main drivers using extended UTAUT. Business Process Management Journal, 29(3), 737-756. (SSCI indexed, Impact factor: 4.1)
2. Sharma, A., Sharma, A., Bhatia, T., & Singh, R. K. (2023). Sharma, A., Sharma, A., Bhatia, T., & Singh, R. K. (2023). Blockchain enabled food supply chain management: A systematic literature review and bibliometric analysis. Operations Management Research, 16(3), 1594-1618. (SSCI indexed, Impact factor: 9)
3. Sharma, A., Bhatia, T., Singh, R. K., & Sharma, A. (2023). Sharma, A., Bhatia, T., Singh, R. K., & Sharma, A. (2024). Developing the framework of blockchain-enabled agri-food supply chain. Business Process Management Journal, 30(1), 291-316. (SSCI indexed, Impact factor: 4.1)
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Conference

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Chapter: 1 Introduction

In recent years, the agriculture sector has played an increasingly important role in ensuring sustainable growth by integrating best agricultural practices and protecting the environment. The agri-food sector is undergoing a new revolution due to modernization and digitalization making convenient to deliver products from farm to fork. However, the complex network is not without its challenges. Issues such as traceability, transparency, and the overall efficiency of the food supply chain have been areas of concern. In recent years, due to technical advancements, many innovative technologies, namely the Internet of Things (IoT), Artificial Intelligence (AI), big data analytics, blockchain, etc., have had a significant impact on the emerging supply chain industry [1]. These technologies help the agri-food supply chain to speed up the processes, manage global food demand, track food origin to assess the quality and safety of food, minimize risks, maximize efficiency, and manage complexity [2 & 3]. Blockchain stands out among these technologies, which has received much attention from the scientific community in integrating with the food supply chain over the past few years [4]. The decentralized, traceable, tamper-proof, and other technical features of blockchain technology help to solve many issues in traditional supply chain [5]. By decentralizing the system, blockchain eliminates the need for a centralized authority, fostering a transparent and secure environment. The traceability feature of blockchain allows stakeholders to track the entire journey of products from their origin to the consumer. Moreover, the tamper-proof nature of blockchain safeguards against fraudulent activities and provides an additional layer of security. These technical attributes make the agri-food supply chain more resilient and responsive.

While the exploration of blockchain technology within the food supply chain has witnessed significant advancement in recent years, it remains in its nascent stages of development. Given its novelty, the existing literature lacks comprehensive case studies, leaving uncertainties regarding the potential benefits of blockchain in the agri-food supply chain. Katsikouli et al. [6] conducted an analysis of the challenges encountered by Danish food supply chain companies, including Twisted Leaf, Centrarogeriet, Eskelyst, and Einar Willumsen. Through employee interviews, it was revealed that the industry's readiness to adopt blockchain technology is hindered by a lack of understanding and education on the subject. Furthermore, the absence of defined standards further compounds the reluctance towards blockchain

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adoption within the industry. Blockchain technology has an unprecedented impact on agri-food supply chain innovation but it is essential to understand the behavioral intention of stakeholders behind its adoption. This study initially explores the challenges in the conventional agri-food supply chain. Further, this study examines the capabilities of blockchain-enabled agri-food supply chains are examined. Then, it performs an empirical analysis to understand the behavioral intentions of stakeholders in adopting blockchain solutions in the agri-food supply chain sector.

1.1 Agri-food supply chain

Agriculture holds paramount importance in India, with the agri-food supply chain serving as a vital and integral component of this crucial sector. The agri-food supply chain is a structure that helps ensure that agricultural products are delivered to customers promptly and efficiently. It also helps the farmers and stakeholders guarantee fair prices for their products while also ensuring consumers have access to high-quality goods and nutritious food. The agri-food supply chain is also essential for the economic development of rural areas, as it provides employment opportunities and helps to improve the standard of living of people in these areas. The journey begins with farmers cultivating and harvesting crops, employing various agricultural practices to yield high-quality production. The distribution network involves transportation and logistics and facilitates the transportation of goods from production centers to wholesale and ultimately to consumers. It is a very complex and dynamic sector that involves several intermediaries such as farmers, suppliers, manufacturers, packing firms, transporters, exporters, wholesalers, and retailers to reach out to the end product. Factors such as changes in climate, technological advancements, and market dynamics influence the resilience and sustainability of agri-food supply chains [7]. Different phases of the agri-food supply chain are shown in Figure 1.1. The production phase defines all the activities done by farmers for the growth of the crop; the processing and distribution phase includes packaging and transportation of products depending upon the delivery time and day and retailing and consumption phase defines the selling of products to the customers who are the end-users of the products [8 & 9]. The supply chain processes are inherently complex across industries that face various challenges such as sustainability, equity, and globalization. The integration of advanced technologies has the potential to improve the efficiency and sustainability of the agri-food supply chain by providing visibility and healthier relationships between stakeholders, improving product safety and quality, and reducing bottlenecks [10].

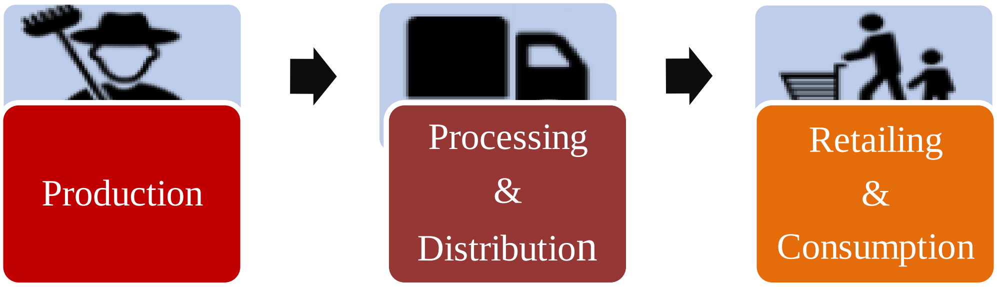


Figure 1.1 Different phases of conventional food supply chain management

The following Section 1.1.2 outlines the various challenges in the conventional food supply chain and then explores the technological developments to overcome from them.

1.2 Challenges of conventional agri-food supply chain

The globalization of the food supply chain increases the number of actors, elongated movement of products, and discrepancy of information, which results in the complex structure of food supply chains. The complexity of the food supply chain and the existing centralized technological system threaten the transparency, quality, risk of cost, and trust issues at every stage. The agri-food systems are multitier and complex, involving multiple actors and often cut local, national and geographical boundaries to deal with other actors. The multitier structure and lack of information sharing directly impact a product's quality, cost and delivery time of product [2]. Additionally, a lack of coordination between supply chain partners increases the risk of food contamination at various supply chain stages, furthering concerns about health and food quality. Moreover, there is no productive framework in the supply chains to maintain the discrepancy of the complex food supply chain [11]. The poorly developed food supply chain can cause various disruptions in the agriculture industry. Several risks and challenges are hindering fruitful and sustainable agri-food supply chains as shown in Figure 1.2. This section attempted to identify and highlight the present problems encountered in agri-food supply chain.

- **Volatility in prices:** Farmers are the nation's backbone to serve food and raw materials for food products to the people. Nevertheless, they remain in agony despite their production and productivity. They faced severe problems, such as uneven price distribution for selling their products and a lack of knowledge about the new technology and the Internet. A crucial challenge is the lack of access to timely and accurate market information, leaving farmers unaware of prevailing prices and consumer demands.

- **A large number of intermediaries:** The presence of intermediaries in the agri-food supply chain is considered the most crucial challenge that can hinder establishing a direct farmer-consumer relationship. The dependency on intermediaries can result in charging fees or commissions for their services, reducing the overall profit of farmers [12 & 13]. In India's 2024 budget declared, 20,0000 Cr for the welfare initiates for the farmers. However, no one knows how much that amount and delivery of subsidies actually reaches the farmers.
- **Food security**: The agriculture sector is in the throes of a severe crisis in which assured marketing, food security, and privacy are the biggest challenges faced by multiple stakeholders in the food supply chain [14]. The most prominent risks are natural disasters, worker strikes, government regulations, and food safety.
- **Traceability**: In the agri-food supply chain, lack of traceability can give rise to several other challenges and consequences, affecting various stakeholders, from producers to consumers. It increases the risk of food contamination and quality assurance [8]. It opens doors to fraudulent activities, including food fraud and mislabelling. Also, it can erode consumers' trust, leading to skepticism about the integrity of the agri-food supply chain and the safety of products. The limited resources, standardization, and trained staff for technical assessment are some of the barriers to refining and deploying traceability solutions across the food supply chain environment. [15 & 12].
- **Transparency**: The other crucial factor to be encountered is to provide confidentiality of information shared by the stakeholders in the agri-food supply chain. It refers to the difficulty in achieving and maintaining clear visibility and openness throughout the various stages of production, distribution and consumption [16]. The lack of transparency can significantly affect food safety, quality assurance and ethical practices.
- **Information asymmetry**: Among the above-mentioned challenges, information asymmetry is another crucial challenges that influence the performance of agri-food supply chains [15]. This can lead to pricing disparities between stakeholders, and information gaps about quality standards and compliance can also lead to variations in product quality. The lack of information can restrict the farmers from accessing the market opportunities for fair trade.

- **Demand and supply:** The imbalance of demand and supply of the product due to inadequate demand forecasting is a major challenge for the management of the agri-food supply chain, especially for small producers. It can impact the efficiency, responsiveness, and sustainability of the entire supply chain [17].
- **Technological disparities:** The lack of modern technologies in the agri-food supply chain owing to different challenges in real life. Manual and traditional processes without the aid of technology can lead to inefficiencies in various stages of the supply chain and increased operational costs and delays [18]. Without using technology for storage, transportation and inventory can escalate post-harvest losses.

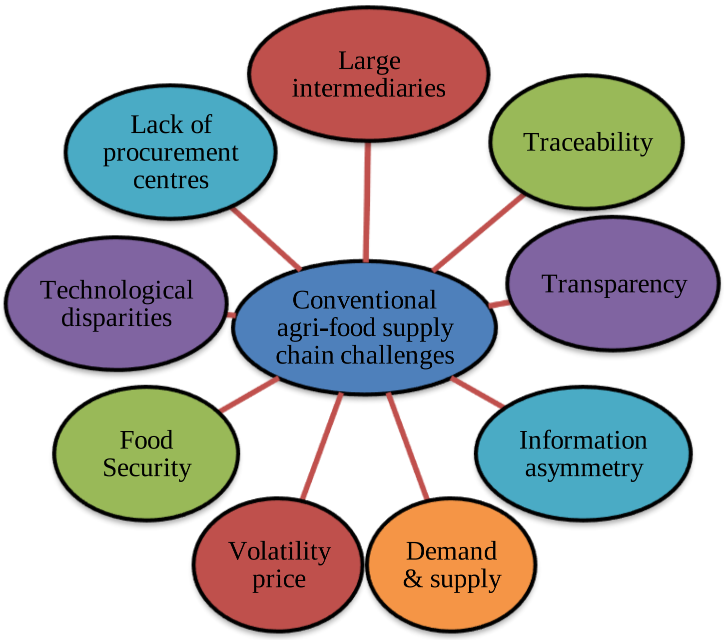


Figure 1.2 Conventional agri-food supply chain challenges

- **Shortage of procurement centres:** The agricultural sector is lagging in various challenges related to procuring, storing, food wastage, food quality, and inefficient use of resources. The shortage of an ample number of procurement centres in India loses farmers the chance to bargain their production, and the inefficiency of resources leads to passing their production to the local agents and stakeholders at local prices, which is far less than minimum support price [19].

1.3 Role of digitalization in the agri-food supply chain

Technological innovations played an essential role in coordinating the supply chain through hardware and software processes. The structure of food supply chain has changed over the last 35 years, and the main goal of the food industry is to combine the purchasing, transportation, physical distribution, and logistics of food products [20]. To meet the customer requirements for top quality, healthy, and nutritious products, there is a need to fully track forward or backward the food supply chains efficiently. As many efforts have been made to incorporate tracking solutions in supply chains, the mobile application has been developed to provide essential information such as weather forecasts, agriculture-related news, and Mandis’s price of products to the farmers. The application also controls the water pump through SMS and Bluetooth.

The shift in trends, marked by growing urbanization, industrialization, changing lifestyles, and health concerns, has promoted developing countries to bolster their agriculture sector. This involves educating farmers, embracing new technologies, and streamlining communication and collaboration among stakeholders through precise, effective, and electronic means [16 & 21]. Furthermore, the advent of the industrial revolution, called Industry 4.0, has introduced a wide range of technologies such as the IoT Things, robotics, Big Data, AI, and blockchain technology. Industry 4.0 and its related technologies can address the challenges of the agri-food supply chain by providing security, transparency, and traceability in line with sustainable development goals. These technologies led to the transformation of traditional agriculture into an intelligent and industrialized agricultural industry [22 & 23]. These technologies help the agri-food supply chain to speed up the processes, manage global food demand, track food origin to assess the quality and safety of food, minimize risks, maximize efficiency, and manage complexity [2, 3 & 24]. Among them, blockchain technology has been found to be one of the most promising technologies that not only securely stores data but also preserves user privacy in food supply chains and provides several benefits in the field of agri-food supply chains [25 & 26].

1.4 Blockchain technology

Satoshi Nakamoto [27] introduced blockchain technology in 2008 with the creation of Bitcoin. Since then, the scope of blockchain applications has expanded significantly beyond cryptocurrencies, encompassing domains such as food traceability, ballot tracking, identity verification, real estate processing, and supply chain management. Functioning as an information and communication tool built on cryptographic principles, blockchain ensures secure transactions between parties by forming a chain of blocks containing recorded, executed, and shared transactions. This decentralized technology eliminates the need for centralized network, operating through smart contracts that autonomously execute agreements between parties. Transactions within the blockchain are cryptographically hashed and transparent to involved parties, with each block cryptographic hash containing the previous block hash value to maintain the chain's integrity. Blockchain presents various opportunities, including transparency, trust, traceability, and security, particularly within the food supply chain [28], offering promising solutions to address transparency and security challenges across the entire supply chain ecosystem.

1.4.1 Features of blockchain

Blockchain technology offers several fundamental features that contribute to its uniqueness and make it suitable for various applications as shown in Figure 1.3. Some of the fundamental properties are explain as follows [29 & 30].

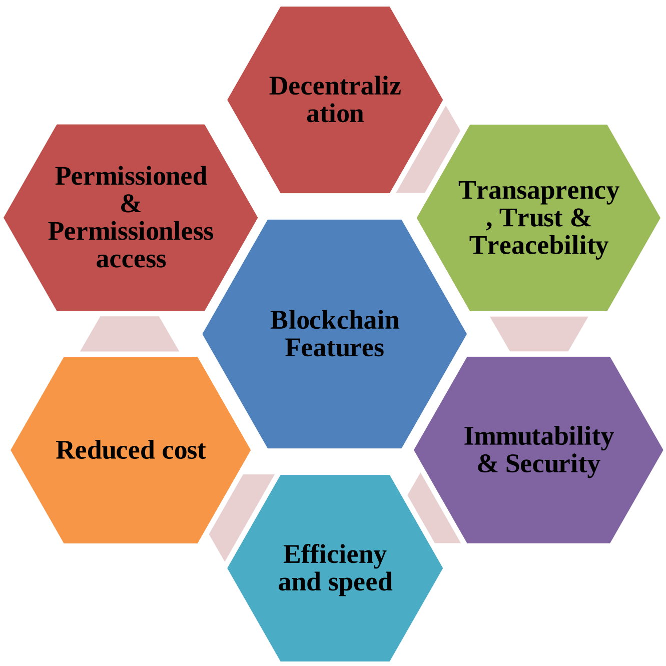


Figure 1.4 Features of Blockchain technology

- **Decentralization:** One of the defining features of blockchain technology is its decentralized structure. The network operates on a peer-to-peer basis without having any centralized authority or intermediary controlling system.

- **Transparency:** Blockchain provides a transparent and temper-resistant ledger where all the transactions are recorded. Each participant in the network can see the entire history of transactions occurring between any number of users. It ensures visibility and accountability.
- **Improved traceability:** The visibility of the entire journey of transactions occurring between any two parties can enhance the traceability in which the participants can track the transactions from the first step to the end step.
- **Immutability:** Blockchain provides the feature of immutability in which, once a block is added to the blockchain, it is impossible to alter or delete the information contained in it. This nature of blockchain technology enhances the reliability of the recorded information and prevents fraudulent activities.
- **Security:** It employs cryptographic techniques such as hashing, digital signatures, and encryption, which help to secure transactions and access control to the network. The unauthenticated users can be detected by the use of various consensus mechanisms, which enhance the security of the network.
- **Efficiency and speed:** Removing intermediaries can streamline processes and automate manual tasks through smart contracts. This can lead to a faster and more efficient exchange of transactions between participants.
- **Reduced cost:** Elimination of third party, reduces transaction cost and operational expenses. The automation of blockchain technology reduces the need for manual intervention, streamlining operations and reducing labour costs.
- **Increased trust:** Blockchain enables a trust less environment in which the participants can transact and interact without the need for absolute trust in each other. Trust is established through the inherited security and transparency features of the blockchain network.
- **Permissioned or permissionless access:** Participant can access different types of blockchain (public or private) depending upon their requirements. Public blockchain are open to everyone, while private blockchain restrict access to approved entities.

These features of blockchain collectively contribute to the robustness, security, and versatility of blockchain technology, making it suitable for a wide range of applications across different industries and organizations.

1.4.2 Applications of blockchain technology

Blockchain technology has explored its applications across various industries due to its decentralized and transparent nature. Some of the blockchain applications are discussed as follows:

- **Cryptocurrencies:** The first and most well-known application of blockchain technology is cryptocurrency, known as Bitcoin. It is a type of digital currency that uses cryptography techniques for security. Unlike traditional currencies issued by the government or banks, cryptocurrency operates on a decentralized network. It is maintained by a network of participants and does not need any third party for the transaction. Participants can pay another party directly through digital transactions [9].
- **Supply chain management:** Blockchain is used to enhance transparency and traceability in supply chains. It allows the real-time tracking of products from farms to customers, reducing fraud and guaranteeing the authenticity of products [31].
- **Finance and banking:** Blockchain technology facilitates financial transactions in a faster and more cost-effective manner. It eliminates the need for any third party, which makes it more convenient to streamline international transactions by reducing their cost and improving speed [32].
- **Healthcare data management:** It is also used in the healthcare system to secure the exchange and interoperability of patient data. Blockchain can be used to trace the entire lifecycle of pharmaceuticals from manufacturing to delivery. Implementing blockchain in healthcare systems can revolutionize how data is managed, shared, and utilized, ultimately improving patient outcomes and the overall efficiency of the healthcare system [33].
- **Real estate:** Blockchain facilitates transparent and secure property transactions by recording details such as ownership history, title deeds, and legal agreements on a decentralized ledger. The risk of fraud is reduced and ensures the integrity of property records [34].
- **Voting systems:** It is also the most famous application of blockchain technology, which provides a transparent and secure platform for voting

systems. It authenticates each and every user before voting, hence reducing the risk of tampering [35].

- **Gaming and collectibles:** Non-fungible tokens are popular applications in this area. It is used in gaming for secure ownership of in-game assets and digital collectibles [36].

In relation to the above-mentioned applications of blockchain technology, this study prioritizing focuses on supply chain management, especially on agri-food supply chains, as discussed in further sections.

1.5 Unveiling the power of blockchain in the agri-food supply chain

Blockchain was originally developed as the underlying technology for cryptocurrencies. Offer a decentralized and tamper-resistant ledger that can be applied to secure and streamline various processes. In the context of the agri-food supply chain, where stakeholders range from farmers and producers to distributors and retailers, the need for a transparent and trustworthy system is paramount. The integration of blockchain technology into supply chain management offers enhanced fraud detection capabilities by enabling traceability of components from harvest to end-user, fostering transparency and building trust among stakeholders. This collaboration between distributed ledger platforms and supply chain management has the potential to propel significant advancements in the food supply chain management system. [6]. IBM is considered to be the leading enterprise blockchain provider for the food supply chain [37]. Numerous enterprises are adopting blockchain technology to enhance supply chain agility and elevate employee productivity by ensuring fair compensation for workers and farmers. For instance, Denver-based Coda Coffee collaborated with bext360, leveraging a blockchain platform to track coffee operations and facilitate transparent payment processes for farmers. [38].

One of the critical advantages of blockchain in the agri-food supply chain is its capacity to enhance traceability and transparency. Each transaction is securely recorded in a block. These blocks are linked chronologically, creating an unalterable chain of information. This transparency not only ensures the authenticity of food products but also provides consumers with unprecedented visibility into the origins and journey of the items they purchase [28 & 39]. Blockchain technology facilitates fair trade among stakeholders, bolstering their market position and fostering trust through transparent information sharing. The distributed ledger technology ensures accountability and traceability for end consumers, maximizing profits across the supply chain. Additionally, blockchain streamlines coordination among stakeholders, offering practical solutions and an inclusive framework for data exchange within the food supply chain. This heightened visibility and transparency enhance the integrity of shared data, ultimately benefiting all parties involved [31]. Moreover, blockchain technology introduces efficiency by automating and validating processes, reducing paperwork, and minimizing the potential for fraud errors. Smart contract streamlines the interactions between various stakeholders. This not only accelerates the pace of transactions but also minimizes the risk of disputes, fostering a more collaborative and secure agri-food supply chain ecosystem. The combination of traceability, transparency, and security provided by blockchain contributes to the overall integrity and efficiency of the food supply chain.

1.6 Thesis contribution

The agri-food supply chain faces multiple obstacles and challenges that can impact its efficiency, sustainability, and overall performance. To address these challenges, the adoption of blockchain technology is increasingly seen as an urgent and transformative solution. The development and implementation of blockchain framework in the agri-food supply chain hold significant implications and benefits to address the challenges of various stakeholders and customers. Blockchain technology provides an immutable and transparent record of every transaction in the agri-food supply chain, making it difficult for bad stakeholders to engage in food fraud and the selling of counterfeit products in the market. Also, it provides real-time visibility into the movement of products from farm to customer, enabling stakeholders to monitor and track the status of products at each stage. The significance of providing a blockchain framework in the agri-food supply chain lies in its potential to tackle longstanding issues, improve operational efficiency, and create a more transparent, secure, and sustainable ecosystem for all stakeholders.

1.6.1 Need and motivation for research

The agri-food supply chain is a complex structure that collaborates with many stakeholders, leading to insufficient transparency, traceability, and provenance information. At the ground level, it is overwhelmed with several challenges and has a significant impact from production to consumer. As all know, farmers are the backbone of the agriculture sector and contribute significantly to the economy. They face various pricing issues that can impact their livelihood, economic sustainability, and social status. These challenges arise from a combination of factors related to the market dynamics, complex supply chain structure and various external influences. Some common pricing issues faced by farmers involve the presence of numerous intermediaries in the agri-food supply chain, which can lead to a significant price difference between what consumers pay and what the farmer receives. Intermediaries take a massive share of profit, leading farmers with smaller margins. They also face difficulty negotiating fair prices for their produce, particularly when dealing with powerful intermediaries and financers.

Moreover, they have inadequate market linkages due to their geographical remoteness and inadequate transportation, storage, and processing facilities. Farmers may also lack access to exact and timely information about the market conditions, prices, and demand of people, which makes it challenging for them to make informed decisions. Therefore, they often sell their produce to a limited number of buyers or processors, giving these stakeholders significant market power, which leads to unfair pricing. Also, small-scale farmers in developing regions may lack access to modern agricultural technologies, which hinders their productivity and improvements. Overcoming these pricing and quality issues requires a multifaced approach that includes improving market infrastructure, promoting fair trade practices, enhancing farmers' access to information, and fostering competition.

Ensuring and maintaining food quality throughout the agri-food supply chain is another crucial aspect of the industry. To increase farmers' income, they contaminate the produce with pathogens and pesticides, which pose a significant threat to food quality. Improper storage conditions and lack of transportation can also lead to the deterioration of food quality. The inability to trace products in the agri-food supply chain makes it challenging to promptly identify their exact price and quality issues. The existence of multiple intermediaries and fraudulent practices such as food adulteration and mislabeling lead to counterfeit products entering the agri-food supply chain, deceiving consumers and posing a risk to public health.

To address these challenges, a holistic approach of transformation, collaboration among stakeholders, investment in infrastructure, and policy support by the government is required, which could be possible by introducing digital solutions in the agri-food supply chain. Adopting advanced technologies can offer numerous benefits, such as enhancing efficiency, sustainability, and overall productivity of the agri-food supply chain. Blockchain is considered transformative and the most efficient solution for agri-food supply chain management. Through its immutable and distributed nature, it has various capabilities to resolve the issues encountered along the supply chains. Despite these benefits, blockchain is still in its infancy, and there is ongoing exploration in the supply chain sector. Before realizing its benefits, this research explores the multiple challenges of conventional agri-food supply chain faced by farmers and other stakeholders. Therefore, the primary goal of this research is to explore multiple challenges of conventional agri-food supply chain and the adoption behavior of blockchain technology among stakeholders in agri-food supply chain processes, which helps to gauge their interest and engagement with this new technology.

Assessing the adoption among stakeholders is a foundational step that informs the researchers to take subsequent decisions and actions in developing and implementing a blockchain-based framework in the agri-food supply chain industry. Therefore, after analyzing the adoption of blockchain technology, this research moves forward with implementing a blockchain-based framework. The blockchain based framework for the agri-food supply chain is developed on a private Ethereum network with proof of stake consensus. The proposed framework used interplanetary file storage system to store all food product information, images, and videos. This framework is mainly concerned with increasing the farmer's income, providing trust and a transparent platform among stakeholders and in the agri-food supply chain, which enables direct transactions between buyers and sellers, eliminating the need for intermediaries, and providing broader access to the market, negotiating prices, and receive fair compensation of the products.

This study provides an evident role from both physical applications and business perspectives, with significant potential to drive the overall impact of blockchain technology in the agri-food supply chain. It allows stakeholders to trace the entire journey of agricultural products from farm to fork. This transparency enhances trust among consumers, authenticity of products and accountability throughout the agri-food supply chain. This also helps the consumers to receive genuine, high-quality products and helps prevent fraud or counterfeit goods from entering the market. Also, blockchain technology helps to optimize the agri-food supply chain by seamlessly sharing data and collaborating with supply chain participants. Smart contracts automate and enforce agreements, reducing administrative overhead, minimizing errors, and accelerating transaction times. This optimization leads to cost savings, improved efficiency, and enhanced supply chain performance. From a business perspective, blockchain enhances risk management by providing a tamper-proof compliance record with food safety regulations and standards. Organizations can demonstrate due diligence and accountability by leveraging blockchain to track critical parameters such as temperature, humidity, pH levels, and chemical residues. Transparency and traceability provide a competitive advantage in the marketplace.

By showcasing their commitment to quality, sustainability, and social responsibility, companies can differentiate their products and attract discerning consumers who value transparency and ethical sourcing. It also opens up new market opportunities as consumers increasingly demand greater visibility into their food's provenance and production practices. Overall, blockchain enhances consumer trust by providing access to information about the products. Through mobile apps, QR codes, or online platforms, consumers can scan product labels to view information recorded on the blockchain, such as origin, production methods, sustainability practices, and social responsibility initiatives. Adopting blockchain in the agri-food supply chain brings tangible benefits in traceability, transparency, quality control, optimization, risk mitigation, market access, consumer trust, and sustainability. By leveraging blockchain technology, companies can enhance their competitive position, meet regulatory requirements, and drive positive social and environmental impact across the agri-food value chain.

1.6.2 Research objectives

On the basis of the existing literature, the following research objectives have been identified to explore under the research entitled "**A framework for improving agri-food supply chain with blockchain technology**."

1. To examine the challenges faced by farmers in conventional agri-food supply chain management.
2. To examine the challenges faced by government officials in conventional agri-food supply chain management.
3. To examine the attitude of farmers and government officials involved in agri-food supply chain management towards the adoption of blockchain technology.
4. To design the framework for improving the agri-food supply chain with blockchain technology.

1.6.3 Summary of contributions

To achieve the first and second objectives, a comprehensive and thorough study of existing challenges in the agri-food supply chain has been done. Various challenges related to economic, technical, and marketing challenges have been reviewed that people face in everyday life. It was found that the lack of traceability and transparency, lack of trust, and unfair pricing are some of the critical issues. The covariance-based structural equation modeling (CB-SEM) method was employed in this study to rigorously test and verify the identified challenges within the agri-food supply chain. It is a powerful statistical technique that allows researchers to examine complex relationships among variables and test theoretical models by analyzing both observed and latent variables simultaneously.

To address these challenges and make an efficient agri-food supply chain, this thesis mainly focuses on using blockchain technology in the agri-food supply chain. To fulfill this objective, this study first focuses on analyzing the importance of blockchain technology in the agri-food supply chain by analyzing the capabilities of blockchain technology using thematic analysis. It allows for a nuanced exploration of the multifaceted roles that blockchain technology can play in transforming the agri-food supply chain. Further, this study proceeds to delve deeper into understanding the intricate relationships among the identified capabilities of blockchain technology within the agri-food supply chain. This is accomplished through the application of Total interpretative structural modeling, a systematic approach used to elucidate the hierarchical relationships and dependencies among various factors.

After examining the importance of blockchain technology, the research model has been designed to analyze the attitude of stakeholders in the adoption of blockchain technology in the agri-food supply chain to attain the third objective. To empirically validate the model, structured equation modeling has been applied, a robust statistical technique widely used to analyze complex relationships among variables in research. It enables researchers to simultaneously examine both observed and latent variables and assess the direct and indirect effects among them. The results found that people are willing to adopt blockchain technology in the future to make the agri-food supply chain more efficient and sustainable.

To fulfill the fourth objective, the blockchain platform has been developed to provide transparency and traceability to each stakeholder that is involved in the agri-food supply chain processes. In blockchain, smart contracts were generated using Solidity language and deployed on Vs code using Metamask Ethereum wallet, which allows users to interact with the Ethereum blockchain.

1.7 Thesis outline

The thesis is structured into eight chapters. The concise overview of each chapter is discussed below and also presented in Figure 1.4.

Chapter 1 Introduction is divided into four sections. Section 1.1 gives an overview of the agri-food supply chain, its structure, and its associated challenges. Moreover, this section also discusses the integration of digital infrastructure in the agri-food supply chain to overcome the challenges. Section 1.2 provides the details of blockchain technology, its various properties, and the application of blockchain technology in various sectors, followed by section 1.3, which uncovers the power of blockchain technology in the agri-food supply chain. Section 1.4 describes the significance of this research study and the motivation behind this research study. A brief description of the thesis organization is provided in Section 1.5.

Chapter 2 The Literature review presents the background information of the research topics and identifies the research gaps that existed in the research. Section 2.1-2.3 discuss the research methods, technology adoption models and the adoption of blockchain technology in agri-food supply chain. Section 2.4 describe the key concepts of blockchain such as their types of blockchain, cryptographic primitives etc. Section 2.7-2.9 presented the blockchain architecture, the consensus mechanisms and challenges of blockchain technology. Section 2.10 and 2.11 explains the blockchain initiatives and the emergence of blockchain in agri-food supply chain. Lastly, Section 2.12 and 2.13 discuss the role of blockchain in agri-food supply chain and the existing frameworks of agri-food supply chain.

Chapter 3 Examining the challenges in conventional agri-food supply chain: An empirical study using covariance-based structural equation modelling chapter provides issues that people face in the agri-food supply chain structure. Section 3.1 and 3.2 provides the introduction and related work. Section 3.3 discuss the hypothesis development related to the study. Section 3.4 describe the research design and methodology used to achieve the goal. Later, section 3.5 explains the data analysis and results and Section 3.6 presented the discussion and findings.

Chapter 4: A conceptual framework for blockchain enabled Agri-food supply chain: A dynamic capabilities view perspective presents the capabilities of the blockchain-enabled agri-food supply chain. Start with Section 4.1 which explains the introduction and Section 4.2 explains the literature review related to the topic. Section 4.3 describe the research methodology and Section 4.4 presents the results and findings of the study. At last the Section 4.5 explains the discussions and implications of the study.

Chapter 5: Enablers of blockchain adoption in Agri-food supply chain with dynamic capability perspective: A total Interpretive Structural modelling approach of this thesis presents the relationship between capabilities of blockchain technology. Section 5.1 discuss the introduction and Section 5.2 present the related study. The Section 5.3 and Section 5.4 explains the research methodology and analysis and findings of the study. Section 5.4 presents the discussions.

Chapter 6: Blockchain adoption in Agri-food supply chain: An empirical study of main drivers using extended UTAUT presents the opinion of stakeholders in adopting blockchain technology in the agri-food supply chain. Section 6.1 and Section 6.2 present the introduction and related work in accordance with the study. Section 6.3, 6.4 and 6.5 shows the hypothesis development, conceptual framework and research design and methodology. After applying the method, Section 6.6 present the findings and the interpretation of the study. Section 6.7 provides the discussion and findings.

Chapter 7: Secure and Traceable decentralized Agri-food supply chain framework using Ethereum Blockchain and IPFS platform provides the proposed solution for various stakeholders to transparently purchase or sell food products from one place to another. Section 7.1 and Section 7.2 shows the introduction and review of literature. Section 7.3 presents the proposed blockchain based agri-food supply chain framework. The implementation details are provided in Section 7.4. The Section 7.5 provides the results and analysis.

Chapter 8 Conclusion and Future research scope of this thesis typically summarizes the key findings and experimental results drawn from the study. It serves to provide a comprehensive overview of the research outcomes and their implications as provided in Section 8.1. Additionally, this chapter outlines the potential area for future research scope as presented in Section 8.2, which can be applied or expanded upon in subsequent research endeavors.

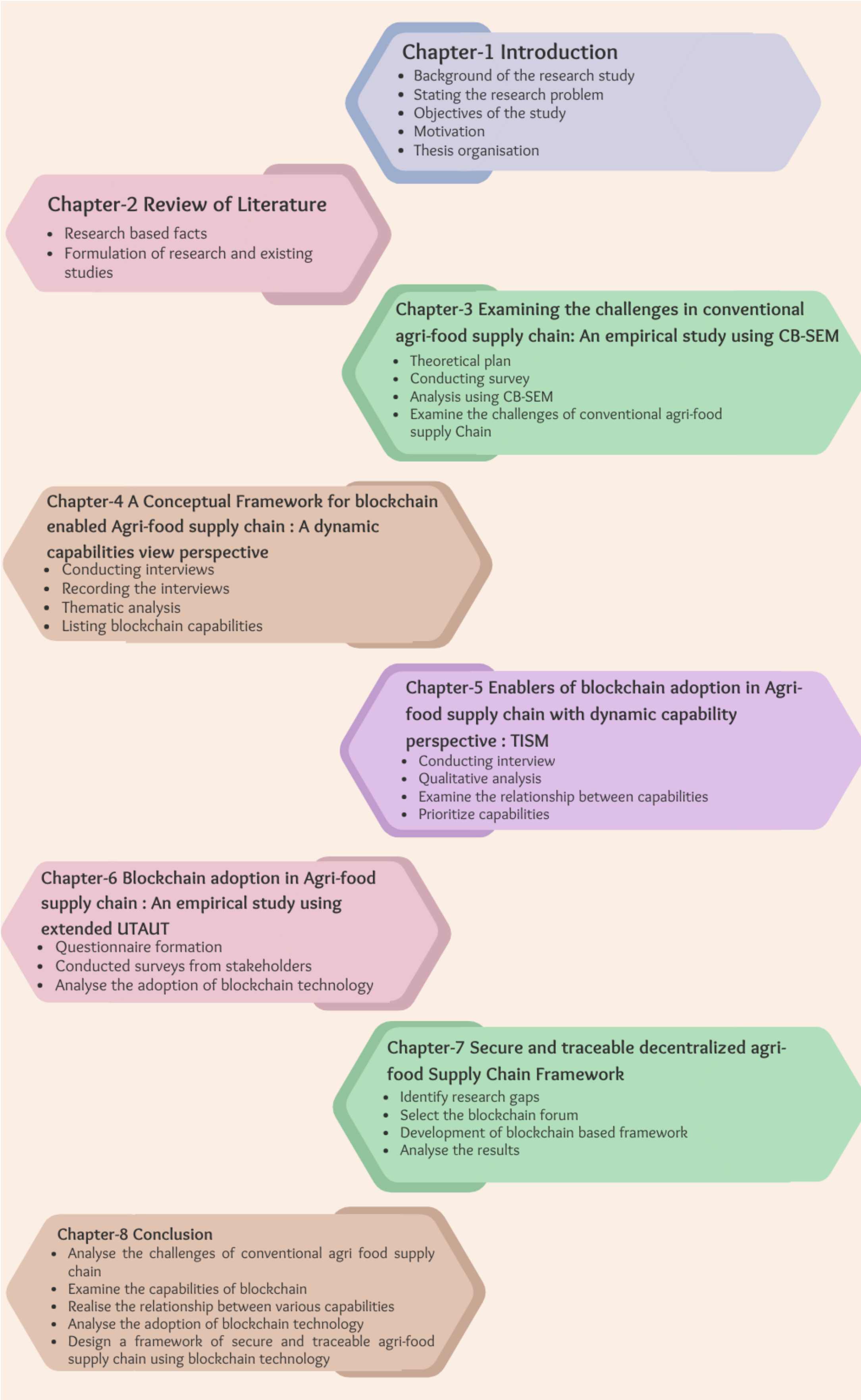


Figure 1.5 Organization of thesis

1.8 Summary

Agri-food supply chain structure faces various challenges that can significantly disrupt the seamless flow of goods from manufacturers to consumers. These disruptions can impact the production schedules, inventory management, unfair pricing of farmers, transportation logistics, customer dissatisfaction, and operational efficiency of the agri-food supply chain. One of the major issues in this industry is the lack of visibility into the journey of food products, leading to difficulties in tracking and verifying the origin of products. Blockchain technology has emerged as a transformative force to mitigate these challenges, offering increased efficiency, transparency and traceability. It provides a transparent and immutable record of every transaction and movement of food products within the agri-food supply chain to access their real-time information. Also, it reduces the risk of fraud and ensures the quality standards of food products. Therefore, leveraging blockchain technology in the agri-food supply chain becomes more efficient, accountable, and resilient, ultimately enhancing food safety and building consumer trust.

Chapter 2: Literature review

This chapter is a critical and comprehensive examination of the research methods, adoption models, blockchain technology and existing research on the role of blockchain in agri-food supply chains. Qualitative and quantitative research, along with adoption models, plays a crucial role in the success of new technologies by providing a comprehensive understanding of user perspectives, market dynamics, and factors influencing the adoption of technology. Qualitative study helps to delve into the subjective experiences and opinions of users. This can help to understand the needs, preferences, and pain points for tailoring the technology to meet specific requirements. It also provides the social, cultural and contextual understanding that might impact the adoption of new technology. While quantitative research enables researchers to identify patterns, trends, and statistical correlations of numerical data. It helps to measure the adoption rates and identification of factors that correlate with the successful adoption of technology. The adoption models provide information vital for predicting and influencing the acceptance of technology in the market. All these methods provide a holistic understanding of the technological landscape and insights that enable developers and businesses to make informed decisions, tailor their strategies, and increase the likelihood of successful technology adoption in the market.

This chapter has also presented a detailed description of blockchain technology architecture, working and their role in the agri-food supply chain. Blockchain technology is pivotal in revolutionizing the agri-food supply chain by introducing transparency, traceability and efficiency into the entire ecosystem. This technology allows for the creation of a transparent and tamper-proof record of the journey of food products from production to consumer, enabling stakeholders to verify the authenticity of products, monitor their conditions, and ensure adherence to quality standards. Blockchain technology not only addresses the challenges of information asymmetry and inefficiency but also builds trust among consumers by providing a clear and verifiable history of the agri-food supply chain.

The content of this chapter have been reviewed and communicated for publication in:

- *Sharma, A., Bhatia, T., & Sharma, A. Digitalization of agri-food supply chain with Blockchain technology: A systematic review, taxonomy and open research issues. Transactions on Emerging Telecommunications Technologies.*

2.1 Qualitative and quantitative research methods

The research design of this study integrates a blend of both qualitative and quantitative research methodologies to garner a nuanced understanding of blockchain technology in the agri-food supply chain industry. The study aims to triangulate data from diverse sources, ensuring the robustness and reliability of the findings. The methodologies are explained as follows:

- **Qualitative research** is a methodological approach used to explore and understand human experiences and individual experiences. It seeks to understand the entire context and considers the interconnectedness of various factors influencing the phenomenon under study. It begins with open-ended questions, allowing users to express their thoughts and experiences in their own words [40]. This method revolves around understanding "what" individuals think and delving into the "why" behind their thought processes. It involves various methods, but the most common are described below.
    - **Interviews:** One-on-one communication between the researchers and the participants to explore their experiences, feelings, attitudes, and perspective.
    - **Focus groups:** These involve making small groups of participants engaged in discussions by the researchers to explore a specific topic and exchange ideas.
    - **Content analysis** refers to examining written, visual, and audio material to identify themes, patterns, and meanings.
    - **Qualitative surveys:** These involve surveys that include open-ended questions, allowing participants to provide detailed responses.

Collectively, these methods contribute to providing a deep understanding of the phenomenon by exploring subjective experiences and meanings associated with them.

- **Quantitative research:** It is a systematic empirical investigation that uses numerical data to answer a specific set of research questions and make generalized claims about the population. It involves collecting data from people and analyzing data in the form of numerical measurements, statistics, and mathematical equations. A predefined plan for data collection and analysis has been set in this research type. It often involves large sample sizes to increase the statistical power of the analysis and enhance the generalizability of the findings [41]. It comprises various methods:
    - **Survey and questionnaire:** It consists of standardized surveys and questionnaires to collect data from the sample of the study.

- **Experiments:** It involves using mathematical formulas and experiments to provide some numerical values. Also, it refers to manipulating independent variables in controlled settings to observe their effects on dependent variable**s.**
- **Secondary data analysis:** It involves the analysis of pre-existing data such as public datasets, organizational records, or statistical data available online
- **Correlational studies:** It examines the relationship between two or more variables without manipulating them.

In the context of this study, a mixed-method approach is used in which both qualitative and quantitative research methods are incorporated to analyze the various aspects of blockchain technology usage in the agri-food supply chain. This approach allows researchers to gain a more comprehensive understanding of the study by combining the strengths of both qualitative and quantitative research methods.

2.2 Technology adoption models

Recognizing the needs of the users and the acceptance of technology is the first step in the development of any technology, and this understanding would be helpful to realize the behavior of people regarding the acceptance or rejection of technology. Despite the benefits of technology, a large number of researchers attested that people refuse to comply with new technologies. Therefore, the adoption models are invented to understand or predict the behavior of people in accepting or rejecting new technology in the future. In general, acceptance is an opposition to refusal and refers to the decision to use an innovation. Researchers should understand the reasons behind people's acceptance of new technologies, and employing these inquiries can guide them in employing more effective approaches for designing, evaluating, and predicting user responses to emerging technologies [42]. Literature has presented several theories of adoption models. The most significant of these models are described below:

- **Diffusion of innovation theory:** The theory is proposed by Roger [43] in 1995 as a conceptual framework for understanding how innovations are communicated and adopted by the environment. This theory comprises four essential components: innovation itself, communication channels, temporal aspects, and social systems. Innovations refer to the range from technological innovations to new behavior or social aspects. Communication is the process through which knowledge and understanding about innovations are exchanged between participants. The temporal dimension refers to the timeline of the innovation process and the rate of adoption, while the social system represents a cohesive unit of individuals or groups of people sharing a common objective regarding the innovation. The theory outlines the process of adoption and diffusion and identifies the key factors influencing the acceptance of innovations. While this theory is a valuable framework for understanding new ideas, it is not without its limitations. One of the key limitations is the simplification of reality, which may not fully capture the complexity and nuances of real-world adoption.

- **Theory of planned behavior (TPB):** It was developed by Icek Azen [44] in 1991 and is an extension of the earlier Theory of Reasoned Actions (TRA) that was developed by Fishbein [45] in 1975. It is a widely used physiological model to predict and explain human behavior based on individual intentions. TPB is influenced by three main factors such as attitude toward the behavior, subjective norms, and perceived behavior control. These factors, in turn, make an individual intend to perform a specific behavior. Attitude pertains to the individual's assessment whether positive or negative, of engaging in a particular behavior. The subjective norms involve the perceived social pressure regarding the approval or disapproval of a behavior by significant others. The perceived behavior control influences the individual perception of the ease or difficulty of performing the behavior influenced by factors such as skill, resources, and opportunities, while the behavioral intention is the individual motivation and readiness to engage in a specific behavior, which is a direct precursor to actual behavior. While the TPB has been influential in understanding and predicting a wide range of behavior, it has some limitations. The model has limited predictive power and for complex behavior examination, TPB may not provide a complete understanding, as it is primarily focuses on intentional behavior [46].
- **Technology adoption model (TAM):** TAM, proposed by Fred Davis in 1989, has been considered the most dominant model in predicting the behavior intentions of users for accepting and rejecting a technology for the last few years. The model explains the factors influencing user's acceptance or rejection of information technology. The components of TAM include perceived ease of use (PEOU), perceived usefulness (PU), behavioral intention (BI), and actual system use. The two main predictors of the TAM model are PEOU and PU, which are the primary constructs of other models. The PEOU is defined as the degree of the user's perception of using technology. PU refers to the user's belief that using technology will enhance their job performance and productivity.

BI acts as the dependent variable and captures the user's intention or willingness to use the technology in the future, while actual use represents the real usage of technology by the users and it is an essential outcome in TAM [47,48,49 & 50].

- **Extended technology adoption model (TAM2):** In 2000, Venkatesh [47] and Davis extended and refined the original TAM model and developed TAM2 to address some of the limitations and enhance the explanatory power of the original model. It incorporates additional constructs, namely social influence, job relevance, output quality, and outcome expectancy. Social influences refer to the subjective norms and social image that play an essential role in shaping users' attitudes and intentions to use technology. Job relevance is considered an external variable that affects PU and emphasizes the importance of users perceiving technology as relevant to their job task, while output quality reflects the quality of results produced by using the technology. Similarly, outcome expectancy is also introduced as an external variable and refers to users' expectations regarding the positive outcomes or benefits they anticipate from using the technology. Image is used as an external factor that influences the PU and represents the social image associated with using a particular technology. Also, the cognitive instrumental process considers a user assessment of the system's utility and usability based on their experience and perception. While TAM2 addresses some limitations of TAM, it has its own set of criticisms and challenges. TAM2 makes the model more complex and does not fully account for the contextual variations in different industries. The external factors may be subjective and difficult to quantify accurately and may face an issue in keeping up with the swift evolution of technology [51].
- **Unified theory of acceptance and technology (UTAUT):** In 2003, Venkatesh et al. [48] came out with the UTAUT model by consolidating and testing variables in the eight dominant theories and models such as TRA, TAM, TPB [52], combined TPB/TAM, the model of PC utilization, innovation diffusion theory, social cognitive theory, the motivational model. UTAUT considers four core variables such as performance expectancy (PE), effort expectancy (EE), social influence (SI), and facilitating conditions (FC), and the four moderating variables are gender, age, experience, and voluntariness of use. PE refers to the user's perception of the extent to which using a particular technology will help them achieve their job tasks and improve their performance. EE is defined as the ease of use associated with adopting and using

new technologies, whereas the SC factor refers to the user acceptance of technology having influence from colleagues and the social environment. FC is defined as the degree to which users believe that sufficient organizational and technical infrastructure supports and facilitates the use of the technology. The UTAUT model has proven to be the superior and most widely used model among all due to its simplicity, parsimony, and robustness. UTAUT model explained about 56% of the variance in behavioral intention to use technology and 40% variance in technology use. The original UTAUT has been used in various research and has inspired scholars to integrate factors from multiple existing models. The model is widely validated and extended in subsequent research fields, and its applicability has been demonstrated in various domains [53].

- **Extended Unified Theory of Acceptance and Technology (UTAUT2):** It is an extension of UTAUT and was proposed by Venkatesh et al [49] in 2012, aiming to enhance the explanatory power and predictive capabilities of UTAUT. It incorporates additional constructs such as Hedonic Motivation (HM), Price Value (PV), Habit, Gender, Age and Voluntariness of Use (VOL). HM captures the user perception related to the enjoyment and pleasure of using technology. PV represents the cost associated with using technology, while Habit reflects the extent to which users develop a pattern of using technology. VOL reflects whether the use of the technology is perceived as mandatory and may influence the relationship between models. Also, age and gender are considered as the moderators. All these additional constructs and moderators provide a more nuanced understanding of technology acceptance [50]. (Venkatesh et al., 2016).

Out of the above, this study has considered UTAUT as the suitable approach by the inclusion of three more variables such as trust, transparency, and Interfirm trust derived from existing research studies [54, 55, 56 & 57]. As blockchain is an emerging technology and is still in the early stages of development, researchers may opt to defer factors like habit and price value until a technology becomes more established. Consequently, the main objective of this study is to recognize the adoption of blockchain technology using the UTAUT model. This model is chosen to provide a solid theoretical foundation and demonstrate significant predictive efficacy in explaining and forecasting user intention to embrace technology, especially during its early developmental phases.

2.3 Blockchain adoption models in agri-food supply chain

The adoption models are applied to understand how individuals and organizations adopt and incorporate new technologies. The above mentioned adoption models in Section 2.2 contribute valuable insights for business, policy makers, researchers, offering structured approach to understand the dynamics of technology adoption in various contexts. Related studies like Sheel et al. [58] have led to a more profound understanding of adopting blockchain technology in the supply chain, indicating that it can improve supply chain adaptability, alignment, and agility, leading to a competitive environment and better firm performance. On the other side, in their empirical study, Wang et al. [59] investigated the use of blockchain in the supply chain and discussed how it can transform the supply chains in the future. The experts conducted the interview to gain valuable insights into the emerging nature of blockchain technology and its potential to revolutionize the concept of trust in supply chains. Karamchandani et al. [60] traced the evaluation of the perception and benefits of using Enterprise blockchain (EBC) among service industry practitioners in India. An extended TAM and IDT model evaluated the results and examined that the perception of EBC among service industry practitioners was dependent on the theory of EBC benefits or the publicity about the suitability of EBC. In the proposed model, perceived EBC benefits were found to significantly affect perceived usefulness in all six dimensions of service supply chain management, specifically, information quality, mass customization, service quality, supply uncertainty, delivery reliability, and customer relationship. Similarly, Miraz et al. [61] used a quantitative approach to adopt blockchain technology in the logistic food industry in Asia or blockchain enthusiasts and potential blockchain users worldwide. They proposed a research model based on UTAUT2 using SPSS and the Smart PLS platform for descriptive and testing analysis. The results indicated that blockchain could raise the transparency of the supply chain to a new level. Also, the proposed model significantly contributes to blockchain businesses and merchants in Asia.

2.4 Blockchain key concepts

Blockchain is characterized as a distributed ledger technology for recording transactions and sharing within the distributed network of nodes [62]. The transactions operate in a peer-to-peer network, and the node consists of a number of blocks for each input. Each block comprises of a block header and block body, in which block headers are important to record the present cryptographic hash value and the previous hash header value in the current block, and all the transactional information is stored in the block body. The blocks are linked together using the cryptography technique to record the transactions securely and permanently [63 & 64]. As part of a blockchain network, each computer maintains a copy of the ledger, and all copies are updated and validated at the same time on different systems. Blockchain is considered a type of database that stores and securely manages data. However, it is substantially different from conventional databases for storing data in rows, columns, tables and files. Blockchain stores data in the form of blocks that are digitally chained.

Blockchain technology establishes transparency and ensures eventual, system-wide agreement on the validity of the entire transaction history. Moreover, data integrity, decentralization, and high reliability are the main features of blockchain technology. In addition, it does not rely on third parties for communication and financial transactions, and all the transactions are traceable and immutable [65]. Blockchain technology acts as a digital platform to provide authentic information on the provenance of agricultural products. Further, it helps to reduce the food fraud and adulterations that occur in the agri-food supply chain. The peer-to-peer network of blockchain operates without central authority, where participants or nodes communicate directly with each other as shown in Figure 2.1. Each node in the network maintains a copy of the entire blockchain, ensuring decentralized data storage and redundancy.

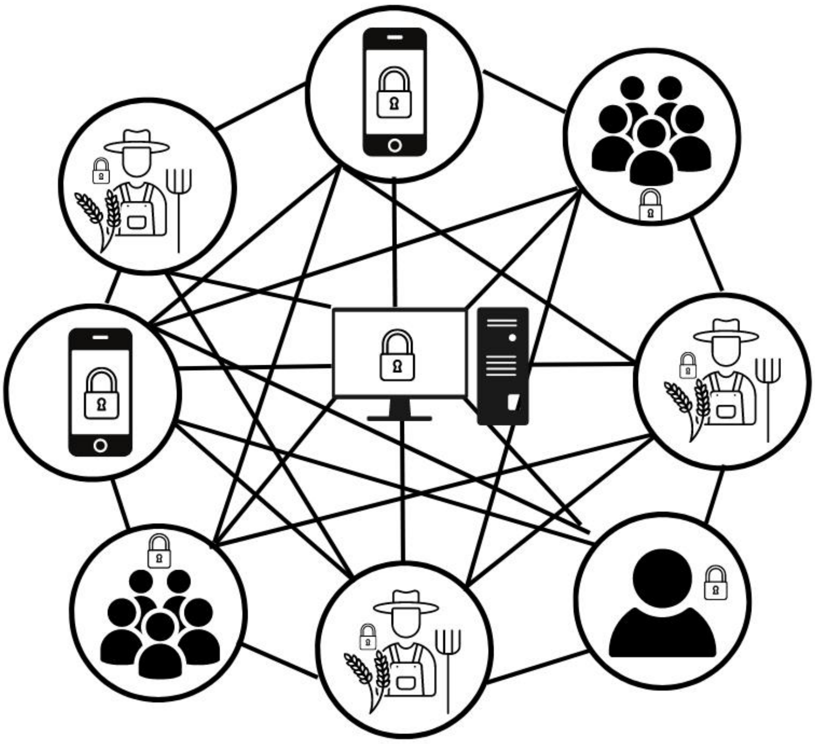


Figure 2.1 Structure of Blockchain

2.4.1 Blockchain networks

Several blockchain networks have been existed and each network is designed for specific use and functionalities are described as follow [66]:

- **Bitcoin:** It is the most popular and well-known blockchain, created to enable peer-to-peer electronic cash transactions without the need for a third party. It stands as the pioneering cryptocurrency and a transformative force in the realm of decentralized finance. The core tenets of Bitcoin include decentralization, immutability and transparency. Decentralization is established by a network of nodes that collectively validate and record transactions. Immutability ensures the security and integrity of the blockchain, as once a block is added, it cannot be altered. Bitcoin employs a proof of work (PoW) consensus mechanism, where miners engage in a competitive process to solve intricate mathematical puzzles to authenticate and append blocks to the blockchain [27]. Also, transparency allows for open scrutiny of all transactions on the public ledger, reinforcing trust and accountability. Bitcoins' journey has been marked by volatility, regulatory developments, and increasing institutional interest, solidifying its status as a revolutionary force in the world of finance and technology.
- **Ethereum:** It is a public blockchain that functions as the development and execution of smart contracts and Decentralized Applications (DApps). It operates on a proof-of-work (PoW) consensus mechanism, where miners can compete with each other to mine a new block. It is known for its programmability, enabling developers to construct a wide range of decentralized applications on its platform. Ethereum currently uses a proof of stake (PoS) consensus mechanism, transitioning from PoW. PoS relies on validators who lock up a certain amount of cryptocurrency as collateral to secure the network and validate transactions, while in a PoW system, miners can only compete with each other to solve the complex mathematical puzzle in order to validate transactions and add a new block to the blockchain without spending any cryptocurrency.
- **Fabric:** It is based on a permissioned blockchain network. It is an open-source collaborative project under the LINUX foundation that aims to advance cross-industry blockchain technologies. It is designed to develop enterprise-grade blockchain solutions with a focus on modularity, scalability, and confidentiality. It provides an extensive array of tools and libraries that enable the creation of distributed ledgers and

smart contracts. Hyperledger projects such as Hyperledger Fabric, Sawtooth, and Indy provide customizable solutions for various industries, including finance, supply chain, healthcare, and many more.

2.4.2 Ethereum blockchain

This study mainly focuses on the Ethereum blockchain from the above-mentioned blockchain networks. Ethereum is the most versatile blockchain platform that allows developers to build DApps. The Ethereum was first launched in 2015 by Vitalik Burterin. It goes beyond Bitcoin's primary use case as a digital currency, aiming to provide a versatile and programmable blockchain ecosystem. Over the past few years, there has been a notable surge in academic interest in the field of study pertaining to Ethereum. It is a public blockchain platform and offers a resilient framework for the implementation of smart contracts. It provides the virtual decentralized computer known as Ethereum Virtual Machine (EVM), which is the run time environment that executes smart contracts on the Ethereum network. It ensures uniform execution of code across the decentralized network, promoting consistency and reliability. Ether serves as the native cryptocurrency on the Ethereum platform, providing compensation to miners for validating transactions and carrying out smart contract executions. Ethereum blockchain is widely used for creating tokens through standards like ERC-20 (fungible tokens) and ERC-721 (non-fungible tokens/NFT'S). These tokens facilitate various use cases, including ICOs and the creation of unique digital assets. It has been a central player in the rise of decentralized finance (DeFi) applications. These applications provide financial services without traditional intermediaries, offering lending, borrowing, trading, etc. Ethereum is currently working on Ethereum 2.0, a major upgrade that aims to improve scalability, security and sustainability. Ethereum blockchain technology goes beyond simple value transfer, facilitating a diverse array of decentralized applications and fostering innovations in the blockchain space [67].

Ethereum has been at the forefront of advancing digital technologies, notably expanding its functionality to encompass an entire network complete with its own web browser, programming language, and trading platform. One of its standout features is its support for users in constructing distributed applications on the Ethereum blockchain. It is user-friendly, particularly when it comes to the development of decentralized applications. Ethereum introduced a sophisticated, Turning-complete language designed for crafting smart contracts at a high level of abstraction known as Solidity. It initially emerged as the primary language for smart contracts within the Ethereum platform and has evolved into a standard for other platforms with similar contract capabilities.

2.4.3 Ethereum virtual machine

The EVM is a crucial component of the Ethereum blockchain and serves as a runtime environment for executing smart contracts. It utilizes a stack-based language equipped with a predefined set of instructions, known as opcodes, along with their respective arguments. These opcodes perform specific tasks, such as arithmetic operations, data storage, and control flow within the EVM. A contract can be viewed as the opcode of statements that the EVM systematically executes in order to ensure that the smart contract on the Ethereum network can run consistently and securely across all nodes in the blockchain network.

The EVM operates on the principle of determinism, which means that the outcome of executing a smart contract is the same for all the nodes on the Ethereum network. This uniformity is crucial for upholding the integrity of the blockchain and guaranteeing that all participants reach a consensus on the state of the system. Smart contracts are compiled into the EVM bytecode before deploying on the Ethereum network, and the EVM executes this bytecode, updating the state of the blockchain according to the contract's logic [68].

2.4.4 Smart contracts

Smart contracts are contracts with self-executing terms where the fulfilment of conditions is automated. These contracts run on the blockchain network. When predefined conditions coded into the smart contracts are met, the contract automatically executes and enforces the agreed-upon terms. It is associated with a decentralized platform like Ethereum and introduced this concept. It operates without the need for intermediaries, as their execution is automated based on predefined rules. They run on a decentralized blockchain network, ensuring transparency, security, and tamper resistance. The smart contracts are relying on cryptographic techniques to secure transactions and the integrity of the contract.

The execution and validation of smart contracts are governed by the consensus mechanism of the blockchain. On platforms like Ethereum, the execution of smart contracts incurs gas fees.

Gas is a metric quantifying the computational effort necessary to execute operations on the network, and Gas fees are the charges paid by the users to compensate miners for the computational resources expended in processing and validating transactions. Smart contracts may interact with other smart contracts or external systems through predefined interfaces. These aspects are crucial for developers and stakeholders involved in the creation, deployment, and interaction of smart contracts on a blockchain platform.

Solidity programming languages are employed to script smart contracts for Ethereum. Each operation within the smart contract consumes gas, and users pay gas fees to compensate miners for processing the computations. Gas fees ensure that the network is not abused and incentivize miners to include the transactions in the block. Miners validate and execute the smart contract by running its byte code on the EVM. They verify the conditions are met and execute the associated actions. The compiled contracts are deployed to the blockchain. Once deployed, the smart contract is initialized and any necessary parameters and values are set. This may involve the interaction with other smart contracts [69]. The results of the smart contracts' execution, along with any output, are recorded on the blockchain.

2.4.5 Solidity

Solidity is a programming language crafted especially for developing smart contracts on blockchain platforms. It was developed by Ethereum Co-founder Gavin Wood. It is most commonly associated with Ethereum. It was created to enable the creation of self-executing contracts with the ability to run on the EVM. The syntax of solidity language is similar to JavaScript, making it more accessible for developers with experience in web development. It supports object-oriented programming concepts, allowing developers to structure their code using classes, inheritance, and other familiar constructs. Developing secure smart contracts requires careful consideration of the transparent and permanent characteristics of blockchain transactions. Solidity includes features and best practices to enhance security, emphasizing the importance of secure coding practices to mitigate potential vulnerabilities [70 & 71]. As the Ethereum ecosystem continues to evolve, Solidity remains pivotal in reshaping the landscape of decentralized applications and blockchain-based agreements.

2.4.6 Metamask

MetaMask functions as both a cryptocurrency wallet and a portal to DApps that run on blockchain networks, primarily Ethereum as shown in Figure 2.2. As a browser extension, it permits users to manage their Ethereum-based assets, interact with DApps, and securely store private keys. MetaMask serves as a bridge between traditional web browsers and the Ethereum blockchain, providing users with a user-friendly interface to access blockchain-based services. Participants can create and manage Ethereum wallets within MetaMask. Each wallet has a unique address and a corresponding set of private keys. Private keys are kept locally on the user's device and encrypted with a password. When interacting with DApps or sending transactions, MetaMask prompts users to review and approve transactions by signing them with their private keys. The Metamask provides introperability between different Ethereum networks, such as the mainnet, testnets (Ropsten, Rinkeby, Kovan), or custom networks [72]. This flexibility is helpful for developers testing applications on different environments.

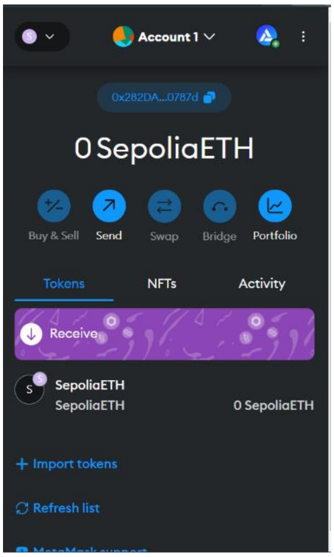


Figure 2.2 Metamask Wallet

2.4.7 Etherscan

Etherscan functions as a platform for blockchain exploration and analytics, specializing in designing for the Ethereum blockchain as presented in Figure 2.3. It allows users to explore and analyze activities on the Ethereum network. The participants can search and view details of individual transactions on the Ethereum blockchain. This includes information about the sender, recipient, amount transferred, gas fees and transaction status. It allows users to explore details about the Ethereum address to view the balance, transaction history, and token holding associated with it. Also, Etherscan provides information about the contract's source code, contract creation details and interaction with the contract. Etherscan provides Application Programming Interface (API) that developers can use to integrate Ethereum blockchain data into their applications or services [73].

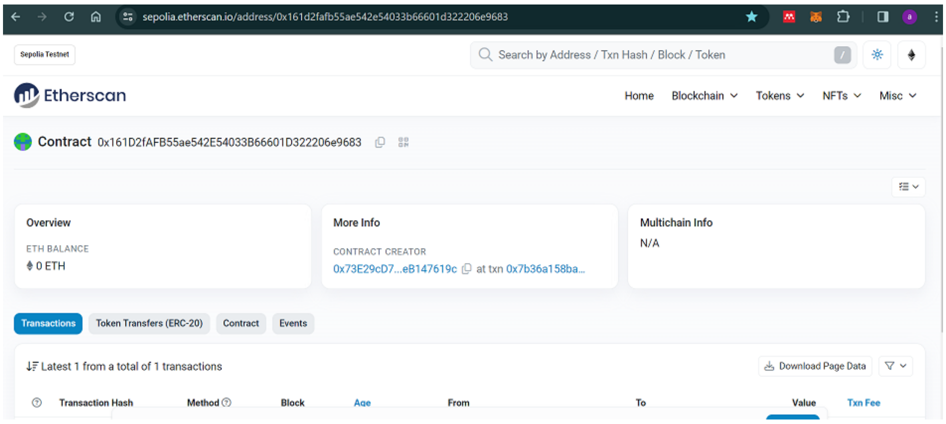


Figure 2.3 Etherscan webpage

2.5 Types of Blockchain

There are several types of blockchain, each designed with specific characteristics to suit different use cases and requirements [74]. The main types of blockchain are explained as follow:

- **Public blockchain:** It is also known as a permission less blockchain and a type of decentralized network that is open to anyone. Participants can join, validate transactions, and add blocks to the chain without the need for approval. They are often associated with cryptocurrencies. The design of a public blockchain can offer transparency, openness, trust among participants, and inclusivity. The participants can view the entire transaction history and contribute to the consensus process. The public blockchain is accessible to anyone with an internet connection. Example: Bitcoin and Ethereum
- **Private blockchain:** It is also known as permission blockchain; it is a type of blockchain network where access to the network and participation in the consensus mechanism is restricted to a specific group of participants. Participants must be invited or approved by the network administrator to be a part of the blockchain network. It

needs authorization to join and contribute to the network. Private blockchain are operated by a single organization or a group of collaborating organizations. It offers advantages in terms of efficiency, privacy, and control.
Example: Enterprise solution

- **Consortium blockchain:** It operates within a semi-decentralized structure, under the governance of a collective of organizations rather than a singular entity. In a consortium blockchain, multiple organizations collectively maintain and govern the blockchain network. It is designed to maintain a balance between the decentralized public blockchain and the controlled access of the private blockchain. It offers high transaction throughput and efficiency as compared to a fully decentralized public blockchain. Example: R3 Corda. Differences between various types of blockchain technology are presented in Table 2.1, with an example.
- **Hybrid blockchain:** A hybrid blockchain is a combination of public and private blockchain networks, offering a flexible and customizable approach to blockchain technology. In a hybrid blockchain, certain aspects of the network are public, allowing for transparency and decentralization, while other aspects are private, providing enhanced privacy and control over sensitive information. This hybrid model enables organizations to leverage the benefits of both public and private blockchain, tailoring the network architecture to suit their specific needs and requirements.

Table 2.1 Types of Blockchain technology

Features	**Public blockchain**	**Private blockchain**	**Consortium blockchain**	**Hybrid blockchain**
Accessibility	Anyone can access the system	Only the permissioned users can access	Permissioned blockchain	Permissioned and permissioned less
Number of users participate	Any number of users can participate	Limited number of participants can register	Only known identities participants	Public and private users both
Trust among participants	Require no trust among participants of the network	Participant requires trust	Trusted participants	Both participants
Transaction speed	Slower	Faster than the public blockchain	Lighter and Faster than private and public blockchain	Optimize transactional speed
Transaction cost	High	Low	Low	Low
Consensus mechanism	Proof of Work	Proof of Authority	Practical Byzantine Fault Tolerance	Hybrid Proof of Work and Proof of Stake
Existing platforms	Ethereum, Cardano, Harmony	Hyperledger, Ripple, Ethereum express coin	R3 Corda	Quorum

2.6 Cryptography primitives in Blockchain

Cryptography plays a foundational role in ensuring the security, integrity, and privacy of transactions and data within blockchain technology. Several cryptographic primitives are discussed below:

2.6.1 Symmetric key cryptography

Symmetric key cryptography is a cryptographic technique where the same key is used for both the encryption and decryption of data. The communication between parties share a common secret key, known only to them, which is utilized for converting plaintext into ciphertext in the encryption process and subsequently back into plaintext during decryption as shown in Figure

2.4. Symmetric key algorithms are efficient and fast, making them suitable for encrypting large volumes of data and securing communication channels. However, one of the primary challenges lies in securely distributing and managing the shared secret key among the communicating parties. Despite this challenge, symmetric key cryptography is a fundamental component in various security applications, ensuring confidentiality, integrity, and authentication in data protection and secure communication [75].

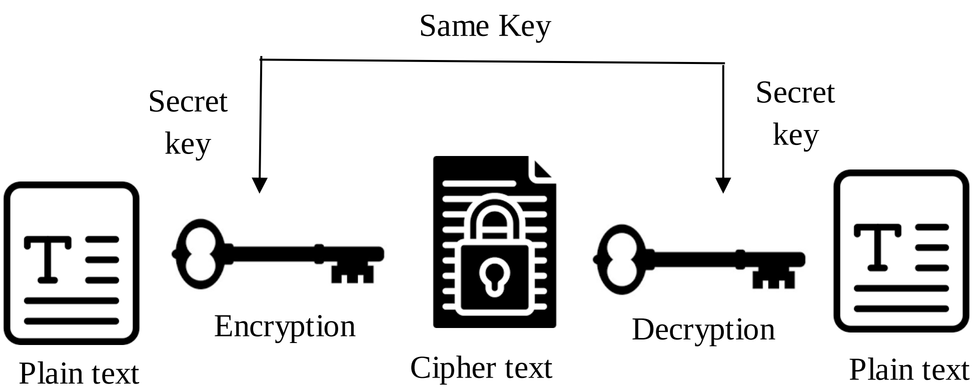


Figure 2.4 Symmetric key cryptography

2.6.2 Asymmetric key cryptography

Asymmetric key cryptography, commonly referred to as public-key cryptography, is a cryptographic system that employs a duo of distinct yet mathematically related keys for encryption and decryption. In this, each participant has a public key, which is widely distributed and can be shared openly, and a private key, which is kept confidential by each user, as shown in Figure 2.5. The public key is employed for encrypting messages, and conversely, the private key is utilized for decrypting them. What sets asymmetric cryptography apart from symmetric key cryptography is that information encrypted using the public key can solely be deciphered by the corresponding private key and vice versa. This system provides a secure and efficient method of ensuring secure communication, implementing digital signatures, and facilitating key exchange in a myriad of applications. In blockchain technology, asymmetric key cryptography is used to ensure the authenticity, integrity, and confidentiality of transactions in a decentralized and trustless environment [76].

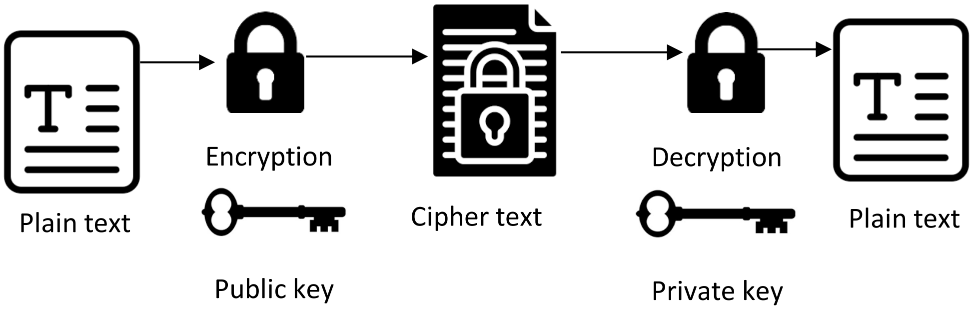


Figure 2.5 Asymmetric Key Cryptography

2.6.3 Digital signatures

A digital signature is a cryptographic technique used to verify the authenticity and integrity of digital messages and transactions. It provides a way for the sender of a message to provide their identity, confirm the sources of the information and ensure that the content has not been altered during transmission. It plays a crucial role in securing electronic communications and transactions.

The process begins with the generation of a cryptographic key pair for the individual. This key pair consists of a private key and a corresponding public key. For signing a digital message, the sender uses their private key to perform a mathematical operation on the content. This operation generates a unique string of characters known as digital signatures. On the other side, to verify the digital signature, the user sends their public key to check the digital signature. If the signature is valid, it confirms that the message was signed by the authentic user and the content has not been tampered with. The security of digital signatures relies on the secure management of private keys. If the private key is compromised, it could lead to unauthorized signing [77].

2.6.4 Hash function

In blockchain cryptography, its function is to play an important role in ensuring the integrity and data security. It is a mathematical algorithm that accepts an input and generates a string of characters with a fixed size known as the hash value. In the hashing, the same input will always produce the same hash output. Also, regardless of the size of the input, the hash function always produces a fixed-size output. It should be computationally impossible to reverse the process of hashing and determine the original input from its hash value.

Hash functions ensure the integrity of data on the blockchain. Every block within the blockchain comprises a hash of its content. Any change in the block data would result in a different hash, altering the network to potential tampering. Each block contains the hash derived from the preceding block. This establishes a sequence of blocks, and any modifications to a block would change its hash, breaking the blockchain [78].

2.6.5 Merkel hash tree

Merkle tree is referred to as hash tree, particularly employed in blockchain to ensure the integrity of transaction data within a block. The structure of a Merkle tree involves a hierarchy of hash values, starting from individual pieces of data at the bottom level as presented in Figure 2.6.

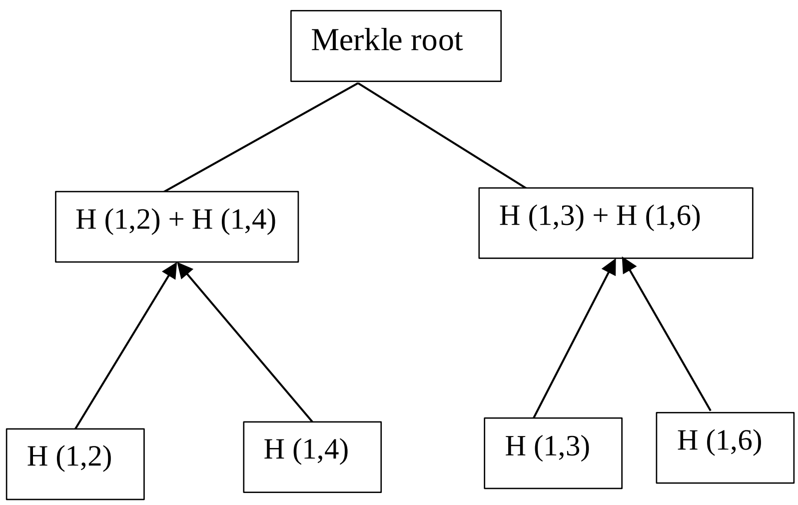


Figure 2.6 Merkle tree structure

The leaves are hashed in pairs, and the resulting hash values are combined and hashed again until a single root, known as Merkle root, is obtained at the top of the tree. The Merkle root represents a compact and unique fingerprint of the entire data set. By comparing only, the Merkle root and a few intermediate hashes along the path, the user can confirm whether a specific piece of data is included in the tree without the need to process the entire dataset [79]. This efficiency is particularly valuable in blockchain systems, where a large amount of transaction data is organized in blocks.

2.6.6 Working of cryptography in Blockchain

Blockchain is a decentralized technology that allows multiple parties to have a secure, transparent and tamper-resistant record of transactions. Blockchain technology uses a cryptography technique for secure transactions by using mathematical algorithms to create digital signatures, hash functions, and encryption of data [80]. The working of cryptography in blockchain is represented in Figure 2.7 Blockchain employs asymmetric or public-key cryptography. Every participant in the network possesses a pair of keys, such as a public or private key. The public key is shared across the network, while the private key is kept secret. The message is encrypted with the public key and can only be deciphered with the corresponding private key. Upon initiating transactions, users utilize their private key to generate a digital signature for that transaction.

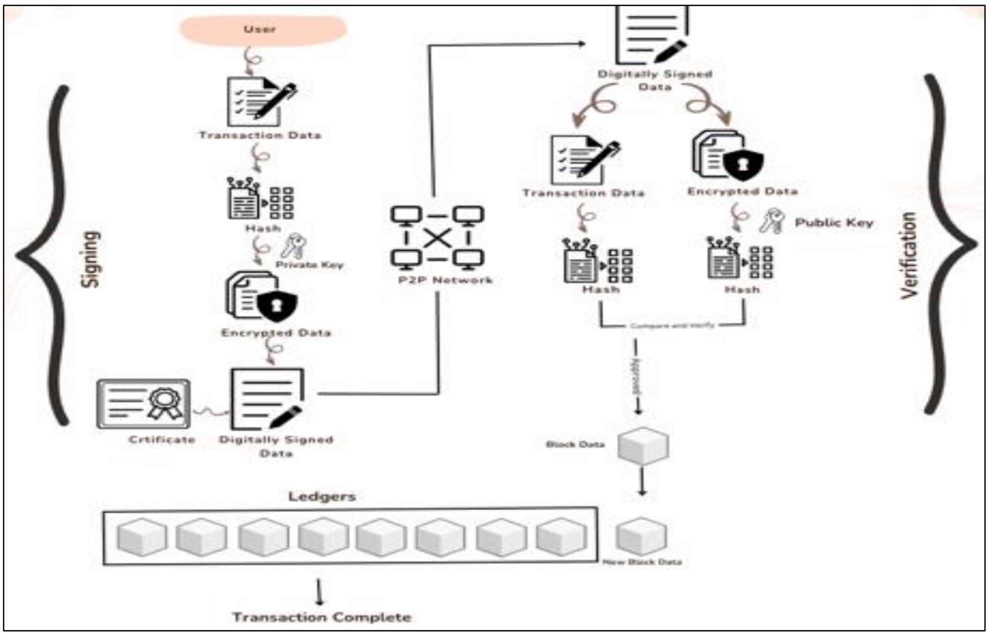


Figure 2.7 Working of blockchain network using cryptographic techniques

The digital signature provides proof of authorization that the transaction is sent by the owner of the private key without revealing the key itself. The transaction is broadcasted to the network, making it visible to all the participants. Nodes on the network validate the transactions by verifying the digital signature using the public key of the sender's address. If the digital signature matches the sender's address, the transaction is validated and verified by the other user. Moreover, the transaction, along with others, enters the consensus mechanism process where participants collectively agree on the order and the validity of transactions. Once confirmed through consensus, the transaction is added to a block.

2.7 Blockchain architecture

The blockchain network is made up of many components. It is a decentralized and distributed ledger technology that enables secure and transparent transactions without the need for a third party. The architecture of blockchain is represented in Figure 2.8 In which N number of blocks are interconnected with each other to form the chain of blocks [81]. The key components and their roles in the blockchain network are described below:

- **Nodes:** These are individual computers or devices that participate in the blockchain network. Each node stores the entire copy of the blockchain, making it distributed across the network. It is further categorized into different types of nodes, such as full nodes and lightweight nodes. The full nodes can validate transactions and mine blocks, while lightweight nodes rely on full nodes for the verification.
- **Blocks:** Each block in the blockchain refers to the collection of data that is bundled together and added to the blockchain. Each block contains a set of transactions and is linked to the previous block through the cryptographic hash, forming a chain of blocks. The block includes the following components:
    - **List of transactions:** This is the actual information stored in the block. It consists data that is exchanged between two parties in the form of list of transactions.
    - **Timestamp:** It represents the time at which the block is created
    - **Nonce:** It is the random value included in the block header that is adjusted during the mining process to meet the specific criteria for the block to be considered valid or mined.

- **Merkle tree root**: It represents the hash of all the transactions within the block. It is arranged in a Merkle tree structure, which provides an efficient way to verify the integrity of the transactions.
- **Hash:** It uniquely represents the identity of the block and is crucial for preserving the integrity of the blockchain network.

The initial block of the blockchain is referred as the "genesis block." The subsequent blocks are connected with the hash of the previous block in their block header, which creates a chain of blocks. If any information in a block is altered, it affects the hash of that block, which in turn affects the hash of the subsequent blocks. Due to this, blockchain technology is immutable in nature. The process of adding a new block to the blockchain network is known as "mining" in the context of PoW consensus mechanisms. Miners need to solve the complex mathematical puzzle, and the first one to solve it gets the right to add a new block to the blockchain. The use of blocks and the linked structure in a blockchain that provides a secure and transparent solution to record and verify transactions, ensuring the immutability and integrity of the data on the network.

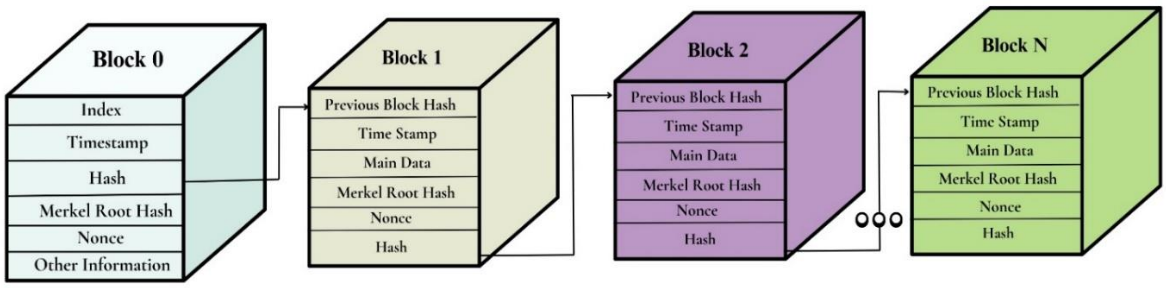


Figure 2.8 Blockchain architecture

2.8 Consensus mechanisms

Consensus mechanisms are the algorithms that allow multiple decentralized participants to agree on the state of the distributed ledger. In the trustless and decentralized blockchain environment, consensus plays an important role in all the participants agreeing on the validity and the order of transactions, preventing double spending, and maintaining the integrity of the blockchain network. It makes sure that each newly added block to the blockchain represents a consensus truth unanimously agreed upon by all nodes in the network [30]. Some of the working process of consensus mechanisms are discussed below:

- **Proof of Work (PoW):** It is one of the most popular consensus mechanisms in which participants, known as "miners," who compete with each other to solve complex mathematical puzzles. The first to solve the puzzle broadcasts the solution on the network, and others verify it. If verified, the block is added to the blockchain, and the miners are awarded.
- **Proof of Stake (PoS):** The most common alternative to the PoW is PoS. It is a mechanism in which validators are selected to create a new block based on the amount of cryptocurrency they hold or have staked. Instead of solving complex puzzles, validators invest in coins by locking up some of their coins as stakes. Validators will validate the blocks by betting on them and finding a block that can be added to the chain. Afterward, all the validators will get rewarded according to their bets, and their stakes will increase accordingly. In terms of computational power, PoS consume less computational power than PoW.
- **Proof of Burn (PoB):** In this type of mechanism, participants burn some of their cryptocurrency to gain the right to mine or validate blocks based on a random selection process. If the validator burns more coins, the better their chances of selection to mine the next block.
- **Proof of Authority (PoA):** In the PoA consensus mechanism, validators are pre-approved and trusted to create a new block in the blockchain network. The process is relying on the reputation and identity of validators rather than computational work or stake of coins.
- **Practical Byzantine Fault Tolerance (PBFT):** This type of consensus mechanism is suitable for permissioned blockchain. It requires a predetermined number of nodes to reach a consensus on a transaction before it is added to the ledger. It provides faster transaction confirmation than other consensus mechanisms.

2.9 Blockchain key issues

This section discusses some of the current challenges encountered by blockchain technology, which may help in fostering research in this area as described follows:

- **Lack of standards and user experience**: Blockchain technology is commonly known for cryptocurrency, but the technology has widened its application in various fields over the last few years. Several pilot projects are running, and some European countries adopted blockchain technology in different organizations. Due to the less implementation of blockchain technology in developing countries, some researchers conclude that technology is still in the initial stages and is immature till now. There is also a problem of insufficient skills of users to operate and implement the new technology [29].

- **Implementation cost:** A lot of costs, including time and money, would be taken to change the system. Firstly, the cost of sensors, chips, and tags is very high and secondly, the traceability system requires a huge amount of investment, so the complete implementation cost of blockchain technology might be too high. There are both negative and positive aspects of using new technology, it increases the implementation cost at an initial stage, but on the other side, it also increases the efficiency of various systems, reduces the overall cost in the future, and helps preserve the security of data [82].
- **Scalability issue:** The blockchain has gained a lot of attention over the last few years. The number of users and transactions also increased day by day making blockchain bulkier. It could not fulfil the requirement of processing thousands of transactions at one time. Issues related to scalability occur in blockchain as block sizes grow larger leading to adverse effects on factors, like transaction throughput, computational energy, and cost [83].
- **Interoperability:** Achieving interoperability between different blockchain platforms and networks remain a challenge [82].
- **Energy consumption:** PoW consensus mechanisms, used by some prominent blockchain, consume significant amount of energy [82].
- **Consensus algorithm:** The consensus mechanism has a vulnerability of about 51%, which a malicious attacker can easily attack. The software mechanism of blockchain technology would address some issues, such as the consensus algorithms' data uploading speed of the blockchain platform and capacity to store the number of transactions [83].
- **Security and privacy issues:** Despite the benefits of blockchain such as immutability of data storage, decentralized network, and peer-to-peer communication which enhances security and privacy. However, blockchain technology faces a problem related to the security and privacy of data. Several attacks might be feasible in the

blockchain system, such as selfish mining attacks, decentralized autonomous attack, border protocol hijacking attack, eclipse attack etc [29].

2.10 Blockchain initiatives

Blockchain implementation varies across countries, and governments, industries, and organizations worldwide. They are exploring and adopting this technology for diverse use cases. Here are some examples of blockchain implementation in various countries, such as China, which has been actively working on the development and implementation of its digitalized currency issued by the central bank, commonly referred to as DCEP. In the United States, several U.S. companies are exploring the application of blockchain in the retail and food sector to enhance transparency and traceability in supply chains. Also, U.S. government agencies are exploring its applications for improving efficiency in processes such as identity verification. The city of Dubai has also implemented blockchain in various sectors through its Smart Dubai initiative, including land registration, government services, and supply chain management. Moreover, The Monetary Authority of Singapore (MAS) has been running Project Ubin, exploring the use of blockchain for clearing and settlement in the financial sector. South Korea has implemented blockchain in healthcare to manage patient data securely [29, 72 & 74]. Several Indian states are exploring blockchain for applications such as land records, education certificates, and supply chain management. According to the National Institution for Transforming India (NITI Aayog**)** report on Blockchain: The Indian Strategy 2020, blockchain is acknowledged as a technology with the potential to revolutionize various facets of our lives. It has the potential to transform all industries and economies. It is believed that blockchain could generate USD3 trillion per year by 2030 and add value to the business by streamlining processes, diminishing inefficiency, cost optimization, etc.

Niti Ayog, in partnership with PwC and Intel, started a pilot project to optimize the fertilizer subsidy supply chain using blockchain technology to maintain a transparent and tamper-proof ledger to track and trace the fertilizer movement across the supply chain. Additionally, blockchain has been implemented in various applications such as land record systems, pharma skeptical supply chains, superset: anti-fraud intelligence blockchain solutions for educational certificates, and many more.

According to a report on the National Strategy on Blockchain Towards Enabling Trusted Digital Platforms by the Ministry of Electronics and Information Technology Government of

India in December 2021, blockchain technology adds business value to many innovative companies that will implement blockchain solutions and create worth $10 billion. It is estimated that by 2025, blockchain will add a business value that will grow to over $176 billion and will also increase further to $3.1 trillion by 2030. By 2030, blockchain technology is projected to serve as a foundational technology for 30% of the global customer. Furthermore, the estimation of the Global Blockchain Government Market by Geography in the period of 2020- 2027 from Maximize Market Research Pvt. Ltd depicts that the adoption of Blockchain technology for Government use cases will rise over time. Despite all these opportunities, blockchain has faced some challenges, such as technology adoption, regulatory compliance, awareness and skill set, data format, and identification of suitable use cases [84].

The Ministry of Electronics and Information Technology (MeitY) has recognized blockchain as one of the important research areas and has explored its potential in different sectors such as governance, banking and finance, agriculture, e-voting, cybersecurity, etc. Some of the automobile industry has launched their blockchain platforms known as mobility open blockchain initiatives to make it greener, safer and more affordable. In India, some of the initiatives have already been introduced in the past few years, such as Bank Chain, which collaborates with 27 banks on the blockchain platform. The India chain, developed by NITI AYOG, explores the health, education, and agriculture sectors. It is currently piloted in the education sector for issuing educational certificates. Indian Institute of Technology (IIT), Bombay and IIT Delhi have been chosen for the trials. Andhra Pradesh has launched the land registry and transport sector project. Maharashtra has also launched projects in the areas of financial inclusion, land record keeping, supply chain financing, insurance, and motor vehicle registration. Some other states, such as Telangana, Karnataka, and Gujrat, are also planning to start pilot projects to explore the blockchain platform [85].

2.11 Emergence of blockchain in agri-food supply chain

Satoshi Nakamoto first introduced the term blockchain in his paper "Bitcoin: A peer-to-peer electronic cash system" in 2008. In its starting phase, it was used in the financial sector for cryptocurrency, in which the transactions were directly sent from one user to another without the intervention of any other party [27]. Since 2014, blockchain has been actively exploring its potential applications across diverse domain such as supply chain, healthcare, voting systems, cross-border payments, real estate and property transactions, energy trading, pharma supply chain [86], transport and logistics [87] and many more [9]. Blockchain technology provides security and privacy of the data and provides a highly trusted platform to reduce the intervention of third parties [88].

Blockchain is considered a solution to the food supply chain and ensures risk reduction and trust among various stakeholders. Also, it is transparent and secure and can rebuild consumers' confidence without the need for intermediaries, which revolutionizes the agriculture and food industry. Therefore, this study is inclined towards the scope of blockchain in the agri-food supply chain. In the food supply chain, blockchain technology tracks the complete information of the product and keeps a record of different stakeholders involved in the process. Also, it ensures the supply of multiple products between different vendors to enhance the overall performance of the supply chain. It can make a secure and transparent food supply chain and create trust among various parties involved in the system [89]. For example, AgriDigital was founded by Australian farmers in 2015. Agribusiness professionals have eight years of experience in the grain industry using blockchain technology to develop security and trust and add value to the agricultural sector [90]. Similarly, the application of blockchain technology has been developed in China, and it is observed that a blockchain-based system was more efficient and authentic and helped the government, customers, and manufacturers to monitor all the transactions in the food supply chain as compared with the traditional supply chains [91]. Despite examining in most of the developing countries the benefits of blockchain technology in the food supply chain, it is still in its conceptual phase and not in practice till date.

In 2018, Walmart was the first to implement "Blockchain technology" in the food supply chain. It was used for the tracking of pork in China and mangoes in America. In collaboration with IBM Solution, Walmart accomplished blockchain adoption in its two pilot studies in 2017. It reduced the tracking duration of mangoes reduced significantly from 7 days to 2.2 seconds and successfully developed full traceability of the food supply chain and trust among customers. This traceability solution has also cut costs and maintained food safety in the supply chain [92]. After Walmart executed blockchain technology, the trend of blockchain technology is rising day by day. The various countries are adopting blockchain solutions such as USA, Switzerland and China. Cortez-Zaga et al. [93] proposed the model of Peruvian agriculture by using smart contracts and blockchain technology for the commercialization of agriculture products. Moreover, to validate the model, a survey was conducted from the companies for the acceptance of new technologies, which shows that 50% of them were appraised as "very acceptable" and the rest 50% as "acceptable." Furthermore, on the marketing side, 60% of them are considered "very acceptable" and 40% as "acceptable," which shows that selling agricultural products through smart contracts was a promising task. In 2020, Liu et al. [94] developed a green agri-food supply chain to create trust among companies and trace product quality from beginning to end in the supply chain in China. Implementing blockchain and big data in the green agri-food supply chain would increase consumers' belief in food safety. The supply chain members would also optimize the cost by using the valuable information from the system.

Chandra et al. [95] proposed the blockchain framework to address challenges in the Halal food sector, such as poor harmonization of Halal certification, poor regulation of raw materials, and scrutiny of suppliers. The hyper-ledger fabric composer was used to design the new Halal food business model to track the history of the product. The model has faced some of the limitations such as cost, participant's incompetency, scalability, cryptographic key management, and other financial risks.

2.12 Blockchain in agri-food supply chain

This research study is mainly focused on the agri-food supply chain to make it a transparent, traceable, and decentralized system that enhances efficiency and trust among stakeholders. The workflow of the blockchain-based agri-food supply chain system is shown in Figure 2.9. At the production stage, farmers take care of everything, from sowing seed to planting and harvesting to processing. All the data will be recorded as a block on the blockchain. Each product is labelled with a unique QR code linked to the blockchain network, enabling stakeholders to track the product journey. Smart contracts or self-executing programmable agreements will be executed between two parties when they deal with each other. The industry purchases the products from the farmers and transforms them into more finished goods. All the data is recorded on the blockchain platform in chronological and unchangeable form with unique identification. Furthermore, the products move to distributors who are responsible for the inventory, expected deliveries and shipments to retailers. Retailers sold the products to the wholesalers, Marts, etc. In the end, consumers can get the product from the market, access the entire journey of the product, and verify the authenticity, quality, and origin of the purchased item, promoting transparency and consumer trust.

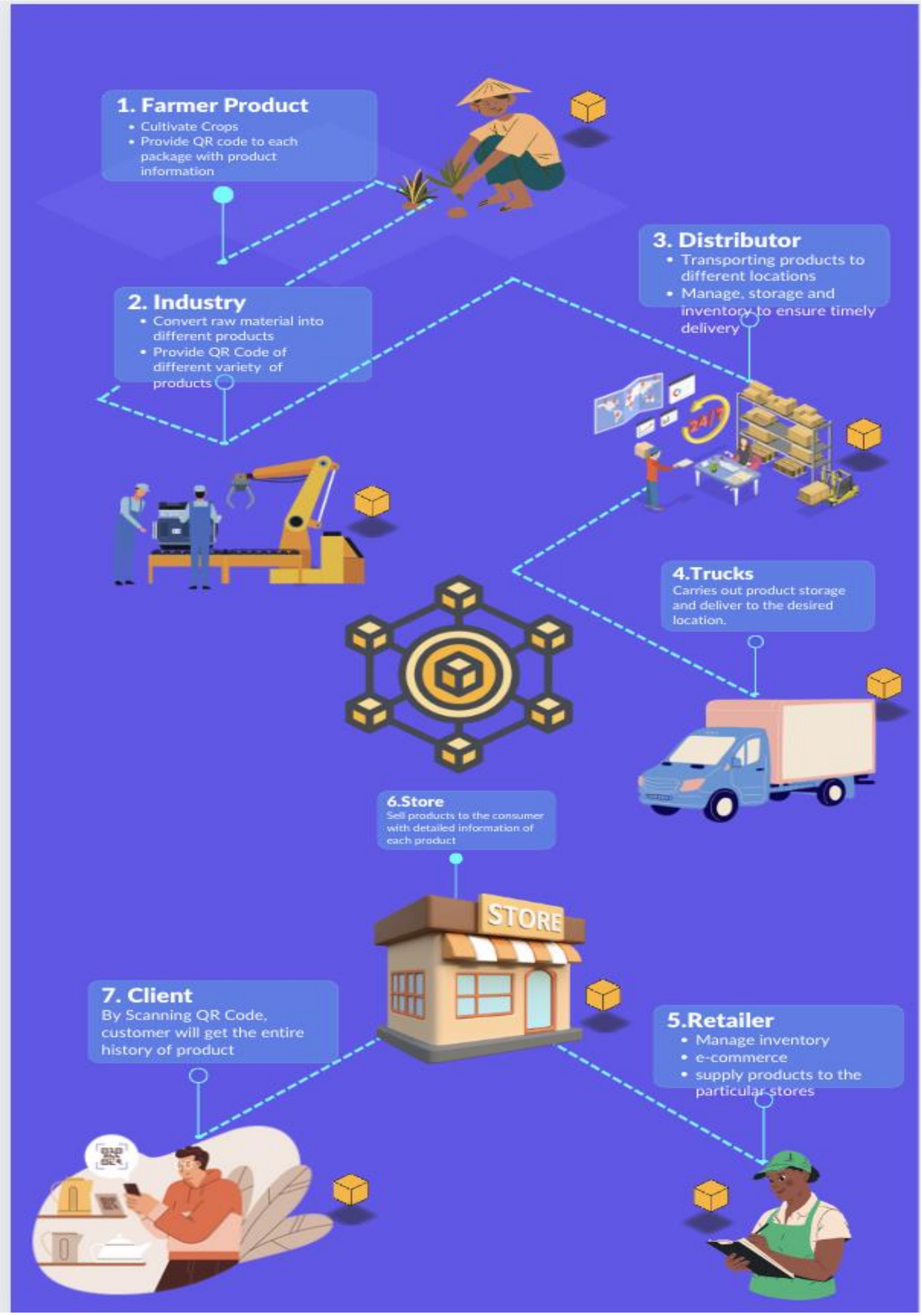


Figure 2.9 Blockchain technology in agri-food supply chain management

2.13 Blockchain-based frameworks in agri-food supply chain management

The existing literature has explored various platforms based on public, private, Consortium and hybrid blockchain. Both private and public blockchain are equally important, depending on the service and convenience they provide to the user. The existing summary of blockchain based frameworks are presented in Table 2.2 which describes the product-based blockchain framework & Table 2.3 describes the general blockchain frameworks in agri-food supply chain. Tian. [29] described the conceptual framework for traceability of the agri-food supply chain. It helps the traceability of the product, manages transparency, enhances credibility, and also helps to find frauds. Lin et al. [96] proposed an ICT-e agriculture system with blockchain technology infrastructure used locally and nationally. A shift from ICT to blockchain creates trust among various stakeholders, immutable functioning, and transparency for the users. Kumar et al. [97] presented a theoretical model of blockchain technology in the entire rice supply chain process, starting from the paddy of farmers to the consumer. This system helps to reduce fraud and system error and provides the entire history and traceability of the rice supply chain. Liu et al. [63] developed a data storage model of an integrated IPFS using blockchain technology. The application system was also designed for the traceability of agricultural products, and it is superior and ensures data security. Lucena et al. [98] described the application of blockchain technology in the agriculture sector for grain quality assurance tracking systems. This could increase the efficiency of the industries and save time and cost throughout the supply chain. Similarly, Caro et al. [76] presented the agri block-IoT system for agri-food supply chain management. The prototype was evaluated by comparing it on two different blockchain platforms, Ethereum and Hyperledger Sawtooth. The performance of the two was evaluated in the context of latency, CPU load, and network usage. Hyper ledger saw tooth platform showed better results as compared to Ethereum platform. Leng et al. [99] designed a public blockchain for agriculture supply chain based on double chain architecture to provide a public service platform, adaptive rent-seeking and matching mechanism. It ensures the transparency and security of the system. Furthermore, it enhances the credibility of the public platform and the efficiency of the system. Helo et al. [81] developed a Blockchain-based Logistic Monitoring System to track the whole history of the process. The result shows that it is a promising platform for data transparency, automation, and creating trust among users, but the shift from a traditional supply chain to a blockchain supply chain was not an easy task. Lin et al. [77] proposed a food traceability system based on blockchain and EPC service. They successfully removed the data explosion problem on blockchain to guarantee information security and avoid spam attacks. Furthermore, this model was superior to the centralized, EPICS-based, and specific blockchain-based systems in terms of information traceability, privacy protection, tamper-proof ability, and degree of decentralization. Baralla et al. [100] proposed a European agri-food supply chain traceability system. This model addressed the critical challenges of the centralized supply chain system, and users were allowed to see the identity of any participant involved in the whole supply chain, which creates trust among users. Kale et al. [101] integrated IoT devices and blockchain named agri-food supply chain management system or Agri-block IoT. The results indicate that the blockchain-based decentralized system is faster than the traditional centralized system. Similarly, Devi et al. [64] proposed an architecture that integrates IoT and blockchain for smart agriculture. The IoT blockchain-based smart agriculture was designed by considering smoke and fire control nodes. The system stored smoke fire details transactions, monitored smoke fire status transactions, and finally accessed the transaction. The throughput and latency of the system were evaluated to enhance the performance of security and data transparency. Dasaklis et al. [102] developed the blockchain-enabled supply chain traceability system to determine the granularity level of different levels of the supply chain system. This architecture addresses the benefits of trust, suitability, quality, and traceability of the food supply chain. Casino et al. [103] developed an automatic food supply chain traceability system to deliver high-quality products to consumers. Arena et al. [30] presented BRUSCHETTA, a blockchain-based application for the traceability of the extra virgin olive oil supply chain using OMNet++ simulator from plantation to consumers. The result revealed that the proposed approach could not be suitable due to the varying transaction arrival rates. So, the new mechanism for dynamic auto-tuning of blockchain parameters was developed to store information data quickly in the blockchain. Containerized food was vulnerable to the hygiene and quality of the product, so the authors designed a framework to track the containerized food from farm to fork in Greece [104]. Mao et al. [88] proposed a Food Trading System with Consortium Blockchain (FTSCON), which increases the privacy and security of transactions. The author also improved the existing Practical Byzantine Fault Tolerance (PBFT) consensus algorithm into (iPBFT) to increase the efficiency of the system. FTSCON addresses the security requirements such as privacy protection of transactions, transaction authentication, data integrity, and no duplicity of transactions and provides a robust and scalable system.

Grecuccio *et al*. [105] developed a framework to solve the challenges of food integrity and safety. Bumblauskas et al. [82] implemented blockchain technology for the traceability of eggs from production to consumers in a company in the Midwestern USA. Patel et al. [70] developed a Farmer's Credit scheme based on a blockchain platform to ensure the quality of agricultural food. Majdalawieh et al. [67] proposed a blockchain and IoT-based framework to improve the safety and quality of food products. Zhang et al. [106] crafted a reliable traceability model encompassing the entire supply chain for grain and oil food from processing, warehousing, transportation, and sales to consumers. The blockchain master–slave multichain storage mechanism was adopted over the single-chain architecture to solve the problem of large and complex data and thus meets the efficiency and improves the reliability of data information storage. The comprehensive traceability model can standardize the production process and ensure product quality, safety, and reliability of traceability information by using smart contracts. Valencia-Payan et al. [83] developed the traceability mechanism of coffee beans for the proper management of coffee sacks. The application of a honey supply chain based on smart contracts has been developed by Marchesi et al. [72] to track the information on honey from all the processes until the end. In contrast, Patro et al. [68] proposed a model to track the operations of the fishery supply chain. Brazil was the 21st largest exporter of grain globally, and blockchain was considered a fair-trading system for them. So, Brazilian agriculture gave us the real-life implementation of blockchain business networks in supply chain management. Varavallo et al. [107] developed a traceability mechanism based on Green Blockchain emphasizing a low energy consumption, minimum environmental impact, and cost savings for the Fontina PDO cheese supply chain. The Algorand blockchain, the most powerful and sustainable blockchain, was used and applied a Pure Proof-of-Stake validation mechanism. This new consensus procedure requires minimal computational power and is highly scalable. Khan et al. [108] proposed a framework to analyze the regular transactions that existed for price forecasting. In their work published in 2022, Ehsan et al. [71] introduce a traceability model based on blockchain, aiming to uphold the integrity and transparency of the system. Subashini and Hemavathi. [109] developed the permission blockchain to track the origin of agricultural products. The smart contract based on Ethereum private blockchain and simulation results shows reducing the execution time, latency, and throughput overheads. Valencia-Payan et al. [69] proposed the permissioned blockchain network for the traceability of food social sales. A smart contract was generated on Hyperledger Caliper, which had an average throughput of 12.6 transactions per second and an average latency of 0.3 seconds for the asset and update process.

Table 2.2 Comparison of the existing Product-specific frameworks using blockchain technology in the food supply chain

Paper	Product	Technology involved & Consensus Mechanism	Blockchain platform	Type of blockchain	Description	Advantages	Disadvantages
[97]	Rice	Blockchain technology and smart contracts	Theoretical framework	-	The conceptual framework was designed to track the whole product history, which helps reduce system errors.	1) Fraud reduction 2) Minimization of system error. 3) Create a permanent history of the rice from manufacturer to sale	1) The implementation has not been seen yet
[98]	Grain (GEN)	Blockchain, scanner, and cloud computing	Hyper-ledger fabric	Private blockchain and consortium blockchain	Desktop application-based was designed to control and verify the quality assurance of grain which reduces the overall cost of the supply chain.	1) Disputes among business partners are reduced. 2) The efficiency of the industry is increased. 3) Saving time and cost. 4) Increased the overall throughput of the trade process.	1) The complex structure of international trade has yet to be proven.
[110]	Soya bean	IoT, sensors, cameras, GPS locator, 4G communication, and blockchain technology, smart contract	Ethereum	Public blockchain	The framework was designed using Entity-relationship diagrams, and sequence diagrams to describe the number of entities involved the algorithm has been designed to increase the efficiency of this new system.	1) To trace, trail, and perform business transactions. 2) To remove intermediaries across supply chain management.	1) The challenges such as scalability, privacy standards, and regulations are still to be addressed.

[30]	Olive oil (BRUSCHETTA)	IoT, sensors and blockchain technology, smart contracts and consensus algorithm	Hyper ledger fabric	Permission/ private blockchain	The blockchain-based application has designed and various parameters such as maximum transactions per block, transaction rate, consensus algorithm execution time and maximum block generation time of the system was evaluated.	1) Track the entire manufacture process from the plantation to reach at consumer. 2) Give tamper-proof copy of the entire history of transaction.	1) The approach cannot be realized in a real-time Industry. 2) Transaction arrival rate may vary over time.
[104]	Containerized food	IoT, smart sensor and blockchain technology, Proof of concept consensus algorithm	Hyper-ledger fabric framework	Private blockchain	The framework was designed, exchange data and additional cost are the key parameters for documenting feasibility.	1) To track the quality of containerized food. 2) To track the farming processes. 3) Maintain a focus on third-party logistics.	1) The cost of implementing blockchain technology is challenging. 2) The high cost of using sensors to collect the data.
[82]	Egg tracking system from farm to fork	IoT sensors, blockchain, proof of concept consensus algorithm, proof of elapsed time	Hyper-ledger saw tooth v1.0	Permission/ private blockchain	The web application was designed for the customer end to track the whole history of an egg.	1) Ensures traceability 2) Improved tracking methods and supply chain analytics. 3) Revolutionary technology to transform the food supply chain.	1) Hurdle to adopt a new technology system. 2) Standardization is required.
[74]	Carasau bread of Italy	IoT, RFID tags, IPFS,	Ethereum blockchain	Permissionless blockchain	This study developed a decentralized application that manages the whole Carasau bread supply chain to verify the features of the foods	1) It assures the quality of agri-food product by integrating all the stakeholders onto a single platform 2) It provides a transparent system and, all the actors in the chain 3) No tampering is possible.	1) The cost of the system is not taken into consideration 2) Also, the cost of gas to execute the Ethereum transaction, the of external database and the cost of setting up the WSN are not described
[67]	Poultry food supply chain industry	Smart contract, Solidity	Ethereum blockchain	Public blockchain	This study proposed blockchain and IoT-based frameworks to control and observe the functioning of poultry industry's and hence improve the quality of products formed	It provides tamperproof and immutable transactions It prevents to deliver poor quality and deteriorated products	-

[83]	Coffee beans	Smart contracts, sensors,	Hyper ledger fabric & Hyperledger Caliper tool	Private blockchain	Due to the improper handling, transportation and storage in warehouses of coffee sacks, this study proposed the smart contract and traceability mechanism to reduce the loss	1) The throughput is high, with an average of 246 transactions per second 2)The average throughput of 10.4tps and an average latency of 0.7s, which displays that it is fast to be used in a real environment 3) Acquired transparency, security, and reliability of the data. 4) Profit is increased which improve the efficiency	1) Development is in its early stage 2) Knowledge is less to make it more robust and practical to use in another stage. 3)Validation rules are not considered
[72]	Honey supply chain of Sardinian	Ethereum, smart contract, Solidity language	Ethereum blockchain	Permission blockchain	This study proposed Ethereum-based smart contracts (SCs) to develop dApps to track agri-food supply chains and it is a semi-automatic configurable system that supports the entire class of supply chains for the agri-food industrial domain.	1) The consumer can be aware of the origin and quality of the product 2) On-site inspection was reduced 3) While maintaining a high level of security, the development time and cost of the software were reduced 4) Ensure food safety and cut downs the paperwork	1) The cost in terms of gas and execution is high 2) Only Ethereum platform was used
[68]	Fishery supply chain	Ethereum, smart contract, Remix IDE tool for run smart contracts	Ethereum blockchain	Private blockchain	This study proposed blockchain model to efficiently manage fishery supply chain functions	1) It is secure and no risk of DoS attacks 2) The proposed solution is preserving the data 3) It prevents different types of fish fraud 4) It ensures transparent interactions among all stakeholders.	1) The solution is not deployed on the real Ethereum network

[106]	Grain and oil food industry	Kafka consensus mechanism	Hyperledger fabric	Private blockchain	This study designed an model of information traceability system for grain and oil food supply chain	1) It solves the problems of opacity, insecurity and low transaction rates 2) It keep the safety and reliability of information 3) It also ensures the product quality	1) No authenticity of data collected
[107]	Fontina PDO cheese supply chain	Proof-of-Stake mechanism	Algorand Blockchain	Consortium blockchain	This study proposed a blockchain traceability platform based on Green Blockchain with low energy consumption and cost savings to record information from the dairy supply chain to guarantee the quality and promotion of Fontina PDO cheese	1) It allows consortium operators to record all the information 2) It guarantees the immutability of data 3) The transactions are validated with very less energy and within a few seconds. 4) It reduces the cost of the transaction	1) All the operators are not digitally oriented 2) The use of a digital wallet may be complicated the blockchain platform

Table 2.3 Comparison of the existing general frameworks using blockchain technology in the food supply chain management

Paper	**General**	**Technology involved & consensus mechanism**	**Blockchain platform**	**Type of blockchain**	**Description**	**Advantages**	**Disadvantages**
[29]	Agri-food supply chain	QR codes and RFID	Conceptual framework	-	Design the agri-food supply chain traceability system to track the history of a product from farm to fork.	1) Extinct the need for a trusted centralized party. 2) Increase transparency and traceability of the product. 3) Decrease the error rate by the human factor.	1) The high cost of implementation. 2) Blockchain technology is immature.

[96]	IT e-agriculture system	Information and Communication Technology and Blockchain technology, Proof of work consensus algorithm	Ethereum platform	Private blockchain	Designed the ICT e-agriculture prototype with blockchain infrastructure by using GCOIN.	1) ICT e-agriculture was immutable. 2) Enhances farmer access to agriculture services. 3) Improve traceability and transparency. 4) Reduce the risk of manipulating data.	1) Implementation of this prototype not applying to environmental data.
[99]	Agriculture supply chain system with Double Chain Architecture	Matlab, blockchain technology, proposed a consensus algorithm considering weight based on the Proof of stake consensus algorithm.	Public service platform	Public blockchain	Designed agriculture supply chain system with double chain architecture based on blockchain and distributed computing technologies.	2) It assures the transparency and security of transactional data 3) Improve the trustworthiness of the public platform. 4) Increase the whole efficiency of the system.	1) The speed and efficiency of the consensus algorithm are an issue.
[76]	Agri-Block-IoT Blockchain	IoT devices, blockchain technology, sensors, smart tags	Ethereum and hyper ledger saw tooth	Private blockchain	Compare the two blockchain platforms, i.e., Ethereum and Hyper-ledger saw tooth to evaluate the performance in terms of Latency, CPU load and network usage.	1) Agri-Block-IoT creates transparent, immutable, fault-tolerance, and auditable records 2) Hyper ledger saw tooth has better results in terms of metrics than Ethereum. 3) Ethereum has higher latency than saw tooth with scalability and reliability.	1) The consensus algorithm of Ethereum is quite CPU intensive.
[63]	Agriculture product tracking system	IPFS, IoT sensors, blockchain technology	Go-Ethereum 1.9 blockchain	Public blockchain	The data storage model IPFS based on blockchain was designed, which increased the storage efficiency by 6 times.	1) Integrate IoT, IPFS, and blockchain to design an agriculture product provenance platform. 2) Stored data is tampered-resistant and improves traceability of data. 3) Avoid malicious user entry. 4) Improve storage efficiency.	1) Improving storage efficiency will reduce the real-time characteristics of provenance data. 2) Do not make a trade-off between them.

[102]	Blockchain enabled supply chain traceability framework	IoT, RFID tags, sensors, blockchain technology, smart contract	Ethereum blockchain	Private blockchain	The blockchain-enabled food traceability system was designed based on smart contract modulators.	1) The automated system increases efficiency of the supply chain traceability process and removes hidden costs. 2) Create trust and improve the audibility of transactions. 3) Increases the quality of the product.	1) Scalability is an issue.
[81]	Blockchain-based Logistics Monitoring System (BLMS)	IoT, sensors, blockchain technology, Smart contracts	Ethereum blockchain	Public blockchain	The HTML Web page was designed using the ethereum blockchain platform and JavaScript to track the history of the product.	1) Blockchain-based logistics monitoring system for parcel tracking. 2) An immutable record of transactions 3) Creates transparency, automation, and trust in the supply chain	1)Still in its nascent stage 2) Difficult to collaborate with multiple stakeholders. 3) Scalability and data privacy issues
[100]	Agrifood Supply Chain Traceability System (ASTS)	QR codes, Proof of elapsed time (PoET BFT), and Dev Mode consensus.	Hyper ledger saw tooth	Permission private blockchain	Developed the blockchain system for traceability of the agri-food supply chain by using SDK in Python.	1) Create trust among the actors of the supply chain. 2) The information was not reversible. 3) Transparency in the documentation.	1) Scalability of saw tooth platform. 2) Immature technology platforms.
[77]	Prototype for food safety traceability on blockchain and EPCIS	IoT, EPC information services, RFID tags, SHA-256 hash algorithm, smart contracts	Ethereum Geth 1.8.2 blockchain	Public blockchain	Designed the food traceability system. The average time of information query response is 2ms The amount of On-chain data and query count was 1GB and 1,000 per second respectively.	1) Assure information of security and avoid spam attacks. 2) Having a high tamper-proof ability 3) Cut down the cost for small and medium-scale food enterprises. 4) The high degree of decentralization.	1) A consensus algorithm restricted the speed of data uploading. 2) Fragmented node is not implemented.
[101]	Smart Agri-Food Supply Chain Managemen t	IoT, sensor, QR code, Proof of work algorithm, Ethereum hash	Ethereum 1.0 platform	Private blockchain	The web page was developed by using the Ethash algorithm for complete traceability of the supply chain.	1) Data flow faster than a traditional centralized system.	1) Challenges are still to be removed.

						2) Decrease errors at different stages of the supply chain. 3) Provide complete traceability of the supply chain. 4) Better than existing supply chain management systems.	
[64]	Smart Agriculture for Enlightening Safety and Security.	IoT, sensors, blockchain technology, Proof of concept consensus algorithm.	Ethereum platform	Private blockchain	Smart agriculture architecture was designed by merging IoT and blockchain technology. The management hub JavaScript was used to connect IoT devices and blockchain. CoAPBench tools were used to test the performance.	1) Enhances data security. 2) Improves data transparency.	1) Only the PoC consensus algorithm was used.
[88]	FTSCON	A smart contract, Java Script, PBFT consensus mechanism.	Ethereum platform	Consortium blockchain	Developed the food trading system using consortium blockchain in web server form based on PHP and the client user page was written using HTML/CSS/JavaScript.	1) Improves security and privacy of transactions 2) Maximizing merchant profit. 3) The proposed algorithm is better in comparison to the branch-and-bound and backtracking algorithm 4) To reduce the competition of buyers, an online double auction mechanism was used.	1) Problems still arise in computational resources and transactional cost 2) Slow block speed 3) Scalability issues.
[103]	Food supply chain	Smart contract, IPFS	Ethereum platform	Private blockchain	The study develops a decentralized and automated food supply	1) It provides automated food supply chain platform.	1) It is a simple relatively FSC network

	traceability system				chain traceability system	2) The automated system removes the hidden cost and paper load from FSC processes. 3 Avoid denial of service attack 4 Offers extreme-quality food products	2) The feature of trust and visibility is not explored fully 3) Scalability issue
[105]	Food-chain traceability system	BC and IoT Proof of concept	Ethereum platform	Public blockchain	The framework was developed to solve the problem of food integrity and safety in food supply chains.	1) BC quadrans was used in the proposed architecture using Ethereum and smart contracts, with an average block time of around 5 seconds. 2) Directly communicate with the cloud structure 3) Fast, straightforward and user friendly 4) Increase the marketing of products.	1) The transaction time would be reduced for automation. 2) Cost was high.
[70]	Kranti: blockchain-based credit scheme for farmers in the agriculture food supply chain	Solidity v0.6.0, Proof of work, IPFS	Ethereum blockchain	Public blockchain	This study developed the blockchain-based Farmer's Credit scheme for quality assurance of agricultural food and establish trust among the stakeholders	1) The latency is less than 1 millisecond with 99.99% reliability compared with LTE with 5G 2) Improves scalability 3) Cost effective 4) It delivers farmers with a special credit-based scheme to accumulate capital for improved agriculture food products goods	The overall cost cannot be optimized
[108]	Agriculture supply chain	Smart contracts, metaheuristic-enabled genetic algorithm	Hyperledger Sawtooth	Private blockchain	The study proposed blockchain and metaheuristic-enabled distributed architecture to analyze the day-to-	1) It delivers an efficient E-agriculture commodity price forecast with an accuracy of 95.3%.	1) Challenges of the proposed model have not been explained

					day transactions of commodity forecasting, scheduling, and management, as well as ledger protection and preservation for smart agricultural practices	2) It sustains transparency, integrity, provenance, availability, and secure operational control and access to agricultural activities.
[71]	Agriculture food supply chain system	A smart contract, proof of authority consensus algorithm, Solidity and hyper ledger fabric	Ethereum blockchain	Private blockchain	This study presents a model of traceable solutions that ensures the integrity and transparency of the system	1) The payments can be processed directly which improves performance 2) It increased efficiency 3) Provide robust security to the agriculture system

2.14 Research gaps

After reviewing the literature, following research gaps have been identified:

- The pivotal role of supply chain in diverse industries is well-established. While supply chain management has undergone substantial advancements in the field of manufacturing and logistics, limited attention has been directed towards comprehensively understanding and optimizing the intricacies of the agri-food supply chain.
- The scarcity of in-depth exploration hampers the identification of tailored solutions and innovative technologies such as blockchain that could enhance traceability, quality control, transparency and overall efficiency with the agri-food supply chain.
- Lack of adaptability and adoption of blockchain technology in agri-food supply chain. Majority of the existing frameworks are not implemented in the real world on food traceability and security. A very little research has been done to uncover the importance of agri-food supply chain management and the integration of agriculture sector with blockchain technology to address its specificity.
- To the best of my knowledge, there exists one study on Indian sub continental that to on Madhya Pradesh region. The authors have determined the views of local farmers and government officials only for the adoption of blockchain technology in agricultural sector. Punjab region has not been explored yet.
- Most of the international studies have focused on conducting survey from farmers for the adoption of blockchain technology. But consumers and blockchain expert's attitude towards adoption of blockchain technology and uncovering the risks associated with blockchain implementation is not explored much.
- Most of the existing studies often focus on isolated aspects of blockchain implementation in agri-food supply chain. No study has provided the complete solution of agri-food supply chain management using blockchain technology and DApps. As blockchain has limited storage capacity, most of the existing frameworks are storing

data on blockchain rather than any storage mechanism which leads to high cost and slow transaction processing time.

2.15 Summary

The agricultural sector is the main source of income for half of the world's population, and agri-food supply chain activities are among the ones that are most likely to be transformed by blockchain technology. This chapter gave a fundamental and comprehensive understanding of how blockchain can be integrated with the agri-food supply chain. It provided qualitative and quantitative research methods, each offering distinct insights into different aspects of its implementation, adoption and impact. This chapter delved into the intricate details of blockchain technology, covering its various types, blockchain networks, consensus mechanism etc. It explored the blockchain initiatives worldwide and the emergence of blockchain in agri-food supply chain. Based on tools and techniques, this chapter has discussed the various existing frameworks of blockchain in agri-food supply chain. The efficient implementation of blockchain technology can reshape agri-food supply chain activities in the real world.

Chapter 3: Examining the challenges in conventional agri-food supply chain: An empirical study using covariance-based structural equation modelling

The agri-food supply chain structure is characterized by a complex structure involving numerous stages from cultivation to consumption. It encompasses a diverse network of farmers, processors, distributors, retailers, and consumers, each playing a vital role in the flow of goods from one place to another. The intricate and multifaceted nature of the agri-food supply chain gives rise to myriad challenges. Moreover, analyzing these challenges within the complex network is a critical endeavor that unveils intricate issues affecting the farmers, stakeholders, and industry's efficiency, sustainability, and resilience.

3.1 Introduction

The food industry is very dynamic, with constant changes in the demands of producers and consumers. This has revolutionized the food supply chain around the world. In developing countries, a significant challenge in the food supply chain is food loss at the beginning and middle of the process, which arises due to the inadequate supply chain infrastructure, low level of technology usage, fewer investments, scarcity of public support and policy institutions and lack of financial support in the field of the food supply chain [111]. Global supply chains are riskier due to the various links interconnected nationally and internationally on the wide range of networks. At the same time, it increases the number of producers, stakeholders, retailers, and distributors, which increases complexity and complicates it.

Additionally, it faces other numerous challenges, such as lack of tracking and safety of food [16], information asymmetry between stakeholders [112] that impact supply chain efficiency, sustainability, and resilience. Furthermore, there have been other barriers, such as inefficient transactions and a lack of trust among stakeholders [113], that hinder the safety and quality of supply chains in the food industry. Furthermore, counterfeit products threaten the integrity of various brands as well as the well-being of consumers.

The agri-food supply chain is a system that connects the producer to the consumer, with the primary goal of delivering the food to the consumer [114]. It represents a complex chain structure including farmers, agro-processors, distributors, transporters, retailers and consumers, each playing a crucial role in providing various food products to the market [115]. It is also defined as the degree to which an organization works efficiently upstream and downstream to underpin the position of each participant in the supply chain network. Over the past years, the food supply chain industry has been transformed by changing marketing techniques and consumption trends. In addition to expanding market access and cost efficiency, it complicates supply chains. The increasing complexity of agri-food supply chain structures has indeed intensified various challenges, such as the risk of food security, lack of infrastructure, finance, institutional support policies, and food frauds, which imbalances the structure and decrease the efficiency of supply chain processes [111 & 116]. Additionally, inadequate market channels and poor transportation connectivity pose a financial barrier for stakeholders. Unequal distribution of information, lack of standardization, and lack of technological education among user's lower productivity and hinder the adoption of best practices.

These challenges encompass limited traceability, hindering the identification of contaminated products, inefficient record keeping, delays and inaccuracies, and lack of connectivity among stakeholders. Additionally, farmers often encounter difficulties in accessing the market, the value of products, and receiving fair compensation for their production. By meticulously analyzing these challenges, stakeholders and farmers gain a comprehensive understanding of the systematic issues with the agri-food supply chain and help in decision-making and strategizing effective solutions for the future. Also, this thesis serves as a diagnostic tool, allowing researchers to diagnose and understand the root cause of inefficiencies. Armed with this knowledge, they can work collaboratively towards creating a robust, transparent, and sustainable agri-food supply chain that can benefit all stakeholders, from farmer to consumer, and contribute to the overall resilience of the food system. Therefore, the rapid adoption of new technologies not only addresses existing challenges but also helps the agri-food supply chain to navigate future complexities.

3.2 Related work

This section summarizes relevant studies that quantitatively or qualitatively defined the challenges of the supply chain, food supply chain, and agri-food supply chain. Nevertheless, this industry faces significant obstacles. These include, but are not limited to, demand gaps versus supply gaps; rising prices; consumers' demands for safe and high-quality foods; market information access to farmers; technology handover; insufficient up-to-date information and intelligence; a disorganized and insufficient market setup of supply chains; and many others [117]. According to Fu et al. [118] and Shahid et al. [119], the traditional supply chain faces various issues, such as lack of transparency, audibility, and accountability because it is built on a centralized system and depends on a third party for transactions. The issues arise during the processing phase and continue to the customer. Zhao et al., [120], on the other hand, use quantitative methods to examine the hazards in the agri-food supply chain. They took a multi-method approach in which they classified the hazards using MICMAC analysis, thematic analysis, Total Interpretive Structural Modeling (TISM), and fuzzy cross-impact matrix multiplication. Furthermore, numerous difficulties, advancements, objectives, and dimensions of the agriculture food supply chain were examined by Ganeshkumar et al. in [121]. They identified several factors, including poor handling, inadequate storage, inadequate transportation, and other flaws, that contributed to farmers wasting food at various points throughout the supply chain.

India ranks as the world's second-largest producer of two of the most crucial crops, wheat and rice [122]. However, the Indian agricultural sector faces numerous challenges, including issues with procurement, storage, food wastage, food quality, and inefficient resource utilization [123]. Moreover, there is no productive framework in the supply chains to maintain the discrepancy of the complex food supply chain [11]. Gandhi and Jain. [124] has focused on the issues of India's public food supply chains, including a dysfunctional transportation system, issues with product quality, and inadequate coverage of rural markets. Similarly, Bhat and Joudu. [113] and Mor et al. [125] examined the problems and difficulties in India's agri-food supply chain, such as lack of infrastructure, purchase and distribution strategy, many intermediaries, and price volatility. Meena et al. [126] identified Indian agri-food supply chain strengths, weaknesses, opportunities, and threats. They were ranked these challenges by using the SWOT-fuzzy-AHP (analytical hierarchy process) approach. Also, Weerabahu et al. [111] explored the challenges of food security for agri-food supply chains using qualitative methods of interviews. The findings of the study reveal that high prices of fertilizers, insufficient supply of quality seed, lack of affordability of agriculture technology, etc., are some of the challenges. Also, to address these challenges, the authors proposed a strategic framework and promoted urban-rural linkages among multiple stakeholders. Recently, Singh et al. [22] conducted a study analyzing the barriers to the sustainable agro-food supply chain in the context of India using a method of Interpretive structural modelling (ISM). The findings of the study show transparency and traceability, inadequate infrastructure, implementation of government schemes, and inadequacy of risk management as some of the important barriers experienced by the agro-food industry.

Moreover, India accounts for more than 65% of employment in the agriculture sector. Indeed, despite accounting for a significant portion of employment, this study shows some related studies such as identified challenges of the agriculture supply chain in India like weather variations, low seed quality, market accessibility, regulations of the government, adoption of new technology, and involvement of supply chain stakeholders. Yadav et al. [7] also discussed the challenges of the agri-food supply chain in terms of sustainability, food waste, food safety and security, etc. The authors provide the research contributions in redesigning the agri-food supply chain network and also describe the performance indicators for measuring the performance of the agri-food supply chain. Kumar et al. [127] explored the thirty-four challenges of the Indian agri-food supply chain associated with six drivers such as facilities, inventory, transportation, information, pricing, sourcing, and several other aspects. Along with challenges, the author also provides six opportunities, such as collaboration and coordination, enabling technologies, forecasting models, government roles and initiatives, and investments to overcome these challenges. Sindhu et al. [24], use the TISM technique to analyze the challenges of adopting 4.0 technologies in the agri-food supply chain in India, including the need for government support, availability of funds, and customer orientation towards food safety, quality, and modernization.

Several studies have been conducted in the past to address the above-mentioned challenges and consistently found that technology adoption is the critical solution [128]. Therefore, digitalization and the adoption of new emerging technology have been found to be transformative forces that not only improve information exchange and reduce market risks but also enhance overall efficiency and sustainability [129].

3.3 Hypothesis development

This section develops specific and testable hypotheses that express the researcher's expectations and relationship between variables. Table 3.1 presents the constructs of challenges related to the challenges classified by the study. The explanation of different challenges with their hypothesis formation is described below:

- **Economic challenges:** Agri-food supply chain faces environmental, economic, and social problems for sustainable growth [117]. The counterfeit and forged products generate loss in market share and lose confidence among supply chain players [130]. It has been found that prior to final consumption, the agri-food supply chain is subject to varying dangers in its production, storage, processing, and distribution phases. Additionally, a fluctuating and diversified agricultural market caused economic and financial problems in distribution. In the digitization of supply chains, blockchain technology automates business transaction procedures, facilitates tighter contacts between participants, tracks multi-stakeholders to handle supply chain complexities while minimizing costs, and improves supply chain performance. Building upon the theoretical foundations and supported by empirical evidence unearthed in the study, the subsequent hypothesis emerged:

  H1: Each indicator significantly contributes to the measurement of economic challenges

- **Marketing challenges:** The multiple networks of the supply chain make it complex and complicated. Marketing strategy plays a vital role in creating a superior supply chain by reducing costs and providing profit margins, overall firm profitability, and corporate growth. Farmers have trouble maintaining their products' prices competitive owing to demand from industries and consumers, low margins of products for the producers and insufficient supply of products in the market. Unsustainable supply chain distribution channels force farmers to distress sell, which enriches intermediaries and diminishes farmers' revenue. For fruits and vegetables, several stakeholder and commission agents charge fees ranging from 4% to 8%, while for grains, it ranges from 1% to 2.5%. In the marketing of products, loading and unloading fees, purchase tax, and weighing fees are also charged. Vegetable and fruit market charges in Gujarat are 8.5%, while they are 15% in other states, making the supply chain erratic [131]. Blockchain technology can be applied to mitigate supply chain risks by recording all supply chain transactions. It offers a secure, synchronized, decentralized, and distributed record of digital transactions without a third party. It also increases transparency, gives consumers more insights into supply chain activities, and improves supply chain efficiency. Based on the considerable literature, the following hypothesis has emerged:

H2: Each indicator significantly contributes to the measurement of the marketing challenges

- **Technological challenges:** After exploring the issues of agri-food supply chain, Parwez. [21] raised its concern in educating the farmers and supply chain stakeholders about post-harvest losses, including food safety, transportation, distribution process, and food quality. The information technology implementation is the most important barrier to implementing a sustainable supply chain. Incorporating technology in the supply chain connects all the users onto a single network and, gains insights about customer demand, transportation restrictions, and suppliers' lead times, and makes decisions that affect the overall performance of the supply chain [1]. Therefore, blockchain technology has come into the picture to reduce the risks and challenges by bringing traceability, transparency, and accuracy to the supply chain sector. The records entered in the blockchain network cannot be lost, destroyed, or replaced by a third party. It enables the creation of a transparent network that is constantly visible to all stakeholders. It also ensures the food quality and standards are met while selling the products in the market. As a result of the theoretical and empirical research, the hypothesis has been developed as follows:

  H3: Each indicator significantly contributes to the measurement of technological challenges

  H4: The overall model provides a meaningful and statistically valid representation of the challenges in the agri-food supply chain

Table 3.1 Constructs of theoretical framework and their measures

Constructs	**References**	**Items**
Economic challenges (EC)	[111 & 118]	EC1: Stakeholders are dependent on various intermediaries for the loan of agricultural practices rather than government organizations. EC2: Lack of regulatory compliance cost due to which people do not comply with the standards and regulations may result in penalties, fines, and damage to the reputation of the business. EC3: Global economic uncertainty due to which stakeholders face challenges in predicting demand, managing inventory, and making long-term investments.

		EC4: Lack of infrastructure for the distribution channel to sell their production.
		EC5: Rapid changes in commodity prices can affect the profitability of farmers, manufacturers and distributors.
Marketing challenges (MC)	[113 & 125]	MC1: Lack of transparency of food products among stakeholders and consumers.
		MC2: Lack of traceability solutions in the supply chain to look forward or backward.
		MC3: Lack of interconnection and communication between stakeholders in which nobody has any information or record regarding marketing and the supply of the food products.
		MC4: Lack of risk management between various departments due to which the farmers do not get the actual value of their product.
		MC5: Differentiate marketing strategies may find it challenging for the stakeholders to differentiate their products and services, especially if the market is saturated.
		MC6: Lack of trust among stakeholders in government organizations for their well-being and business activities.
Technological challenges (TC)	[113 & 117]	TC1: Lack of data accuracy due to manual data entry that increases the likelihood of errors, order fulfillment, and other critical information
		TC2: Lack of trust in using new innovative technologies in the system.
		TC3: Lack of compatibility of using new innovative technologies in the system.
		TC4: There exists a lack of technological information communication technology infrastructure to provide benefits to the agriculture sector in Punjab.
		TC5: Lack of awareness among people is one of the reasons to use new technologies.
		TC6: Limited technology adoption by stakeholders.
		TC7: Lack of connectivity in rural areas.
		TC8: Higher cost of technology implementation can be one of the barriers for stakeholders, small farmers and smaller businesses in the supply chain.

3.4 Research design and methodology

3.4.1 Measurement development

To fulfill objectives 1 and 2 of this research used an exploratory-descriptive research design is conducted on primary data. The study carefully examines the challenges from the literature existing in the conventional agri-food supply chain. The identified risk is further investigated by conducting a questionnaire survey method to verify the potential threats that can jeopardize the Indian agri-food supply chain. Conducting surveys anonymously offers a pathway for more candid and unequivocal responses compared to alternative research methodologies. The survey was conducted physically via face-to-face interaction with the respondents.

Various risks have been encountered and modified to prepare the questionnaire. The difficulties experienced by the stakeholders in the agri-food supply chain were validated in this study using the quantitative research method because the literature only provides broad information. Therefore, a self-structured questionnaire was created based on a Likert scale rating. The questionnaire had 19 items on a 5-point Likert scale (1=strongly disagree to agree 5=strongly). This research has used multi-item construct measures in the questionnaire to increase reliability, measurement error, survey respondent variability, and validity. Based on these questionnaires, the researchers have utilized the confirmatory factor analysis on every construct based on a minimum of three measurement items [132]. The total sample size is calculated according to the Hair et al. [139] as follows:

$$Sample\ size = Total\ number\ of\ items\ * 5$$

Therefore, according to this guideline, a minimum sample size of 95 should be considered for each stakeholder. Additionally, for the analysis of CB-SEM, a larger sample size of 200 for each stakeholder is opted for this study to enhance the reliability and generalizability of the findings.

3.4.2 Demographic profile

Farmers and government officials at distinct phases of the agri-food supply chain served as the participants of this study.

Table 3.2 Demographic profile of government officials

Variables	Numbers	Percentage %
Male	165	91
Female	16	9
<20years	0	0
20-30years	64	35
> 50 years	55	30
30-50 years	62	34
Working experience		
Less than 1 year	11	6
2-5 year	55	28

More than 5 years	134	67

The study's statistical population included the Punjab region of North India. Punjab, which makes up 1.57% of India's total land area and generates 13–14% of the nation's overall production of food grains, is referred to as the "Granary of India". Punjab has also supplied 30–40% of India's rice production and 40–75% of its wheat production over the past two decades [17 & 133].

Table 3.3 Demographic profile of farmers

Variables	**Numbers**	**Percentage (%)**
Male	166	83
Female	34	17
<20years	9	5
20-30years	80	40
30-50 years	82	41
> 50 years	29	15
Qualification		
Under metric	42	23
Matriculation	42	23
Twelfth	54	30
Graduation	43	24
Annual income		
< lakhs	11	6
1-2 lakhs	43	24
2-3 lakhs	67	37
>3 lakhs	60	33

The total sample of this study is 400, out of which data from 381 participants was collected, as 181 belong to government officials and 200 to farmers. The male community participated more in numbers as compared to females, as shown in Table 3.2 and Table 3.3, which indicate that the female ratio in both farming and government sectors, 17% and 9 %, respectively, is particularly low. From the entire sample, 9 stakeholders, or 2% are less than 20 years of age, while 144, (or 38 %), are between 20 and 30, 144, (or 38%), are between 30 and 50, and the remaining 84, (or 22%), falls under the category of more than 50 years.

3.4.3 Characteristic of respondents

This study consists of stakeholders involved in the agri-food supply chain, such as government officials and farmers. Government officials are those respondents that belong to various government institutions, agencies such as agriculture departments, agriculture and farmer welfare departments and Punjab agriculture research intuitions such as Punjab Agriculture University (PAU) and Regional Research Station, PAU, Bathinda, and some of the other government officials that deal with trade and commerce of agricultural products. Regarding the experience of government officials, this study found that out of the total respondents, only 11 (or 6%), have experience of less than 1 year, 55, (or 28%), lie in between 2 and 5 years, and the rest, 134 (or 67%) are having more than 5-year experience.

Secondly, farmers are taken as the respondents for this study as farmers are the backbone of the agriculture industry. They have direct and practical experience with day-to-day operations. Their first-hand knowledge is valuable for understanding the realities, distinctions, and intricacies of the agri-food supply chain industry. Their insights can help researchers and industries to comprehend specific issues affecting agriculture productivity, sustainability, and profitability. The total sample of 200 farmers includes 61.5% of small-scale farmers and 38.5% of large-scale farmers. Out of the total sample, 93.9% of farmer's farm on their own lands, and only 6.1% farm on rented lands, for which they pay a maximum of 60,000Rs per acre per annum. At the time of selling their production, 54.5% Of farmers sold their production through middlemen, 30.5 sold to Government agencies, and the remaining 15.5 % sold it to processors, exporters, and retailers. Therefore, the majority of farmer communities sell their production to middlemen, causing them to consume most of their profits.

3.4.4 Measurement scale

Three multi-item constructs, EC, MC, and TC, are included in this research study. The study uses a self-developed scale to identify the risks that impact the efficiency of the agri-food supply chain. The total risks were categorized into economic, marketing, and technological challenges. The EC & MC consists of 6 items, whereas TC consist of 8 items. The main goal of this survey is to determine the stakeholders' requirements and suffering they experience in the agri-food supply chain processes while selling or purchasing goods. Before examining the reliability and validity of the measurement items, it is necessary to test the assumptions of constant variance, the occurrence of outliers, and normality, as presented in Table 3.4. The assumption of normal distribution has been tested through normal distribution plots, skewness and kurtosis. In order to assess the skewness and kurtosis of residuals by projected values, this study plotted residuals against predicted values. Mahalanobis distances were used to find multivariate outliers [134].

Table 3.4 Sample characteristics

Name	Mean	Standard deviation	Excess kurtosis	Skewness
EC1	4.063	1.094	0.95	-1.301
EC2	3.918	1.067	0.806	-1.182
EC3	3.979	1.026	0.791	-1.133
EC4	3.737	0.997	0.497	-0.813
EC5	3.768	1.01	0.122	-0.739
MC1	3.979	0.951	1.428	-1.173
MC2	3.982	0.919	1.755	-1.23
MC3	4.084	0.882	3.198	-1.6
MC4	4.047	0.911	1.954	-1.332
MC5	3.824	0.914	1.106	-0.974
MC6	4.197	0.865	2.333	-1.447
TC1	4.221	0.864	3.91	-1.747
TC2	4.184	0.878	3.479	-1.678
TC3	4.082	0.871	3.491	-1.621
TC4	4.211	0.863	3.203	-1.603
TC5	4.174	0.871	3.285	-1.591
TC6	4.203	0.891	3.154	-1.621
TC7	4.218	0.884	2.512	-1.498
TC8	4.282	0.878	2.679	-1.612

The skewness and kurtosis of each item were determined to have maximum absolute values of 1.256 and 1.488, respectively. The data (univariate skewness = 2, kurtosis = 7) are substantially within the range of the previous study (Curran et al., 1996). This study used Mardia's (1970) coefficients [135] of multivariate skewness and kurtosis to test for multivariate normalcy, they were non-significant $p \leq 0.05$, indicating multivariate normality. Both in the graphs and statistics, there were no discernible departures from the assumptions.

3.5 Data analysis and results

3.5.1 Method

This study used a method of covariance-based structural equation modelling (CB-SEM), a statistical technique used to analyze complex relationships between observed and latent variables. It is used to examine how well the proposed model aligns with observed data [136]. Various statistical software packages offer tools for conducting CB-SEM. In the context of this study, the latest version of Smart PLS 4 software is used to perform CB-SEM, which was earlier used in AMOS software [137]. The latest version of Smart PLS 4 released in 2023 includes a number of new features for CB-SEM that was not included in the earlier versions of Smart PLS. It has the ability to import covariance metrics directly and conduct bootstrapping for model fit assessment. In CB-SEM, analysis typically involves two main components: the measurement model and the structural model. The measurement model examines the factor loadings, which shows how well the observed variables measure the challenges and identify the structure of factors. On the other hand, the structural model extends the analysis, explores the relationship between the latent variables (challenges), and allows for the direct and indirect effects among them. The overall model field has been observed using various fit indices. A good model fit indicates that the specified model is consistent with the empirical data. While applying statistical tool, convenience sampling is used. And to mitigate the risk associated with convenience sampling, the study purposively selects the participants from various locations and demographics to ensure broader coverage of the population of interest.

3.5.2 Measurement model

In gauging and analyzing the reliability and accuracy of the measurement model, confirmatory factor analysis (CFA) was carried out on all the constructs. The study analyzes how well the CFA and structural model fit together using chi-square statistics, the goodness-of-fit index (GFI), the comparative fit index (CFI), and the root mean square error of approximation (RMSEA) [138]. The goodness-of-fit of a model can be evaluated using several fit indices, as discussed [139]. The cut-off value for GFI, NFI, and $CFI \geq 0.90$. The acceptable threshold amount of $RMSEA \leq 0.08$. The findings of the measurement model carried out as goodness-to-fit indices $X^2 = 174.053, df = 149, RMSEA = 0.021, GFI = 0.954, AGFI = 0.941, CFI = 0.993, NFI = 0.953$ from CFA shown in Table 3.5 Everything fits within the accepted norms. The model indicates to be good enough as shown in Figure 3.1. Furthermore, the evaluation of convergent validity, discriminant validity, and reliability are examined.

Table 3.5 Model fit indices

Fit index	Measurement model	Structural model
CFI	0.993	0.991
GFI	0.954	0.952
AGFI	0.941	0.940
RMSEA	0.021	0.020
NFI	0.953	0.950

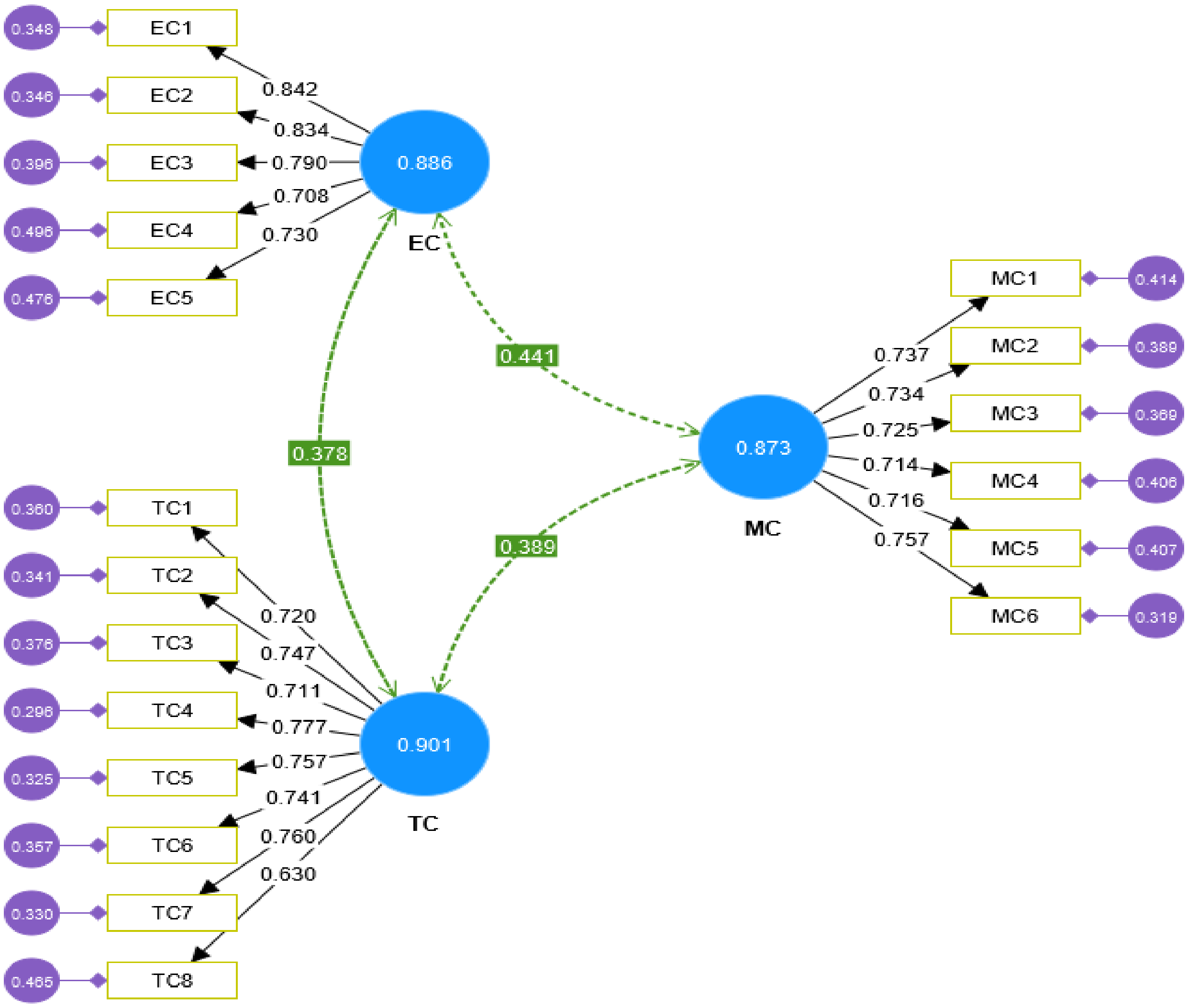


Figure 3.2 Measurement Model of analysing challenges

Table 3.6 Construct reliability and convergent validity

	Items	Standardized loadings	Cronbach's alpha (unstandardized)	Composite reliability	AVE
ECONOMIC CHALLENGES	EC1	0.842	0.887	0.889	0.613
	EC2	0.834			
	EC3	0.790			
	EC4	0.708			
	EC5	0.730			
MARKETING CHALLENGES	MC1	0.737	0.872	0.873	0.534
	MC2	0.734			
	MC3	0.725			
	MC4	0.757			
	MC5	0.716			
	MC6	0.757			
TECHNOLOGICAL CHALLENGES	TC1	0.720	0.901	0.902	0.535
	TC2	0.747			

	TC3	0.711
	TC4	0.777
	TC5	0.757
	TC6	0.741
	TC7	0.760
	TC8	0.630

Convergent validity indicates that each construct can be accurately represented by its own set of indicators. Items, their means, standard deviations, average variances extracted (AVE), and composite reliability (CR) are presented in Table 3.6. According to Hair et al. [139], the value of CR coefficients in all cases exceeded the suggested threshold of 0.7. Regarding convergent validity, all item loadings proved statistically significant and exceeded the suggested threshold of 0.6, and AVE coefficients were also higher than 0.5, indicating that it accounts for at least 50% of the variation. The loading values of each observed variable quantify both the strength and direction of the relationship between a latent variable and its observed variables. A high standard loading indicates that the observed variable is a valid and accurate reflection of the underlying latent construct. Therefore, this study provides evidence of consistency, which means the convergent validity of the scales are supported.

Table 3.7 Correlation matrix and discriminant validity

Challenges	**EC**	**MC**	**TC**
EC	0.783		
MC	0.441	0.731	
TC	0.378	0.389	0.731

Discriminant validity was determined by Fornell and Larcker in 1981 [140]. The correlation between the latent constructs and square roots of AVE is presented in Table 3.7. The observed square roots of AVE in all cases were higher than correlations between the underlying constructs. Therefore, discriminant validity can also be achieved. The overall measurement model supports hypotheses H1, H2 and H3, which indicate that the observed variables are reliable indicators of the latent variables.

3.5.3 Structural model

The structural model explores the relationship between latent variables and tests the hypothesis about the direct and indirect effects among them. It reflects the theoretical model of the study. Since convergent and discriminant validity estimations are satisfactory, it is possible to analyze the structural model further. After the validation of the measurement model, the relationship between various constructs was performed. All three risks, that is, economic risks, marketing risks, and technological risks, were found significant.

Table 3.8 Structural model of challenges of conventional agri-food supply chain

Challenges	**Parameter estimates**	**Standard errors**	**T values**	**P values**
EC	0.848	0.087	9.786	0.000
MC	0.491	0.062	7.956	0.000
TC	0.386	0.049	7.835	0.000

The result of the CB-SEM and hypothesis testing is shown in Table 3.8, which provides support by the path coefficient values for risk analysis and their relationship among them. Therefore, H4 is supported by this study and shows that the proposed model provides a meaningful and statistically valid representation of the challenges in the agri-food supply chain. Also, the economic, technological, and marketing risks associated with conventional agri-food supply chains are crucial challenges that are faced by stakeholders in processing goods. The total hypothesis explained 88.6% of the variance.

3.6 Discussion and findings

The study identified various issues associated with India's conventional agri-food supply chain. This chapter empirically examines the elements posing difficulties and analyzes their impact on stakeholders in the agri-food supply chain structure. The implications of the study in relation to the difficulties theoretically and practically are discussed in the subsequent sections.

3.6.1 Theoretical implications

The findings of the study fully supported hypothesis H1, H2, H3 and H4 and confirmed that economic, marketing, and technological **c**hallenges are the significant difficulties faced by the stakeholders in the agri-food supply chain.

The economic challenges are related to the problems or obstacles that stakeholders face within the economic context. These challenges can impact various aspects of economic well-being, distribution, production, consumption, employment and overall economic stability. According to this study, stakeholders can face various economic challenges. However, the most promising ones are the presence of intermediaries in the agri-food supply chain, the lack of regulatory compliance regarding standards, and the existence of global economic uncertainty. The presence of several intermediaries often leads to additional costs and can reduce the profit margin for farmers and increase the final cost for the consumers. Most of the farmers are dependent on intermediaries for market access, transportation and other services. This dependency can exploit the farmers to negotiate prices and offer lower prices for their production. This can also result in a lack of transparency in pricing and transactions, due to which farmers may not have a clear, visible picture of their product prices at different stages of the agri-food supply chain. These results are also highlighted by Kumar & Agrawal. [141] in their study that these middlemen raise the cost of products by including their profits and services, due to which the farmers receive only one-third of the price of the product paid by the customer. Regulatory compliance can lead to various consequences for businesses, consumers, and the overall market. However, non-compliance with quality and safety standards can pose a serious risk to consumers' health, safety, and trust and may lead to supply chain disruptions. Similarly, uncertainty about the global economy can lead to decreased confidence among consumers and businesses, which can reduce spending, investment, and overall economic activity. Also, it has a huge impact on trade and emerging markets. The findings of this study are in line with the previous studies that stated that the financial risk damaged and undermined the performance and efficiency of the agri-food supply chain [142 & 143]. Zhao et al. [120] analyzed the risk factors in the supply chain using empirical research and identified that verbal agreement between partners, shortage of skills, lack of investment and funds, and lack of technological development are some of the issues that hinder the flow of agri-food supply chain processes. Similarly, Kumar et al. [144] identified the risks of the agri-food supply chain in India. They found that the demand-supply gap, agri-produce waste, and unequal profit distribution among stakeholders and logistics suppliers are some of the challenges that exist in agriculture.

Secondly, the study focused on the marketing challenges in which lack of transparency, mismanagement between departments, and lack of trust among stakeholders are found to be the most significant. Lack of transparency makes the agri-food supply chain easier for fraudulent activities, including the production and distribution of counterfeit products. Also, it becomes challenging to trace the origin of products and verify whether they were produced under ethical and suitable practices. Moreover, the nonexistence of transparency may lead to inefficiencies in the agri-food supply chain, and businesses may incur higher costs due to operational inefficiency, inaccurate forecasting, and an inability to identify and address bottlenecks.

The findings encountered a lack of mismanagement between various departments, resulting in farmers not receiving the actual price of their product, and agriculture markets can experience significant price volatility. In the absence of robust risk management, there may be information asymmetry within the agri-food supply chain, which also interrupts farmers' timely access to market information and hinders their ability to make informed decisions about when and where to sell their products for the best value [145]. Also, insufficient risk management may lead to challenges in maintaining quality standards throughout the supply chain. These challenges are similar to Yadav et al. [7] study in which they highlighted that farmers faced various issues related to information sharing, insufficient availability of resources, marketing, transporting, less negotiating power, and many more.

Trust is an essential component for effective collaboration, transparency, and the smooth functioning of the supply chain. When stakeholders lack trust in each other, collaboration becomes one of the challenging tasks. This can hinder the sharing of information, resources, safety, and quality of food and impact the overall efficiency of the agri-food supply chain. Moreover, in the marketing of food products, if stakeholders are not transparent and do not trust each other, it can be challenging to trace the origin and entire journey of the product and exert lasting impacts on brand reputation and customer loyalty.

Thirdly, the study focused on technological challenges that refer to the difficulties that arise in the adoption, implementation, and use of technology. The most significant challenge is the lack of technological information and communication infrastructure that disrupts the implementation of traceability solutions in the agri-food supply chain processes. Insufficient infrastructure may restrict farmers' access to real-time information on market prices, demand forecasting, financial inclusion, and access to credits for agriculture products. Also, it can impede collaboration and information sharing among stakeholders, leading to coordination challenges. Moreover, the study also reveals that the connectivity of information technology in rural areas is another challenge faced by the stakeholders, which may restrict their access to crucial information related to market prices, weather forecasts, and best farming practices.

Additionally, the awareness of technological and communication technology is another issue faced by stakeholders. Without awareness of available technologies in the agri-food supply chain, farmers may continue to rely on traditional and less efficient practices, which can result in suboptimal resource use, lower yields, and increased operational costs. Farmers may miss out on reaching new markets and maximizing their sales. The findings are similar to the existing study by Howland et al. [146], which emphasized that lack of skilled staff and the use of information and communication technology were found to be the most significant risks in the Brazilian-to-US mango supply chain. Similarly, Panetto et al. [147], stated that the agriculture industry has experienced a positive trend in digitalization in the past few years, but efficiently introducing and implementing these initiatives is a major concern. Sharma et al. [148], found that lack of technology, lack of farmers' knowledge and awareness, and insufficient government policies are the major challenges in the Indian agri-food supply chain for adopting a circular economy.

3.6.2 Practical implications

The Indian agricultural sector employs more than 58% of India's population, and its farm production output is the second largest in the world. Despite its extensive involvement, its Gross domestic product contribution to the national economy is still very low, i.e., around 19% [141]. However, the complexity of the agri-food supply chain is indeed a major concern for the agriculture industry. Strategies such as creating direct farmer-consumer relationships, using digital platforms, and establishing fair trade practices will be introduced to make the supply chain efficient. In order to minimize the risk linked to a lack of regulatory compliance, the government should establish a robust compliance management system and food safety standards so that stakeholders can stay informed about relevant regulations and ensure that their practices adhere to legal mandates. This can only happen by leveraging various technological solutions and collaborative platforms to communicate, share compliance-related data, and work together to address the issues collectively. Moreover, global economic uncertainty often requires coordinated efforts by governments, businesses, and international organizations. Promoting transparency, fostering effective communication, and implementing well-established policy responses can play a pivotal role in alleviating the adverse effects of global uncertainty, thereby contributing to a more stable economic environment.

Stakeholders should prioritize lack of transparency as the major concern in agri-food supply chain operations. These can be mitigated by implementing traceability systems, adopting technologies like artificial intelligence, blockchain, etc., and fostering open communication with stakeholders. Also, to address the issue of mismanagement between various departments, clear and effective communication channels should be developed within the agri-food supply chain structure. Both formal and informal communication methods ensure the information flows seamlessly across the organizations. Additionally, investment in information and communication technology solutions can connect different departments and provide a decentralized platform for sharing data and insights. This can improve coordination, reduce data silos and enhance the overall visibility of the agri-food supply chain operations.

There is a need to offer guidance on how the agri-food supply chain can overcome technological challenges and investment in upgrading information and communication infrastructure. This can be done with the help of deploying new emerging technologies such as IoT, blockchain, and data analytics which will improve visibility, traceability, collaboration, communication, food safety and quality across the entire agri-food supply chain. However, firstly, efforts should be directed toward increasing awareness and providing education on relevant technologies, which is an urgent requirement. This should include organizing training programs, workshops, and outreach initiatives by government organizations to ensure that stakeholders are informed about the potential benefits and applications of technology in agriculture. Moreover, the connectivity of technology in rural areas is another major concern of stakeholders for which the development of infrastructure, investments in telecommunications companies, and the deployment of technologies that can function in low-connectivity environments should be provided by government agencies. This will bridge the gap of digital divide and redesign the agri-food supply chain structure. This will create an inclusive and technology-enabled environment that empowers farmers, enhances agricultural productivity, and contributes to sustainable rural development.

3.7 Summary

This chapter presented the status of the Indian agri-food supply chain and its associated challenges using quantitative research methodology. The literature review reports that there is a lack of research on the study and empirical analysis of Indian agri-food supply chain challenges, especially from the viewpoint of stakeholders. As new innovations and the use of technology are tuned to reshape the agri-food supply chain, the researcher needs to understand the challenges affecting the sustainable agri-food supply chain. For this, the study examines the working of the agri-food supply chain and the role of various stakeholder and their associated challenges. A total of nineteen challenges that cause inefficiencies in the agri-food supply chain have been identified. It is observed from the findings that among the total, six main challenges belonging to economic, marketing, and technological are more significant than others. The proposed model accounted for 88.6% of the variance, indicating its strong fit with the observed data and its substantial explanatory power for the variability in the dependent variable. Also, each identified challenge is mapped with the corresponding issues and opportunities presented in this study. The recommendations will help the stakeholders, policymakers, investors, and government institutions to make the agri-food supply chain effective and efficient.

Chapter 4: A conceptual framework for blockchain enabled agri-food supply chain: A dynamic capabilities view perspective

Blockchain technology serves as a pivotal mechanism in enhancing agri-food supply chain processes, catalyzing the evolution of organizational capabilities. Examining the capabilities of blockchain technology is crucial due to its potential to bring about transformative changes across various industries. It also helps organizations and people make informed decisions before adopting blockchain solutions and understand how blockchain can address challenges within the agri-food supply chain. Hence, this study employed a qualitative research approach, leveraging semi-structured interviews to glean insights from experts and professionals regarding the potential of blockchain-enabled agri-food supply chains. A systematic coding methodology, inclusive of open, axial, and selective techniques, was applied to unravel and delineate the emerging themes within the context of blockchain-enabled agri-food supply chains.

4.1 Introduction

To cope with the issues and challenges of the food industry, organizations must establish trusted food supply chain networks to protect people from fraudulent stakeholders and provide a secure information structure about transactions. Information technology in the agriculture and food industry has transformed today's business environment by running faster transactions and seamless coordination of processes in a company's value chain. It helps to connect the inter-organizational system and reduce business-to-business (B2B) system boundaries to connect farms, traders, and the food industry electronically. One of the promising ways to cope with these issues is for people to start adopting emerging technologies such as artificial intelligence, IoT, blockchain technology, robotics, drones, as well as big data analytics [149 & 150].

Considering the potential increase in the global market, blockchain technology will facilitate future industry and revolution [151]. Integrating blockchain technology with the supply chain in the agri-food industry has emerged as a significant area for researchers and practitioners in recent years [152]. Blockchain technology is a reliable and unaltered distributed data ledger to monitor transactions through the distributed consensus process. Blockchain technology boosts

Some of the work of this chapter have been peer reviewed and published in:

- *Sharma, A., Bhatia, T., Singh, R. K., & Sharma, A. (2023). Sharma, A., Bhatia, T., Singh, R. K., & Sharma, A. (2024). Developing the framework of blockchain-enabled agri-food supply chain. Business Process Management Journal, 30(1), 291-316.*

traceability, transparency, and information sharing, which leads to improving the supply chain performance by integrating supply chain processes and activities. It is regarded as a promising technology to be used in the agri-food supply chain in the upcoming years [153]. It has the potential to simplify and integrate all the processes of agriculture supply chains, enhance food safety, reduce risk in trade and marketing, and create smarter market information for customers and stakeholders [154]. Indeed, through its decentralized and efficient traceability system, this technology holds the potential to mitigate fraudulent activities.

This study is based on the dynamic capability (DC) view. An organization's DC emerged as the most vibrant topic in strategic management, and it has also been referred to as a new concept in performance-based management. A dynamic capability refers to the ability of the organization to integrate, build, and reconfigure internal and external capabilities in response to a quickly changing environment to reach a higher economic value than its competitors [155 & 156]. As a result, DC has been applied in various studies to figure out the food supply chain issues and make it efficient and sustainable.

Although a vast amount of literature exists to explore the benefit of blockchain technology in the agri-food sector [157], it still needs empirical insights into the blockchain-enabled agri-food supply chain based on some theories. Therefore, this research aims to fill the existing knowledge gap by exploring the capabilities of blockchain in the agri-food supply chain under the conceptual view of DCs. To accomplish this, the study used the qualitative research methodology by collecting information from experts and professionals in the food supply chain and blockchain sector. Qualitative research is an interpretive and naturalistic method of studying people's opinions in order to describe the association with their experiences in descriptive terms [158]. Moreover, this study presents a conceptual framework that can help in improving the agri-food supply chain using blockchain technology. In this connection, some firms have already embraced investing in blockchain technology, while others still need to explore their benefits from various perspectives.

4.2 Related work

The recent studies underline that the existing challenges in the agri-food supply chain can be resolved through the adoption of blockchain solutions that consider not only the agriculture production methods but also the entire agri-food supply chain processes [159 & 160]. One of the most relevant applications of blockchain in the field of production and supply chain quality control is the agri-food sector. For the last few years, blockchain innovation has gained massive interest in supply chain management. The primary goal of blockchain in the supply chain sector is to reduce fraud and identity theft, increase efficiency, and lower the cost of transactions [161]. It also helps to make participants accessible to each other with dissimilar distances and time zones, which provides better performance by building trust among stakeholders in the supply chain [162]. With the supply chain, blockchain allows all the stakeholders to access the same information, which improves the transparency and traceability of information shared on the network. It also provides food safety and counterfeit-proofing in the food supply chain [163] and authenticity of information due to its immutable nature [164]. Increased traceability in the food supply chain identifies the source and place of the food from where it comes to quickly eliminate contamination and thus reduce health hazards.

It is a promising technology that can deal with supply chain issues such as trust, product information sharing, and quality inspection [130]. In the food supply chain, blockchain technology tracks the complete product information and keeps a record of different stakeholders involved in the process. Also, it ensures the supply of multiple products between different vendors to enhance the supply chain performance. It has the ability to create a secure and transparent food supply chain and provide trust among various parties involved in the system [112].

Dynamic capability (DC)

The term DC was proposed by Teece and Pisano. [155]. It is the potential of organizations to integrate, rebuild, renew, and reconfigure internal and external competencies to address a rapidly changing environment. Dynamic capability considers two key components: resources and strategies, which include employees, equipment, tools, and techniques that can be replaced if needed for market transactions. Another critical component is the strategy that directly connects with analysis, policies, and actions required to respond to the high-stake risks [165]. The combination of dynamic capability theory with the supply chain attracts much attention among researchers and practitioners. The supply chain practices positively impact supply chain dynamic capabilities [166]. The role of dynamic capability in firms refers to managing resources at each stage across a supply chain in remodeling the changing business environment Nowadays, organizations in the food industry are suffering from misleading information and errors due to paper-based processes and information technology systems. All these problems may seriously threaten the safety and quality of food. Blockchain technology is one such technology that could benefit the agri-food supply chain sector in the upcoming years. Despite the advantages of blockchain, its use in the agri-food supply chain sector has yet to be studied. Therefore, this study examines how blockchain technology has been implemented in practice and highlights the various capabilities related to the agri-food supply chain.

4.3 Research methodology

This study employs a semi-structured interview approach to gain a profound understanding of the phenomenon by analyzing multiple viewpoints of different individuals. A comprehensive and deep understanding of their capabilities must be known first to integrate blockchain technology with agri-food supply chains. This can only be reached by probing blockchain expert's thoughts, views, feelings, and perspectives on how blockchain-enabled agri-food supply chains can transform the food business industry. Therefore, the main objective of this study is to examine blockchain technology's capabilities and then analyze how blockchain capabilities improve the agri-food supply chain. In response, an exploratory qualitative research approach was used. According to Thakkar et al. (2012), using statistical approaches such as linear regression for qualitative research raises some concerns and can resist knowledge about their processes, activities, and outcomes. Therefore, this study uses an approach that allows researchers to get close to the participants, get into the internal logic, and expound their understanding of reality. Additionally, this study focuses on theory development and aims to find out the capabilities of blockchain that appear to influence the adoption of blockchain-enabled agri-food supply chain systems.

This chapter presents the three-fold structure. Firstly, the study explores blockchain technology characteristics, functionalities, and capabilities in the agri-food supply chain and verifies through expert opinions. Secondly, the study explains how these capabilities help to improve the agri-food supply chain efficiency. Lastly, the study provides the framework of a blockchain-enabled agri-food supply chain. DCs were considered an appropriate tool for discovering blockchain capabilities due to their various advantages, such as traceability and transparency (Stranieri et al., 2021). Furthermore, the exploratory research method was considered to be a powerful tool to represent individual views and perceptions to recognize trends and insights (Fawcett et al., 2014). Therefore, followed by a detailed thematic analysis, this study develops five prepositions and represents the blockchain-enabled agri-food supply chain conceptual framework.

4.3.1 Data collection

Qualitative research consists of three types of data collection such as (1) observation of participants or ethnography, (2) in-depth interviews with participants, and (3) focus group discussions [149]. The face-to-face semi-structured interview method was used among the other data collection methods for several reasons: 1) The semi-structured interviews are designed to interrelate the expectations and the viewpoints of interviewees that are expressed openly rather than in a standardized type of conversation, as in questionnaires , 2) The semi-structured interviews allow the collection of rich and detailed data on a specific area from knowledgeable people, 3) face to face interaction facilitate the exploration of new themes by providing experts with the freedom to express their ideas openly and 4) it provides a high response rate for predefined questions by using face-to-face connection contrasting with other data collection methods [167]. The questionnaire was developed containing a set of open-ended questions and probes to elicit information on implementing blockchain in the agri-food supply chain. A questionnaire was developed precisely with blockchain industry people for the proposed model, as shown in the Appendix I.

The purposive sampling methodology was used in this study. Also, this study targeted two overlapping groups of participants. The first group comprises blockchain experts, consultants, researchers, IT experts, and entrepreneurs with knowledge of blockchain capabilities and trends. The second group includes food supply chain experts, procurement managers, and logistics managers. To mitigate the risk of bias encountered by purposive sampling technique, the study has employ diverse sampling strategies. For example, they can use maximum variation sampling to intentionally select participants who represent a wide range of characteristics or perspectives relevant to the research question. This study contacted 200 blockchain and food supply chain experts via email and LinkedIn messages to participate in the study between February and June 2022. After multiple gentle reminders, a total of 37 participants replied and indicated to share and express their views. However, out of these, only 32 participants agreed to be a part of this interview session. To maintain the confidentiality of participants' information, this study marked the participants (R1–R32), R stands for Respondent, and 1-32 is the number of respondents).

4.3.2 Data analysis

All interviews were transcribed unaltered. This study has extracted various themes and subthemes using thematic analysis to analyze the empirical data collected from the given sample. The research design used by this study is shown in Figure 4.1. Interview transcripts were encoded several times to maintain internal consistency [168]. The feasible themes appeared and were compared with the secondary data material that is publicly available. Through the method of triangulation, this study was able to find out the research problem from a variety of angles and provide a more comprehensive analysis to increase the validity of the results.

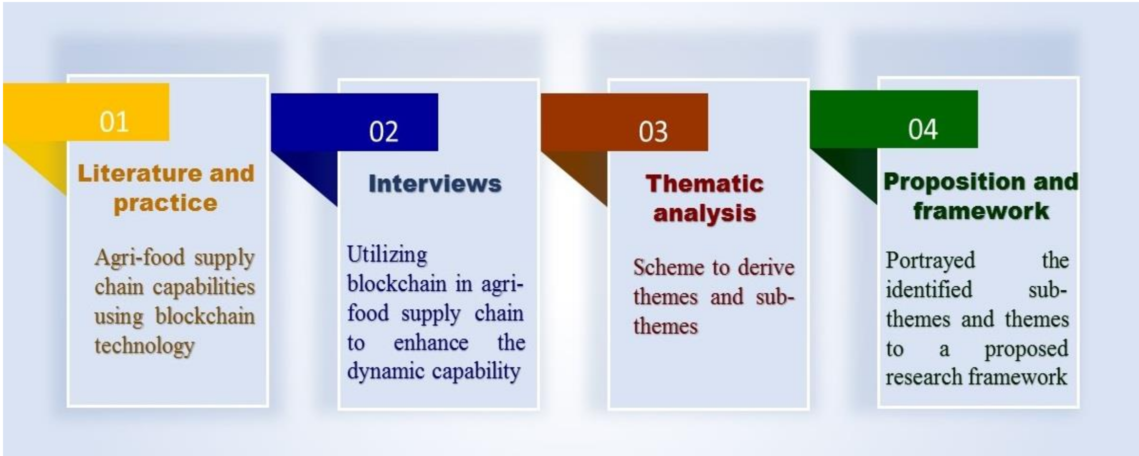


Figure 4.1 Research design of the study

4.4 Results and findings of the study

The analysis of interview data revealed significant and interesting findings about implementing blockchain in the agri-food supply chain sector and analyzing their capabilities to improve agri-food supply chain organizations in the future.

4.4.1 Capabilities of blockchain-enabled agri-food supply chain

During the interview session, multiple respondents' perspectives were considered in implementing blockchain in the agri-food supply chain. Overall, the analysis of the literature reveals significant findings, resulting in five clear themes from the empirical data: (1) traceability, (2) transparency, (3) information security, (4) transaction, and (5) trust and quality.

Each theme is further discussed in the context of the blockchain-enabled agri-food supply chain.

- **Traceability:** It is defined as the system that enables tracking of agri-food supply chain products from farm to fork, leading to an increase in the trust between stakeholders and a decrease in the counterfeiting of products. According to Sharma et al. [153], traceability was found to be the most prominent enabler of the agriculture supply chain in terms of the circular economy. The traceable solutions provided by blockchain technology can increase the performance of the agri-food supply chain. Table 4.1 shows the related axial codes and quotes to traceability.

Table 4.1 Theme and codes identified under traceability

Theme and codes identified under "Traceability"		
Axial Code	**Characteristics of Respondent**	**Supporting codes from interviews and open code**
Food origin tracking	Associate from a consulting firm with 7 years of experience	R4: Blockchain has great potential across the food supply chain and helps to track the origin of food so that people know where their food comes from Open codes: Blockchain-enabled agri-food supply chain helps positively in the tracking of food.
Prevention of raw material adulteration	Senior analyst from a food supply chain firm with 8 years of experience	R21: We can access the data from the first phase to see the mixing of inferior products and trace the replacement of products with fake products Open codes: Blockchain-enabled agri-food supply chain brings adulterant-free products to the market.
Tracing of food from supplier to consumer	Procurement manager from a Warehouse management firm with 10 years of experience	R29: We can access the whole history of food products from production to processing until the end of the consumer on the blockchain platform Open codes: Blockchain technology provides a traceable agri-food supply chain
Reduce counterfeit products by tracking at each stage.	A manager from a Procurement management firm with 11 years of experience	R16: By analyzing the real-time tracking of data, we can find the fake products delivered in the market and reduce the falsification in the different stages of the agri-food supply chain

		Open codes: Blockchain-enabled agri-food supply chain enhanced the reliability and integrity of food
Enhance food safety and quality.	Blockchain analyst working in the field of supply chain for the last 3 years	R8: The nature of distributed ledger technology is that we can record the information on food products at every stage of the agri-food supply chain, which ensures the hygienic condition, identifies the safety measures, and maintains the quality of food Open codes: A blockchain-enabled agri-food supply chain increases food safety and maintains quality at each step.
Fraud preventions	System integrator with a computer science and engineering background and expertise in the blockchain area.	R25: Blockchain technology could help organizations to understand how finished products are passed through each sub-contractor and reduce profit loss and fake marketing, which helps to reduce fraud and also helps to reduce the paper agreements workload, which automatically helps to reduce the fraudulent activities related to fraud stakeholders or fraud transactions Open codes: Blockchain technology can enhance the traceability of the agri-food supply chain.

- **Transparency:** It is a procedure that involves the process of tracing food's journey from where it is grown, produced, handled, and stocked to how it is transported or processed, leading to the development of an authentic product and transparent food ecosystem. In the food ecosystem, it helps to maintain the safety and quality of food. Table 4.2 shows the related axial codes and quotes to transparency.

Table 4.2 Theme and codes identified under transparency

Theme and codes identified under "Transparency"		
Axial Code	**Characteristics of Respondent**	**Supporting codes from interviews and open code**
Provide entire visibility across the supply chain	A senior analyst from a firm with 8 years of experience	R7: Blockchain technology can digitalize the physical assets and create a decentralized network of records of all transactions, which helps to track the assets from the first stage to the final stage, which increases the agri-food supply

		chain transparency and provides more visibility to the business processes and to the consumers Open codes: Blockchain-enabled supply chains can increase the visibility of events that occurred by various stakeholders.
Validate and authenticate the food product and brand credibility	An associate consultant from a consulting firm with 7 years of experience	R13: As all the transactions are visible to all its participants and users, we can verify the food product's authenticity by scanning the code and checking its brand value, leading to an increased brand reputation. Open codes: Technology helps in authentication and enhances brand credibility
Create confidence among consumers.	Operations manager and logistics with 11 years of experience.	R26: The whole history of the product is available to the consumers by scanning the QR code, which increases the confidence of consumers in buying the product from small or large stakeholders Open codes: blockchain-enabled agri-food supply chain brings self-confidence among consumers in buying a product.
Reducing financial risks	Senior Demand planner from the retail sector with 9 years of experience.	R12: The whole network is transparent to the users who are involved in the agri-food supply chain processes in which the transactions are operated digitally without any risk and intervention of intermediaries Open codes: Blockchain-enabled agri-food supply chain reduces risk
Reduce intermediaries	Manager of a food supply chain firm with knowledge of blockchain and new technologies updated with 4 years of experience.	R20: Smart contracts are automatically generated at every stage that does not require third-party participation or any human intervention and the users can access the blockchain platform by using mobile apps, which leads to reducing the irrelevant stakeholders from the agri-food supply chain Open codes: Blockchain-enabled agri-food supply chain helps to decrease the intermediaries by using smart contracts

- **Information security:** It protects sensitive and secret information from authorized users, modifications, and disruptions in the supply chain sector. The blockchain network helps record authenticated transaction records and eliminate unauthorized users from the agri-food supply chain. The primary objective is to guarantee the safety and privacy of customer data, financial data, and all the data related to agri-food supply chain processes stored in the network. Table 4.3 shows the related axial codes and quotes to Information security.

Table 4.3 Theme and codes identified under information security

Theme and codes identified under "Information security"		
Axial Code	**Characteristics of Respondent**	**Supporting codes from interviews and open code**
Recording of real-time transactions	Senior Supply Chain manager from the organization with 10 years of experience	R3: The unique feature of the distributed database provides real-time audit and inspection of transactions that occur automatically by using smart contracts, which helps to maintain the security of information Open codes: Blockchain enabled agri-food supply chain to track real-time transactions.
Eliminate intermediaries	Senior logistics coordinator from the organization with 7 years of experience	R14: A large number of intermediaries in the agri-food supply makes it complex and blockchain technology helps to decrease the intermediaries and increase the security of data with an efficient agri-food supply chain Open codes: Blockchain simplifies the supply chain structure by eliminating unwanted intermediaries.
Authenticated transactions	A senior manager from the retail sector with 8 years of experience	R: 24 The transactions recorded on the blockchain platform are difficult to manipulate and cannot change. Blockchain technology provides the audit trail, which reduces the unsuspected manipulations and forgery of data Open codes: Technology refers to the phenomenon that is unchangeable, which leads to the security of data saved in the platform

- **Transaction:** It is defined as the data structure that encodes the transfer of values between various participants. In the blockchain network, the transactions are stored securely using cryptographic techniques, and the transaction record is publicly available to all the users of the blockchain network. All the transactions are operated digitally without the intervention of multiple users. Table 4.4 shows the related axial codes and quotes to transactions.

Table 4.4 Theme and codes identified under transaction

Theme and codes identified under "Transaction"		
Axial Code	**Characteristics of Respondent**	**Supporting codes from interviews and open code**
Reduce transaction cost	Blockchain analyst working in the field of supply chain for the last 3 years	R32: The decentralized database and cryptographic signature protection and reduction of intermediaries contribute to the reduction of transaction cost Open codes: Blockchain-enabled agri-food supply chain helps reduce transaction costs.
Secure and quick transactions	A product manager from the IT company with expertise in the blockchain	R27: Due to the distributed network of nodes blockchain technology itself has a great value in securing transactions and it takes only a few seconds to complete the process to serve the customers on time Open codes: Blockchain technology speeds up the processes in the agri-food supply chain
Automate the transactions	Innovation officer from the organization with 5 years of experience	R1: Smart contracts stored on a blockchain network are *automatically executed when predetermined terms and conditions without compromising on authenticity and credibility* Open codes: Technology helps in simplifying business processes
Fair pricing to all the stakeholders	Supply chain manager and logistics with 10 years of experience.	R22: Blockchain technology reduces the layer of intermediaries and, therefore, speeds up processes and reduces the associated cost with each transaction Open codes: Blockchain helps in setting fair price
Less dependence on intermediary's services	HR from the retail sector with 6 years of experience.	R9: Smart contract programs give network automation and can convert paper agreements into digital contracts without any involvement of intermediaries Open codes: Blockchain-enabled agri-food supply chain is helpful in designing the network with reduced intermediaries

- **Trust and Quality**: Trust acts as a belief of stakeholders to ensure the integrity of the agri-food supply chain. Suppliers rely on building trust with their customers to ensure timely delivery of goods at agreed-upon prices. Transparency and collaboration can build a trustworthy environment for stakeholders as well as consumers. Maintaining quality is another important aspect for organizations to attract users to develop trust throughout the agri-food supply chain. Table 4.5 shows the related axial codes and quotes to trust and quality.

Table 4.5 Theme and codes identified under trust and quality

Theme and codes identified under "Trust & Quality"		
Axial Code	**Characteristics of Respondent**	**Supporting codes from interviews and open code**
Maintain the quality and standard of food	Testing analyst from a consulting firm with 6 years of experience	R23: The entire information is recorded on blockchain platform and it is a fully digital, visible, and tamper-proof ledger, creating a secure and resilient supply chain that influences the organization to uphold the quality and standard of food Open codes: Blockchain technology enhances food quality in the agri-food supply chain.
Create trust among users	A senior analyst from an IT firm with 7 years of experience	R5: The technology has created a new platform for business relationships and users. It is a record-keeping and trust-building technology that, once implemented, makes records invulnerable to deletion or tampering. Which reduces the chances of fraud and creates trust among users Open codes: Blockchain encourages trust among all the peers
Collaborate supply chain processes	Procurement manager from a Warehouse management firm with 10 years of experience	R10: The blockchain is a distributed ledger technology that combines all the processes of the agri-food supply chain into a single network Open codes: Technology integrates and optimizes the agri-food supply chain process.
Increase consumer awareness and satisfaction	A senior manager from a supply chain management firm with 10 years of experience	R19: Blockchain can provide traceability, transparency, security and simplification in the purchase process, which helps to increase trust and satisfaction among users

	Open codes: Blockchain technology brings customer loyalty to the agri-food supply chain.

4.4.2 Development of propositions

This study used a methodology of semi-structured interviews to collect data and represent the empirical findings. This method provides fascinating developments and implications of DC through blockchain that can further enhance the agri-food supply chain processes having complex and complicated structures.

The agri-food supply chain is a complex and complicated structure to understand. Traditional supply chains face many problems at each stage, such as late delivery, fraudulent acts, miscommunication between stakeholders, and some issues that visual acts cannot capture. According to R2, "The traditional agri-food supply chain encounters many issues of inaccuracy and difficulty of managing the whole system because not everyone has access to information which greatly diminish the integrity of agri-food supply chain. We should integrate new technology with agri-food supply chain to overcome the challenges and combine all the supply chain processes on a single platform". Blockchain technology has come into the picture for the last few years to embrace its potential in the field of the supply chain. It plays a vital role in providing traceability solutions to the market. Therefore, experts recommend developing and investing in blockchain solutions to achieve more value for the product as R18 stated that blockchain technology can enable tracking in the supply chain and has the potential to increase supply chain traceability by providing access to the users to record price, date, quality, certification and other relative information. The availability of this information on the blockchain platform reduces losses and counterfeit products in the market, enhancing a firm position. Regarding DC, firms dynamically shift their strategies to reflect demand and supply changes. According to R28, blockchain analyzes consumer and market demand by easily tracing the processes of demand and supply and, after that, aligning the supply chain operations. These highlights lead to the following proposition:

P1: Under the complex and complicated structure of an agri-food supply chain, it is crucial to track the origin and history of the product and in such a situation, blockchain plays a vital role in providing a traceability mechanism to avoid disruptions and maintaining the integrity

The world is moving from manual systems to digitalization in the agriculture sector; many technologies such as RFID tags, sensors, big data, artificial intelligence, blockchain etc.

integrated with the supply chain sector to provide a better solution in terms of its efficiency and processing speed and can replace the traditional supply chain [169]. Insufficient transparency in the supply chain creates unsafe working conditions and contributes to fraudulent acts of untrusted actors and corruption within the food supply chain. The increased visibility due to blockchain can help users to prevent fraud and corruption. The user can track the history of a product from its origin and verify the transactions between stakeholders. A transparent environment can also reduce the administrative cost by reducing unwanted intermediaries. According to R6, "Apart from the benefits of many technologies, there is a focus on the forecast of supply chain processes. Hence, blockchain technology can address various issues in the agri-food supply chain and open the horizon for more supply chain collaborations on its platforms". The blockchain advantages significantly impact the organization and the users in watching customers in real-time. Firms are embracing their use cases to meet the customers' needs as well as to improve their service levels. Customer interaction will help acquire market demand, gain insights into the changing preferences, and implement personalized solutions in the system. In the words of R17, "Blockchain-based agri-food supply chain will facilitate better visibility across the whole supply chain. It helps to create confidence among consumers by reducing irrelevant stakeholders and various risks related to financing". Therefore, developing DC transparency across the supply chain and building confidence among consumers and stakeholders is necessary for a firm to adjust the system with modern equipment quickly. In COVID-19, the major challenge of demand and supply was faced by the industry due to the lack of information visibility and accessibility. The blockchain-distributed network helps provide a transparent environment to users, and smart contracts help automate the processes and information exchange details between any two parties. Blockchain technology enhances agri-food supply chain performance and reduces threats.

The preceding discussion leads to the subsequent proposition:

P2: During the period of long disruption in the agri-food supply chain, blockchain technology can be used by organizations to increase visibility, see information, and process transactions to improve the efficiency of the system by integrating various processes on a single network.

Therefore, with increased customer expectations of high-security and quality food products, organizations have optimized their processes and built a more secure platform for the agri-food supply chain using blockchain technology. The unsecured structure of the supply chain contains a number of invalid transactions by fake actors, which create a mess in the whole system. According to R31, "Blockchain technology is based upon consensus mechanism, cryptography, and decentralization principles which make it more secure than any other technology of industry 4.0. Additionally, it gives an extra layer of security, ensures that data does not fall at the wrong place, and gives access to record the real-time transactions on the platform by each user". In terms of DC, the security of information data plays an essential role in the organization to prevent it from various hacks. Therefore, it is easier for the organization to identify the key supply chain processes in terms of security and reconfigure the necessary resources for the firm to maintain the security and integrity of data.

The above discussion comes to the following proposition:

P3: During the condition of an unsecured platform, blockchain technology is perceived as a highly secure platform to store data in an immutable and tamper-proof manner, which in turn removes the supply chain risks

Smart contracts are defined as a set of computer programs stored within the blockchain network. This program allows you to verify the users participating in the supply chain processes and execute a program automatically and quickly. By streamlining and automating the processes of the agri-food supply chain with blockchain, transactions can be completed faster and more efficiently. In the traditional supply chain, no contracts are executed for the buying and selling of products at each stage were executed. Moreover, limited contracts were taken place, which are based on paperwork. Therefore, it is recommended by the experts to execute smart contracts in the supply chain processes, as R30 stated that "Smart contract operates on blockchain platform instead of a server or a personal computer, eliminating the need for human intervention to verify any authenticity of a user. It also helps in reducing the cost as middleman services fees disappear in this contract". The manual transactions are steady, slow, and sometimes even take a number of days to execute. This problem emerges because of insufficient resources or a well-developed digital platform for the agri-food supply chain. According to R11, As the transactions are done automatically, the time invested is reduced in comparison to contracts done manually and in the presence of many intermediaries. The platform guarantees the immutability of data and allows contracts to be made without knowing each other and avoid mistakes in the management and execution of contract. In terms of DCs, organizations dynamically makeshift in their strategies and change the platform for executing blockchain processes in the agri-food supply chain with experts and knowledgeable engineers. It will streamline the entire process and safeguard the organization's interests based on the gathered data.

These highlights generate the following proposition:

P4: In the case of automatic and digital transactions, blockchain technology executes a smart contract, which is a software program that directly and automatically controls the transfer of digital assets and provides potential benefits such as reducing transaction costs, increasing security, and avoiding reliance on individual servers.

With the rise of blockchain technology, it builds a tool that automates user trust. The records are stored on a single digital ledger that is shared among participants. Everyone has to access the same information regarding the same process they are searching, which in turn maintains trust among each other without the need for numerous intermediaries. Therefore, experts must invest in blockchain technology to attain more resilience in the supply chains. According to R15, "The chaining of blocks in the network ensures that the content of blocks is trustworthy at all times. Blockchain technology reconfigures trust in society. Blockchain technology also provides a collaborative platform to the users in which all the events are recorded on the same platform in an immutable and transparent manner, which leads to organizations maintaining the quality of food. The fake products are easily captured, and change of a single transaction in the data necessitates changing all subsequent records, extinction of the entire network". In terms of DCs, blockchain technology could help us to establish a cashless society and help foster new values and skills in the employees working in the organization that they feel valued. The above discussion heads to the following proposition:

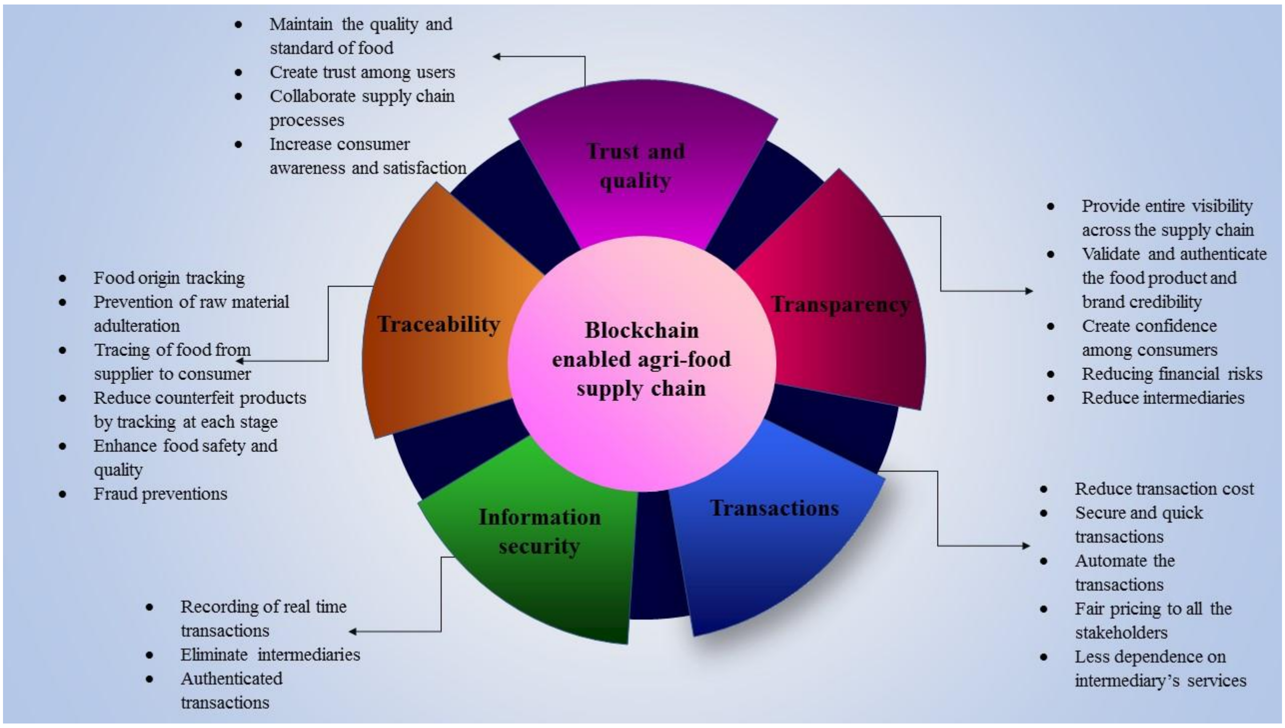


Figure 4.2 Capabilities of Blockchain-enabled agri-food supply chain conceptual framework

P5: Under the condition of an untrusted environment and diminished quality of food products, distributed ledger technology establishes trust between distrustful parties by allowing for safe transactions, which enables trust among its users and a transparent nature to maintain the quality of food throughout the supply chain

Based on the five propositions, this study constructed a conceptual framework as shown in Figure 4.2.

4.5 Discussions and Implications

This study extends the literature by presenting exciting and valuable insights in relation to existing knowledge on blockchain-enabled agri-food supply chains while adopting the lens of DC. The interview sessions explored the various aspects of respondents on the key drivers of implementing blockchain in agri-food supply chain management. Afterwards, the five major capabilities have been derived which can help the organizations and various firms in reaping the benefits of the blockchain-enabled agri-food supply chain in the future. Figure 4.2 reveals the analysis's findings, including blockchain relation with the capabilities. Traceability, transparency, information security, transactions, trust, and quality are five capabilities. Recent studies have examined the role of blockchain technology in designing and developing agri-food supply chain structures. However, this study conceptualizes DC as an appropriate approach to examine and critique the implication for theory and practice for the blockchain-enabled agri-food supply chain.

This study concludes that transaction costs are reduced by using blockchain technology in agri-food supply chain processes, which is in line with the previous study [170]. The cost is considered as the deriving variable for blockchain adoption due to its benefits, but some users perceive it as a costlier technology to implement [171]. However, the blockchain technology platform helps maintain fair pricing among all the stakeholders [172]. It also helps in reducing the overall cost of the supply chain in terms of reducing production costs, transportation costs, food recall, and maintenance costs, thus helping the business organizations to become economically sustainable [173]. Also, the transactions on the blockchain system can run automatically by using smart contracts, which reduces the involvement of intermediaries and transactional frauds [174]. Smart contracts are programs that can run automatically when a certain condition is met, which minimizes the fluctuating demand and supply of the food supply chain.

Traceability is one of the capabilities that help all the stakeholders to access real-time data and improve supply chain visibility, which is supported by the existing study of Kamble et al. [3]. The blockchain platform can give users access to check the authenticity of food items and trace them throughout the supply chain [103]. The blockchain-based platforms provide information on product origin and all the involved processes. TraceX Technologies has initiated a start-up in the tracking of the maize value chain for 1000 farmers in the Belgaum district of Karnataka by using blockchain technology [175].

Blockchain technology can provide a transparent and more precise information-sharing platform than any other information system, as supported by the study of Iansiti and Lakhani. [176]. Blockchain can improve the transparency of the system through which an organization can communicate and report all the actions across the supply chain network [3]. Also, it can enhance the visibility among various processes and thus radically transform the industry. Information security is another capability of the blockchain-enabled agri-food supply chain. The previous studies are consistent with the results that blockchain needs to be adopted in the agri-food supply chain processes to minimize their risks [177]. As earlier, the government schemes do not reach the people due to corruption or misleading information, which can be monitored by using blockchain-based platforms. For example, the Indian Public Distribution System (PDS) should be embedded with the help of blockchain technology to improve its efficiency and provide food security [18]. Blockchain technology eliminates the intermediaries that help to deal directly with firms and organizations. It will help to minimize uncertainty and empower secure communication between stakeholders [9].

Trust and quality are other capabilities analyzed by this study, which is in line with the existing studies of Queiroz & Wamba. [178]. To meet the strict food quality and trust issues among stakeholders, there is a need for blockchain technology adoption in supply chains. The agricultural supply chain system faces stringent scrutiny from regulatory bodies on various fronts for maintaining the safety and quality of food. Therefore, organizations and firms explore blockchain technology to comply with regulatory bodies [159]. The increased transparency by blockchain can help the users to better access the quality of food products [179].

According to this study, blockchain technology helps organizations and managers in developing countries like India to make agri-food supply chains more sustainable and improve their performance due to its capabilities such as reduction of food recall, transactional cost, risk management cost, providing traceable and transparent platform, improving information sharing, trust between stakeholders and collaboration, which is contrasting with the existing studies by Wong et al. [56] that shows the negative relationship between blockchain technology and performance expectancy. The reason can be that earlier blockchain technology was considered to be immature technology, and its benefits did not convince the managers and firms to implement it at that stage. This may occur because of a lack of awareness, knowledge, and blockchain developers and their expertise. Some Indian states, such as Maharashtra, Haryana, and Uttar Pradesh, have successfully run pilot projects based on blockchain technology to link land records, land ownership, and registration databases with e-courts [180]. Therefore, the adoption of blockchain technology has started initializing and leveraged to develop new business models.

4.5.1 Theoretical Implications

This research contributes to the existing body of literature by conducting empirical investigations into the functionalities of agri-food supply chains empowered by blockchain technology. Many studies have explored the role of blockchain in the supply chain. However, in the agri-food supply chain, there is a lack of empirical evidence of implementing blockchain solutions in relation to dynamic capabilities. This study prepares the comprehensive base for implementing blockchain in the agri-food supply chain through expert opinions. This study addresses the knowledge gap in three ways. Firstly, by exploring the capabilities of the blockchain-enabled agri-food supply chain through interviewing experts. This provides empirical evidence of how blockchain capabilities can help in improving agri-food supply chain processes. Second, this study has also addressed the gap in the relationship between blockchain technology and dynamic capability. This study appreciates the role of DC in blockchain-enabled agri-food supply chains in the complex structure of existing supply chains. The DC motivated firms of other industries to adopt blockchain technology in various fields. Therefore, this study offers interesting insights into developing sufficient capabilities to reduce the risks and challenges of multiplex agri-food supply chains. Third, grounded on the open, axial, and selective coding of the empirical data, this study provided five propositions that emerged from the views of professionals. The five propositions have developed a five-dimensional framework that represents the components of the blockchain-enabled agri-food supply chain that have gained importance in the future. These propositions provide a cuttingedge foundation for future research studies and will help business organizations to enhance and improve the agri-food supply chain. It also opens various opportunities for companies and organizations to implement blockchain in several other sectors.

4.5.2 Practical Implications

This study provides an understanding to the managers, organizations, firms, and technical analysts about the role of blockchain-enabled agri-food supply chain and their capabilities that can affect blockchain adoption. Traceability is identified as one of the capabilities of a blockchain-enabled agri-food supply chain that facilitates the monitoring and tracing of food products across the supply chain. Blockchain can potentially enhance traceability solutions in supply chains through a decentralized network of nodes. Food traceability reduces risk to ensure the trust and safety of stored data for better food security [4 & 181]. Further, blockchain transparency provides visibility to all supply chain members with access to the distributed database. It plays a crucial role in the fair trade movement, where blockchain provides a truthful environment and gives information about the value they pay for the product returned to the farmers [182]. From the literature and expert's opinion, it is proved that in industry 4.0 emerging technologies, blockchain technology proves to be significant in integrating with supply chains and establishing a trusted environment to build a transparent, traceable and more suitable agri-food supply chain by combining all the key stakeholders onto a single platform [9]. Blockchain technology also provides information security, which prevents malicious users and defrauding activities in the supply chains. It also helps to reduce transaction costs and time by using distributed ledger technology. It automates transactions using smart contracts and eliminates various intermediaries in the agri-food supply chain. Counterfeit products are a major concern of society which lowers the trust of people [128]. Hence, blockchain technology contributes to the verification and protects the products from mixing in and reaching out to consumers [183]. The study also provides distinctive opportunities for agri-food supply chain members to employ blockchain technology to nourish the movements and improve the efficiency of critical activities in the supply chain. The blockchain-enabled agri-food supply chain not only provides traceable solutions to the users but also provides trust among consumers, which in turn helps to increase the confidence of users in adopting new technologies in the environment. The agri-food supply chain sectors were primarily dependent on the farmers and laborers, where people faced issues such as lack of knowledge about advanced technologies, and information technology skills. Therefore, before implementing blockchain in the agri-food supply chain, professionals need to consider some facts: (1) awareness and knowledge of blockchain among users, (2) provide knowledge of sensors and information technology skills to the users, (3) benefits of blockchain technology adoption among various users and their usage. Technological solution providers can utilize blockchain capabilities such as traceability, transparency, information security, cost, trust, and quality for achieving sustainable solutions in the agri-food supply chain sector by reducing fraud, corruption, miscommunication between stakeholders, quality of food, and fair product payments to farmers and reduce exploitation of laborers and small scale, farmers. It will help business organizations, managers, and firms to accelerate blockchain adoption. The findings reveal that blockchain technology provides additional safety and lower transaction costs and can create trust among users. Blockchain-enabled agri-food supply chains automate the agreements using smart contracts between parties. In this way, adopting blockchain technology will not only enhance the firm's readiness and cope with uncertainty, but also helps to maintain sustainability in the supply chain processes. After all these benefits, blockchain technology adoption is in its early stages. Therefore, the study highlighted the components in the proposed conceptual framework that will help users enhance the blockchain adoption strategies and analyze the capabilities required for implementing blockchain in the agri-food supply chain. Therefore, this study provides implications for both theory and practice.

4.6 Summary

Agri-food supply chain management is the most important area in today's dynamic world. A supply chain is flexible in responding to dynamic changes in an environment where people usually cannot trust the product and the company that does the production and satisfies the customers. Hence, blockchain is considered to be the one technology that enhances visibility in procurement, ensures accurate and reliable data for analytics, and fosters increased trust among all stakeholders. It helps to eliminate the human interaction in non-value-added activities. It also helps to maintain the security of the entire network and organization. Additionally, this study adopts the lens of the dynamic capability to conceptualize the blockchain dynamic capabilities that are quick to adapt to a dynamic environment. This study used semi-structured interviews and conducted a debate with experts and professionals to inspect how blockchain technology is used as a DC of an organization to strengthen the execution of a smart supply chain. As a result, five capabilities have been recognized, such as traceability, transparency, information security, transaction trust, and quality, and are strongly related to each other. In considering DCs, this study explored the capabilities of blockchain at an organizational level and how these capabilities of blockchain technology can improve agri-food supply chain performance. Moreover, this study developed and presented the framework of a blockchain-enabled agri-food supply chain. Therefore, blockchain technology can be helpful in improving traceability and transparency through continuous monitoring of supply chain processes and ensuring the quality and safety of food products throughout the agri-food supply chain. It also helps to maintain the security of data stored on the distributed network, which in turn increases the confidence of users. In conclusion, this study presented in-depth knowledge and findings on implementing blockchain-enabled platforms and systems to enhance the effectiveness of the agri-food supply chain.

Chapter 5: Enablers of blockchain adoption in agri-food supply chain with dynamic capability perspective: A Total Interpretive Structural Modelling approach

In the context of blockchain technology, it is a new digital technology approach that ensures data integrity and prevents tampering and single-point failure by providing fault-tolerance, immutability, trust, transparency, and full traceability of transaction records to all partners along the agri-food value chain. This chapter discusses the extended version of blockchain capabilities and analyzes the relationship among different capabilities of the blockchain-enabled agri-food supply chain. Further, this study also analyzed how these variables make agri-food supply more efficient by collecting responses from 32 agri-food supply chain professionals and blockchain experts.

5.1 Introduction

Several industries are disrupted by the revolutionary technologies of the 4th industrial revolution that are shattering all the stages of production and business models. At the same time, these emerging technologies provide new opportunities for businesses to increase competitiveness. Still, simultaneously, they pose new challenges to managers in understanding the implementation of these technologies so that processes can be optimized to increase economic growth [170]. The food industry faces key challenges that affect supply chain events, such as quality of food, safety of food, wastage of food, price of food, volatility, product origin traceability, transparency, and smart farming safety [113].

An agri-food supply chain comprises key players, namely producers, in which farmers play an essential role in the sowing, harvesting, and producing of food products using traditional methods. Processors aim to refine the production in the industry and enforce quality checks and standards, and distributors are allowed to store and transport products from supplier to retailer and importers [184]. Customers check the governance standards of the food products delivered to the market, and retailers sell the food products and processed food directly to the market and in local stores. In the end, consumers purchase the product and have a right to expect the safety and quality of food products, as shown in Figure 5.1. A centralized agri-food supply chain based on a single authorization and various processes was run by multiple stakeholders, making it complicated and unstructured. Consumers do not have the right to raise their opinion about the food control procedures, standards, and quality of food delivered to them. As a result, food traceability cannot be established within the agri-food supply chain, which further leads to food fraud, data tampering, and counterfeit information delivered to stakeholders [185].

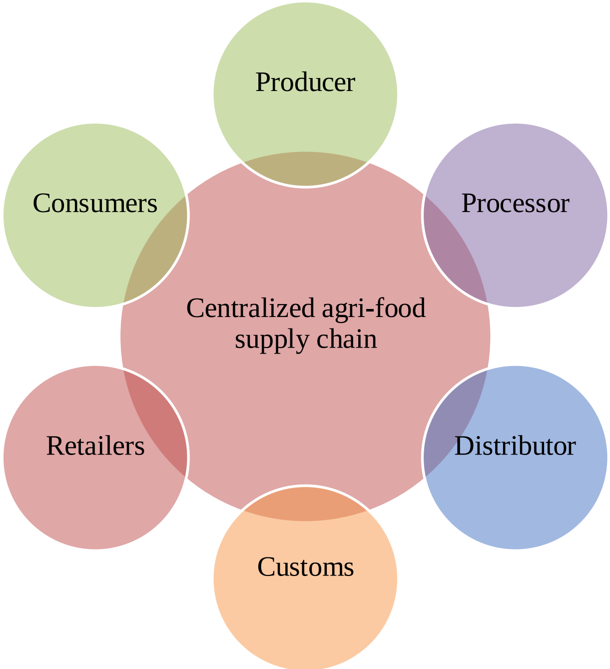


Figure 5.1 Conventional agri-food supply structure

The recent emergence of blockchain technology provides many benefits to supply chain management. It is a type of technology for storing data that makes it virtually impossible to hack or alter the data [38]. Blockchain technology is the new approach applied in supply chain management to monitor the various aspects of supply chain processes and have a great influence on supply chain and business models [186]. Amongst other benefits, blockchain technology can solve the problem of the complex supply chain such as privacy and security, traceability, transparency, resilience, trust, uncertainties, fraud preventions and reduction of cost [187 & 188]. Thus, integrating blockchain technology with supply chains is a robust and trusted approach for remodeling the supply chain processes and increasing the efficiency of various organizations.

Many researchers like Kamilaris et al. [9], Kumar et al. [144], and Pandey et al. [65] have shared their opinions on implementing blockchain in food supply chain management that helps to develop a safe and secure food supply chain and increase the performance of the system. Blockchain technology continues to be developed, and it will contribute significantly to the agro-food supply chain sector by improving accountability, transparency, and traceability across all supply chain partners by maintaining information symmetry [3]. Agri-food supply chain sector is selected for two reasons. First, this sector is broadly ignored by researchers despite its high impact on the economy. Second, it has a very complex structure, which makes it difficult to understand [189]. Therefore, this study explores the impact of blockchain technology on the agri-food supply chain and how the key aspects of the blockchain-enabled agri-food supply chain are related to each other**.** This study adopted a multi-method approach. First, a TISM model approach is generated to identify the relationship between constructs of the blockchain-enabled agri-food supply chain. Second, this study adopted an empirical research methodology to test further and verify the relationship that emerged from TISM. This study aims to uncover the relationship structure among factors that contribute to minimizing the disruptions and that lead to the blockchain-enabled agri-food supply chain. In light of the aforementioned discussion, it is clear that blockchain technology has the potential to bring significant reformation to the agri-food supply chain.

5.2 Related study

Agricultural supply chains are complex systems that handle the circulation of agricultural products from production to distribution and bring agricultural products from the farm to the table**.** The various stakeholders are involved in the agri-food supply chain, with multiple other bodies such as government organizations, national and international agriculture agencies, and non-government institutions, which make it complex and complicated to perform trustful acts [190]. Every stakeholder has issues and problems in running their associated activities, as discussed by McCullough et al. [191] in their study. Not only do stakeholders face challenges, but consumers have food safety and quality issues, fluctuation of prices, and lack of standardization related to agricultural products. The key goal of the supply chain is to integrate all the processes which may enhance the operational performances by reducing the demand riskiness, delays in the changing environment, and inefficient performance of supply chain stakeholders, which ultimately reduces the uncertainties that exist in the business environment [192 & 193]. Transparency and traceability are other aspects that could be considered key components of the supply chain for better performance.

- **Traceability (TRC)**: It involves the capability to track the progression of food across designated phases of the agri-food supply chain. Blockchain technology is considered a way to facilitate traceability with trusted information [194]. It is the ability to access all information related to the product under consideration and can be traced backward and forward via the time stamp. The traceability function in blockchain technology can enhance food safety and integrity. Moreover, it also helps the companies to quickly mitigate food safety failures and identify the reason for the disruptions.

- **Transparency (TRN)**: Transparency in the blockchain network means a level of understanding and access to information about the food product requested from the users of the agri-food supply chain and this should be thorough, precise, and free from distortion or extraneous details [195]. Blockchain technology brings transparency to the agri-food supply chain network. Which automatically builds trust between various parties. A distributed ledger system manages agriculture information and safeguards agriculture activities by providing complete visibility to all users. Ultimately, it minimizes prices, improves quality, and requires the management of the organizations to report their activities under the eye to the public.
- **Information security (IS)**: Every action, along with all the transactions, is recorded to the blockchain network, an immutable means to store information by all participants in the agri-food supply chain. The information captured is further validated by all the participants of the blockchain network, which automatically creates security [9].
- **Transaction (TRS):** The transactions are operated by smart contracts that are self-executing and self-verifying programs and perform a transaction among mutually untrustworthy parties in the agri-food supply chain. Each contract execution history is recorded in the blockchain network in an immutable nature [65].
- **Trust and quality (TNQ)**: Blockchain technology helps to eliminate the middleman involved, allowing the stakeholders to function and connect directly with the users of the blockchain-enabled agri-food supply chain. Direct communication between various users and a transparent structure can build trust among them. The transparent system can increase the quality of food products as counterfeiting food products is easily recognizable in blockchain networks [196].

Dynamic capabilities

The term dynamic capabilities emphasize two key aspects. The term "dynamic" refers to the changing environment and the need for specific strategies, including internal and external organizational skills, resources, and functional expectations toward changing paces of innovation, which are accelerating, and future competition and markets can be difficult to predict. The term "capabilities" refers to the importance of strategic management in successfully adapting, integrating, and reconfiguring an organization's internal environment [197]. In the changing business environment, the concept of dynamic capabilities (DC) refers to a combination of existing competencies that can be developed, reconfigured, and Enhanced to align with the evolving needs of the ever-changing business environment**.** In today's environment, to meet changing business demands, firms need to integrate, build, and reconfigure firm-specific capabilities [198]. As dynamic capability enhances the performance of the company, several researchers are integrating the dynamic capability approach with supply chain management [199]. Our study analyzes the capabilities and characteristics of blockchain-enabled agri-food supply chains based on a dynamic capability approach. The framework of dynamic capabilities was developed by the author Pavlou and El Sawy. [200] to assist firms in identifying capabilities that need redesigning and reconfiguration, as well as understanding their operational capabilities and improvement plans. A growing body of literature on dynamic capabilities in supply chain management exists. Dynamic capabilities enable an organization to acquire knowledge and create new capabilities effectively. The result is the discovery of competitive advantages. Furthermore, dynamic capability boosts competitiveness by encouraging continuous supply chain learning and knowledge management [201]. From the above-mentioned discussion, it is clear that dynamic capability plays a vital role in developing a blockchain-based agri-food supply chain.

5.3 Research design and methodology

A mixed method approach is used in this study that elucidates the identification of blockchain-enabled agri-food supply chain capabilities, building the level of hierarchy using interpretive structural modeling (ISM) and then applying TISM to know casual relationships and direct and indirect linkages between constructs, before quantitatively analyzing and validating the hierarchal model and hypothesis. In TISM, the interpretive knowledge base is the repository of understanding the relationship between different elements within a system. It involves interpreting the data collected through interviews, surveys and literature reviews to derive meaningful insights about the interconnection and dynamic within the system. Interpretive knowledge base serves as the foundation for informed decision making, strategic planning and hypothesis generation in research. It helps researchers derive deeper insights, uncover patterns, and make sense of complex phenomena by integrating diverse sources of information and applying interpretive frameworks.

This study adopts a method used by authors Friedman and Ormiston. [181] for the agri-food supply chain, where in-depth interviews were conducted with an expert to understand their opinion regarding the challenges in the agri-food supply chain and how blockchain technology can assist in preventing such challenges. The thematic analysis was also used to examine appropriate insights and help in developing the model. Moreover, a three-step coding approach, such as open, axial and selective coding, is used to frame constructs and sub-constructs. This chapter is the extension of the previous study, building the constructs and sub-constructs proposed earlier. The survey research method empirically validates the model and the results of the present study. Figure 5.2 presents the research design used in this study.

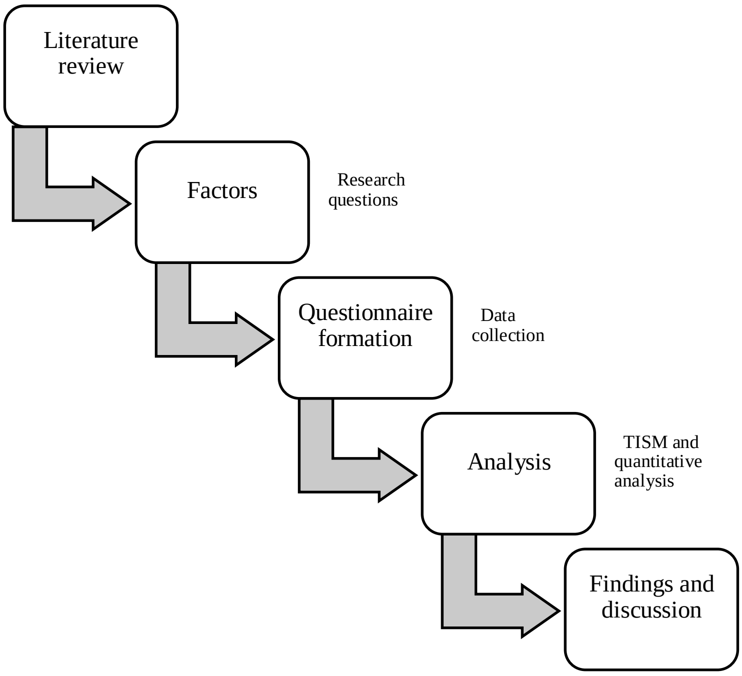


Figure 5.2 Research design of the study

Data collection

The different stakeholders and firms worldwide are experiencing various challenges in the agri-food supply chain from different perspectives. The impact seems to spread to many businesses, industries and ground-level actors in the agri-food supply chain. Understanding how producers, manufacturers, and agri-food supply chain stakeholders are handling these issues and how to organize their reactions helps organizations identify the most disruptive challenges and find a way to overcome them using new technologies and techniques. Firms updated their system with digital and latest technologies to predict and prevent these challenges. To understand the benefits of blockchain technology to agri-food supply chains and how firms can apply the blockchain capabilities, we have interviewed 32 professionals and experts from agri-food supply chain and blockchain who have adequate knowledge of blockchain use cases and their capabilities. The study used a method of purposive sampling for the analysis. After recognizing the results and findings received, a TISM framework was constructed. Further, a survey research method was used to form scale development and test the developed hypothetical model. The questionnaire was prepared by identifying appropriate measures from the extensive literature survey and studies on the blockchain and agri-food supply chain. The questionnaire was sent to 370 professionals and experts in the field of agri-food supply chain and blockchain, from which 260 responses were received. Two hundred forty-five responses were considered for further analysis based on the filled survey. Elimination was based on incomplete responses and where responses were not received from the experts in two different domains.

5.4 Analysis and Findings

The analysis is done in two phases: In the first phase, we interviewed 32 professionals and experts from agri-food supply chain and blockchain to understand the relationship between variables and further develop the TISM model. In the second phase, a survey-based questionnaire was generated, and data were collected for further analysis, leading to testing the model. Furthermore, a hypothetical framework was developed by using TISM.

5.4.1 Phase I: Total Interpretive Structural Model technique

In 1974, Prof. John N. Warfield first developed the interpretive structural model (ISM). This method can be used to develop a hierarchy of processes and define the relationships between variables. Over the past few years, academics of operations have been paying more attention to TISM as a better way to manage operations [202]. In addition, ISM is used to map the complex relationships among variables and understand how variables relate. In comparison to ISM, the TISM model performs better and captures causal ties between its constructs better than the former. Through TISM, complex systems are broken down into small pieces and a structural model is developed by utilizing experts' insights and experience on the subject matter.

- **Development of the TISM Model**

The first step to developing the TISM framework is to identify the dimensions that we have adopted. The interpretive knowledge base was then developed to record expert opinions. Experts in the supply chain domain who have either knowledge of technology-enabled supply chains or have implemented it in their work domain have been involved. The expert involved have great experience with supply chain systems, and we have sought their opinion about the construct we have considered for analysis. After verifying it from experts, data was collected for the TISM process. The steps involved in developing an interpretive model are the following:

Step 1: Identification/adaptation of variables of the blockchain-enabled agri-food supply chain through literature review and further verification through experts' opinions.

Step 2: A relationship among all the blockchain-enabled agri-food supply chain variables is established.

Step 3: Constructing a structural self-interaction matrix (SSIM), a pairwise comparison among blockchain-enabled agri-food supply chain variables is made to develop SSIM. The pairwise relationship is described in the form of V, A, X, and O where:

V: variable CD_i influences CD_j.

A: vaiable CD_j influences CD_i.

X: variable CD_i and CD_j influences each other, and

O: variable CD_i and CD_j are not related.

(Where CD_i and CD_j are two variables)

Step 4: Develop a reachability matrix by converting SSIM into a binary matrix

Step 5: After checking for transitivity in the reachability matrix, the development of a final reachability matrix is performed.

Step 6: Develop the level hierarchy/level portioning after a series of iterations.

Step 7: Construct the level hierarchy in diagram form.

Table 5.1 Symbols used in TISM

Symbol used	Conversion in the initial reachability matrix
V	In the event that the SSIM entry (i, j) is V, the entry (i, j) in the initial reachability matrix entry changes to 1 and the entry (j, i) to 0.
A	In the event that the SSIM entry (i, j) is A, the entry (i, j) in the initial reachability matrix entry changes to 0 and the entry (j, i) to 1

X	In the event that the SSIM entry (i, j) is X, the entry (i, j) in the initial reachability matrix entry changes to 1 and the entry (j, i) to 1
O	In the event that the SSIM entry (i, j) is O, the entry (i, j) in the initial reachability matrix entry changes to 0 and the entry (j, i) to 0

- **Data Analysis**

The contextual matrix was developed amongst variables after recognizing the initial feedback from industry practitioners, leading to the emergence of a structured self-interaction matrix (SSIM), as shown in Table 5.1

Table 5.2 SSIM Matrix

Variables	**BSC**	**TRN**	**TRC**	**TNQ**	**TRS**	**IS**
BSC		A	A	A	A	O
TRN			O	V	V	A
TRC				V	A	A
TNQ					A	O
TRS						O
IS						

The SSIM is then converted into the Reachability matrix (Table 5.2), as explained in Step 4.

Table 5.3 Reachability Matrix

Variables	**BSC**	**TRN**	**TRC**	**TNQ**	**TRS**	**IS**
BSC	1	0	0	0	0	0
TRN	1	1	0	1	1	0
TRC	1	0	1	1	0	0
TNQ	1	0	0	1	0	0
TRS	1	0	1	1	1	0
IS	0	1	1	0	0	1

Table 5.4 Final Reachability matrix

Variables	**BSC**	**TRN**	**TRC**	**TNQ**	**TRS**	**IS**
BSC	1	0	0	0	0	0
TRN	1	1	1*	1	1	0
TRC	1	0	1	1	0	0
TNQ	1	0	0	1	0	0
TRS	1	0	1	1	1	0
IS	1*	1	1	1*	1*	1

Next, the final reachability matrix was developed using the principle of transitivity as proposed by Farris and Sage (1975). The main logic of the transitivity principle is as follows: if X leads to Y and Y leads to Z, then x must lead to z. The final reachability matrix is prepared based on the same logic, as shown in Table 5.3.

Level Partitioning (LP): The process of dividing up multiple variables into their respective levels is known as level partitioning. The calculation of reachability and antecedent sets from Table 1 is the first step in determining the levels of variables [203 & 204]. In the process, iteration continues until the reachability set becomes the intersection set, as shown in Tables 5.4 to 5.8.

Table 5.5 LP Iteration-1

Elements	**Reachability set (RS)**	**Antecedent set (AS)**	**Intersection set (IS)**	**Level**
BSC	1	1,2,3,4,5,6	1	Level 1
TRN	1,2,3,4,5	2,6	2	
TRC	1,3,4	2,3,5,6	3	
TNQ	1,4	2,3,4,5,6	4	
TRS	1,3,4,5	2,5,6	5	
IS	1,2,3,4,5,6	6	6	

Table 5.6 LP Iteration-2

Elements	**Reachability set (RS)**	**Antecedent set (AS)**	**Intersection set (IS)**	**Level**
TRN	2,3,4,5	2,6	2	
TRC	3,4	2,3,5,6	3	
TNQ	4	2,3,4,5,6	4	Level 1I
TRS	3,4,5	2,5,6	5	
IS	2,3,4,5,6	6	6	

Table 5.7 LP Iteration-3

Elements	**Reachability set (RS)**	**Antecedent set (AS)**	**Intersection set (IS)**	**Level**
TRN	2,3,5	2,6	2	
TRC	3	2,3,5,6	3	Level III
TRS	3,5	2,5,6	5	
IS	2,3,5,6	6	6	

Table 5.8 LP Iteration-4

Elements	**Reachability set (RS)**	**Antecedent set (AS)**	**Intersection set (IS)**	**Level**
TRN	2,5	2,6	2	
TRS	5	2,5,6	5	Level IV
IS	2,3,6	6	6	

Table 5.9 LP Iteration-5

Elements	**Reachability set (RS)**	**Antecedent set (AS)**	**Intersection set (IS)**	**Level**
TRN	2	2,6	2	Level V
IS	2,6	6	6	Level VI

Figure 5.3 and Table 5.9 are the final outputs of the TISM process, which clearly show the interaction among variables. The dotted lines in Figure 5.3 depict the transitive relationship, while the solid lines depict the direct relationship based on the feedback received from the experts.

Table 5.10 Summary of transitive links

Variables	**BSC**	**TRN**	**TRC**	**TNQ**	**TRS**	**IS**
BSC						
TRN			Visibility across the supply chain			
TRC						
TNQ						
TRS						
IS	Fasten speed and recording of real-time transactions .			Visibility across supply chain	Eliminate intermediari es	

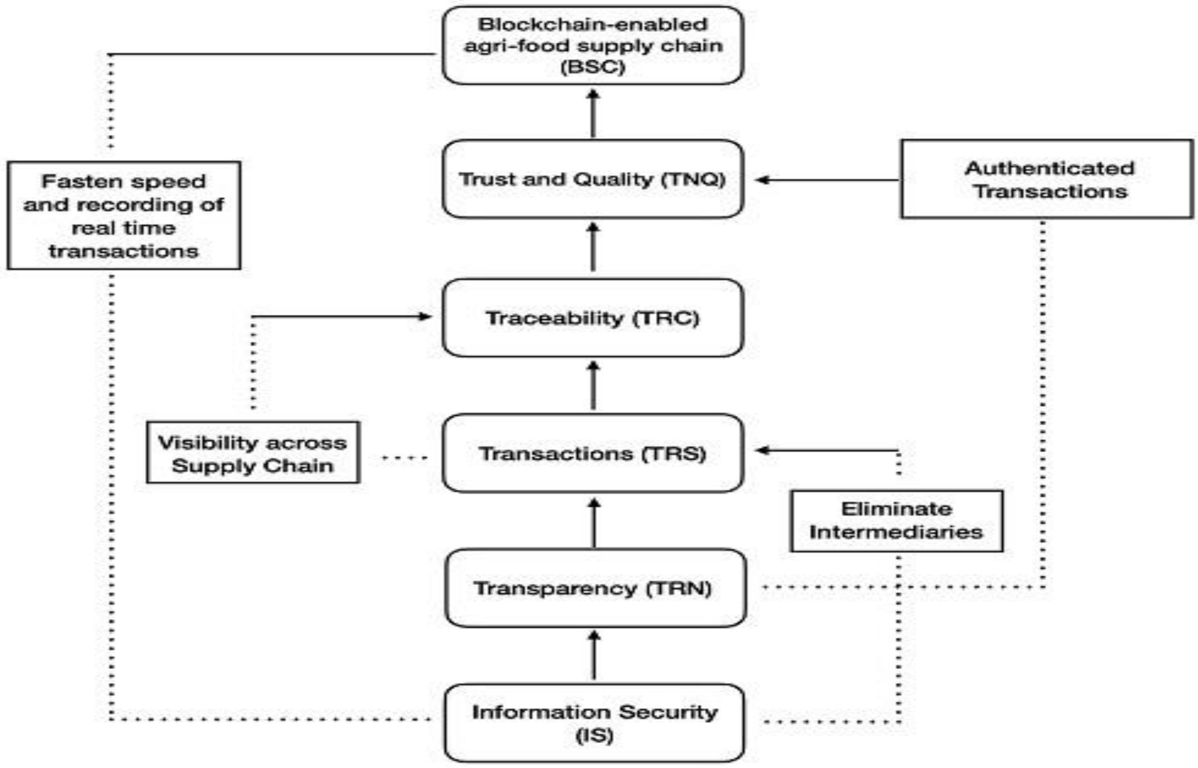


Figure 5.3 Blockchain enabled agri food supply chain framework using TISM

This study draws an inference from Table 5.10 and Figure 5.3 that information security creates the base to increase the performance of the agri-food supply chain. Security and privacy of supply chain processes enable the firm to pass on-error-free information to all the stakeholders, which leads to minimizing the issues in the agri-food supply chain related to food security and quality. Blockchain is an emerging technology that reduces the risks intrinsic to the agri-food supply chain, creating an auditable, immutable, and unchangeable history of transactions at each stage of the supply chain process. By design, blockchain technology is based upon timestamps and records all the transactions securely and permanently. All the transactions related to each actor of the supply chain can verify purchase and selling events that have come from a genuine customer. Therefore, counterfeiting a transaction is impossible. Cryptographic techniques have been used in blockchain technology in which transactions are encrypted with the private key, making the blockchain structure tamper-proof. In the agri-food supply chain, digital signatures by each participant initiate the transaction and make it immutable. Therefore, blockchain creates a tamper-proof, trustworthy and sequential audit trail of transactions. The primary objective behind information security is to build trust among people and run transactions efficiently by removing unnecessary intermediaries involved in the supply chains.

It also helps farmers and other small-scale stakeholders to increase their income by adopting new technologies in the agriculture sector.

5.4.2 Phase II: Quantitative survey research

The survey method is used further to test the hypothetical framework from TISM. A questionnaire was developed on blockchain-enabled agri-food chain supply variables and their items. The questionnaire was sent to the blockchain experts with the knowledge and understanding of implementing blockchain in supply chains in January 2022. We used SPSS v.21 for the data analysis. Appendix A presents the information of respondents.

- **Common Method and Non-Response Bias**

In an effort to reduce the potential of common method bias in this study, we asked respondents not to answer the questionnaire solely based on their experience but also to refer to their website and internal systems for gathering information related to the topic [205]. There is usually a concern about non-response Bias present in empirical research [206]. As a result of this, the responses are compared in two waves to validate the non-response bias [207]. The t-statistics $p = 0.08$ show no potential concern in the data collected.

- **Measurement validation**

In this study, no theoretical foundation exists to predict the links among constructs, as shown in Figure 5.3, which was extracted from interpretive logic. The reliability of each component is measured. Furthermore, the construct validity was measured using convergent validity, composite reliability and discriminant validity. The findings of the factor loading, composite reliability and AVE were obtained and presented in Table 9. It is approved that a factor loading value greater than or equal to 0,7 is ideal, but 0.5 is also acceptable if the AVE value of the construct meets the requirement [140]. Their respective item loadings were higher than .05, which is consistent with the findings of the previous studies of Kumar and Singh. [208 & 209]. The minimum value obtained for loading is 0.610, for SCR is 0.562, and for AVE, it is 0.560. These results led to the conclusion that the convergent validity of the scale can be concluded.

Table 5.11 Convergent validity, Composite Reliability, and AVE

Item	**Loading**	**SCR**	**AVE**
IS 1	0.808	0.886	0.662
IS 2	0.779		
IS 3	0.737		
IS 4	0.715		
TRC1	0.825	0.885	0.607
TRC 2	0.801		
TRC 3	0.775		
TRC 4	0.758		
TRC 5	0.735		
TNQ 1	0.864	0.870	0.629
TNQ 2	0.824		
TNQ 3	0.778		
TNQ 4	0.697		
TRS1	0.879	0.862	0.560
TRS 2	0.792		
TRS 3	0.755		
TRS 4	0.680		
TRS 5	0.610		
TRN 1	0.838	0.890	0.620
TRN 2	0.837		
TRN 3	0.794		
TRN 4	0.711		
TRN 5	0.651		
BSC 1	0.817	0.562	0.835
BSC 2	0.816		
BSC 3	0.728		
BSC 4	0.622		

In order to demonstrate discriminant validity, the correlation coefficient's absolute values must be lower than the square root of AVE's absolute value [140]. The AVE values in Table 5.1 1 are greater than 0.5, which aligns with the recommendation of the study by [138]. Table 5.11 shows the result for discriminant validity.

Table 5.12 Correlation Coefficient

	BSC	**IS**	**TRC**	**TNQ**	**TRS**	**TRN**
BSC	**0.562**					
IS	0.273	**0.662**				
TRC	0.345	0.199	**0.607**			
TNQ	0.184	0.281	0.148	**0.629**		
TRS	0.388	0.318	0.174	0.368	**0.560**	
TRN	0.178	0.197	0.246	0.305	0.233	**0.620**

It is utilizing regression analysis to examine the hypothesis testing. Table 5.12 presents the summary of the Hypothesis used in this study. According to results obtained from the regression analysis, each of the five links of the theoretical framework is statistically supported $p < 0.05$. From Table 5.12, it can be observed that the regression coefficient of path IS→TRN is positive (0.178). It refers to information security influencing transparency. It guarantees that blockchain technology maintains the information security of data and services in an immutable manner. Blockchain information security can help the participants record price, date, location, quality, certification, and other relevant information, which leads to the transparency of the agri-food supply chain processes.

Table 5.13 Structural Estimates: Summary of Hypothesis Testing

Effect Of	**Effect On**	**Beta**	**p-value**	**Results**
IS	TRN	0.178	***	Supported
TRN	TRS	0.197	***	Supported
TRS	TRC	0.246	***	Supported
TRC	TNQ	0.305	***	Supported
TNQ	BSC	0.233	***	Supported

The regression coefficient of path TRN→TRS is positive (0.197), which refers to the positive association between transparency and transaction solutions. Blockchain technology can increase visibility and enable real-time data sharing on the decentralized network. Thus, it can support traceable transactions that cannot be changed or deleted once all the users approve them. Therefore, the accuracy of these transactions is permanently known to all supply chain members. Additionally, when a firm's activities may result in controversial business activities, supply chain members monitor all the transactions and data and adjust their activities accordingly when finalizing future transactions. Therefore, it will help the organizations to minimize the challenges of the agri-food supply chain.

The regression coefficient as presented in Table 5.13 for path TRS→TRC is positive (0.246) and statistically significant $p < 0.05$. The transactions within the blockchain network are trackable at every step of the agri-food supply chain. The analysis supports the hypothesis that transactions will positively influence traceability solutions. Blockchain technology can potentially improve traceability and reduce transaction costs by eliminating intermediaries in the agri-food supply chain. It accelerates product and transaction traceability by developing an effective tool for organizations for strategic planning and better future programs.

The regression coefficient of path TRC→TNQ is positive (0.305), indicating that traceability can positively achieve trust and quality among users. The blockchain-based traceability system would provide flexibility and authority to all partners to trace forward and backward their supply network and create a transparent and sustainable supply chain, which in turn creates trust among users and maintains the quality of products throughout the supply chain. It will help firms decrease the counterfeiting of products to improve brand credibility.

The regression coefficient for path TNQ→BSC is positive (0.233) and strategically significant $p < 0.05$. The trust and quality effect of users is positively associated with the blockchain-enabled agri-food supply chain. The adoption of blockchain technology can increase trust among users and between firms is crucial to the agri-food supply chain's success. It also ensures that trust throughout the supply chain improves performance and reduces disruptions.

5.5 Discussions and Implications

This study offers a deep understanding of blockchain-enabled agri-food supply chains and how different characteristics of blockchain technology can help increase agri-food supply chain performance. The TISM and empirical analysis results show the independent behavior of agri-food supply chain constructs. Different agri-food supply chain elements examine the driver-dependent relationship, which is further verified through an empirical analysis used in this study. The interconnected and combined business activities and continuous flow of data directly fetched from sensors and then embedded on the blockchain platform help to ease the manufacturing facilities, delivery processes, price transparency, and security and privacy of the system. Furthermore, it helps to ease communication between supply chain stakeholders and create trust among people. Therefore, with the rise of technological platforms and new technologies, namely artificial intelligence (AI), IoT, and blockchain, the agri-food supply chain has become smarter with the supervision of all the processes [210]. This way, blockchain presents the opportunity for the agri-food supply chain to achieve traceability, transparency, and system security, which are the key drivers of making the agri-food supply chain more efficient and help them handle uncertain events in the supply chain processes.

5.5.1 Theoretical Implications

The study's outcome gives intriguing implications that can help understand how blockchain technology is used in the agri-food supply chain and make it efficient. However, researchers have different views on achieving performance among agri-food supply chain events. Wamba et al. [211] developed and tested a model of blockchain technology's influence on supply chain performance in two different countries, India and the US, respectively. The results indicated that knowledge sharing and trading partner pressure play an important role in influencing practitioners in the adoption of blockchain adoption, which in turn improves the supply chain performance. Blockchain technology provides users with real-time information on the agri-food supply chain, but its adoption is still in its infancy [151]. Blockchain enables traceability in the agri-food supply chain, while smart contracts enable smooth agribusiness operations. Hence, it enhances sustainability by tracking conformance for each activity in supply chain operations [212]. It also helps maintain the security and privacy of data in the supply chain system [213]. Therefore, the organizations are better positioned once they sense the associated risks and prepare the agri-food supply chain processes to avoid and resist the tasks first and then make a plan to recover from disruptive events. In addition, the agri-food supply chain enabled with blockchain technology is helpful not only in increasing its performance but also in helping the managers and decision-makers to make decisions quickly and plan the supply chain processes in a continuous form under various circumstances.

5.5.2 Practical Implications

Blockchain is recognized as a technology with significant promise among agri-food supply chains these days. Traceability and transparency provided by the blockchain in the agri-food supply chain help to maintain consumer and supplier demands and expectations. This study presents practical implications for managers, decision-makers, and knowledge experts for building smart agri-food supply chains. Today's technical experts rely on data usage and develop strategies to tackle disruptions in the system. In contrast, blockchain technology stores data with full security, and smart contracts automatically execute the process and agreement between various parties so that all participants can promptly ascertain the outcome without delay. The managers and experts can employ blockchain for real-time coordination that enhances the participation of each stakeholder in the supply chain, build trust among partners, and reduce uncertainties. In today's era, experts need to employ blockchain solutions in the agri-food supply chain by identifying the existing challenges, developing new models and testing novel approaches toward an efficient agri-food supply chain. The managers further bring transparency to the agri-food supply chain ecosystem, making it easier to figure out contaminated and fraudulent products in the market. The blockchain brings fair pricing through the agri-food supply chain for all the actors involved. It allows the managers and experts to execute programs easily and automatically with minimum disruptions.

Different supply chains and stakeholders have different problems and issues. However, not all the challenges can be solved by blockchain technology. As blockchain technology offers many benefits to the agri-food supply chain, the accuracy of data collected from various sensors or by people cannot be guaranteed. Thus, it cannot be reliable. Furthermore, the adoption of blockchain technology is lacking in society [214]. This study first developed a TISM model to understand the driving factors and dependent elements to gauge the relationship between factors. However, future research studies can be suggested to generalize further the results obtained from this study to drive more variables associated with blockchain-enabled agri-food supply chains and explore their relationship.

Further, the study has explored the adoption of blockchain technology in developing countries and various supply chains. Future studies can also discover the potential of blockchain technology and its implications in the agri-food chain by evaluating users' behavioral intentions in implementing blockchain solutions in supply chain processes. This study used cross-sectional data for the empirical analysis. Future research could use data collected over time to make the findings more reliable and applicable to a wider population.

5.6 Summary

This study contributes to the literature on agri-food supply chain management and blockchain technology by highlighting the driving and dependence variables of the agri-food supply chain and how blockchain technology enabled the agri-food supply chain to make it efficient. The study also highlighted how blockchain technology enabled the agri-food supply chain driving variables to be influenced by each other through empirical analysis, where all the hypotheses are supported. Blockchain technology can help organizations and experts respond to the ever-changing business world and address the challenges that exist in the existing supply chain networks. Further, blockchain can provide a traceable and transparent network to the users to mitigate the risks at different levels of supply chains and create value for the users. Blockchain can further provide a secure network of nodes by storing authenticated data and can build trust among users. In summary, blockchain technology facilitates government organization. It enhances the technological capabilities of the agri-food supply chain to communicate with different stakeholders and collaborate with them on a single platform without any disruptions.

Chapter 6: Blockchain adoption in agri-food supply chain: An empirical study of main drivers using extended UTAUT

Blockchain technology can overcome many complicated problems related to confidentiality, integrity, and availability of fast and secure distributed systems in the agri-food supply chain. In emerging economies like India, blockchain applications in the agri-food supply chain are still new, and their adoption needs to be developed. This chapter aims to investigate the drivers of blockchain technology adoption and their effect on the behavioral intention of stakeholders in adopting blockchain technology among various stakeholders in the agri-food supply chain. This chapter attempts to develop an adoption model using the extended unified theory of acceptance and technology model with interfirm trust and transparency as additional factors.

6.1 Introduction

In recent years, the agriculture sector has played an increasingly important role in ensuring sustainable growth by integrating best agricultural practices and protecting the environment. The agri-food sector is undergoing a new revolution due to modernization and the use cases of digital agri-food supply chain have made it convenient to deliver products directly from farm to fork. Over the past few years, among other technologies, blockchain has received much attention from the scientific community in integrating with the food supply chain [4]. The decentralized, traceable, tamper-proof and other technical features of blockchain technology help solve many issues in traditional supply chain finance. It also helps improve the safety and quality of the global food supply distribution and transforms many aspects of the agriculture industry. It provides a better monitoring approach and connects the various food supply chain actors on a single platform [215]. IBM is considered the leading enterprise blockchain provider for the food supply chain [37]. The digital flow of the agri-food supply chain using blockchain technology is shown in Figure 6.1. The topmost physical flow illustrates the various actors, including grower, producer, supplier, processor and consumer, in the agri-food supply chain and the digital flow describes multiple devices such as Radio frequency identification (RFID) tags, barcodes, sensors and cameras connected with the agri-food supply chain processes to provide end-to-end supply chain visibility and improved business operations as discussed by Pfahl and Moxham. [216] in their study. Every action on the agri-food supply chain is recorded

The major findings of this chapter have been peer reviewed and published in:

- *Sharma, A., Sharma, A., Singh, R. K., & Bhatia, T. (2023). Blockchain adoption in agri-food supply chain management: an empirical study of the main drivers using extended UTAUT. Business Process Management Journal, 29(3), 737-756.*

on the bottom layer, that is, the blockchain network. Growers can record information about the crops, fertilizers, pesticides and machinery used.

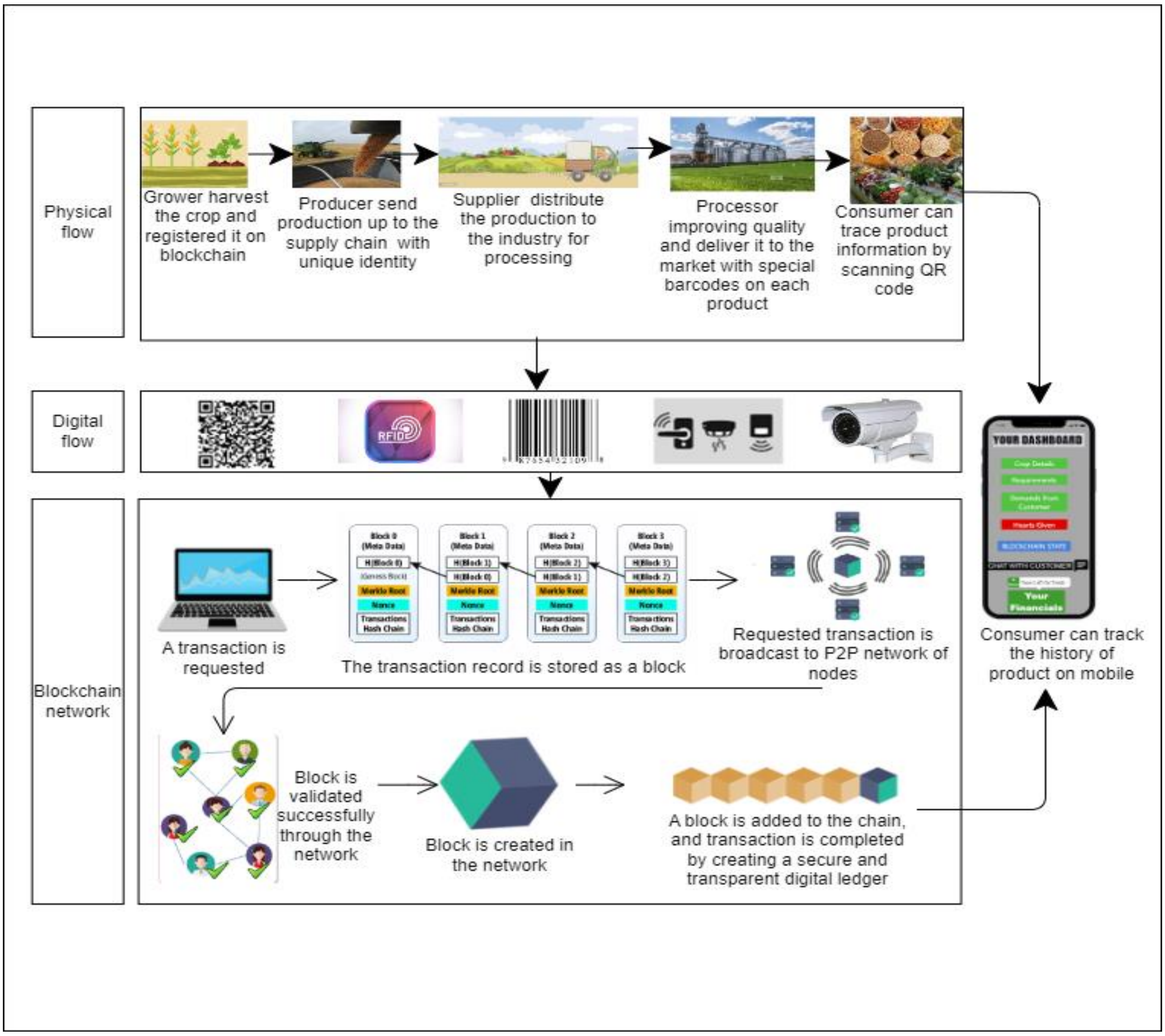


Figure 6.1 Digital flow of blockchain network

A producer can record information about the farm, farming practices, and crop cultivation process. Suppliers can record information regarding shipping details, storage conditions, transit time, and financial transactions between producers and distributors. The processor can record information about the processing methods, factory and equipment used, financial transactions, quality and quantity, expiration time, shelf time, etc. The blockchain network explains the working of distributed ledger technology in which the transaction is broadcasted to the network through a block. The block is successfully validated through the network by various business stakeholders involved in the food industry, and finally, the transaction is complete, and the block is added to the chain. Lastly, consumers can use a website or web app on mobile phones to trace all the information about the product by scanning a QR code. The distributed ledger increases the visibility and transparency of stored transactions. It is immutable, which ensures trust between parties and allows the automation of transactions. Also, a blockchain-based network eliminates the need for an intermediary to facilitate transactions. Therefore, it reduces the transactional cost and operates at a meager transaction fee. For example, Noahcoin helps Filipino workers in Japan perform transactions at a meager cost. A similar situation would be true for the Indian community [217].

Implementing blockchain technology in the agriculture sector makes the agri-food supply chain transparent, traceable, trustworthy and secure which can help to enhance consumer trust and prevention of product fraud during the entire journey of food supply chain operations [218]. Blockchain technology is a revolutionary approach. However, its impact is still hard to anticipate. Recently, numerous efforts have been made to adopt blockchain technology in supply chains, but it is yet to fully realize its potential, particularly in agri-food supply chains. Therefore, this study aims to investigate the main drivers for adopting blockchain technology and then analyze the adoption behavior of stakeholders in the agri-food supply chain.

While the literature on blockchain technology is proliferating, it is clear from the early research that a broader view is needed to understand the adoption behavior. Adoption of technology is not a new concept; many theories have aimed to determine user behavior towards certain technologies. Various technology acceptance models and theories, such as TAM (47), the task–technology fit (TTF) theory, the Diffusion of Innovation (DOI) theory, the model of PC utilization (MPCU), TRA [45], TPB [44], UTAUT [48] and social cognitive theory (SCT) has been existed in the literature and applied in a wide variety of domains to understand or predict the user behavior to assess the usage of upcoming, developed and implemented technology [42].

6.2 Related work

The following section first describes the adoption theories of blockchain in the field of food and agri-food supply chains. Several adoption theories have been given by various researchers, such as Thiruchelvam et al. [219], who predicted the importance of blockchain technology in the coffee supply chain in Burundi using TAM. It was determined that the actors of the Burundi coffee industry require technological adoption, automation and digitization of processes to ensure fair trade and price equality for consumers without the intervention of a third party.

Also, adopting blockchain technology solutions would offer transparency, greater sustainability, scalability, safety, and food security. The research conducted by Sheel et al. [58] has advanced our comprehension of blockchain adoption in the supply chain, demonstrating its potential to enhance supply chain adaptability, alignment, and agility. This fosters a competitive environment and enhances firm performance, offering valuable insights into the transformative impact of blockchain technology on supply chain dynamics. Wang et al. [59] conducted an empirical investigation into blockchain application in supply chains, highlighting its potential to revolutionize future supply chain operations. Their study delves into the transformative capabilities of blockchain technology, offering insights into its promising role in reshaping supply chain dynamics for the future. The experts conducted the interview to gain valuable insights into the emerging nature of blockchain technology and its potential to revolutionize the concept of trust in supply chains. Similarly, Tayal et al. [220] used a PCA-TISM-MICMAC integrated methodology by integrating Principal Component Analysis (PCA), TISM, And Matrice Impact Croises Multiplication Applique a un Classement (MICMAC) to find out the main drivers of the implementing blockchain technology in the food supply chain. Experts believe that transparent systems, fraud detection, inventory management with tracking, scalability, secure systems, cost reduction, safety and quality food, customer satisfaction, and government regulations are some of the nine critical success factors for adopting blockchain technology in the food supply chain. Kamble et al. [221] proposed a model based on three adoption theories, such as TAM, TRI and TPB, to understand the supply chain practitioners' perception of blockchain adoption in supply chain management in India. In 2020, Kamble et al. [3] extended their research on blockchain technology in agriculture supply chains. They identified thirteen blockchain enablers in the agriculture supply chain from the literature and validated them through a group of experts using ISM and Decision-Making Trial and Evaluation Laboratory (DEMATEL). They recommended for checking the cause-and-effect relationship between enablers of blockchain technology and used SEM for future research studies. Similarly, Wong et al., [170] proposed a blockchain operation supply chain management model using a technology, organization and environment framework among Malaysia's small-scale enterprises.

Alazab et al. [57] presented a modified version of the Classical Unified Technology Acceptance and Use Theory. It integrated it with the TTF and information system success models in the UTAUT with two Trust-Based Information Technology and Innovation Acceptance Models to shed some light on the adoption of blockchain technology in the supply chain in the Australian context. The results revealed that inter-organizational trust and trust in technology directly influences behavioral expectations towards blockchain adoption. Similarly, Stranier et al. [157], interviewed the supply chain stakeholders and applied thematic analysis to reap the results. They concluded that blockchain technology leads to more efficient management of tractions, reduces behavioral uncertainty, improves collaboration among supply chain stakeholders, and reduces the augmented bilateral dependency among supply chain actors after blockchain technology adoption. It also helps strengthen the relationship between stakeholders and the quality of collaboration among them.

Regarding blockchain technology, several researchers have focused on empirical studies of blockchain adoption in the supply chain [54, 56, 57, 59, 60, 61, 170, 178, 221, 222] and food supply chain [219 & 220], and agri-food supply chain [3]. Only limited studies take into account the blockchain adoption, specifically in the field of agri-food supply chain by the Indian community [3, 159, 214 & 223]. Therefore, the main goal of this research is to identify the drivers that influence blockchain adoption and then examine the behavioral intentions of stakeholders in adopting blockchain in agri-food supply chain management by proposing and validating a modified version of UTAUT. This blockchain adoption model will help stakeholders and practitioners understand blockchain technology adoption better with empirical evidence.

6.3 Hypothesis development

From the above discussion, technology acceptance models exist to explain the nature of technology adoption by different users. The present study used the extended UTAUT model by considering two more constructs from the literature, such as Interfirm trust and Transparency, to predict the drivers of blockchain adoption. By reviewing recent literature, the moderators were dropped in this study as it creates a variation in the adoption and respondents had no experience in the field of blockchain as a technology is in its recent stages [57 &178]. Based on the literature, performance expectancy, social influence, facilitating conditions, and effort expectancy were identified as predictors of behavioral intentions [47, 48, 49 & 50], while interfirm trust [54, 56, 57 & 178] and transparency was adapted from the existing literature [54 & 178]. A detailed description of the drivers of blockchain and their corresponding hypothesis formation is described below:

Performance expectancy: It is the extent to which a person believes that using a system will help in attaining gains in job performance [49]. In this study, the performance expectancy believes that using blockchain technology in the agri-food supply chain increased the overall performance and efficiency of its processes. The smart contracts in the blockchain are automatically executed programs by the blockchain platform, which leads to a high level of automation and streamlines the supply chain processes [59]. Blockchain technology reduces the time of transactions, improving logistics and supply chain efficiency.

H1: Performance expectancy directly influences the behavioral intention of adopting blockchain technology

Effort expectancy: It is the measure of ease associated with using a system [49]. In our model, effort expectancy is the ease of using blockchain technology in agri-food supply chain processes. Technology is less likely to be used if perceived as more challenging and requires extra effort than existing methods. Effort and performance expectancy are related to each other as they are aligned toward the system's efficiency, expectations, and effectiveness [54].

H2: Effort expectancy directly influences the behavioral intention of adopting blockchain technology

Social influence: It refers to the degree to which an individual perceives how important other individuals believe he or she should use the new system [49 & 224]. In the proposed model, social influence indicates how people influence the behavior of others to adopt blockchain technology. The previous study by Alazab et al. [57] clearly stated that social influence is highly affected by society, family, and friends' beliefs and actions. The following hypothesis captures this relationship.

H3: Social influence directly influences the behavioral intention of adopting blockchain technology

Facilitating conditions: It is the degree to which an individual believes that the organizational and technical infrastructure exists to support the use of the system [49]. In the proposed model, facilitating conditions refer to the availability of essential resources to the stakeholders to adopt blockchain technology in the future. Also, if there is sufficient technological, organizational, network and human support for blockchain technology, users will be more likely to be engaged with this technology and have a more effortless and pleasant experience with blockchain.

H4: Facilitating conditions directly influence the behavioral intention of adopting blockchain technology

Inter-firm trust: Interfirm trust is also essential in defining the trust between various organizations in the same supply chain. Lack of trust or faith in technology plays a vital role in technology adoption. Trust is demonstrated in the literature as the main fundamental aspect influencing technology adoption. Interfirm trust in the agri-food supply chain using blockchain technology creates trust among various organizations and secures information exchange between various parties. Miraz et al. [61] used trust as the construct to check the impact of behavioral intentions and the usage of blockchain technology for supply chain traceability. Stranier et al. [157] emphasized that blockchain technology builds trust-based relationships among stakeholders in the food supply chain. Blockchain networks' transparency and visibility help build trust in the supply chain actors. Additionally, it plays a vital role in avoiding fraudulent activities and providing trust among various actors. Alazab et al. [57] highlighted that inter-organizational trust plays an essential role in building strong relationships between organizations and therefore, is a significant factor in adopting blockchain technology. Seminal contributions have been made by Ghode et al. [225], showing that inter-trust organizations and transparency are the critical factors that influence the adoption of blockchain technology in the supply chain. Based on these arguments, the following hypothesis has been formulated.

H5: Interfirm trust directly influences the behavioral intention of adopting blockchain technology

Transparency: Blockchain technology positively influences the user and adds value to the supply chain. Due to the distributed nature of blockchain technology, the data is distributed among all the network members, and records of transactions and various processes are open for every member of the blockchain, which provides transparency to the users [59]. The use of blockchain technology can make agri-food supply chains more efficient and reliable by linking all the aspects of the food supply chain with a traceable and immutable data system.

H6: Transparency directly influences the behavioral intention of adopting blockchain technology

Behavioral intention: According to the definition, behavioral intention refers to the subjective likelihood that a person has developed an attentive policy to perform some planned behavior. In our study, behavioral intention is the stakeholders' attitude or intention toward using blockchain technology in the agri-food supply chain. Behavioral intention depends on the various factors, as defined by Ghode et al. [225], that influence the stakeholders' adoption or rejection of a particular technology.

6.4 Conceptual model

Based on the existing literature on UTAUT and its variants, a conceptual model has been derived and is summarized in Figure 6.2 to understand the role of blockchain adoption in the agri-food supply chain by various stakeholders from the North Indian state of Punjab. Since blockchain technology is still developing, the constructs have been drawn mainly from the existing literature using TAM and UTAUT on supply chain and agri-food supply chain theories. The research will look up the direct relationship between dependent and independent variables.

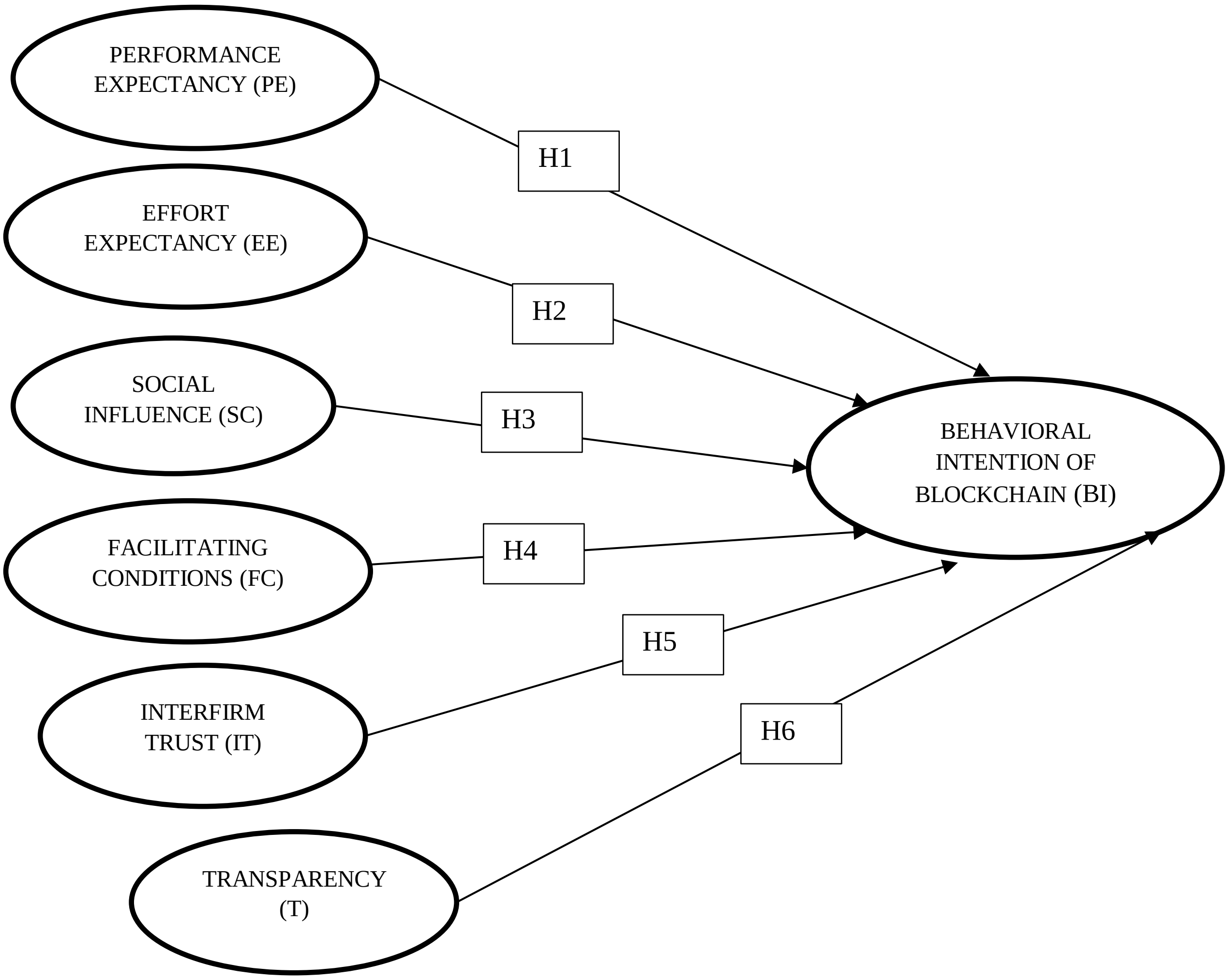


Figure 6.2 Conceptual model of blockchain adoption in agri-food supply chain management

6.5 Research design and methodology

To attain objective 3 of this thesis, the authors have used the exploratory research design. The study examines stakeholders' perceptions of adopting blockchain technology in agri-food supply chain processes in the upcoming years. The survey questionnaire technique can be used to recognize the attitudes of stakeholders. The survey was conducted physically by interacting with each respondent, providing a clearer vision of people adopting new technologies in the industry. Since this study explores the adoption of blockchain technology from an ordinary people perspective, individuals associated with agri-food supply chain officials are selected to respond to the instrument. The individuals are typically farmers and government officials dealing with the core realities of agri-food supply chain processes. From the total sample of 400, a total of 381 data were collected, of which 181 belong to government officials and 200 to farmers, as shown in Table 6.1 and Table 6.2.

Table 6.1 Demographic profile of government officials

Variables	Number	Percentage (%)
Male	165	91
Female	16	9
<20years	0	0
20-30years	64	35
> 50 years	55	30
30-50 years	62	34
Working experience		
Less than 1 year	11	6
2-5 year	55	28
More than 5 years	134	67

Table 6.2 Demographic profile of farmers

Variables	Number	Percentage (%)
Male	166	83
Female	34	17
<20years	9	5
20-30years	80	40
30-50 years	82	41
> 50 years	29	15
Qualification		
Under metric	42	23
Matriculation	42	23
Twelfth	54	30

Graduation	43	24
Annual income		
< lakhs	11	6
1-2 lakhs	43	24
2-3 lakhs	67	37
>3 lakhs	60	33

This study consists of two types of stakeholders, such as government officials and farmers, that are involved in the agri-food supply chain processes. government officials belong to the agriculture departments, agriculture and farmer welfare department, and Punjab agriculture research intuitions such as PAU and regional research station, Bathinda, and several other government officials that deal with logistics and transportation. Secondly, the farmers are considered whose insights can contribute to the development of sustainable and context-specific solutions that are more likely to be embraced and implemented by the farming community. Their opinions will also help in understanding how well the industry is adapting to change and what specific challenges arise during the time of transition.

The present study collected data from the North-western region of India, Punjab. Punjab is known as the Food Bowl of India [133]. It comprises 1.57% of the country's total geographical area and contributes 13-14% of total food grain production in the country. It is also known as the "Granary of India" [17]. In the past two decades, Punjab has contributed 30-40% of rice and 40-75% of wheat production in India. According to the India village directory, 12858 villages in Punjab contribute to the agriculture sector. The study used convenience sampling technique for covering farmers and government officials from the Barnala, Patiala, Sangrur, Ludhiana and Bathinda districts of Punjab state. To mitigate the risks of convince sampling, the study also uses quota sampling within framework to ensure proportional representation of different subgroups within the population. It involves setting quotas for specific demographic groups and purposively selecting participants to meet these quotas. This approach helps to balance and to minimize the sample composition and minimize bias by ensuring adequate representation across key demographic variables.

A preliminary questionnaire was distributed to a pilot group of 50 people based on convenience sampling to assess the reliability and validity of the data. This pilot group comprises academicians and agri-food supply chain experts. The suggestions were incorporated into the questionnaire. The questionnaire (scale) is a good fit (in terms of questions and language quality) for the respondents. The respondents are feeling happy because the questionnaire is converted into a local language, which is easy to understand. The questionnaire was divided into two sections in which first section is all about the challenges in agri-food supply chain along with demography profile of respondents, introduction that describes the goal of the study and others. After analyzing various challenges, the authors held seminars in different villages and educated the stakeholders about the importance of digitalization in the agriculture industry. Thereafter, a brief description them about the blockchain technology and its benefits in agri food supply chain processes were given. Later, their views have been generated about the adoption of blockchain solutions using a questionnaire survey. It is worth noting that the respondents had not yet deployed any blockchain technology, and blockchain technology was first introduced them and its uses in the agri-food supply chain. The total 30 items constructs were measured on a 5-point Likert scale (i.e., '1= = strongly disagree' to '5 = strongly agree'). The total sample size of this study is calculated according to the Hair et al. [139] as follows:

$$Sample\ size = Total\ number\ of\ items\ * 5$$

Therefore, according to this guideline, a minimum sample size of 150 should be considered for each stakeholder. Moreover, for the analysis of PLS-SEM, this study uses a sample size of 200 for each stakeholder namely farmers and government officials. By opting for a larger sample size in the context of PLS-SEM, the study endeavors to achieve a more thorough understanding of the underlying constructs and their interrelationships.

6.5.1 Measurement scale

To attain the objective of the study, the survey method is used as it is useful in describing the characteristics of the population. The questionnaire consists of items adopted from UTAUT and has added two additional items related to the adoption of blockchain technology. In light of our interest, we considered all types of blockchain as well as their different uses (e.g., tokens, smart contracts, traceability systems, etc.). Therefore, a questionnaire is developed to capture stakeholders' views on adopting blockchain technology in the future. The questionnaire was developed in English and the local language, Punjabi. The scales for the current study were adapted from previous empirical studies related to UTAUT to ensure their validity and reliability. Based on prior literature, a model has been developed in which the six indicators of PE contribute to capturing the performance expectancy to improve their efficiency using blockchain technology. The four indicators of EE reflect the efforts needed to adopt the new technologies in the agri-food supply chain sector; the four indicators of FC can contribute to the presence of sources and infrastructure to support blockchain technologies; also, the four indicators of SI reflect the influence of other people to adopt blockchain technology; the three indicators of IT are associated with the inter-firm trust between various organizations by blockchain technology in the agri-food supply chain; the four indicators of T show the level of transparency among stakeholders provided by the blockchain technology in future and the five indicators of BI reflects the intention to use blockchain technology in the agri-food supply chain. Based on this reasoning, the chosen indicators can be adapted to a blockchain context. All the items were measured using the Likert scale from strongly disagree to strongly agree.

6.5.2 Methodology used

Partial Least Square Structural Equation Modeling (PLS-SEM) is suitable for predictive modelling, assessing the predictive relevance of constructs and situations where the prediction is the primary goal. It is robust to violations of normality assumptions and can provide more reliable results in studies with limited data availability or non-normal data distributions. PLS-SEM is often used for theory development, hypothesis generation, and model exploration. It has the ability to explore complex relationships and identify new patterns in the data. Therefore, this study has used a method of PLS-SEM for predicting blockchain adoption in the agri-food supply chain sector. Also, it explains the multiple statistical relationships through visualization and model validation [136 & 226]. Smart PLS 4 software tool was used to evaluate the research model using the PLS-SEM [227]. It focuses on the analysis of variance and has a strong statistical capability. Applying PLS-SEM allows researchers to effectively evaluate the measurement models and structural paths, particularly when the structural model involves latent constructs based on multi-item indicator variables, multiple levels of constructs, and multiple dependent variables [228]. It prevents TYPE II errors and is effectively applied to non-normal and small samples of data [229].

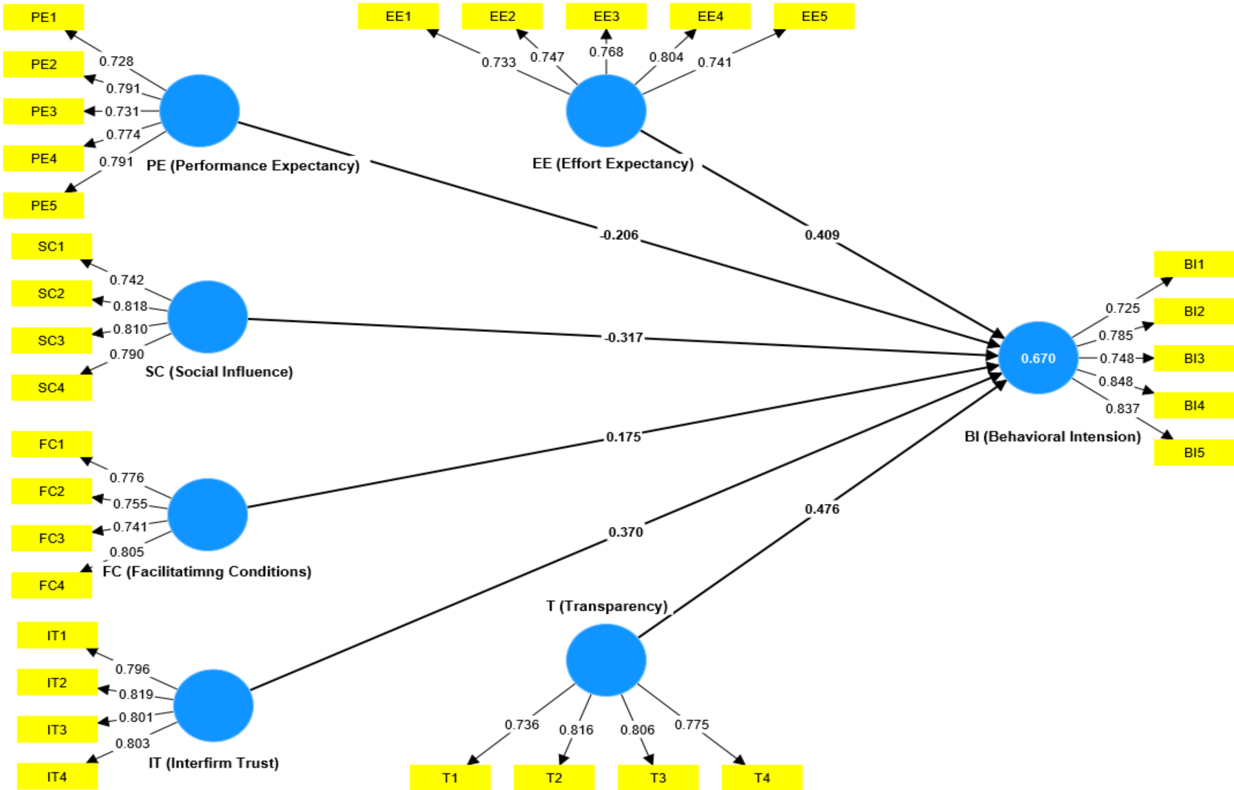


Figure 6.3 Measurement model of blockchain agri-food supply chain management

Visualization in PLS-SEM, such as path diagrams and graphical representations of latent variables, provide a clear, intuitive understanding of the predictive model. Additionally, validation of the model ensures that the predictions are reliable and generalizable, enhancing the study's credibility and applicability to real-world scenarios. In light of our exploratory study, PLS-SEM is an appropriate strategy for studying blockchain adoption in the agri-food supply chain. In the previous literature, PLS-SEM using Smart PLS 3 was utilized by various researchers to analyze the adoption of blockchain technology [111, 208 & 228]. In line with the existing research, this study also used PLS-SEM using Smart PLS 4 to examine the behavioral intention of stakeholders in adopting blockchain technology in the agri-food supply chain. The measurement model is shown in Figure 6.3, which describes the relationship between latent (independent) variables and their observed indicators. The factor loading of each latent variable and its corresponding observed indicator is ≥ 0.05, which is acceptable and shows the strength and direction of the relationship between them. The values of factor loadings indicate how much variation in an observed variable is explained by the latent construct [229].

Table 6.3 Validity and reliability

	Cronbach's alpha	**Composite reliability (rho_a)**	**Composite reliability (rho_c)**	**Average variance extracted (AVE)**
BI	0.848	0.848	0.892	0.624
EE	0.816	0.820	0.872	0.576
FC	0.771	0.775	0.853	0.593
IT	0.819	0.819	0.880	0.648
PE	0.821	0.822	0.875	0.583
SC	0.800	0.807	0.869	0.625
T	0.791	0.798	0.864	0.614

Validity and reliability of the constructs: Convergent validity of the constructs can be assessed by Cronbach alpha, composite reliability and average variance extracted (AVE) according to Fornell & Larcker. [140]. All the values are shown in Table 6.3, indicating that the composite reliability is acceptable only when the threshold value exceeds 0.7, as Nunnally. [230] and the AVE value are greater than 0.50 [140 & 229]. Thus, the model exhibits good construct reliability and validity.

Table 6.4 Fornell and Larcker criterion

Blockchain drivers	**BI**	**EE**	**FC**	**IT**	**PE**	**SC**	**T**
BI	0.790						
EE	0.754	0.759					
FC	0.706	0.764	0.770				
IT	0.733	0.759	0.755	0.805			
PE	0.735	0.891	0.783	0.880	0.764		
SC	0.713	0.780	0.772	0.774	0.788	0.790	
T	0.725	0.760	0.727	0.730	0.765	0.950	0.784

Furthermore, the discriminant validity of the construct, as shown in Table 6.4, is measured by evaluating the square root of AVE for each construct with its correlation with other constructs; therefore, this confirms that the discriminant validity is in the range recommended by Fornell and Larcker. [140]. In light of all the conditions being met, it was appropriate to proceed with the analysis. The measurement model qualifies goodness-of-fit indices because various fit indices are within the prescribed limits.

6.6 Findings and its interpretation

The findings of the study comprise outer loadings, path coefficient, and model fit. Table 6.5 depicts β-values for constructs and their sub-constructs, which indicates the path of latent constructs in terms of the observed variable; the value of the threshold should be greater than 0.60. All of the values for the BI sub-constructs are over 0.70. BI4 loaded high on BI, which shows that people would be willing to start using blockchain in the future.

Table 6.5 Outer loadings and VIF values

	BI	**EE**	**FC**	**IT**	**PE**	**SC**	**T**	**VIF**
BI1	0.725							1.543
BI2	0.785							1.768
BI3	0.748							1.558
BI4	0.848							3.027
BI5	0.837							2.872
EE1		0.733						1.470
EE2		0.747						1.866
EE3		0.768						1.926
EE4		0.804						1.767
EE5		0.741						1.584
FC1			0.776					1.415
FC2			0.755					1.536
FC3			0.741					1.415
FC4			0.805					1.691
IT1				0.796				1.738
IT2				0.819				1.861
IT3				0.801				1.693
IT4				0.803				1.664
PE1					0.728			1.442
PE2					0.791			2.045
PE3					0.731			1.748
PE4					0.774			1.760
PE5					0.791			1.856
SC1						0.742		1.566
SC2						0.818		1.822
SC3						0.810		1.606
SC4						0.790		1.591
T1							0.736	1.558
T2							0.816	1.814
T3							0.806	1.579
T4							0.775	1.500

Therefore, on the basis of outer loadings, this study concludes that all of the variables are appropriate. Furthermore, to check multi-co linearity, the value inflation factor (VIF) was calculated, and all the values were below the recommended value of 3.00. So, there exist no co-linearity problem existed in this study.

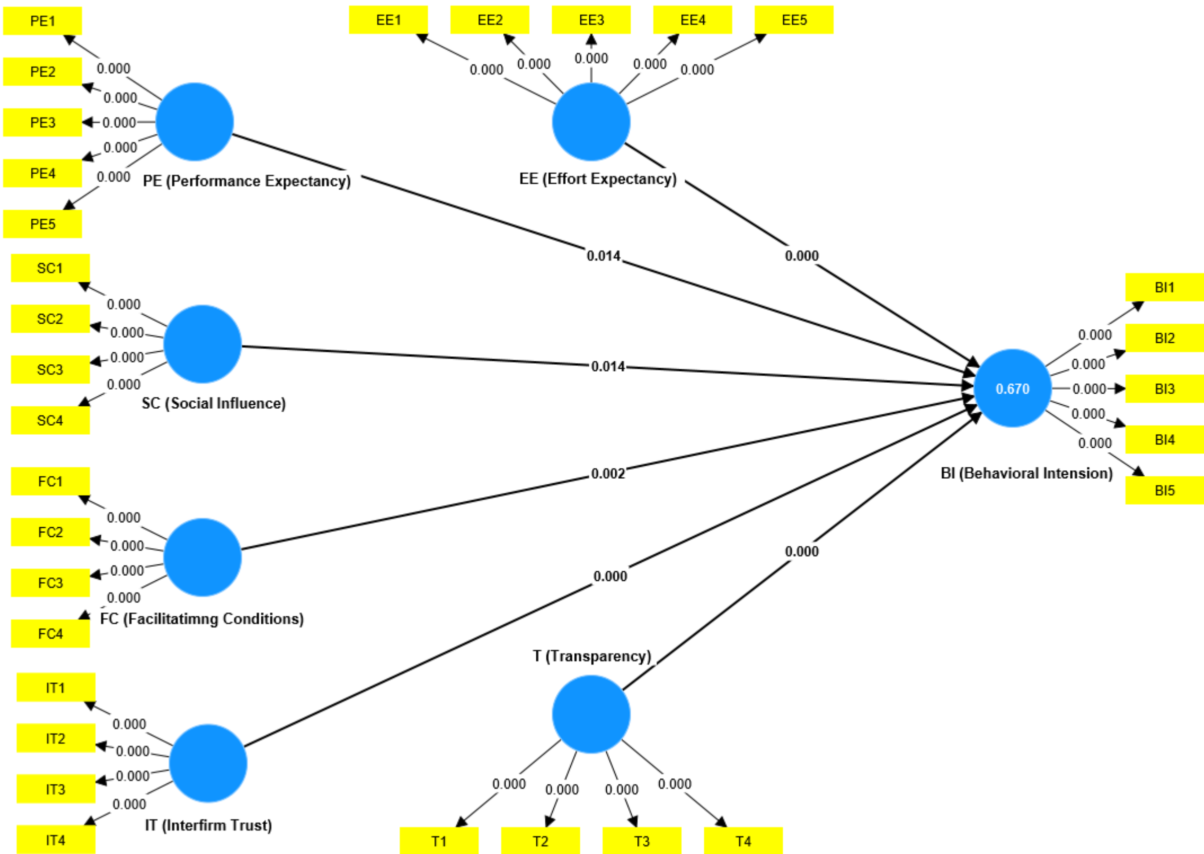


Figure 6.4 Statistical model to examine the relationship between PE, SC, EE, IT, and T.

Table 6.6 Paths coefficients and Model fit

	Original sample (O)	**Sample mean (M)**	**Standard deviation (STDEV)**	**T statistics (|O/STDEV|)**	**P values**	**F^2**
EE -> BI	0.409	0.406	0.079	5.169	0.000	0.089
FC -> BI	0.175	0.177	0.055	3.169	0.002	0.028
IT -> BI	0.370	0.365	0.073	5.065	0.000	0.079
PE -> BI	-0.206	-0.200	0.084	2.464	0.014	0.014
SC -> BI	-0.317	-0.313	0.129	2.463	0.014	0.024
T -> BI	0.476	0.473	0.115	4.125	0.000	0.065
	R Square –Square			**R Square adjusted**	**Adjusted**	**square**
BI	0.670			0.665		

The goodness-of-fit indices indicated the appropriateness of the model shown in Table 6.6. All six independent variables, namely performance expectancy, effort expectancy, facilitating conditions, social influence, interfirm trust, and transparency, were found significant in relation to the behavioral intention of blockchain adoption, as shown in Figure 6.4. The results of the SEM provide support for Hypotheses H1, H2, H3, H4, H5 and H6. All the variables have a significant positive effect on behavioral intention. A p-value less than 0.05 and a t-value greater than 1.96 indicate that there is a significant positive relationship between constructs and behavioral intention. The findings indicate that the proposed model effectively evaluates the impact of variables on users' behavioral intentions.

The value of $R^2$and the adjusted R^2 is shown in Table 6.6. The $R^2$is defined as a statistical test used to determine how much of the variance in the dependent variable as BI can be accounted for by the independent variable. For instance, an R^2 of 0.50 indicates that the predictor accounts for 50.0% of the variance in the dependent variable (s). According to the data presented in Table 6.6, the value for BI is 0.670, or 67%. To measure effect size, F^2 was adopted. According to Cohen (2003), if the value of F^2 for a particular independent variable in terms of dependent one is $F^2 \geq 0.02$, then the effect size is small, ≥ 0.15 depicts a medium effect size and a value ≥ 0.35 shows a large effect size. In table 10, EE on BI is 0.089, and IT on BI is 0.079. These depict a large effect size; however, for EE on BI, the effect size is small (0.078).

The main objective of this study is to find out the attitude of stakeholders in the adoption of blockchain technology in the agri-food supply chain, which is found to be significant and favorable with a β-value of 0.042 ($p \leq 0.05$**). The results are in line with previous studies [48, 49, 50, 54, 57 & 178]. Therefore, it can be deduced that various constructs of UTAUT, with some additional constructs, positively influence the behavioral intention of stakeholders in adopting blockchain technology and are empirically supported.

6.7 Discussions and Implications

This section focuses on examining further implications of the results. This study developed a modified version of UTAUT to understand the adoption of blockchain technology among stakeholders in agri-food supply chain management among stakeholders from the Punjab state of India. The study findings indicate that the future of the agri-food chain has to be dependent upon the digitization and digital revolution that is going to benefit the lives of farmers and involved stakeholders in the supply chain. The study identified the drivers of blockchain adoption and validated their relationship with the behavior intentions of stakeholders in adopting blockchain technology in the agri-food supply chain. The acceptance of the hypothesis indicated that this study should be conducted in other states of India so that the Government can develop a generalized and decentralized model to overcome the current issues faced by farmers and stakeholders involved in the supply chain.

6.7.1 Theoretical Implications

The results drawn from this study have important implications for researchers and academicians. This study has great relevance for developing countries like India, where the agriculture sector is the major livelihood provider to the people and still needs to catch up in the adoption of technologies compared to other countries. Based on the existing adoption theories, our research has primarily focused on the UTAUT model. One significant theoretical contribution of this study is extending the UTAUT model in the context of blockchain adoption by adding additional predictors, namely interfirm trust and transparency.

This study provides evidence that performance expectancy, effort expectancy, social influence, facilitating conditions, interfirm trust and transparency are the drivers of blockchain adoption and have a positive relationship with behavioral intention. Furthermore, our results indicate that Trust, facilitating conditions, and performance expectancy are the important predictors of blockchain adoption, followed by effort expectancy, interfirm trust, and social influence. This is in line with the study of Queiroz et al. [222], Wong et al. [56] and Nayal et al. [159], in which facilitating conditions, trust, social influence, and effort expectancy were found to be the critical constructs in predicting blockchain technology adoption intention in the Brazilian operational supply chain management field. This indicates that people in developing countries like India rely on the social influence and the opinions of people from their colleagues, friends, and peers. Numerous studies have investigated the influencing factors for the adoption of blockchain technology.

Also, the findings of this study clearly state that Transparency is the highest influencing factor in the adoption of blockchain technology, which is also consistent with previous studies by Kamble et al. [3], Miraz et al. [61], Ghode et al. [225] and Tayal et al. [220]. to provide all the information to all the stakeholders involved in the agri-food supply chain. This implies that the stakeholders are highly inclined to have a transparent system so that their agricultural products can be reached safely and are of good quality. The stakeholders should aim to capture all the information related to the entire cycle of agriculture events onto the blockchain to maintain a trusted source of information for the farmers. This will help the farmers, consumers and other stakeholders involved in the agri-food supply chain to have data related to their quality, demand, payments and sale price on the single platform so that no intermediaries can fraud other people. The adoption of blockchain technology in the agri-food supply chain will connect the food producers and the final consumers. It provides an opportunity for the stakeholders to quantify, monitor, and reduce the risks involved in the agri-food supply chains of developing countries like India.

In line with prior literature, blockchain technology significantly impacts users' behavioral intentions in adopting blockchain in the agri-food supply chain [222]. This study theoretically developed and empirically validated a proposed model to understand the behavioral intentions of stakeholders in adopting blockchain technology in the agri-food supply chain, particularly in the Punjab region of India.

6.7.2 Practical Implications

The empirical findings of this research provide valuable implications for stakeholders. It is essential for stakeholders in India and emerging economies to understand the constructs in the proposed research model so that farmers and consumers can trust and adopt blockchain technology in the agri-food supply chain. The stakeholders in India need to inform the farmers and consumers about the benefits of blockchain technology and convince them to move towards digitalization. The study has empirically validated the significant positive relationship between drivers of blockchain adoption and behavioral intention.

Implementing blockchain technology in the agri-food supply chain will help reduce the risks and fraudulent activities. Transparency and Interfirm trust between various parties will boost food quality, safety and security. It will also help quickly detect warehouse information, food contamination, and safety issues.

From a financial perspective, the existing trade fair method is very complicated, risky, time-consuming, and inefficient, and it involves many stakeholders as intermediaries to sell the product. This hurts small-scale businessmen and farmers as they need to get the exact value of their products. Blockchain technology would help reduce the intermediaries, leading to false payments and delays. The adoption of blockchain also helps reduce the risks for stakeholders and transaction costs for efficient transaction processes and improves the visibility of agri-food supply chain events. The emerging model from this study can be extended to all developing countries to assess the adoption factors for blockchain adoption.

6.8 Summary

This study aimed to investigate blockchain adoption by stakeholders in the agri-food supply chain in the North Indian state of Punjab. As India is a developing country, digitalizing the supply chain and implementing the proposed technical changes that are supported by the Internet will take time on the ground level. The results of the study have supported that the implementation of blockchain technology in the agri-food supply chain will definitely impact from the grassroots level. To the best of our knowledge, the prior literature needs to include the additional drivers of blockchain adoption, especially focused on the agri-food supply chain. To fill this gap, this study presents new constructs that may help predict the drivers of blockchain adoption in the agri-food supply chain. Therefore, to accomplish the goal of this study, a modified version of the UTAUT model that includes the interfirm trust and transparency as the additional constructs has been developed and tested supported by the literature. The study contributes to the theory of identifying the drivers of blockchain adoption and then checking their effect on the behavioral intention of stakeholders in adopting blockchain technology in the future. The proposed model shows a significant positive relationship between drivers of blockchain adoption and behavioral intention, which implies that the stakeholders are highly inclined towards the adoption of new technologies to make the agri-food supply chains more efficient.

Chapter 7: Secure and traceable decentralized agri-food supply chain framework using Ethereum blockchain and IPFS platform

Today's agri-food supply chain structure is a complicated environment that involves several stakeholders, making it unmanageable to validate various important factors such as the origin of food products, stages of production, price of product, and quality standards. Traceability and transparency in the agri-food supply chain provide food safety, food quality, information symmetry, and the original price of the food product to achieve customer trust and reduce miscommunication between stakeholders and fraudulent activities. Blockchain is a distributed ledger and innovative technology that can transform and provide various solutions to the agri-food supply chain industry. Blockchain provides a safe, efficient, reliable, and effective way to trace and track food products and their quality while purchasing the goods. This chapter proposes a secure and traceable agri-food supply chain framework built on private Ethereum blockchain and smart contracts to improve the performance of traceability and transparency across the agri-food supply chain. The proposed solution eliminates the need for a third party and provides all transaction details exchanged between stakeholders, enhancing the safety and quality of food with high reliability. The proposed Ethereum smart contract consolidates all the functionalities into a single, comprehensive contract, which reduces the contact complexity and overall gas consumption, making the framework more cost-effective for users. Additionally, the IPFS (Interplanetary File Storage System) has been integrated with the proposed framework to store all the information instead of the blockchain platform, and this provides a highly efficient and reliable platform.

7.1 Introduction

The agriculture sector in several developing countries is a crucial component of their economies, contributing significantly to the employment, food security and overall development of the economy. It is dynamic in nature, with ongoing efforts to address challenges related to resources, infrastructure, market access, productivity enhancement, and farmer livelihoods [78]. Monitoring the supply chain and the lack of real-time information on market prices are still major concerns in ensuring farmers' ability and food safety.

The major work of this chapter have been reviewed and communicated for publication in:

- *Sharma, A., Bhatia, T., & Sharma, A. Secure and traceable decentralized agri-food supply chain framework using Ethereum blockchain and IPFS platform* (Communicated)

Technological innovations, advanced farming, and sustainable practices are crucial to unlocking the sector's full potential and fostering overall socio-economic progress.

The complex network of the agri-food supply chain involves cultivation, harvesting, packaging, distribution, and retailing; while it plays a vital role in ensuring that the food reaches consumers worldwide [151]. The unpredictable weather pattern, fluctuating consumer demands, inefficient processes, limited visibility, inefficient record keeping, lack of connectivity between stakeholders and involvement of various stakeholders are some of the concerns encountered in recent years [113]. Lack of traceability in the agriculture sector may also cause food adulteration, leading to serious health issues. All these challenges may raise questions about the food quality and safety of the food product. Therefore, to address these challenges, integrating digital technologies has emerged as a key solution to optimize processes and enhance the overall effectiveness of the agri-food supply chain [231].

For the above-mentioned requirement, the traditional centralized system maintained by enterprises and government agencies may not be feasible. Also, it lacks transparency and traceability solutions to trace the flow of goods and information across the agri-food supply chain. The centralized system has a single point of failure in which any malfunction can disrupt the entire process. Moreover, the hierarchical structure of centralized systems leads to prolonging decision-making, and integrating new technologies with it can also be challenging. However, the demand in the current agri-food supply chain is to adopt advanced technologies that can provide transparent, secure, and traceable solutions.

The advent of blockchain technology has appeared as a transformative solution, offering unprecedented efficiency, transparency, traceability and security to the agri-food supply chain. It is a decentralized, secure, immutable, and transparent ledger that logs all transactions throughout a network. Initially, it gained prominence for cryptocurrencies like Bitcoin, but its applications are extended far beyond digital currencies [27]. Among all, the agri-food supply chain is considered one of the most promising and emerging applications of blockchain technology. It offers several advantages that directly address the challenges of the agri-food sector and make it a valuable tool for enhancing transparency, traceability, and overall efficiency. Blockchain technology enables traceability by recording every process of the agri-food supply chain on an immutable ledger. From farm to consumer, each transaction, process and movement is documented, allowing customers and stakeholders to trace the journey of agricultural products. The distributed character of blockchain technology enables secure and transparent data sharing between various stakeholders [232]. The stakeholders can access the real-time data, reducing miscommunication and fostering collaboration among stakeholders. Also, blockchain technology is a cost-effective, secure, and trustworthy solution for the supply chain stakeholders [233]. Blockchain transparency and automation of processes using smart contracts on the distributed ledger contribute to increasing the efficiency of the agri-food supply chain [234].

7.2 Related work

This section typically includes a brief summary of the existing research and identifies gaps or limitations in the current literature. Over the past years, there has been significant development and evolution of blockchain framework in supply chain and agriculture food supply chain. The landscape of blockchain frameworks is dynamic, alongside continuous research and development endeavors focused on tackling the obstacles of the agri-food supply chain sector, improving performance, and expanding the applicability of blockchain technology across the agri-food industry. In the literature, several studies focused on presenting the blockchain-based framework for the agri-food supply chain. Among them, Kaijun et al. [235] developed a double-chain architecture based on public and private blockchain for agriculture supply chain systems. The solution of agriculture business resource blockchain can provide rent-seeking and matching mechanisms for public service platforms. It not only provides traceability and transparency but also improve the credibility of the public service platform. Malik et al. [25], presented a three-tier architecture of the ProductChain framework to ensure the confidentiality of the data shared on the distributed ledger. The query time for the product ledger is in a few milliseconds, even at the time of multiple shards, which is acceptable. According to Salah et al. [110], the Ethereum blockchain and smart contract framework will provide the history of all transactions that occurred during the tracing and tracking of soybeans to enhance the efficiency and safety of food products. The proposed framework is also linked with the IPFS system and is helpful in eliminating the need for a centralized system and intermediaries. The study of Lezoche et al. [75], discussed the potential of IoT devices that offer numerous benefits to the food industry, such as tracking and authenticity for the distribution of agri-food products, smart farming, livestock monitoring and many more; there are indeed faces an issue of centralized architecture that creates the challenges of data security, manipulation and standardization. In an attempt to tackle these issues, Grecuccio et al. [105], developed the integrated framework of IoT and Ethereum blockchain for the traceability of the food supply chain using Quadrans' infrastructure. The IoT devices directly fetch data from the sensors and store it in the Ethereum full node structure to empower the traceability of the food supply chain process.

To cope with the traditional traceability system problems such as data tampering, hazardous-material information management, etc. Zhang et al. [236], proposed a new architecture for the entire grain supply chain based on a hyper ledger fabric platform of blockchain technology with a cloud-based database of MySQL. Prashar et al. [196], also presented a private Ethereum blockchain-based solution with IPFS to remove the centralized data storage mechanism and intermediaries in the food supply chain to optimize their performance and increase the safety of food products. The design of the system has proved significant and requires a throughput of 161 transactions per second with a convergence time of 4.82 seconds over a simulation time of one hour per 30 clients, 10 controllers, and 30 validators. In a similar work, Shahid et al. [237] proposed an integrated Ethereum blockchain and IPFS system to ensure traceability, trust, and delivery operation in the agri-food supply chain. The traceability can be achieved by processing three smart contracts: registration contract, add to lot contract and add transaction contract. The deployment of these contracts provides respective addresses, which help the consumers achieve traceability and data provenance. A trading and delivery mechanism is used to ensure auditable delivery to consumers. Also, a reputation mechanism based on trust values is proposed to ensure the credibility of the owner and the delivery of assets.

In the work of Baralla et al. [100], they developed a smart contract to provide transparency and reliability to all the stakeholders of the food supply chain. In their work, they only provide the conceptual views of forming smart contracts. Later, in their extended work in 2021, Baralla et al. [238] proposed a blockchain-based framework to discover the origin and provenance of food items in a smart tourism region. The authors adopted the method of Agile Block Chain Dapp Engineering (ABCDE) method for the development of software infrastructure development. The proposed system ensures the consumer about the originality of food products and encourages the people to purchase products. Also, Cocco et al. [74] developed a system to guarantee transparent and auditable traceability of the Carasau bread in which each user can verify the quality of the product and check the hygienic-sanitary conditions along the supply chain. The IoT sensors were used to collect data and directly communicate to the Raspberry Pi units that transmit them to IPFS and to the Ethereum blockchain. According to Casino et al. [103], more people are emphasizing food safety and demanding traceability solutions in the supply chain. Therefore, a secured and trustless architecture of food supply chain traceability has been developed and tested. The framework has been developed on local private Ethereum-based blockchain and provides significant advantages in terms of efficiency, trust, quality, and resilience. Similarly, Majdalawieh et al. [67] developed blockchain and IoT-based systems to monitor and track the processes of the poultry food supply chain industry. The Ethereum smart contract helps to identify and eliminate food adulteration and contamination. The proposed model helps to enhance the quality and safety of food and improve the transparency of transactions, which will help to create trust among consumers.

In the research work of Marchesi et al. [72], they presented the overall mechanism of developing the Ethereum supply chain. The authors define the role of each actor involved in the system, determine the entities, and present the relationship between these entities and events to propose a general framework for Ethereum-based smart contracts without going to grasp every detail of the technicalities of supply chain development. Praveen et al., [233] proposed an Ethereum-based smart contract platform to reduce the risk of non-payment between stakeholders during the credit period. Additionally, the results show that blockchain-based frameworks reduce the overall cost by lowering the cost of paperwork and the use of product tracking software. Valencia-Payan et al. [83] developed a blockchain network based on Hyper-ledger fabric. A smart contract has been created to record all the information generated by all the stakeholders, from input to distribution. This will help to perform various recommendations related to product management and penalties based on predefined conditions on smart contracts. The throughput and average latency of sending the read and update transaction to the blockchain network are 246 transactions per second and 0.5 seconds. The results show that the smart contract is running fast enough to respond to the environment. Similarly, Ramkumar et al. [239] presented the Agri-BlockIoT, a decentralized Ethereum blockchain-based traceable platform for managing a global agri-food distribution industry. The proposed system also helps to improve the communication between stakeholders. Recently, Yakubu et al. [240] proposed a framework that has the capability to track and supervise all interactions and transactions involving every participant in the rice chain ecosystem using smart contracts. The framework also includes customer satisfaction feedback to provide up-to-date information about the quality of the product. Security and performance evaluations indicate that the proposed framework surpasses standard techniques in terms of cost-effectiveness, security, and scalability while keeping computational overhead low. Also, Zhang et al. [232] proposed a blockchain-based decentralized supply chain system for secure information sharing between stakeholders, which can ensure the security and provenance of products without being trusted by a third party. Product validation can be done using one-way and transaction-based validation mechanisms. The automatic execution of smart contracts helps to achieve secure registration, authentication and fair payment among stakeholders.

Raza et al. [234] proposed a smart agriculture framework, Agri-4-All, to automate the inter-organizational and intra-organizational processes of the agricultural supply chain. The hybrid smart contract algorithm has been developed using ganache and truffle, which reduces the gas cost by 13.89 times compared to the traditional smart contracts-based model. Babu & Devarajan. [241] presented the integrated framework of blockchain and IPFS (Interplanetary File Storage System) to overcome the blockchain storage explosion. Saranya Maheswari. [78] designed a Proof of Transaction (PoTx) consensus mechanism to achieve scalability by reducing communication overhead and computation power. The proposed system presents a blockchain system with user identification and access control mechanisms to prevent and discover product adulteration while tracing the agriculture supply chain.

The implementation of digital technologies is still in its early stages, but it has shown promising advancements in addressing global challenges of the agri-food supply chain. While considerable attention has been dedicated to sectors such as textiles and healthcare, there exists a noticeable dearth of comprehensive studies on the application of blockchain technology in the food supply chain Cocco et al. [74], Lucena et al. [98] & Lin et al. [77]. Most of the existing blockchain based food supply chain frameworks are theoretical Tian. [29], Kumar et al. [97], Salah et al. [110], Casino et al. [103]. Therefore, this study aims to go beyond theoretical frameworks and conceptual models, offering a practical, real-world perspective on how blockchain technology can be effectively implemented and integrated into every stage of the agri-food supply chain. Through this empirical evaluation, the research aims to provide transparency, traceability and security to agri-food supply chain processes, and highlight the tangible benefits that blockchain brings to the agri-food supply chain. the proposed blockchain based agri-food supply chain framework helps the stakeholders, especially the farmers to receive fair compensation for their produce and market access easily. Also, the security analysis results show the framework provides cost-effectiveness, security and scalability with low computational overhead.

7.3 Proposed Blockchain-based framework for agri-food supply chain management

The proposed framework is designed on a private Ethereum blockchain network. Blocks are mined and added to the blockchain by mining nodes across the private network by invoking the smart contracts based on the proof of stake consensus algorithm. The smart contracts automatically execute various functions, which eliminates the need for the centralized party to execute a particular task. In the blockchain, smart contracts accept the transaction in the form of function calls and events so that all stakeholders can get the information and receive the updates timely. According to the previous literature, agri-food supply chains are not visible and non-traceable in that people cannot get any information about the product, price, and various processes that occurred between several stakeholders. Therefore, the main goal of the proposed framework is to maintain the working practices among stakeholders, guarantee traceability and transparency to check whether anything went wrong along the whole agri-food supply chain and keep an eye on the actual food product value given to the farmers. Besides this, it also helps to provide the security and quality of the product and create trust among stakeholders and customers. Furthermore, all the data is stored in the distributed file storage system, such as IPFS, which creates the hashes of the files, and those hashes will be stored in the blockchain network, making them nonredundant. The proposed framework will increase the integrity, reliability, and security of the agri-food supply chain.

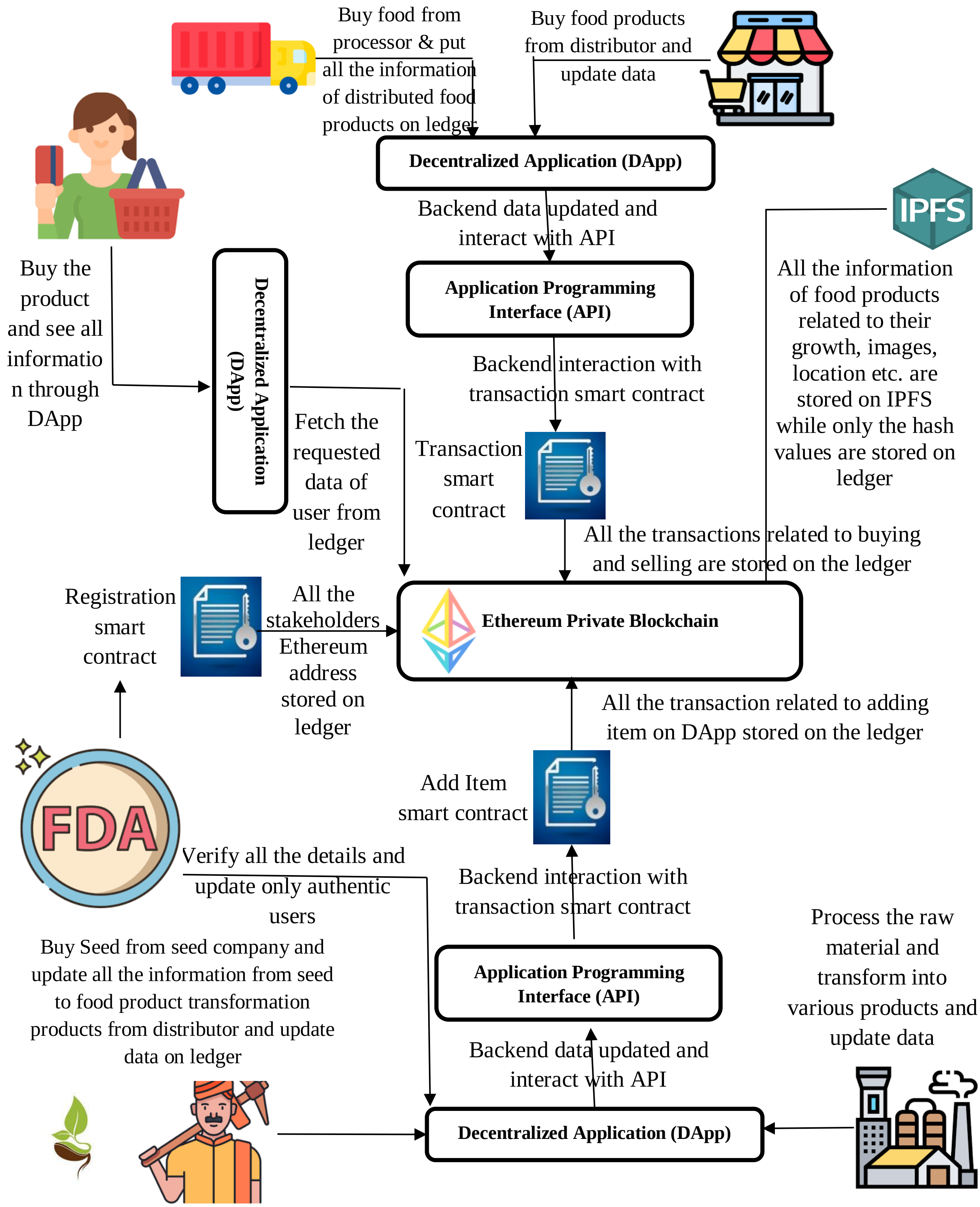


Figure 7.1 Architecture of proposed Ethereum blockchain of agri-food supply chain

7.3.1 System participants and entities

In this section, the system participants and entities in the proposed framework has been discussed. This framework integrates blockchain technology with Ethereum-based smart contracts to establish the connectivity between stakeholders in the agri-food supply chain. Figure 7.1 depicts the architecture of proposed Ethereum blockchain of agri-food supply chain, various stakeholders, and their interaction within the supply chain structure. The framework consists of 7 stakeholders namely FDA, seed company, farmer, processor, distributor, retailer and consumer which are interconnected with the help of blockchain platform. When any transaction takes place between stakeholders, smart contracts get automatically be executed after fulfilling various conditions. The key stakeholders and their responsibilities are described as follows:

- **Food and Drug Administration (FDA):** The FDA is an organization that handles and registers every stakeholder for each business operation in the blockchain network with all stakeholders who are in compliance with the laws. It checks the authenticity of each stakeholder and also imposes penalties at the time of noncompliance with the standards. All entities need to be registered with the blockchain framework and authenticated by the FDA before participating in the agri-food supply chain processes. Each stakeholder who is a part of the blockchain network has a separate Ethereum account, and each one of them has a unique Ethereum address. Ethereum address has a pair of keys, public and private, which are digitally signed and verified by the miners of the network.
- **Seed company:** It is the seed company that acts as a producer of seeds in the agri-food supply chain. It is associated with government-authorized agencies or private sectors for the availability of seeds. The farmers can directly get government-authorized seeds and fertilizers from the seed company, which is free of cost for the small-scale marginal farmers. The seed company also provides a wide variety of seed options and breeding seeds to the farmers at minimal cost. The details of each seed are stored in the IPFS storage system for verification.
- **Farmer:** Farmer is the most important stakeholder in agri-food supply chain. With the conventional agri-food supply chain, the farmers are not getting the actual price of their products. Therefore, the proposed framework is mainly focused on the farmers to provide them transparency in the supply chains. The farmer buys a seed from a seed company and sows it on their agricultural lands. Before raising a crop, the farmers have

prepared the soil by ploughing, leveling and manuring. As we all know, a crop needs some nutrients to grow the yield. Therefore, to provide nutrients to the yield, manuring is followed in which nutritional supplements are provided in the form of natural decomposition of plants and animals and through chemical fertilizers. The information on the location of the farmer, the area of farmland, the seed used, fertilizer, and the type of irrigation are all stored in the IPFS system by the farmers with pictures and videos. After the crop is matured, it is harvested and stored in the warehouses with a specific identification code known as the Farmed Product-Id number. Each sack contains the Product-Id, which is registered with the farmer's name. Now, the product is ready to sell at the marketplaces. The information of quantity and quality of product and their corresponding product Ids are stored in the IPFS system for future auditing of standards. Each farmer can have more than one product Id according to the quality and type of product, and they also set the price for each product at the farmer's end.

- **Processor:** The processor buys products from the farmers, processes them, and converts them into other products. Later, it also conducts tests to check the quality of products and stores all details on IPFS for verification in the future. Each processed product is identified with a unique product Id code. The information of each product is stored in the IPFS. Further, they are stored in the warehouses, and some factors need to be considered at the time of storage, such as temperature, humidity, and preservation time. After processing, it packages each product with a similar Product-Id for one product and a different product Id for different products. After the formation of products, it sells packages to the distributors.
- **Distributor:** The distributor is the firm responsible for collecting orders in bulk and delivering the products to the particular retailer available in the market. The details of vehicles, locations, and shipments are stored in the IPFS system. The Global Positioning System (GPS) location of each vehicle is shared with the buyer and seller.
- **Retailer:** The retailer is responsible for getting products from the processor through the distributors and selling them to the customers. The information on retailer location, and available product details are stored in the IPFS system.
- **Consumer:** The consumer is the customer and the last stakeholder of the agri-food supply chain process. The customer buys products from the Retailer for their own use. The customer can get all the information related to the product, such as their location of production, details of farmer, details of packaging, and distribution.

- **Smart contracts:** It is a self-executing piece of code deployed on the distributed network. It serves as the programmable agreement, automating and enforcing predetermined conditions without the need of a third party. These contracts operate on a trustless system, ensuring that participants rely on the integrity of the code and the decentralized nature of the blockchain technology. By eliminating intermediaries and automating processes, smart contracts can lead to cost savings and faster transactions as compared to traditional systems in various industries [241].
- **Interplanetary File System (IPFS):** This distributed data storage system is designed to revolutionize the way information is stored and accessed on the internet. It employs a peer-to-peer network model, enabling files to be distributed across multiple modes rather than residing on a single server. Each file stored in the IPFS system is given a unique cryptographic hash, ensuring content integrity and facilitating efficient retrieval. It mitigates the risk of data loss and retrieves data from the nearest available nodes, enhancing speed and reducing reliance on specific servers [69].
- **Decentralized Application (DApps):** It is a software application functioning within a decentralized network utilizing blockchain technology. They run on a peer-to-peer network of computers. DApps benefit from enhanced control over their data, lowered risk associated with singular points of failure, and a trustless environment where transactions and interactions are validated by the decentralized network [241].
- **Application Programming Interface (API):** It serves as a crucial bridge between different software applications, allowing them to communicate and share data. API is defined as a set of rules and protocols that enable one application to interact with another, facilitating the integration of functionalities or the exchange of information. The underlying complexities of a system provide a standardized method for developers to avail specific features without the need to understand the intricacies of the underlying code. It is used for various purposes, such as accessing web services, integrating third-party functionalities, or enabling communication between different components of a software ecosystem [68].

7.3.2 System operations

This section demonstrates the operations of the agri-food supply chain. A number of functions and events are used to present the input and output of the stakeholders. Each stakeholder has an Ethereum address and participates in the agri-food supply chain processes by invoking various functions and events within the smart contract. The sequence of operations in proposed blockchain based agri-food supply chain framework is shown in Figures 7.2-7.5. It depicts the interaction between the seed company, farmer, processor, distributor, retailer and IPFS with registration and transaction smart contract. The stakeholders are registered on the blockchain network by the FDA, which acts as the regulatory control. Upon deploying registration smart contract, all the stakeholders are successfully registered with their Ethereum address for creating and receiving transactions by the stakeholders.

On successful registration, each stakeholder according to their functionality deploy the Add Item smart contract to add and update food product items by calling *AddItem()* and *UpdateItem()*. The IPFS system can store the details of each product, such as product name, geographic location, number of products available, quality parameters, quantity available, and price of product. During this process, the add item shares the document and large files with the IPFS, which can be accessed by any stakeholders. After the successful addition and updation of food product item details, the transaction smart contract is deployed. Upon the successful deployment of the transaction contract, the farmer calls the function *PlaceSeedPurchaseOrder()* to create a purchase order for seeds from the seed company. On executing a purchase order, farmers need to share the Ethereum address of the farmer, the Ethereum address of the seed company receiver, the type of seed ordered, and the amount of seed ordered. This function creates a Purchase-Order-Id between the seed company and the farmer, which contains the details of the seed purchase order. After checking the availability, the seed company calls the *ConfirmPurchaseOrder()* function in order to accept or reject purchase order. The farmer executes the function having a purchase order Id. Upon successful acceptance of the seed purchase order, the seed company calls the *ShipmentInitiated()* function. On execution of this function, the function creates a Shipment-Id between the seed company and the farmer, which contains the details of the shipment. In due course, farmers call the *ReceivedShipment()* function to notify all the stakeholders of the receipt of the seed shipment. Later, when the farmer receives the shipment details, the farmer calls the *PaymentInitiated()* function to pay the required amount to the seed company. While executing this function, this function creates a Payment-Id containing the details of the payment. Upon receiving the payment, the seed company invokes the *PaymentReceived()* function to the farmer.

Upon receiving the seed shipment, the farmer proceeds to cultivate the crop, nurturing it through the growth stages until it reaches the point of becoming the final product. The final products added in the Add Item smart contract by calling the *AddItem()* function and their corresponding details in the IPFS. The output of this function sends notifications to all the stakeholders about the addition of food products. Furthermore, the processor uses the *PlaceFarmedProductPurchaseOrder()* function to order the product from the farmer. For the successful execution of this function, a farmer Purchase-Order-Id is generated that includes the details of the Ethereum address of the farmed product purchaser and the Ethereum address of the farmed product seller, the type of product ordered, and their quantity. Upon receiving the farmed product Purchase-Order-Id, the farmer accepts or rejects the purchase order by updating the status using the *ConfirmFarmedProductPurchaseOrder()* function. The farmer initiates the shipment after the confirmation of the purchase order by calling the *FarmedProductShipmentInitiated()* function. Through the successful execution of this function, the farmer generated the Shipment-Id between the farmer and the processor. After receiving the details of the shipment, the processor calls the function *FarmedProductPaymentInitiated()*. While executing this function, a Payment-Id is generated, which contains the details of the payment exchanged between them. Upon successful receipt, when the payment is received, farmer invokes the function *FarmedProductPaymentReceived()* to the processor. Afterward, the processor calls the function *ReceivedFarmedProductShipment()*, which informs all the stakeholders about the status of the delivery.

After the completion of processing the crop by various industries, the processor deploys the Add Item smart contract. After the successful deployment of the Add Item smart contract, the details of each product are updated, which notifies all the stakeholders about the addition and updating of food product items in the list. Figure 8.3 Illustrates the mutual interaction between the processor and distributor using a sequence diagram. The processor uploads all the details of several products with images, large files of videos, and quality-checked certificates in the IPFS and stores the hash value of files and images in the blockchain. The distributor manages to purchase the processed products from the processor and distributes them to the retailer by calling the *PlaceProcessedProductPurchaseOrder()* function. The function is executed successfully, and a Purchase-Order-Id is developed between the distributor and processor and the Ethereum address of both entities. The processor accepts or rejects the purchase order by calling *ConfirmProcessedProductPurchaseOrder()* function. After the confirmation of the purchase order, the shipment is initiated by calling the *ProcessedProductShipmentInitiated()* function. After the successful delivery of processed products to the distributors, *ProcessedProductShipmentReceived()* is called, and all the stakeholders are notified about the status of the consignment. After the successful acceptance of the shipment, the Shipment-Id is created between the distributor and processor. When the distributor receives the details of the shipment, the *ProcessedProductPaymentInitiated()* function is executed. Upon executing the payment, the Payment-Id is generated among them, and when the distributor receives the shipment, the function *ProcessedProductPaymentReceived()* is invoked.

Similarly, the retailer creates a purchase order for the processed product from distributor by calling *PlaceDistributedProductPurchaseOrder()* function to transport them from the distribution company to the retail shops. After that, the distributor accepts or rejects the order by calling the function *ConfirmDistributedProductPurchaseOrder()*. With the successful acceptance of the order, the distributor initiates the shipment by invoking the function *DistributedProductShipmentInitiated()*, which creates the Shipment-Id between the disturber and the retailer. The successful confirmation of retailer shipment function *DistributedProductShipmentReceived()* is invoked to confirm the status of the delivery of products. After getting the shipment details of the distributor, the retailer calls the function *DistributedProductPaymentInitiated()*, and a Payment-Id is generated between them. After receiving the payment from the retailer, the *DistributedProductPaymentReceived()* function is called and notifies the retailer about the received payment. Afterward, the products are available in the market, and the customer buys the final product from the shops. To obtain the record of the product, the customer can scan the QR code, and it will display the entire history of a product from the farm to the end through the decentralized application. The data related to each product is always available on the blockchain network. Therefore, transparency and traceability are provided to all the stakeholders in the agri-food supply chain.

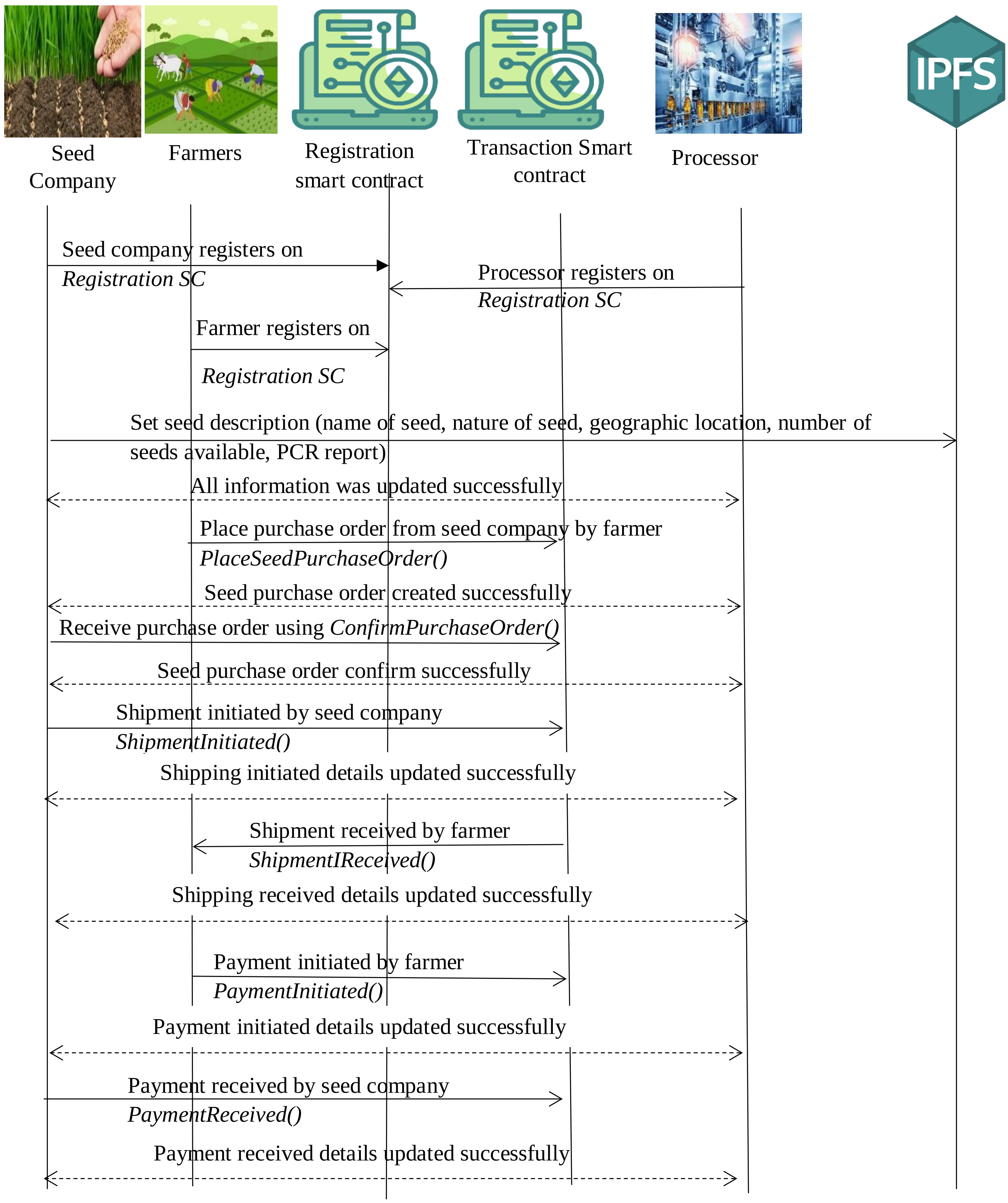


Figure 7.2 Sequence diagram presenting interaction between seed company and farmer

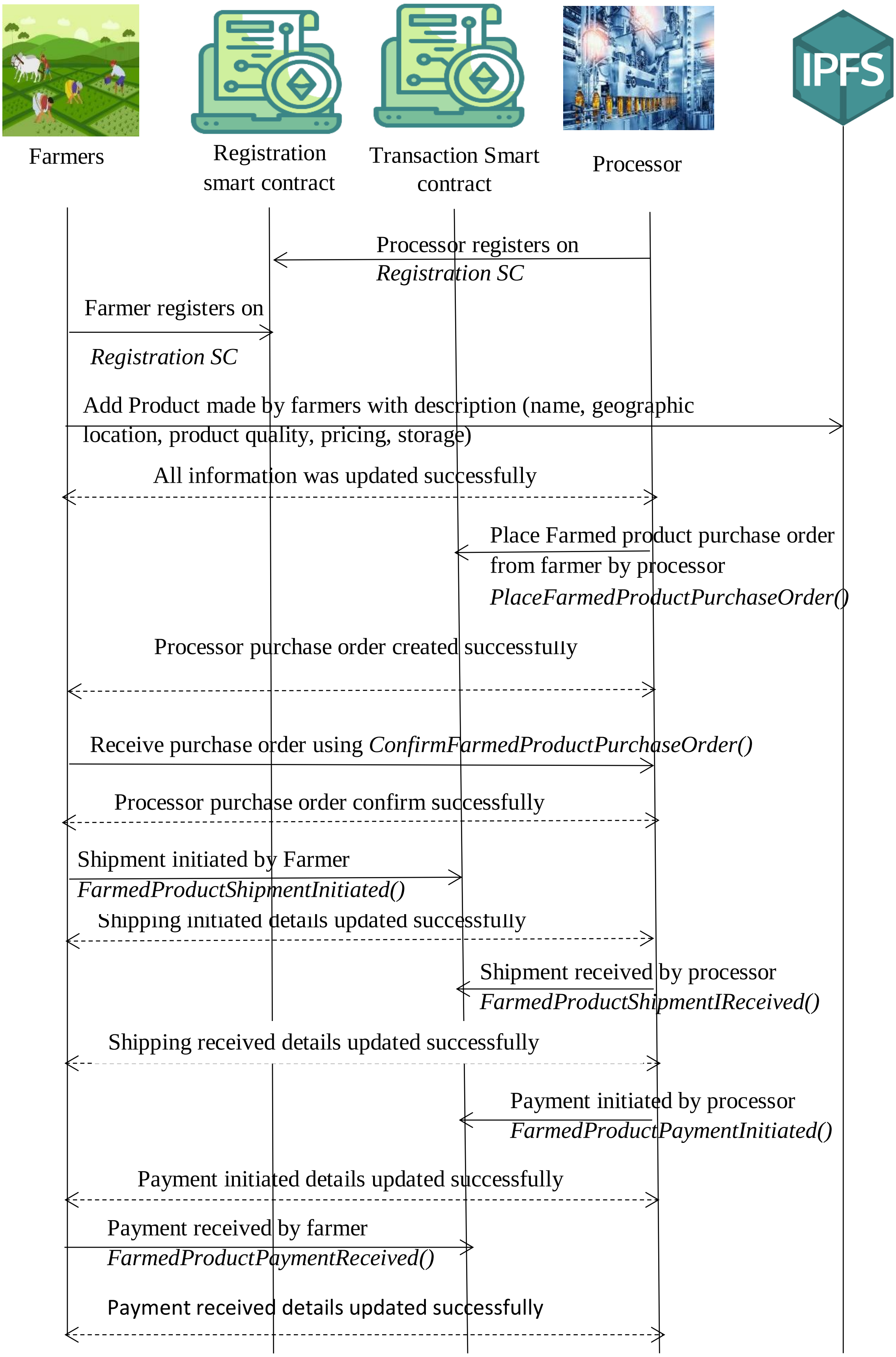


Figure 7.3 Sequence diagram presenting the interaction between farmer and processor

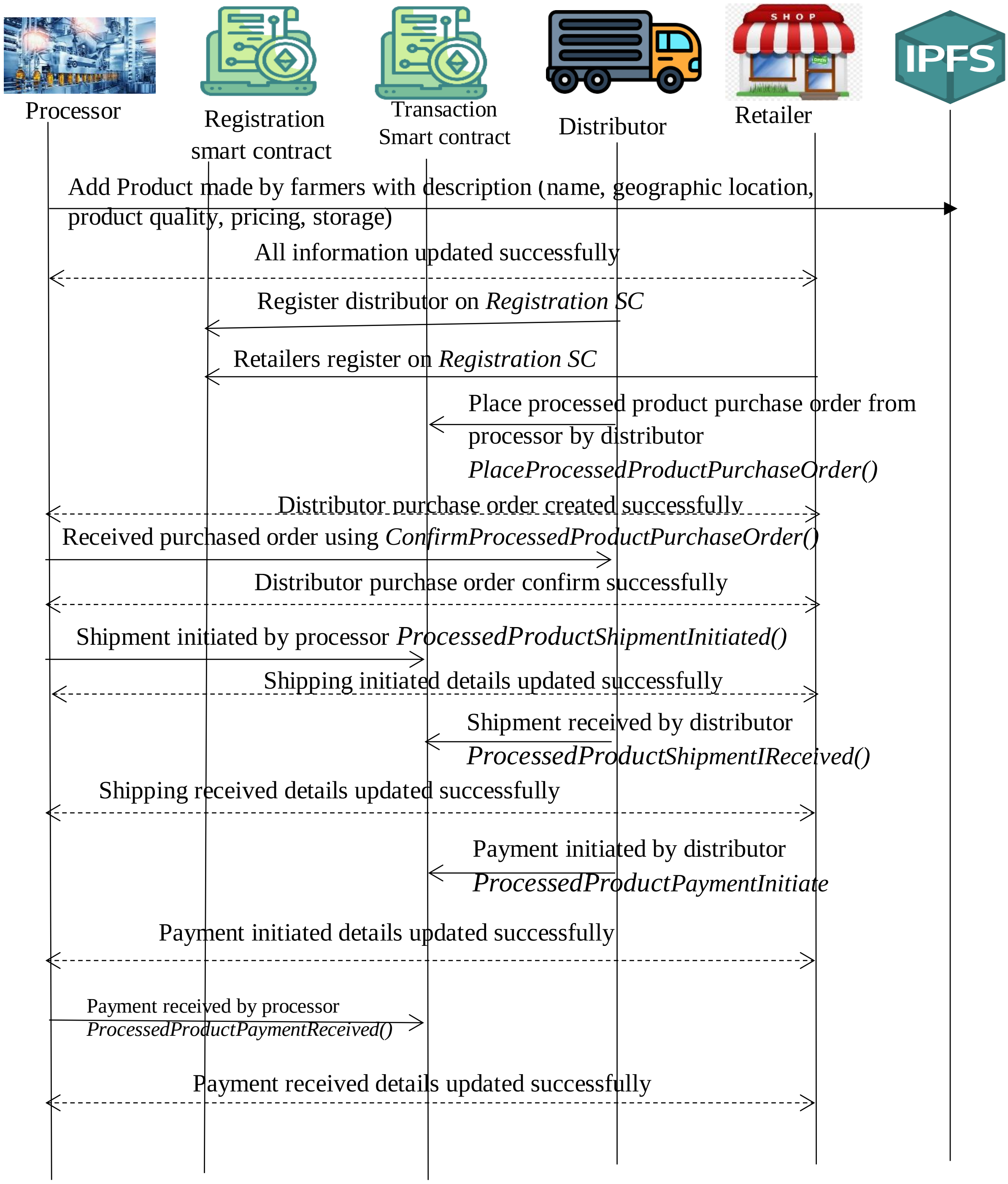
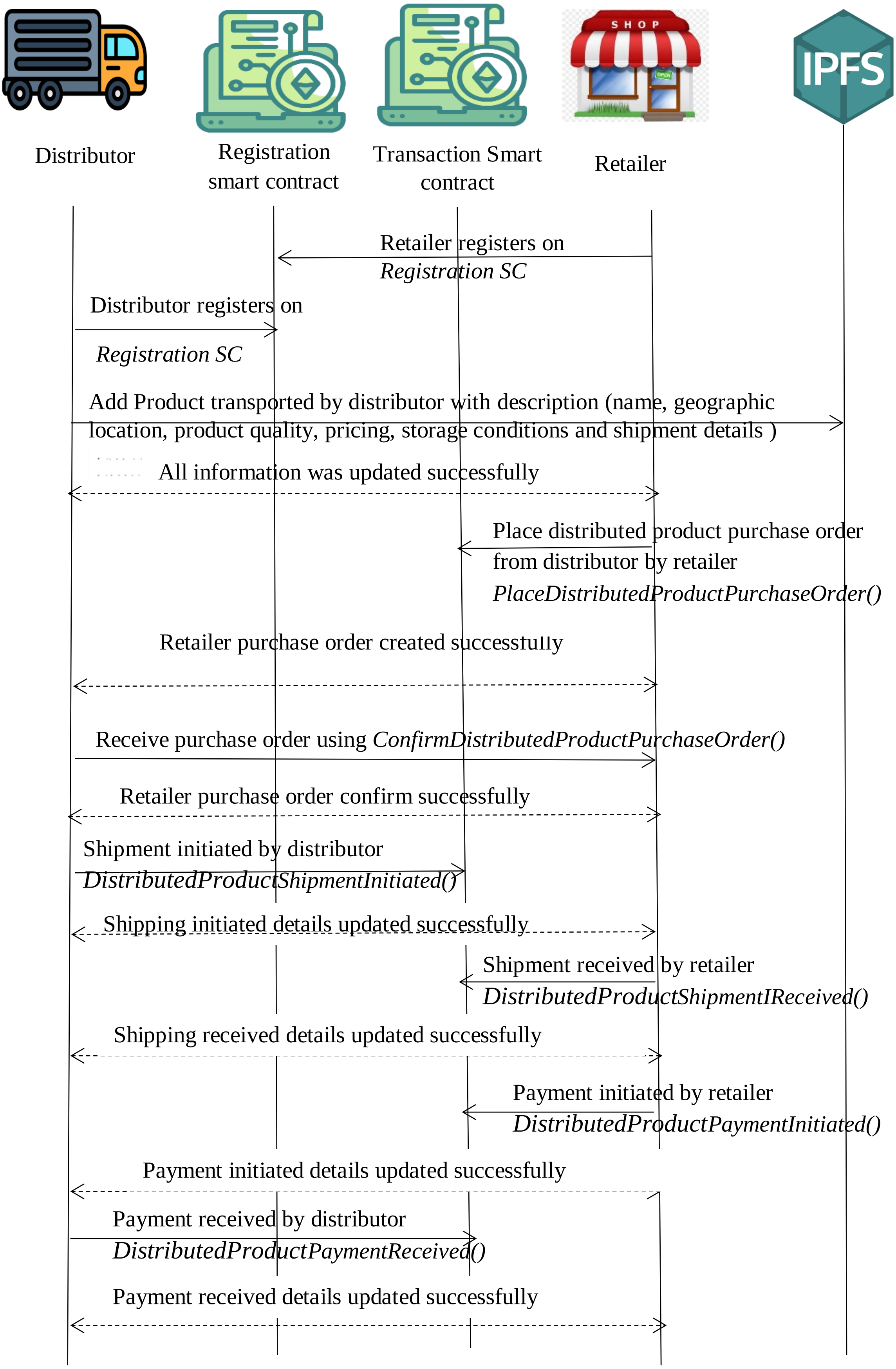


Figure 7.4 Sequence diagram showing interaction between processor and distributor



Distributor
Registration smart contract
Transaction Smart contract
Retailer
IPFS
Retailer registers on *Registration SC*
Distributor registers on *Registration SC*
Add Product transported by distributor with description (name, geographic location, product quality, pricing, storage conditions and shipment details)
All information was updated successfully
Place distributed product purchase order from distributor by retailer *PlaceDistributedProductPurchaseOrder()*
Retailer purchase order created successfully
Receive purchase order using *ConfirmDistributedProductPurchaseOrder()*
Retailer purchase order confirm successfully
Shipment initiated by distributor *DistributedProductShipmentInitiated()*
Shipping initiated details updated successfully
Shipment received by retailer *DistributedProductShipmentIReceived()*
Shipping received details updated successfully
Payment initiated by retailer *DistributedProductPaymentInitiated()*
Payment initiated details updated successfully
Payment received by distributor *DistributedProductPaymentReceived()*
Payment received details updated successfully

Figure 7.5 Sequence diagram presenting interaction between distributor and retailer

7.4 Implementation details

This section presents the algorithm along with its implementation details that define the working principles of the proposed blockchain-based framework. For the development and execution of smart contracts VS code is used.

Algorithm1: Registration of all stakeholder details

Input: Registration smart contract of all the stakeholders involved in the agri-food supply chain
Output: Verify and add various stakeholders on the blockchain

if Function Caller EA != verifystakeholderaddress()
  then
    The Ethereum address of the stakeholder does not exist and new stakeholder is added on the blockchain
end
else
  if Function Caller EA == verifystakeholderaddress()
    then
      The Ethereum address of stakeholder already exists
  end
end

Algorithm 1 explains the process of accepting or rejecting the user request by the blockchain network. First, each user must be registered with the blockchain network validated by the FDA. By validating their details like Aadhar card number, the user is being added to the blockchain system by the FDA. The system provides a unique identification code, such as an Ethereum address, to each new user. At the time of new user registration, the system checks their identification code. If already exists, it shows the user has already registered; otherwise, if it is a new user, then the FDA verifies the user details and adds them to the blockchain network. After logging in with the identification code, the user goes to their profile page, in which they can add, buy, sell, and see the history of products.

Algorithm2: Add items details by different stakeholders

Input: Updating all the details of items and their information in IPFS, such as item name, geographic location, availability, item type and their respective IPFS Hash
Output: Details are stored on IPFS and hash value is returned to blockchain network and event is generated

If FunctionCaller EA!= Stakeholders EA
  then

```
        The Ethereum address of stakeholder does not exist
end
else
        If Function caller EA= additem()
            then
                Notify all the stakeholders by triggering an event about adding an item and
                then add item and their respective details stored in IPFS such as Ethereum
                address of item, item name, geographic location, number of items available,
                type of item, IPFS Hash and update the item details
        end
        else
                Contract comes back to its original state by giving an error message
        end
end
```

Algorithm 2 provides the process of adding and updating the food item details such as product name, quantity available, geographic location, etc. All the information is stored in IPFS and IPFS hash is stored on the blockchain network. According to the proposed system, the user is the stakeholder that adds new items and updates all the information to the Add item smart contract to notify other stakeholders. All the stakeholders must be aware of the items added and the status of the items available or not available to act further. The item name specifies the food item name and its category. The geographic location indicates the origin of the food product and many more. The IPFS storage system is used to store all the information for stakeholder's reference. The hash value of IPFS and the address of the IPFS storage system are then stored on the blockchain network. Using these details, stakeholders become aware of the origin and quality of the product.

Algorithm3: Purchase order between Seed Company and farmers and finally receiving the order at farmer side

Input: Ethereum address of Farmer, Ethereum address of seed company and number of seeds requested and type of seed requested
Output: Seed purchase order function is placed and also shipment and payment details are shared with corresponding stakeholders

```
Modifier VerifySeedProducer ()
        If
           then
                Sender==Seed Producer (continue with function execution)
         else
               Print an error message indicating unauthorized access
        end
        end Modifier
```

```
Modifier VerifyFarmer ():
        If
          then
              Sender==farmer (continue with function execution)
        else
              Print an error message indicating unauthorized access
        end
        end Modifier
Modifier onlyFarmer():
        If
          then
               Length of bytes for farmer [msg.sender] is not equal to 0
         else
              Print and error message indicating unauthorized access
        end
        end Modifier
if Function caller EA != Farmer EA
   then
        This is an incorrect address for farmer
end
else
        if Function caller EA== Farmer EA
          then
             Create PlaceSeedPurchaseOrder() from Seed Company
             Trigger an event to inform the farmer wants to purchase an item and the purchase
              order is placed
        end
        If Function caller EA != Seed company EA
           then
                This is an incorrect address for Seed Company, and Seed Company does not
                 exist
        end
        else
                if Function caller EA== Seed company EA
                  then
                       Accept the PlaceSeedPurchaseOrder() request and change status to
                       Accepted
                 end
                     if function = ConfirmPurchaseOrder()
                       then
                            Purchase order status=confirmed and Trigger an event to inform
                            the   Farmer that the Purchase order is confirmed and update the
                            information of Farmer and seed company
                     else
                           Item is not available or out of stock
                     end
                     if ShippingInitiated() is True
                       then
                           Send all the information of shipping details to the farmer
                    end
```

```
                else
                    Some network issue or shipping delayed
                end
                if ShippingReceived() is True
                   then
                        Shipment received and update information
                else
                        Shipment not received yet
                end
                if PaymentInitiated() is True
                   then
                        Send all the information of payment initiation details to the Seed
                        company
                else
                     Some network issue
                end
                if PaymentReceived() is True
                   then
                        Payment received
                else
                        Payment not received yet
                end
                else
                     Contract comes back to its original state by giving and error message
                end
         else
             Changes the status of Purchased Item to Rejected
         end
     end
```

Algorithm 3 explains the logic of creating a purchase order between the seed company and the farmer, confirming the order by the seed company, sending the shipment details to the farmer, initiating the payment by the farmer to the seed company, and finally receiving the shipment by the farmer. The farmer acts as the purchaser of seeds from the seed company and initiator of the algorithm. The input given by the farmer includes the Ethereum address of the seed company, the type of seed, the quantity of seed purchased, and the status of the purchased order. The seed company declines or confirms the purchase order by checking the availability of seed. Upon creation, a purchase order Id is created between them, which is collision-free. After confirming the order, the shipment details are sent to the farmer with the Shipment-Id, and the farmer can track the status of the purchase order and shipment. In return, the farmer initiated the payment with a Payment-Id and sent details to the seed company. After receiving the payment and shipment from both stakeholders, they send the details to each other, and farmer stars grow their produce.

Algorithm4: Updating farmed product details and creating Farmed product package ID

Input: Farmer Ethereum address, total number of items, item type, weight of each item
Output: Generate FarmedItemDetails Updated event

If function caller EA! = Farmer EA
  then
    The address of farmer does not exist
  end
  else
    if function caller EA== Farmer EA
      then
        Triggering an event to notify all the stakeholders about Update Farmed product details, product name, pre harvest details different Product Id and their corresponding IPFS hash value
    end
    else
      Contract comes back to its original state by giving and error message
    End

According to algorithm 4, the farmer updates the growth details from the infantile to fully grown stage for different products with different product Ids with their own farmer's Ethereum address. The farmer uploads the data about the growth and harvest, which includes the geographic location, total area sown, source of water used, weather details, how much produce was collected at the end, price issued to the produce, and many more things with farmers' Ethereum address to the IPFS storage system. Farmers also upload videos and images of the life cycle, and IPFS hash value added on the blockchain for other stakeholders to examine. All this information provides transparency to each stakeholder to check the entire process of production, which helps to avoid conflicts and misleading information about the produce price and quality.

Algorithm5: Creating a Purchase order between farmer and processor and finally receiving the order

Input: Ethereum address of Farmer, Ethereum address of processor, type product, quantity of product sold
Output: Place farmed product purchase order function and also shipment and payment details are shared with corresponding stakeholders

Modifier VerifyFarmer ()
    If
      then
        Sender==Farmer (continue with function execution)
      else
        Print an error message indicating unauthorized access
      end

```
            end Modifier
Modifier VerifyProcessor ()
        If
          then
               Sender==Producer (continue with function execution)
        else
               Print an error message indicating unauthorized access
        end
        end Modifier
Modifier onlyProcessor()
        If
          then
                Length of bytes for processor [msg.sender] is not equal to 0:
        else
                Print and error message indicating unauthorized access
        end
        end Modifier
if Function caller EA!=Processor EA
then
        This is an incorrect address for processor
end
else
     if Function caller EA== Processor EA
       then
             Create PlaceFarmedProductPurchaseOrder() from farmer
              Trigger an event to inform the processor wants to purchase an item and the
               Purchase order is placed
      end
          If Function caller EA != Farmer EA
            then
                 This is an incorrect address for farmer, and farmer does not exist
         end
         else
                if Function caller EA== Farmer EA
                  then
                        Accept the PlaceFarmedProductPurchaseOrder() request and change
                        The status to Accepted
                 end
                 if function = ConfirmFarmedProductPurchaseOrder()
                   then
                        Purchase order status=confirmed and Trigger an event to inform the
                        processor that the purchase order is confirmed and update the
                        information of processor and farmer
                  else
                      Item is not available or out of stock
                  end
                   if FarmedProductShippingInitiated() is True
                      then
                          Send all the information of shipping details to the processor
                  end
```

```
else
        Some network issue or shipping delayed
end
if FarmedProductShippingReceived() is True
   then
        Shipment received and update information
else
        Shipment not received yet
end
if FarmedProductPaymentInitiated() is True
   then
        Send all the information of payment details to the farmers
   else
        Some network issue
end
if FarmedProductPaymentReceived()
   then
        Payment received
else
        Payment not received yet
end
else
      Contract comes back to its original state by giving and error
      message
end
else
   Changes the status of Purchased Item to Rejected
end
end
```

Algorithm 5 highlights the process of creating a purchase order, receiving the shipment, and payment exchange between the farmer and processor, who convert raw production into various products. Further, the processor purchases the produce from the farmer, and the farmer receives the purchase order and confirms it by calling relevant functions. The processor inputs the history of purchase orders with the Ethereum address of the farmer, such as type of produce, quantity, and type of quality. Then, the system generates the purchase order Id between them, and the farmer sends shipment details to the processor by creating a Shipment-Id. After receiving the shipment details, the payment is initiated by the processor to the farmer by generating a Payment-Id. Finally, the processor receives the shipment, and the farmer receives the payment. The processor sets the market price of different products according to the resources they use, plus adding the margins of the distributor and retailer and, finally, the market value of the product is printed on the packaging. Distributors and retailers are only concerned with delivering the product to the market, and their profits have already been set by the production firm.

Algorithm6: Updating processor description details and creating processed items ID

Input: Farmer and processor Ethereum address, total number of items, item type, weight of each item
Output: GenerateProcessorItemDetails Updated event

If function caller EA!= processor EA
  then
    The address of the processor does not exist
end
else
    if function caller EA== Processor EA
      then
        Triggering an event to notify all the stakeholders about the processing details and update the product details such as product name, their types with different Product Id and their corresponding IPFS hash values
end
else
    Contract comes back to its original state by giving and error message
end

Algorithm 6 explains updating the processed product details for each product and creating different Product-IDs. The processor processes the raw production and converts it into various finished products and adds all the information related to the processing of the product, such as type of products formed, product name, date of processing, conversion of raw material to finished product details, price of each product including profits into IPFS system and IPFS hash value is input into the blockchain network. All the images and videos have been uploaded by the processor to maintain transparency between stakeholders. The date of processing can help stakeholders know the exact date of making products. This will ensure tracking of all the processes that happen in smart contracts.

Algorithm 7: Creating purchase order between processor and distributor

Input: Ethereum address of distributor, Ethereum address of processor, type of product, and quantity of product sold
Output: Place processed product purchase order function and also shipment and payment details are shared with corresponding stakeholders

Modifier VerifyProcessor ()
    If
      then
        Sender==Farmer (continue with function execution)

```
        else
                Print an error message indicating unauthorized access
        end
        end Modifier
Modifier VerifyDistributor ()
        If
           then
                 Sender==Producer (continue with function execution)
        else
                 Print an error message indicating unauthorized access
        end
        end Modifier
Modifier onlyDistributor ()
        If
           then
                Length of bytes for farmer [msg.sender] is not equal to 0:
        else
               Print and error message indicating unauthorized access
        end
        end Modifier
if Function caller EA != Distributor EA
   then
        This is an incorrect address for distributor
end
else
        if Function caller EA== Distributor EA
           then
                PlaceProcessedProductPurchaseOrder from Processor
                Trigger an event to inform the processor that the Buy order is placed
        end
        If Function caller EA != Processor EA
           then
                This is an incorrect address for Processor and Processor does not exist
        end
        else
                 if Function caller EA== Processor EA
                    then
                         Accept the purchase order request from distributor and change the
                         status to Accepted
                 else
                         Changes the status of Buy Item to Rejected
                 end
                   if function = ConfirmProcessedProductPurchaseOrder()
                      then
                          Purchase order status=confirmed and Trigger an event to inform the
                          distributor that the Purchase order is confirmed and update the
                          information of processor and distributor
                    else
                          Item is not available or out of stock
                    end
```

```
            if ProcessedProductShippingInitiated() is True
              then
                   Send all the information shipping details to the distributor
            end
            else
                   Some network issue or shipping delayed
            end
             if ProcessedProductShippingReceived() is True
               then
                    Shipment received and update information
             else
                    Shipment not received yet
              end
              if ProcessedProductPaymentInitiated() is True
                then
                      Payment initiated and Send all the information of payment
                     details to the processor
                else
                     Some network issue
               end
               if ProcessedProductPaymentReceived() is True
                 then
                     Payment received by processor
               else
                     Payment not received yet
                end
                else
                  Contract comes back to its original state by giving and error message
            end
        else
            Changes the status of Purchased Item to Rejected
        end
    end
```

Upon successfully updating the details of products by the processor, the distributor gets a notification about the product's availability. Algorithm 7 explains the purchasing order between processor and distributor. The distributor sends a purchase order to the processor by sending the purchase order input, such as product name, quantity, and the Ethereum address of the processor. The output of this command creates a purchase order Id between them, and the processor confirms the order; otherwise, it is declined. The processor sends the shipment details to the distributor by generating the Shipment-Id, and there, the distributor starts initiating the payment by creating a Payment-Id. The function notifies the processor and distributor about the payment and shipment. Upon receiving payment and shipment, they send notifications to each other about the successful purchase.

Algorithm 8: Updating distributor description details and creating product Id for different products

Input: Distributor and processor Ethereum address, total no of items, item type, weight of each item, IPFS hash value
Output: GenerateDistributorItemDetails Updated event

If function caller EA!= Distributor EA
  then
    The address of the distributor does not exist
end
else
  if function caller EA== Distributor EA
    then
      Triggering an event to notify all the stakeholders about the distributing details and update the product details such as product name, their types with different Product-Id and their corresponding IPFS hash values
end
else
  Contract comes back to its original state by giving and error message
End

Algorithm 8 explains updating the distributed product details for each product and creating different Product-Id. The distributor transport the products to the various location where the product is being delivered. They add all the information related to the distribution of product, such as type of products delivered, product name, date of processing, date of delivery, price of delivery, delivery codes, vehicles details are all added into IPFS system and IPFS hash value is input into the blockchain network. All the images, videos and transportation details have been uploaded by the distributor to provide traceability between stakeholders.

Algorithm 9: Creating purchase order between Distributor and Retailer

Input: Ethereum address of Distributor, Ethereum address of processor, type of product, and quantity of product sold
Output: Place distributed product purchase order function and also shipment and payment details are shared with corresponding stakeholders

Modifier VerifyDistributor ()
  If
    then
      Sender==Producer (continue with function execution)
  else
      Print an error message indicating unauthorized access
  end
  end Modifier
Modifier VerifyRetailer ()
  If
    then
      Sender==Farmer (continue with function execution)

```
        else
              Print an error message indicating unauthorized access
        end
        end Modifier
Modifier onlyRetailer ()
        If
           then
              Length of bytes for Retailer [msg.sender] is not equal to 0:
        else
              Print and error message indicating unauthorized access
        end
        end Modifier
if Function caller EA != Retailer
then
        This is an incorrect address for Retailer
end
else
        if Function caller EA== Retailer EA
          then
              PlaceDistributedProductPurchaseOrder from Distributor
               Trigger an event to inform the distributor that the purchase order is placed
        end
        If Function caller EA != Distributor EA
           then
               This is an incorrect address for Distributor and Distributor does not exist
        end
        else
               if Function caller EA== Distributor EA
                  then
                      Accept the purchase order request and change the status to Accepted
               else
                       Changes the status of Buy order to Rejected
               end
        end
                 if function = ConfirmDistributedProductPurchaseOrder()
                    then
                        Purchase order status=confirmed and Trigger an event to inform the
                         retailer that the purchase order is confirmed and update the
                         information retailer and distributor
                 else
                         Item is not available or out of stock
                 end
                  if DistributedProductShippingInitiated() is True
                     then
                          Send all the information of shipping details to the retailer
                 end
                  else
                          Some network issue or shipping delayed
                  end
                   if DistributedProductShippingReceived() is True
```

```
                    then
                        Shipment received and update information
                  else
                        Shipment not received yet
                  end
                  if DistributedProductPaymentInitiated() is True
                     then
                        Payment initiated and Send all the information of payment details
                        to the distributor
                   else
                        Some network issue
                  end
                  if DistributedProductPaymentReceived() is True
                     then
                        Payment received by distributor
                  else
                        Payment not received yet
                   end
                   else
                  Contract comes back to its original state by giving and error message
                end
            else
               Changes the status of Purchased Item to Rejected
            end
        end
```

Algorithm 9 explains the logic of creating a purchase order between the Retailer and the Distributor in which the Retailer calls the function purchase order from the distributor containing the type of product, quantity, and Ethereum address of the Retailer. The output of this function generates purchase order Id to track the purchase order details. Later, the distributor accepts the order and notifies the Retailer by sending shipment details with the shipment Id. By receiving the shipment details, the Retailer initiates the payment and creates a payment Id. Upon receiving the shipment and payment by retailer and distributor, respectively, it notifies all the stakeholders about confirmation of purchase. In this research, the consumer is the end user, who is not a part of the private Ethereum blockchain but has access to view the history of the product by simply scanning the barcode on the product. Also, consumers can get all the information from retailers who are part of the ledger. The consumer can see the entire history of the product, where it comes from, and its processing, distribution, and retailing process.

Following the implementation details of algorithms, the proposed framework of blockchain based securable and traceable agri-food supply chain is discussed. The proposed framework has developed only one smart contract for the interaction between various stakeholders to reduce the overloading of functions and reduce the gas price. The smart contract is deployed and executed on VS code. Each smart contract is executed and deployed in a code environment. The unauthorized function call can be prevented by using modifiers in the code as well and it also prevents functions from consuming too much gas. This makes code more redundant and needs to be applied across multiple functions in a contract. Whenever some unauthorized stakeholders call the functions, an error notification is triggered, and the code goes back to its original state. Events have been created in the smart contracts, which helps to notify all the stakeholders about the new event occurrence to maintain the provenance of data and traceability of information. Also, it helps to facilitate the communication between the blockchain and the external application to enhance the overall functionality of the decentralized application.

The proposed blockchain framework is depicted in Figure 7.6. First, the stakeholder registered with their name and Aadhar card number on the DApp. The FDA confirms the authenticity of stakeholder by confirming or declining their request. Upon registration on the DApp, Metamask helps to generate the pair of public and private key. The public key is available to everyone, but the scope of the private key is limited to the stakeholder only. The key pair is interconnected with each other to sign the transactions. In this way, stakeholders get connected with the blockchain through the help of Metamask wallet. After successful registration, stakeholders have access to a personalized dashboard where they can view and manage their account information and perform activities such as adding products and purchasing and selling products. DApp can utilize APIs to connect to the blockchain network and monitor various tasks such as user behavior, smart contract activities and insights into the DApp performance. Following, the smart contracts can be automatically executed when any transaction takes place between any two parties. The smart contracts are deployed on the blockchain development environment hardhat. Following the successful execution of the smart contract, they are migrated to the blockchain network along with the stakeholders' public key. Also, IPFS is used to store data, and it generates the hash of the data files and acts as the pointer to the data location. The content identifiers (CID) were used to retrieve files from the IPFS network in the form of file has, and then file hash is added to the blockchain network.

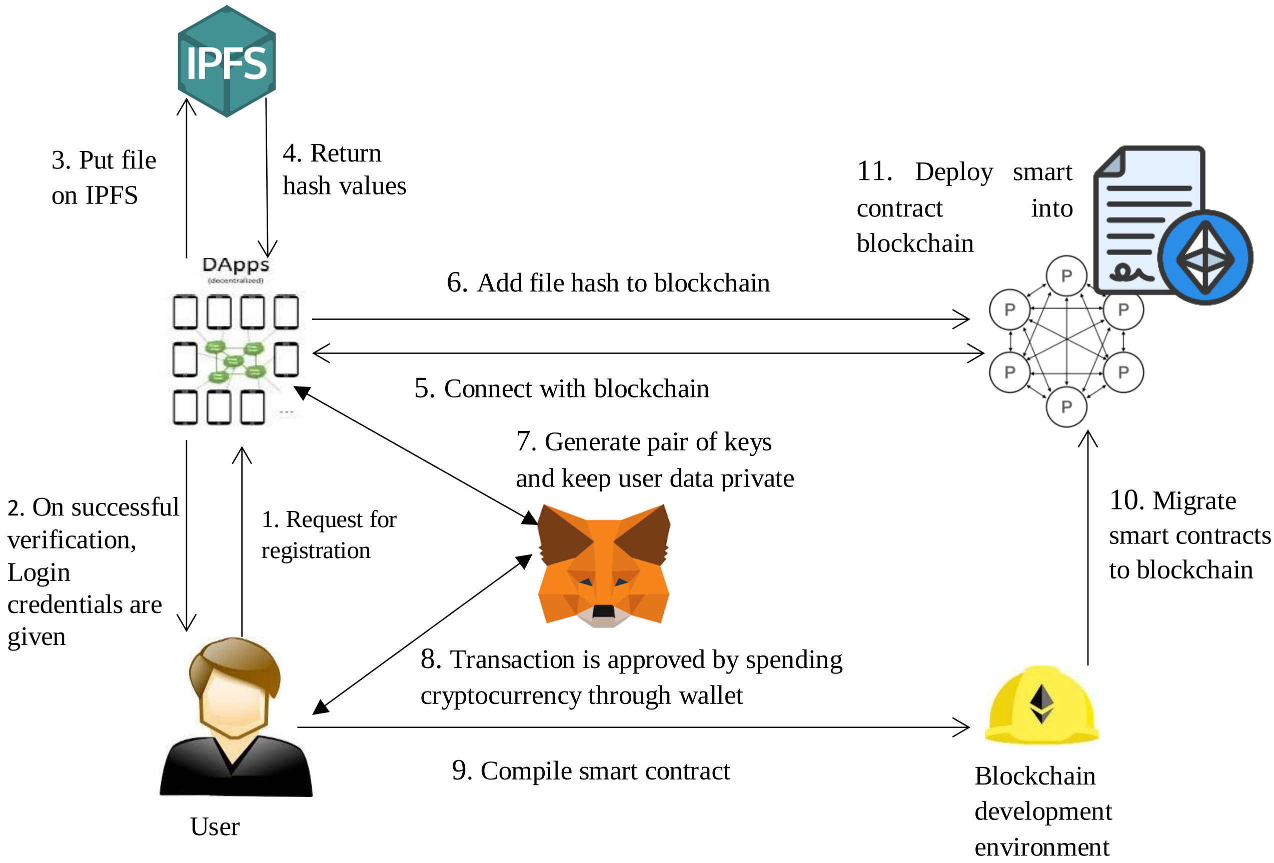


Figure 7.6 Proposed blockchain based agri-food supply chain framework

7.5 Results and analysis

7.5.1 Cost analysis

The blockchain-based, traceable, and transparent framework for the agri-food supply chain is developed on a private Ethereum network with PoS consensus. As blockchain has limited storage capacity, the proposed framework used IPFS, which is capable of storing large files, images, videos and records. The blockchain only stores the hash values of data stored in the IPFS. This framework is mainly concerned with increasing the farmer's income, providing trust and a transparent platform among stakeholders and in the agri-food supply chain, that facilitates direct transactions between purchasers and vendors, eliminating the need for intermediaries, and providing broader access to the market, negotiating prices, and receive fair compensation of the products. The smart contracts were generated using Solidity language with hardhat Ethereum framework installed on window 10. Hardhat is the development environment for building, testing and deploying smart contracts. It is easy to use and support modern development workflows.

The smart contracts are executed and deployed on VS. code using Metamask Ethereum wallet that facilitate user interaction with the Ethereum blockchain. Similarly, the Sepolia testnet was used to test smart contracts and interact with the blockchain without using real cryptocurrency. The testnet is based on the PoS consensus algorithm, which provides a real-world simulation environment. The Ethereum nodes were hosted and maintained by Infura Gateway, which contributes to the consistency and reliability of the Ethereum network. The Processor is Intel(R) Core (TM) i7 with 16GB RAM. The proposed smart contracts used various events and modifiers are shown in Table 7.1. Events allows contracts to notify all the external stakeholders about the state change. While, modifiers are used as a reusable condition that can be applied to functions, promoting code reusability and readability. This study has evaluated the cost analysis of various transactions that occur in smart contract as depicted in Table 7.2. Figure 7.7 shows the varying in US Dollars transaction fees of different functions. For a successful transaction, each operation is evaluated in Gwei and converted into Ethers. Transactions with higher Gwei values receive priority from miners. The transaction cost is influenced by factors such as loops, arrays, mappings, variables, functions, and data types. Ensuring a smart contract is both feasible and cost-effective is crucial. Therefore, the proposed framework relies on the implementation of events, modifiers, and specific functions. Given the fluctuating gas rates influenced by network congestion and varying day-time factors, awareness of high gas prices is essential. Results reveal that the confirmItem function incurs the highest transaction cost, amounting to $8.2463602, compared to other functions. This study has also created DApp as shown in Figure 7.8-7.11, which describe the addition of seed producer, adding item, buying item and payment initiation process.

The transaction fees can be calculated using formula:

$Transaction\ fee = Gas\ used * Gas\ Price$ where (1 ETH $=$ 2,201.28 USD)

$Transaction\ fee\ in\ USD = Transaction\ fee\ in\ ETH * ETH\ to\ USD$

Table 7.1 Modifiers and events corresponding to their function used in the smart contract

Functions	**Events**	**Modifiers**
addSeedProducer	event updated	modifier onlyOwner
AddRetailor	event updated	modifier onlyOwner

addFarmer	event updated	modifier onlyOwner
addDistributor	event updated	modifier onlyOwner
addProcessor	event updated	modifier onlyOwner
addItem	event newItem event updateItem	modifier onlyOwner
buyItem	PurchasOrderPlaced	VerifySeller
confirmItem	PurchaceOrderConfirmed	verifyBuyer
shippingInitiated	ShippingInitiated	verifySeller
shippingReceived	shippingReceived	verifyBuyer
paymentInitiated	PaymentInitiated	verifyBuyer
paymentReceived	PaymentRecived	verifySeller

Table 7.2 Transaction cost of various functions used in smart contracts

Functions	**Transaction fee (ETH)**	**Gas used (Gwei)**	**Transaction cost in US dollars**	**Gas price (Gwei)**	**Gas limit**
addSeedProducer	0.00135902801475676	1359028.01475676	2.9929666	26.681090285	50,936
addRetailor	0.001511756516949296	1511756.516949296	3.3293182	29.705773456	50,891
addFarmer	0.001467226329692425	1467226.329692425	3.2320622	28.793420525	50,957
addDistributor	0.00149286043164606	1492860.43164606	3.28853	29.32121679	50,914
addProcessor	0.001451086161121449	1451086.161121449	3.1975491	28.501289673	50,913
addItem	0.001604523957766838	1604523.957766838	3.5356578	30.694493587	52,274
buyItem	0.003024947973263265	3024947.973263265	6.6656412	30.421360419	99,435
confirmItem	0.003744519607283235	3744519.607283235	8.2463602	30.656347843	122,145
shippingInitiated	0.001657279515921766	1657279.515921766	3.6497402	33.310142422	49,753
shippingReceived	0.001633307027368824	1633307.027368824	3.5969469	32.948176942	49,572
paymentInitiated	0.001071903040454086	1071903.040454086	2.3602812	32.948176942	32,532
paymentReceived	0.0018093546092154	1809354.6092154	3.9841156	34.6606377	52,201

As seen in Table 7.3, the cost analysis of entire smart contract is presented the cost in USD based on the average gas price.

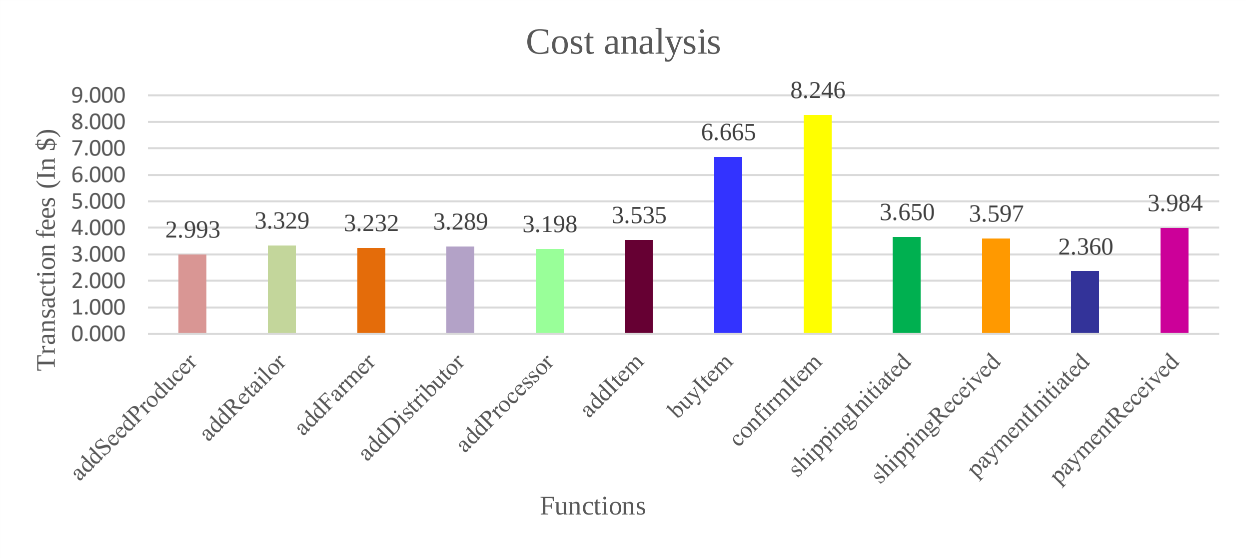


Figure 7.7 Cost analysis of various functions

Table 7.3 Transaction cost of overall smart contract

Smart contract	Gas price	Gas used	Transaction fee	Transaction fee (US dollar)
Transaction smart contract	27.581697346 Gwei	3129146	0.086307157923446516 ETH	189.9862US Dollars where (1 ETH = 2,201.28 USD & 1 USD = 0.000477088 ETH)

7.5.2 IPFS content pinning duration

This study has also presented the in-depth analysis of the IPFS focusing on the temporal aspects of adding data to the network known as pinning time. It pays a crucial role in the performance and efficiency of IPFS, impacting the accessibility and availability of content within the decentralized network. The time it takes to add data on IPFS, including the process of hashing the content, creating the MerkleDag (Merkle Directed Acyclic Graph), and making it available on the network is referred to as pinning time. The duration can vary depending on the factors such as the size of data, the network conditions and the efficiency of the IPFS node. Once the data is pinned, it becomes part of the local node repository and the other node in the network can request and retrieve the content from the pinned copy.

$$Pinning\ time = f(Data\ size, Network\ conditions, Node\ efficiency)$$

- Data size represents the size of content added in IPFS
- Network conditions encompasses the state of the IPFS network, including latency and congestion.

- Node efficiency reflects the performance and capabilities of the IPFS node responsible for pinning operations

Table 7.4 Time taken to add a particular transaction on IPFS

Transactions	**Add time**	**hash value**
Seed producer information added on IPFS	3.23s	bafkreievntkmbi3apnnjuykowydttg5uow34pk357lfawh55fzg6ivf5ke
Add item information on IPFS	2.47s	bafkreihvsztsnt32r2tbh5mbcobj4mzwjfhpxplmsbqzz7exlm7k7mm2we
Adding payment details on IPFS	2.96s	bafkreibdjzsztunvlszwewopfi3nrdydehz45ojewqeoa3e3mpw4tmremy
Adding shipment details on IPFS	3.13	bafkreicd3vmya2zozlsblvtjjjkenu3522kn6hslbhc3nauisxahpcoica

In this study, the pinning operations for adding data to the IPFS were conducted using Pinata gateway. The findings are presented in Table 7.4 in which adding time of a particular transaction and corresponding hash values of transactions is shown.

7.5.3 Security analysis

This study has also used the Oyenete Security Analysis Tool to audit the smart contracts (Yakubu et al., 2022), as shown in Table 7.5. The tool systematically examines the EVM byte code and produces a smart contract call map. Through this analysis, it has been confirmed that the proposed smart contract is devoid of security vulnerabilities. Notably, there are no instances of unchecked expectations within the smart contract that could lead to underflow and overflow conditions of integer transactions. Rigorous testing has been conducted to guarantee the continuous availability of gas throughout the execution, effectively preventing potential re-entrance attacks. Further examination revealed the absence of any flows in the framework, ensuring timestamp dependency, transaction dependency and parity multiple bugs. The integer underflow and overflow depicts the security risk where arithmetic operations cause numbers to exceed their allowable range (overflow) or go below zero (underflow), potentially leading to unexpected behavior. Parity multisig bug checks the vulnerability in the parity multisig wallet contact, allowing attackers to manipulate ownership, leading to unauthorized fund access. Callstack depth attack overwhelm the EVM, causing denial-of-service execution. Transaction-ordering dependence is vulnerability aising from the order of transactions, enabling attackers to manipulate outcomes based on the sequence of transaction execution. Timestamp dependency exploit the timestamp values for malicious purposed, often used in re-entrancy attacks of other time-dependent vulnerabilities. Re-entrancy vulnerabilities occurs when a contract is re-invoked before completing previous execution, allowing attackers to manipulate outcomes, especially in financial transactions.

Table 7.5 Security analysis results

EVM Code Coverage	75.4%
Integer Underflow	False
Integer Overflow	False
Parity Multisig Bug 2	False
Callstack Depth Attack Vulnerability	False
Transaction-Ordering Dependence (TOD)	False
Timestamp Dependency	False
Re-Entrancy Vulnerability	False

7.6 Summary

All the contracts are successfully deployed on the network, and the proposed framework can improve the traceability and transparency of the agri-food supply chain. The proposed model was designed, tested, and validated on the private Ethereum blockchain and smart contract to achieve traceability, transparency, trust, and security of information. The proposed approach provides a secure platform for the stakeholders to record and validate the information on agri-food supply chain processes efficiently. The experimental analysis shows the cost analysis of each function used in the smart contract and the transaction cost to execute the whole smart contract. This study has also presented the time of various transaction to be added in IPFS. Additionally, the security analysis has also been shown to check the security flaws. This approach is capable of tracking stakeholders' functions and their operations. The analysis shows that the proposed framework will provide visibility, traceability and transparency in the agri-food supply chain.

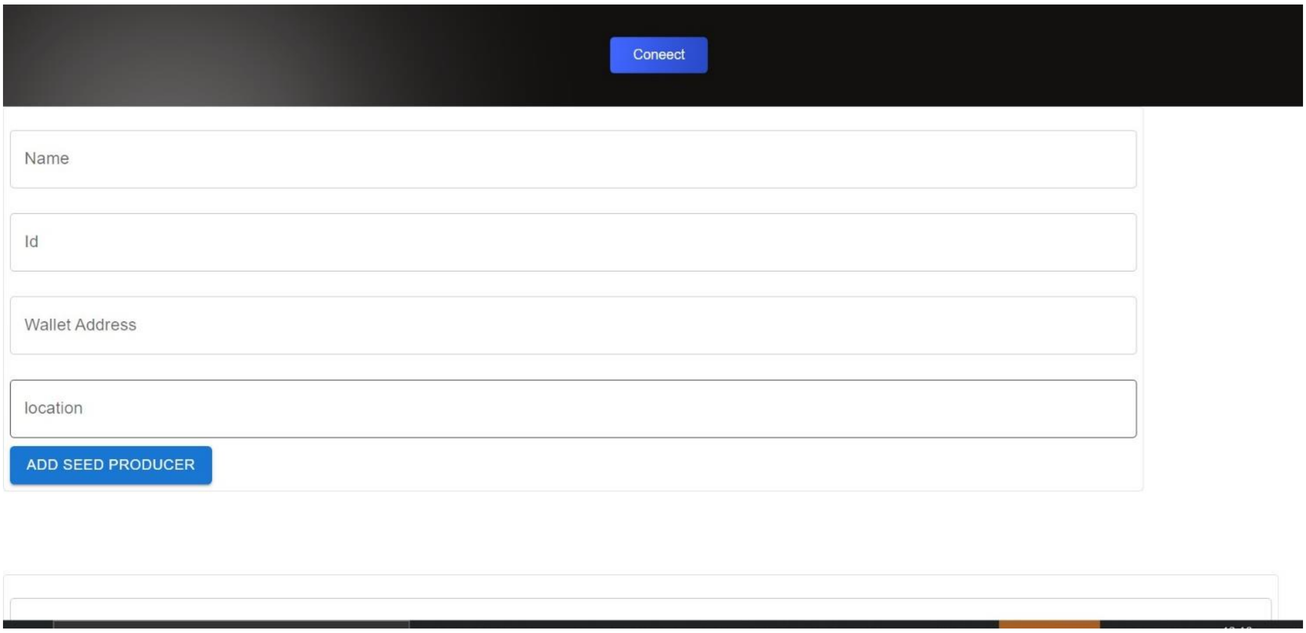


Figure 7.8 Front end for Adding seed producer

Figure 7.9 Front end for Adding item

Figure 7.10 Front end for Buying item

Figure 7.10 Front end for Making payment

Chapter 8 Conclusion and future research scope

8.1 Conclusion

Developing a blockchain-based, secure, and traceable framework for the agri-food supply chain represents a transformative step towards fostering transparency, traceability, trust among stakeholders, and efficiency in the agriculture sector. Through the implementation of decentralized ledger technology, stakeholders across the agri-food supply chain seamlessly collaborate with each other, ensuring the integrity and authenticity of food products delivered to the market. Agreements between stakeholders in a blockchain-based framework for the agri-food supply chain are automated through smart contracts. Smart contracts facilitate and secure transactions while significantly reducing the risk of fraud and errors. Also, this automation of agreements not only reduces the potential for disputes but also contributes to the overall efficiency and reliability of the agri-food supply chain, fostering a more seamless and collaborative ecosystem. The transparency provided by blockchain enhances consumer trust through furnishing verifiable information regarding the origin and quality of food products. Ultimately, the adoption of blockchain in agri-food supply chains holds the promise of creating a more resilient, responsive, and interconnected ecosystem for the benefit of all stakeholders involved.

After having a thorough review of the current stage of blockchain in the agri-food supply chain, the thesis aims to provide a nuanced understanding of how blockchain can revolutionize the agri-food supply chain sector by quantitative assessment. To fulfill the research objectives, the empirical analysis has been used to address the challenges of conventional agri-food supply chains by figuring out the capabilities of blockchain technology. This thesis also presents an adoption study of blockchain in the agri-food supply chain, focusing on insights gathered directly from individuals at the grassroots level. The ensuing exploration delves into the practical implications, and a blockchain-based framework has been developed to leverage blockchain for the sustainable advancement of agri-food systems. The contribution of the thesis is explained as follows:

- The first contribution is towards examining the challenges of conventional agri-food supply chains by using empirical research to make a viewpoint of stakeholders. An exhaustive examination of the current body of literature was undertaken to identify the key challenges related to aspects, and then a quantitative research methodology was formulated for the analysis. Data was collected from 381 stakeholders via a questionnaire survey to obtain the practical examination. Total nineteen challenges were identified that affect the agri-food supply chain, with six key challenges in economic, marketing, and technological domains standing out. The proposed model demonstrated a robust fit with the observed data, explaining 88.6% of the variance and offering substantial explanatory power for the dependent variable's variability. Each challenge was mapped to corresponding issues and opportunities, with recommendations aimed at enhancing the effectiveness and efficiency of the agri-food supply chain for stakeholders, policymakers, investors, and government institutions.

- The second contribution is towards analyzing the capabilities of blockchain in the agri-food supply chain sector. To accomplish this task, a systematic approach of coding using open axial and selective methods has been adopted to identify the themes that represent the blockchain-enabled agri-food supply chain. The data was collected from twenty-nine interviews of selected participants. The results discovered the five critical areas where blockchain can come to enhance agri-food supply chain performance namely traceability, transparency, information security, transactions and trust and quality. This study used the lens of dynamic capability to delve into the organizational-level capabilities of blockchain technology and explore its potential to enhance agri-food supply chain performance. By developing and presenting a blockchain-enabled framework, the study highlights the technology's role in improving traceability, transparency, and security throughout the supply chain. Blockchain ensures food product quality and safety, bolstering user confidence. In conclusion, this research provides valuable insights into implementing blockchain-enabled platforms and systems to optimize the effectiveness of agri-food supply chains.
- The third contribution is to understand the hierarchical model of the capabilities of blockchain-enabled agri-food supply chains. It helps in identifying the key driving factors that significantly influence the blockchain in agri-food supply chain systems and the relationship between these drivers. Understanding these drivers is crucial for effective decision-making. To validate the results of an empirical study, 245 supply chain professionals were surveyed. The findings indicate that information security, followed by traceability and transparency are the most significant capabilities in enabling blockchain in the agri-food supply chain and reducing the impact of disruptions. Blockchain technology offers a solution to the dynamic challenges present in modern supply chain networks by providing traceability, transparency, and security. By establishing a traceable and transparent network, blockchain mitigates risks across

supply chain levels and adds value for users. Through its secure network of authenticated data nodes, blockchain builds trust among stakeholders. Overall, blockchain facilitates government organizations by enhancing the technological capabilities of agri-food supply chains, enabling seamless communication and collaboration among stakeholders on a unified platform.

- The fourth contribution involves examining and assessing the adoption behavior of stakeholders in embracing blockchain technology. This entails a comprehensive examination of stakeholders' decisions to adopt or reject blockchain technology. Understanding stakeholder adoption behavior is crucial for devising effective strategies that encourage widespread acceptance and utilization of blockchain solutions. This attempts to develop an adoption model using extended UTAUT with inter-firm trust and transparency as the additional factors. Data was collected from 382 stakeholders in the North Indian state of Punjab. The empirical analysis was carried out using structural equation modeling by using the Smart PLS4 software tool. The findings of the study reveal that performance expectancy, effort expectancy, social influence, facilitating conditions, inter-firm trust, and transparency are the significant drivers of blockchain adoption and have a 67% effect on the behavioral intentions of stakeholders. Therefore, integrating blockchain technology into the agri-food supply chain offers a solution to mitigate risks and fraudulent activities. Enhanced transparency and interfirm trust among stakeholders will elevate food quality, safety, and security standards. Additionally, blockchain enables rapid detection of warehouse information, food contamination, and safety concerns, contributing to improved overall supply chain management.
- The fifth contribution is towards the development of an Ethereum blockchain-based framework for the agri-food supply chain. The aim of this objective is to develop DApp for the stakeholders and the customers to provide the entire history of the origin and movement of food products from farmer to consumer. The smart contracts in the proposed secure and traceable blockchain-based framework consolidate all the functionalities of buying and selling food products from different stakeholders into one contract, which reduces the contract complexity and overall transaction fees of 189.9862US Dollars making the framework more cost-effective for users than existing framework solutions. Additionally, the IPFS has been integrated with the proposed framework to store all the information instead of blockchain, which provides a highly efficient and reliable platform. The security analysis is accounted 65.3% for the

identification and mitigation of code-based threats, network-level risks, and potential exploits, fortifying the proposed framework against unauthorized access and malicious activities.

8.2 Future research scope

The future research scope for blockchain-enabled agri-food supply chains holds considerable promise for transforming the industry's dynamics. The findings vividly demonstrate the impactful influence of blockchain capabilities on agri-food supply chains. This opens up avenues for potential future studies to delve into the broader implications of blockchain on various supply chains beyond the agri-food sector. Such focused inquiries could yield valuable insights into the nuanced applications and benefits of blockchain technology across diverse industry domains. Therefore, a few of the future research directions are discussed below:

- The study recommends that researchers can extend their exploration and validation efforts to other regions within India and globally. Such endeavors would contribute to assessing the accuracy and applicability of the findings across diverse geographical contexts.
- The future research scope should extend its focus to encompass additional challenges in the agri-food supply chain, including but not limited to security and privacy concerns, technology adoption dynamics, and psychological challenges. A comprehensive exploration of these aspects will provide a more nuanced understanding of the diverse challenges inherent in the agri-food supply chain.
- The evolving landscape of blockchain applications will likely introduce new variables and considerations that influence user acceptance and adoption. Also, the UTAUT2 model will be used to comprehensively capture and analyze the multifaceted aspects shaping user behavior and acceptance in the dynamically evolving blockchain ecosystem after real use case implementation in agri-food supply chain industry.
- In the future, researchers can delve into advancing blockchain-based agri-food supply chain frameworks by using other blockchain, such as hyperledger and consortium. Future research studies could provide valuable insights into the comparative cost analysis of transactions within blockchain frameworks, contrasting them with existing models. Additionally, exploring more consensus mechanisms would contribute to the ongoing efforts to enhance scalability, reduce energy consumption, and improve overall

performance in blockchain networks. This comparative exploration can guide the selection of consensus mechanisms based on specific use cases, offering a nuanced understanding of the trade-offs between security, speed, and resource efficiency.

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Appendix

Appendix I

The agri-food supply chain has witnessed a transformation in the last few years with the emergence of Industry 4.0. Industry 4.0 contains various technologies such as blockchain, artificial intelligence, machine learning, robotics, cloud computing, and the Internet of Things. Among them, blockchain technology is considered to be a disruptive technology for the agri-food supply chain sector. Blockchain technology is the distributed ledger that stores a number of transactions in the form of blocks, which are immutable, transparent, more secure, and trusted by users. The integration of blockchain technology with the agriculture food supply chain can increase the trust and transparency between different stakeholders involved in the agriculture food supply chain management. RFID tags or sensor-based equipment would be attached to the products to automatically retrieve the information of products sold or bought from various organizations, and it is automatically saved in the blockchain platform, where users can check the overall history of the product. It helps to increase the income of farmers as they know everything about their production, which reduces the fraud rate. The traceability and transparency properties of blockchain will enhance product quality and customer satisfaction with buying products and decrease the intermediaries. This semi-structured interview is about finding out the capabilities of blockchain-enabled agri-food supply chains. The detailed response will aid us in gaining deep comprehension of the potential of blockchain technology in the agri-food supply chain and how it transforms the food industry which will, which will be purely applied for academic and research purposes. We request your response as much as elaborative, hence this study kept only nine questions in the survey.

Question no	**Question**
1	As part of a dynamic and regulatory compliance-driven industry, agriculture supply chains face considerable risks. What is your opinion on utilizing blockchain technology solutions in agri-food supply chains to minimize the security and quality of food risk?
2	How important do you realize the disruptive technology such as blockchain for improvement in the agri-food supply chain sector?

3	The agri-food supply chain industry is moving towards innovation. How do you see blockchain during this innovation?
4	One of the most common supply chain issues in the agriculture industry is the difficulty in tracing the food source from its origin to the market. What do you think if blockchain can provide traceable and transparent environment to each user of agri-food supply chain?
5	What do you think that blockchain technology would be able to reduce fraud and farmers would get the actual price of their product?
6	How important do you feel that blockchain technology can improve the agri-food supply chain and bring any change in the food business industry? Will blockchain capabilities motivate organizations to adopt blockchain?
7	Few companies have started implementing blockchain solutions in the supply chain after the COVID-19 disruption. What are your views on this development?
8	How can blockchain technology help in giving a better experience to consumers?
9	What is your opinion about the role of blockchain technology in reducing intermediaries and thereby reducing costs by ensuring minimal wastage?

Appendix II

A. Challenges faced in Agri-food Supply Chain Management						
A1. Economic challenges						
I.	Farmers are dependent on various stakeholders for the loan of agricultural practices rather than government organisations	1	2	3	4	5
II.	Farmers are not getting the actual price of the product due to the number of stakeholders in the Agri-food supply chain.	1	2	3	4	5
III.	Government helps the farmers economically and running many schemes to uplift them	1	2	3	4	5

IV.	Government has sufficient set up for the distribution channel to sell their production	1	2	3	4	5
V.	The government federation does not have sufficient money to develop warehousing activity for farmers	1	2	3	4	5
A2. Marketing challenges						
I.	People are not following the government regulations and incentives	1	2	3	4	5
II.	Existing agriculture infrastructure do not provide any traceability solutions in the supply chain to look forward or backward	1	2	3	4	5
III.	The governmental officials do not have any information or record regarding the supply of the production	1	2	3	4	5
IV.	Though Government procures the production of grain at appropriate time, still there is a mismanagement between various departments due to which the farmers do not get the actual value of their product	1	2	3	4	5
V.	Commission agents and intermediaries play an important role at the time of procurement to gain most of the profit	1	2	3	4	5
VI.	Farmers do not trust the government organisations for their well-being and business activities	1	2	3	4	5
A3. Technological challenges						
I.	Lack of awareness among people is one of the reasons to use new technologies	1	2	3	4	5
II.	Lack of trust in using new innovative technologies in the system	1	2	3	4	5
III.	Lack of compatibility of using new innovative technologies in the system	1	2	3	4	5

IV.	There exists a lack of technological Information & communication technology to benefit the agriculture infrastructure in Punjab	1	2	3	4	5
V.	The government officials are still using manual methods to handle the supply chain activities in the agriculture food-supply chain management	1	2	3	4	5
VI.	Billing system at the time of procurement is not computerized	1	2	3	4	5
VII.	There is no computer database record of the number of intermediaries involved in the supply of their production to the government	1	2	3	4	5
VIII.	The people are not aware of Indian agriculture apps such as AgriApp, Krishi Mitr, AgriMarket, SMARTCROP, DHAANMANDI to provide information and marketing produce	1	2	3	4	5

A. Basics of blockchain		
I.	Have you heard of the term "Blockchain Technology"	Not at all familiar ☐ Slightly similar ☐ Moderately familiar ☐ Very familiar ☐ Extremely familiar ☐
II.	Are you willing for the changes in the Agri-food Supply chain management	Yes No
III.	Are you prepared for this type of change of doing work in Agri-food supply chain sector	Yes No
IV.	Blockchain technology foresee any benefit to uplift your agriculture society	Yes No

B. General attitude towards the adoption of blockchain technology in agri-food supply chain						
B1. Performance expectancy (PE) shows the degree of using technology will provide benefit in performing certain activities						
I.	Integrating new technology in Agri-food supply chain can add value to the products and services	1	2	3	4	5
II.	Blockchain helps to view the demands and expectation of the customer needs.	1	2	3	4	5
III.	Blockchain technology helps to speeds up the processes and Agri-food supply chain models have been improved with the implementation of blockchain technology.	1	2	3	4	5
IV.	Blockchain technology eventually decreased the number of intermediaries in the agri-food supply chain	1	2	3	4	5
V.	Blockchain technology will enhance customer satisfaction in the Agri-food supply	1	2	3	4	5
VI.	Blockchain technology enhances the efficiency and overall productivity of agri-food supply chain management	1	2	3	4	5
B2. Social influence (SI) consider the perspective of important others (e.g. colleagues & family) that they should use a particular technology						
I.	Farmers are positively adopting the existing schemes of government in agriculture sector	1	2	3	4	5
II.	The government will support training and awareness seminars to encourage the adoption of such technologies.	1	2	3	4	5
III.	The opinion of other colleagues influences your behaviour in adopting blockchain technology	1	2	3	4	5
IV.	The integration of different farmers helps to solve the problems of existing supply chains	1	2	3	4	5

B3. Facilitating conditions (FC) shows the perception of the resource and support available to perform a particular task						
I.	There exist necessary resources to use blockchain in agri-food supply chain	1	2	3	4	5
II.	There is some helpline institute to help the users for using new advancements in agriculture sector	1	2	3	4	5
III.	Blockchain collaborate all the events in the supply chain management on single platform	1	2	3	4	5
IV.	After the success of Jan Dhan, Aadhar mobile scheme and now blockchain technology will also change the standards of agri-food supply chain management	1	2	3	4	5
B4. Effort expectancy (EE) reflects the degree of ease and effort in using technology						
I.	Learning how to use blockchain technology is easy and understandable	1	2	3	4	5
II.	It is easy to fix the errors or faults of the food supply chain	1	2	3	4	5
III.	It is helpful for the farmers to use blockchain technology to become more aware about the market value of their product	1	2	3	4	5
IV.	Government running any pilot project for blockchain technology	1	2	3	4	5
B5. Transparency (T)						
I.	Blockchain technology helps to improve the visibility in the agri-food supply chain process	1	2	3	4	5
II.	Blockchain technology can easily find the frauds in the supply chains	1	2	3	4	5
III.	Blockchain technology helps the user to see the whole information of actors involved in the agri-food supply chain	1	2	3	4	5

IV.	Number of stakeholders and government involved in the agriculture supply chain will see all the transactions involved from initial stage to end consumer	1	2	3	4	5
B6. Inter firm Trust (IT) is a characteristic that shows how people tends to believe of using technology						
I.	Blockchain technology helps to enhance communication with other firms	1	2	3	4	5
II.	Blockchain technology is trustworthy	1	2	3	4	5
III.	Blockchain technology helps to preserve the security and privacy of the information	1	2	3	4	5
B7. Behavioural intention (BI) reflects the extent to which people would adopt blockchain technology						
I.	You would intend to use the blockchain technology to increase the marketing of the produce	1	2	3	4	5
II.	You would likely to use blockchain technologies in the coming years	1	2	3	4	5
III.	You will plan to use blockchain technology in the food supply chain	1	2	3	4	5
IV.	South Indian states such as Kerala and Telangana are already adopting blockchain in the food supply distribution to reduce corruption so Punjab government should also adopt it	1	2	3	4	5
V.	Number of countries like Thailand, china, Japan are using blockchain based solutions for the traceability of food supply chain management, so India should also follow the same	1	2	3	4	5

Appendix III

ਪ੍ਰਸ਼ਨ

ਕਿਉਂਕਿ ਖੇਤੀਬਾੜੀ ਖੇਤਰ ਵਿਸ਼ਵ ਦੀ ਆਰਥਿਕਤਾ ਦਾ ਦਿਲ ਅਤੇ ਰੂਹ ਹੈ ਅਤੇ 60% ਤੋਂ ਵੱਧ ਆਬਾਦੀ ਉਨ੍ਹਾਂ ਦੇ ਬਚਾਅ ਲਈ ਖੇਤੀਬਾੜੀ 'ਤੇ ਨਿਰਭਰ ਹੈ. ਖੇਤੀਬਾੜੀ ਸੈਕਟਰ ਦੀ ਮਹੱਤਤਾ ਅਤੇ ਸਪਲਾਈ ਚੇਨ ਪ੍ਰਬੰਧਨ ਵਿੱਚ ਸ਼ਾਮਲ ਅਦਾਕਾਰਾਂ ਨੂੰ ਧਿਆਨ ਵਿੱਚ ਰੱਖਦਿਆਂ, ਇਹ ਪ੍ਰਸ਼ਨਾਵਲੀ ਮੌਜੂਦਾ ਪ੍ਰਣਾਲੀ ਵਿੱਚ ਦਰਪੇਸ਼ ਚੁਣੌਤੀਆਂ ਅਤੇ ਐਗਰੀ-ਫੂਡ ਸਪਲਾਈ ਚੇਨ ਮੈਨੇਜਮੈਂਟ ਵਿੱਚ ਬਲਾਕਚੈਨ ਟੈਕਨਾਲੋਜੀ ਨੂੰ ਅਪਣਾਉਣ ਪ੍ਰਤੀ ਰਵੱਈਏ ਬਾਰੇ ਤੁਹਾਡੀ ਰਿਪੋਰਟ ਨੂੰ ਦਰਸਾਉਂਦੀ ਹੈ। ਮੈਂ ਤੁਹਾਨੂੰ ਬੇਨਤੀ ਕਰਾਂਗਾ ਕਿ ਕਿਰਪਾ ਕਰਕੇ ਇਸ ਪ੍ਰਸ਼ਨਾਵਲੀ ਨੂੰ ਪੂਰਾ ਕਰਨ ਲਈ ਆਪਣਾ ਕੀਮਤੀ ਸਮਾਂ ਕੱ .ੋ. ਇਹ ਕੰਮ ਜ਼ਰੂਰ ਜਾਣਕਾਰੀ ਦੀ ਪੂਰੀ ਗੁਪਤਤਾ ਨੂੰ ਕਾਇਮ ਰੱਖੇਗਾ.

ਅਨੰਦਿਕਾ ਸ਼ਰਮਾ

(901810012)

ਖੋਜ ਵਿਦਵਾਨ

ਥਾਪਰ ਇੰਸਟੀਚਿ .ਟ ਆਫ਼ ਇੰਜੀਨੀਅਰਿੰਗ ਐਂਡ ਟੈਕਨੋਲੋਜੀ, ਪਟਿਆਲਾ, ਪੰਜਾਬ

ਭਾਗ -1

ਨਿਜੀ ਸੂਚਨਾ

1	ਉਹ ਖੇਤਰ ਜਿਸ ਨਾਲ ਤੁਸੀਂ ਸਬੰਧਤ ਹੋ	ਪਿੰਡ
		ਜ਼ਿਲ੍ਹਾ
2	ਨਾਮ:	
3	ਸਾਲਾਂ ਵਿੱਚ ਉਮਰ ਸਮੂਹ:	<20 ਸਾਲ ☐ 20-30 ਸਾਲ ☐ 35-50 ਸਾਲ ☐ > 50 ਸਾਲ ☐
4	ਲਿੰਗ:	
5	ਵਿੱਦਿਅਕ ਯੋਗਤਾ	ਮੈਟ੍ਰਿਕ ਮੈਟ੍ਰਿਕ ਦੇ ਤਹਿਤ ☐ ਬਾਰ੍ਹਵੀਂ ਗ੍ਰੈਜੂਏਸ਼ਨ ☐
6	ਸਾਲਾਨਾ ਆਮਦਨ	<ਲੱਖ ☐ 1-2 ਲੱਖ ☐ 2-3 ਲੱਖ ☐ > 3 ਲੱਖ ☐

7	ਤੁਹਾਡੇ ਸਮੇਤ ਖੇਤੀਬਾੜੀ 'ਤੇ ਨਿਰਭਰ ਪਰਿਵਾਰਕ ਮੈਂਬਰਾਂ ਦੀ ਸੰਖਿਆ		
8	ਭਾਵੇਂ ਤੁਸੀਂ ਆਪਣੀ ਜ਼ਮੀਨ ਜਾਂ ਕਿਰਾਏ ਦੀ ਜ਼ਮੀਨ 'ਤੇ ਖੇਤੀ ਕਰਦੇ ਹੋ		ਆਪਣੀ ਜ਼ਮੀਨ ☐ ਕਿਰਾਏ ਤੇ ਦਿੱਤੀ ਜ਼ਮੀਨ ☐
	8 (ਏ)	ਏਕੜ ਵਿਚ ਤੁਹਾਡੀ ਕਿੰਨੀ ਜ਼ਮੀਨ ਹੈ:	
	8(ਅ)	ਕਿੰਨੀ ਕਿਰਾਏ 'ਤੇ ਲਿਆਂਦੀ ਜ਼ਮੀਨ ਖੇਤੀ ਲਈ:	
	8(ਸੀ)	ਪ੍ਰਤੀ ਏਕੜ ਜ਼ਮੀਨ ਦਾ ਕਿਰਾਇਆ:	
9	ਕੀ ਤੁਹਾਡੇ ਕੋਲ ਖੇਤੀ ਤੋਂ ਇਲਾਵਾ ਕੋਈ ਆਮਦਨ ਦਾ ਸਰੋਤ ਹੈ?		ਹਾਂ ☐ ਨਹੀਂ ☐
10	ਤੁਸੀਂ ਆਪਣਾ ਉਤਪਾਦ ਕਿਸ ਨੂੰ ਵੇਚਦੇ ਹੋ		ਸਿੱਧੇ ਖਪਤਕਾਰਾਂ ਨੂੰ ☐ ਰਿਟੇਲਰ ☐ ਥੋਕ ਵਿਕਰੇਤਾ ☐ ਨਿਰਯਾਤ ਕਰਨ ਵਾਲੇ ☐ ਪ੍ਰੋਸੈਸਰ ☐ ਸਰਕਾਰੀ ਕਾਰਪੋਰੇਸ਼ਨ. ☐ ਵਿਚਾਲੇ ਦੁਆਰਾ ਵੇਚਣਾ ☐ ਹੋਰ (ਨਿਰਧਾਰਤ) ☐
11	ਖੇਤੀ ਲਈ ਕਰਜ਼ੇ ਦਾ ਸਰੋਤ		ਅਧਿਕਾਰਤ ☐ ਅਣਅਧਿਕਾਰਤ ☐ ਲਾਗੂ ਨਹੀਂ ਹੈ ☐
	10 (ਏ)	ਜੇ ਅਧਿਕਾਰਤ ਹਨ ਤਾਂ ਬੈਂਕ ਦਾ ਨਾਮ ਜਿੱਥੋਂ ਤੁਸੀਂ ਕਰਜ਼ਾ ਦਿੰਦੇ ਹੋ	

ਭਾਗ-2

ਕਿਰਪਾ ਕਰਕੇ ਇਸ ਗੱਲ ਦਾ ਸੰਕੇਤ ਕਰੋ ਕਿ ਹਰੇਕ ਬਿਆਨ ਖੇਤੀ-ਭੋਜਨ ਸਪਲਾਈ ਚੇਨ ਪ੍ਰਬੰਧਨ ਵਿੱਚ ਕਿਸਾਨੀ ਨੂੰ ਦਰਪੇਸ਼ ਚੁਣੌਤੀਆਂ ਦਾ ਵਰਣਨ ਕਰਦਾ ਹੈ.

5 = ਜ਼ੋਰਦਾਰ ਸਹਿਮਤ ; 4 = ਸਹਿਮਤ ; 3 = ਨਿਰਪੱਖ; 2 = ਅਸਹਿਮਤ ; 1 = ਜ਼ੋਰਦਾਰ ਅਸਹਿਮਤ

ਏ. ਮੌਜੂਦਾ ਖੇਤੀ-ਖੁਰਾਕ ਸਪਲਾਈ ਲੜੀ ਵਿਚ ਕਿਸਾਨੀ ਦਾ ਸਾਹਮਣਾ ਕਰਨਾ					
ਏ1. ਆਰਥਿਕ ਚੁਣੌਤੀਆਂ					
I.ਐਗਰੀ-ਫੂਡ ਸਪਲਾਈ ਚੇਨ ਵਿਚ ਵੱਖ-ਵੱਖ ਹਿੱਸੇਦਾਰਾਂ ਨੂੰ ਅਸਮਾਨ ਕੀਮਤਾਂ ਦੀ ਵੰਡ ਹੁੰਦੀ ਹੈ	1	2	3	4	5
II.ਐਗਰੀ-ਫੂਡ ਸਪਲਾਈ ਚੇਨ ਵਿਚ ਹਿੱਸੇਦਾਰਾਂ ਦੀ ਗਿਣਤੀ ਕਾਰਨ ਕਿਸਾਨਾਂ ਨੂੰ ਉਤਪਾਦ ਦਾ ਅਸਲ ਮੁੱਲ ਨਹੀਂ ਮਿਲ ਰਿਹਾ.	1	2	3	4	5
III.ਹਿੱਸੇਦਾਰਾਂ ਨੇ ਨਕਲੀ ਉਤਪਾਦਾਂ ਨੂੰ ਉਤਪਾਦ ਦੀ ਅਸਲ ਕੀਮਤ ਨੂੰ ਘਟਾਉਣ ਲਈ ਮਾਰਕੀਟ ਵਿੱਚ ਪਹੁੰਚਾ ਦਿੱਤਾ.	1	2	3	4	5
IV.ਸਰਕਾਰੀ ਸਬਸਿਡੀਆਂ ਕਿਸਾਨਾਂ ਨੂੰ ਬਰਾਬਰ ਵੰਡੀਆਂ ਨਹੀਂ ਜਾਂਦੀਆਂ	1	2	3	4	5
V.ਕਿਸਾਨ ਆਪਣੀ ਫਸਲ ਦੀ ਮਾਰਕੀਟ ਕੀਮਤ ਤੈਅ ਕਰਨ ਲਈ ਸੁਤੰਤਰ ਨਹੀਂ ਹਨ	1	2	3	4	5
VI.ਮਾਰਕੀਟਿੰਗ ਦੇ ਕਮਿਸ਼ਨ ਏਜੰਟ ਕਿਸਾਨਾਂ ਲਈ ਖ਼ਤਰਨਾਕ ਹਨ ਕਿਉਂਕਿ ਉਹ ਉਤਪਾਦਾਂ ਦੀ ਅਸਲ ਕੀਮਤ ਨੂੰ ਘਟਾਉਂਦੇ ਹਨ ਅਤੇ ਆਪਣੀ ਆਮਦਨੀ ਦਾ ਬਹੁਤ ਜ਼ਿਆਦਾ ਲਾਭ ਲੈਂਦੇ ਹਨ	1	2	3	4	5
ਏ2. ਮਾਰਕੀਟਿੰਗ ਚੁਣੌਤੀਆਂ					
I.ਖੇਤੀ ਉਤਪਾਦਾਂ ਦੀ ਮਾਰਕੀਟਿੰਗ ਪ੍ਰਕਿਰਿਆ ਗੁੰਝਲਦਾਰ ਅਤੇ ਮੁਸ਼ਕਲ ਹੈ ਕਿਉਂਕਿ ਇਸ ਪ੍ਰਕ੍ਰਿਆ ਵਿਚ ਸ਼ਾਮਲ ਹਿੱਸੇਦਾਰਾਂ ਦੀ ਗਿਣਤੀ	1	2	3	4	5
II.ਉਨ੍ਹਾਂ ਵਿਚਕਾਰ ਹੋਏ ਸੌਦਿਆਂ ਨੂੰ ਜਾਣਨ ਲਈ ਵੱਖੋ ਵੱਖਰੇ ਹਿੱਸੇਦਾਰਾਂ ਵਿਚਕਾਰ ਜਾਣਕਾਰੀ ਸਾਂਝੇ ਕਰਨ ਦੀ ਘਾਟ ਹੈ	1	2	3	4	5
III.ਪਿਛਲੇ ਸਾਲਾਂ ਤੋਂ ਸਰਕਾਰੀ ਸਕੀਮਾਂ ਨੂੰ ਅਪਣਾਉਣ ਤੋਂ ਬਾਅਦ ਕਿਸਾਨਾਂ ਦੀ ਆਮਦਨ ਵਿੱਚ ਵਾਧਾ ਨਹੀਂ ਹੋਇਆ ਸੀ	1	2	3	4	5
IV.ਐਗਰੀ ਫੂਡ ਸਪਲਾਈ ਚੇਨ ਵਿਚ ਵੱਖ-ਵੱਖ ਅਦਾਕਾਰਾਂ ਦੁਆਰਾ ਕੀਤੇ ਗਏ ਵੱਖ-ਵੱਖ ਸੌਦਿਆਂ ਵਿਚ ਪਾਰਦਰਸ਼ਤਾ ਦੀ ਘਾਟ ਹੈ	1	2	3	4	5

V.ਸਪਲਾਈ ਲੜੀ ਦੇ ਪ੍ਰਬੰਧਨ ਵਿਚ ਉਤਪਾਦ ਦੀ ਅਸਲ ਕੀਮਤ ਅਤੇ ਸਥਾਨ ਦਾ ਪਤਾ ਲਗਾਉਣ ਲਈ ਕੋਈ ਟਰੇਸਬਿਲਟੀ ਹੱਲ ਮੌਜੂਦ ਨਹੀਂ ਹੈ ਜਿੱਥੇ ਇਹ ਵੇਚਣਾ ਹੈ	1	2	3	4	5
VI.ਖੇਤਰਾਂ ਵਿੱਚ ਸੁਵਿਧਾ ਕੇਂਦਰ ਖੇਤੀ-ਭੋਜਨ ਸਪਲਾਈ ਚੇਨ ਪ੍ਰਬੰਧਨ ਨਾਲ ਸਬੰਧਤ ਉਨ੍ਹਾਂ ਦੇ ਸਵਾਲਾਂ ਲਈ ਕਿਸਾਨਾਂ ਦੀ ਸਹਾਇਤਾ ਨਹੀਂ ਕਰਦਾ	1	2	3	4	5
ਏ3 . Techn ological ਚੁਣੌਤੀ					
I.ਪਿਛਲੇ ਕੁਝ ਸਾਲਾਂ ਤੋਂ ਸੂਚਨਾ ਅਤੇ ਸੰਚਾਰ ਟੈਕਨਾਲੋਜੀ ਨੇ ਖੇਤੀਬਾੜੀ ਦੇ ਤਰੀਕਿਆਂ ਨੂੰ ਕੋਈ ਲਾਭ ਨਹੀਂ ਦਿੱਤਾ ਸੀ	1	2	3	4	5
II.ਸੀਮਤ ਸਰੋਤਾਂ ਅਤੇ ਤਕਨੀਕੀ ਸਾਧਨਾਂ ਕਾਰਨ ਕਿਸਾਨ ਤਕਨੀਕੀ ਕਾ innovਾਂ ਨੂੰ ਅਪਣਾਉਣ ਤੋਂ ਅਸਮਰੱਥ ਹਨ	1	2	3	4	5
III.ਜਾਗਰੂਕਤਾ ਅਤੇ ਦੀ ਘਾਟ ਪਹੁੰਚ ਕਰਨ ਲਈ ਗਿਆਨ ਸਮਾਰਟ ਫੋਨ , ਨਵ ਤਕਨਾਲੋਜੀ ਅਤੇ ਤਕਨੀਕੀ ਵਿਕਾਸ ਮੌਜੂਦ ਹਨ ਖੇਤੀਬਾੜੀ ਖੇਤਰ ਵਿੱਚ	1	2	3	4	5
IV.ਫਸਲਾਂ ਅਤੇ ਬੀਜਾਂ ਦੀ ਵਿਕਰੀ ਅਤੇ ਖਰੀਦ ਲਈ platformਨਲਾਈਨ ਪਲੇਟਫਾਰਮ ਦੀ ਇਕ ਰਕਮ ਕਿਸਾਨਾਂ ਦੁਆਰਾ ਨਹੀਂ ਵਰਤੀ ਜਾਂਦੀ	1	2	3	4	5
V.ਕੁਝ ਖੇਤਰ ਅਜਿਹੇ ਹਨ ਜਿਨ੍ਹਾਂ ਕੋਲ ਖੇਤੀਬਾੜੀ ਦੇ ਖੇਤਰ ਵਿੱਚ ਤਕਨੀਕੀ ਤਰੱਕੀ ਦਾ ਸਵਾਗਤ ਕਰਨ ਲਈ ਇੰਟਰਨੈਟ ਦੀ ਸਹੂਲਤ ਨਹੀਂ ਹੈ	1	2	3	4	5
VI.ਭਾਰਤੀ ਖੇਤੀਬਾੜੀ ਦੇ ਐਪਸ ਜਿਵੇਂ ਕਿ ਐਗਰੀ ਐਪ, ਕ੍ਰਿਸ਼ੀ ਮਿੱਤਰ, ਖੇਤੀਬਾੜੀ, ਸਮਾਰਟਕ੍ਰੋਪ, ਧਨਮੰਡੀ, ਜਾਣਕਾਰੀ ਅਤੇ ਮੰਡੀਕਰਨ ਉਤਪਾਦ ਮੁਹੱਈਆ ਕਰਵਾਉਣ ਲਈ ਕਿਸਾਨ ਜਾਣੂ ਨਹੀਂ ਹਨ	1	2	3	4	5

ਭਾਗ-3

(ਕੀ ਸਾਡੀ ਸੋਸਾਇਟੀਨਮ ਬਲਾਕਚੇਨ ਟੈਕਨੋਲੋਜੀ ਲਈ ਤਿਆਰ ਹੈ?)

ਬਲਾਕਚੇਨ ਟੈਕਨੋਲੋਜੀ ਬਲਾਕਾਂ ਦੇ ਰੂਪ ਵਿੱਚ ਕਈ ਟ੍ਰਾਂਜੈਕਸ਼ਨਾਂ ਨੂੰ ਸਟੋਰ ਕਰਨ ਲਈ ਇੱਕ ਵੰਡਿਆ ਹੋਇਆ ਖਾਕਾ ਹੈ, ਜੋ ਉਪਭੋਗਤਾਵਾਂ ਦੁਆਰਾ ਨਿਰਬਲ, ਪਾਰਦਰਸ਼ੀ, ਵਧੇਰੇ ਸੁਰੱਖਿਅਤ ਅਤੇ ਭਰੋਸੇਮੰਦ ਹੈ. ਖੇਤੀਬਾੜੀ ਖੁਰਾਕ ਸਪਲਾਈ ਚੇਨ ਦੇ ਨਾਲ ਬਲਾਕਚੈਨ ਤਕਨਾਲੋਜੀ

ਦਾ ਏਕੀਕਰਣ ਖੇਤੀਬਾੜੀ ਖੁਰਾਕ ਸਪਲਾਈ ਚੇਨ ਪ੍ਰਬੰਧਨ ਵਿਚ ਸ਼ਾਮਲ ਵੱਖੋ ਵੱਖ ਹਿੱਸੇਦਾਰਾਂ ਵਿਚ ਵਿਸ਼ਵਾਸ ਅਤੇ ਪਾਰਦਰਸ਼ਤਾ ਨੂੰ ਵਧਾ ਸਕਦਾ ਹੈ. RFID ਟੈਗ ਜ ਸੂਚਕ ਅਧਾਰਿਤ ਸਾਜ਼ੋ-ਆਪ ਹੀ ਕਰਨ ਲਈ ਉਤਪਾਦ ਨਾਲ ਜੁੜੇ ਕੀਤਾ ਜਾਵੇਗਾ ਵੇਚ ਉਤਪਾਦ ਦੀ ਜਾਣਕਾਰੀ ਪ੍ਰਾਪਤ ਜ ਵੱਖ-ਵੱਖ ਸੰਗਠਨ ਤੱਕ ਖਰੀਦਣ ਹੈ ਅਤੇ ਇਸ ਨੂੰ ਕੀਤਾ ਜਾਵੇਗਾ ਆਪ ਹੀ blockchain ਪਲੇਟਫਾਰਮ ਵਿੱਚ ਸੁਰੱਖਿਅਤ ਹੈ, ਜੋ ਕਿ ਇਸ ਲਈ u ਉਤਪਾਦ ਦੇ ਸਮੁੱਚੇ ਇਤਿਹਾਸ ਨੂੰ ਚੈੱਕ ਕਰ ਸਕਦਾ ਹੈ. ਇਹ ਕਿਸਾਨਾਂ ਦੀ ਅਯੋਗਤਾ ਨੂੰ ਵਧਾਉਣ ਵਿਚ ਸਹਾਇਤਾ ਕਰਦਾ ਹੈ ਕਿਉਂਕਿ ਉਹ ਉਨ੍ਹਾਂ ਦੇ ਉਤਪਾਦਨ ਬਾਰੇ ਸਭ ਕੁਝ ਜਾਣਦੇ ਹਨ ਜੋ ਧੋਖਾਧੜੀ ਦੀ ਦਰ ਨੂੰ ਘਟਾਉਂਦੇ ਹਨ . ਬਲਾਕਚੇਨ ਦੀ ਟਰੇਸਿਲਿਟੀ ਅਤੇ ਪਾਰਦਰਸ਼ਤਾ ਜਾਇਦਾਦ ਉਤਪਾਦ ਦੀ ਗੁਣਵੱਤਾ, ਉਤਪਾਦ ਖਰੀਦਣ ਪ੍ਰਤੀ ਗਾਹਕਾਂ ਦੀ ਸੰਤੁਸ਼ਟੀ ਅਤੇ ਵੱਖੋ ਵੱਖਰੇ ਦਰਮਿਆਨੀਆਂ ਵਿਚਕਾਰ ਧੋਖਾਧੜੀ ਨੂੰ ਘਟਾਏਗੀ. ਇਸ ਲਈ ਮੈਂ ਖੇਤੀਬਾੜੀ ਸਪਲਾਈ ਚੇਨ ਵਿਚ ਤਕਨੀਕੀ ਤਰੱਕੀ ਦੀ ਵਰਤੋਂ ਬਾਰੇ ਤੁਹਾਡੀ ਰਾਏ ਲੈਣਾ ਚਾਹੁੰਦਾ ਹਾਂ ਅਤੇ ਖੇਤੀਬਾੜੀ ਖੁਰਾਕ ਸਪਲਾਈ ਚੇਨ ਪ੍ਰਬੰਧਨ ਵਿਚ ਤੁਸੀਂ ਬਲਾਕਚੈਨ ਤਕਨਾਲੋਜੀ ਦਾ ਕਿਵੇਂ ਸਵਾਗਤ ਕਰਦੇ ਹੋ.

ਏ. ਬਲਾਕਚੇਨ ਦੀ ਬੁਨਿਆਦ	
I.ਕੀ ਤੁਸੀਂ "ਬਲਾਕਚੇਨ ਟੈਕਨੋਲੋਜੀ" ਸ਼ਬਦ ਸੁਣਿਆ ਹੈ?	ਬਿਲਕੁਲ ਵੀ ਜਾਣੂ ਨਹੀਂ ☐ ਥੋੜ੍ਹਾ ਜਿਹਾ ਸਮਾਨ ☐ ਥੋੜੀ ਜਾਣੂ ☐ ਬਹੁਤ ਜਾਣੂ ☐ ਬਹੁਤ ਜਾਣੂ ☐
II.ਕੀ ਤੁਸੀਂ ਐਗਰੀ-ਫੂਡ ਸਪਲਾਈ ਚੇਨ ਮੈਨੇਜਮੈਂਟ ਵਿਚ ਤਬਦੀਲੀਆਂ ਲਈ ਤਿਆਰ ਹੋ?	ਹਾਂ ☐ ਨਹੀਂ ☐
III.ਆਰ ਈ ਤੁਸੀਂ ਐਗਰੀ-ਫੂਡ ਸਪਲਾਈ ਚੇਨ ਸੈਕਟਰ ਵਿਚ ਕੰਮ ਕਰਨ ਦੀ ਇਸ ਕਿਸਮ ਦੀ ਤਬਦੀਲੀ ਲਈ ਤਿਆਰ ਕੀਤਾ ਹੈ	ਹਾਂ ☐ ਨਹੀਂ ☐
IV.ਬਲਾਕਚੇਨ ਤਕਨਾਲੋਜੀ ਤੁਹਾਡੇ ਖੇਤੀਬਾੜੀ ਸਮਾਜ ਨੂੰ ਉੱਚਾ ਚੁੱਕਣ ਲਈ ਕਿਸੇ ਵੀ ਲਾਭ ਦੀ ਉਮੀਦ ਰੱਖਦੀ ਹੈ	ਹਾਂ ☐ ਨਹੀਂ ☐
ਬੀ. ਖੇਤੀ-ਭੋਜਨ ਸਪਲਾਈ ਲੜੀ ਵਿਚ ਬਲਾਕਚੈਨ ਟੈਕਨੋਲੋਜੀ ਨੂੰ ਅਪਨਾਉਣ ਪ੍ਰਤੀ ਆਮ ਤੌਰ 'ਤੇ ਇਕ ਝੁਕਾਅ	
ਬੀ1. ਪ੍ਰਦਰਸ਼ਨ ਦੀ ਉਮੀਦ (ਪੀਈ) ਦੱਸਦੀ ਹੈ ਕਿ ਤਕਨਾਲੋਜੀ ਦੀ ਵਰਤੋਂ ਕਰਨ ਦੀ ਡਿਗਰੀ ਕੁਝ ਗਤੀਵਿਧੀਆਂ ਕਰਨ ਵਿਚ ਲਾਭ ਪ੍ਰਦਾਨ ਕਰੇਗੀ	

I.ਐਗਰੀ-ਫੂਡ ਚੇਨ ਸਪਲਾਈ ਵਿਚ ਨਵੀਂ ਟੈਕਨਾਲੋਜੀ ਨੂੰ ਏਕੀਕ੍ਰਿਤ ਕਰਨਾ ਉਤਪਾਦਾਂ ਅਤੇ ਸੇਵਾਵਾਂ ਵਿਚ ਮਹੱਤਵ ਵਧਾ ਸਕਦਾ ਹੈ	1 2 3 4 5
II.ਬਲਾਕਚੇਨ ਗਾਹਕ ਦੀਆਂ ਜ਼ਰੂਰਤਾਂ ਦੀਆਂ ਮੰਗਾਂ ਅਤੇ ਉਮੀਦਾਂ ਨੂੰ ਵੇਖਣ ਵਿੱਚ ਸਹਾਇਤਾ ਕਰਦਾ ਹੈ.	1 2 3 4 5
III.ਬਲਾਕਚੇਨ ਟੈਕਨੋਲੋਜੀ ਐਗਰੀ-ਫੂਡ ਸਪਲਾਈ ਚੇਨ ਮੈਨੇਜਮੈਂਟ ਵਿਚ ਪ੍ਰਕਿਰਿਆ ਨੂੰ ਤੇਜ਼ ਕਰਨ ਵਿਚ ਸਹਾਇਤਾ ਕਰਦੀ ਹੈ	1 2 3 4 5
IV.ਬਲਾਕਚੇਨ ਟੈਕਨੋਲੋਜੀ ਐਗਰੀ-ਫੂਡ ਸਪਲਾਈ ਚੇਨ ਵਿਚ ਗਾਹਕਾਂ ਦੀ ਸੰਤੁਸ਼ਟੀ ਨੂੰ ਵਧਾਏਗੀ	1 2 3 4 5
V.ਬਲਾਕਚੇਨ ਤਕਨਾਲੋਜੀ ਖੇਤੀ-ਭੋਜਨ ਸਪਲਾਈ ਲੜੀ ਦੀਆਂ ਪ੍ਰਕਿਰਿਆਵਾਂ ਦੀ ਸਮੁੱਚੀ ਉਤਪਾਦਕਤਾ ਅਤੇ ਕੁਸ਼ਲਤਾ ਨੂੰ ਵਧਾਉਂਦੀ ਹੈ	1 2 3 4 5
ਬੀ2. ਸਮਾਜਿਕ ਪ੍ਰਭਾਵ (ਐਸਆਈ) ਮਹੱਤਵਪੂਰਣ ਦੂਜਿਆਂ (ਜਿਵੇਂ ਕਿ ਸਹਿਯੋਗੀ ਅਤੇ ਪਰਿਵਾਰ) ਦੇ ਨਜ਼ਰੀਏ 'ਤੇ ਵਿਚਾਰ ਕਰਦਾ ਹੈ ਕਿ ਉਨ੍ਹਾਂ ਨੂੰ ਇਕ ਵਿਸ਼ੇਸ਼ ਟੈਕਨਾਲੋਜੀ ਦੀ ਵਰਤੋਂ ਕਰਨੀ ਚਾਹੀਦੀ ਹੈ	
I.ਕਿਸਾਨ ਖੇਤੀਬਾੜੀ ਸੈਕਟਰ ਵਿੱਚ ਸਰਕਾਰ ਦੀਆਂ ਮੌਜੂਦਾ ਸਕੀਮਾਂ ਨੂੰ ਸਕਾਰਾਤਮਕ .ੰਗ ਨਾਲ ਅਪਣਾ ਰਹੇ ਹਨ	1 2 3 4 5
II.ਖੇਤੀਬਾੜੀ ਖੋਜ ਮਾਹਰ ਸੋਚਦੇ ਹਨ ਕਿ ਖੇਤੀਬਾੜੀ ਖੇਤਰ ਤਕਨੀਕੀ ਕਾ innovਾਂ ਵਰਤ ਕੇ ਬਿਹਤਰ ਬਣਦਾ ਹੈ, ਉਹਨਾਂ ਦੀ ਰਾਇ ਪ੍ਰਭਾਵ ਕਿਵੇਂ ਤੁਹਾਡੇ ਵਿਵਹਾਰ ਨੂੰ ਬਦਲਦੀ ਹੈ	1 2 3 4 5
III.ਲੋਕ ਨਵੀਆਂ ਟੈਕਨਾਲੋਜੀਆਂ ਨੂੰ ਅਪਨਾਉਣ ਲਈ ਪਹਿਲਕਦਮੀਆਂ ਜਾਂ ਸਿਖਲਾਈ ਪ੍ਰੋਗਰਾਮਾਂ ਦਾ ਸਮਰਥਨ ਕਰਨਗੇ	1 2 3 4 5
IV.ਵੱਖ-ਵੱਖ ਕਿਸਾਨਾਂ ਦੇ ਸਹਿਯੋਗ ਨਾਲ ਖੇਤੀਬਾੜੀ ਨਾਲ ਸਬੰਧਤ ਸਮੱਸਿਆਵਾਂ ਨੂੰ ਹੱਲ ਕਰਨ ਵਿੱਚ ਸਹਾਇਤਾ ਮਿਲਦੀ ਹੈ	1 2 3 4 5
ਬੀ3. ਸੁਵਿਧਾਜਨਕ ਹਾਲਤਾਂ (ਐਫਸੀ) ਕਿਸੇ ਖਾਸ ਕੰਮ ਨੂੰ ਕਰਨ ਲਈ ਉਪਲਬਧ ਸਰੋਤਾਂ ਅਤੇ ਸਹਾਇਤਾ ਦੀ ਧਾਰਨਾ ਨੂੰ ਦਰਸਾਉਂਦੀ ਹੈ	
I.ਉੱਥੇ ਮੌਜੂਦ ਹਵਾਈਅੱਡੇ ਜ਼ਰੂਰੀ ਸਰੋਤ ਐਗਰੀ-ਫੂਡ ਸਪਲਾਈ ਚੇਨ ਦੇ blockchain ਵਰਤਣ ਲਈ	1 2 3 4 5

II.ਖੇਤੀਬਾੜੀ ਸੈਕਟਰ ਵਿਚ ਨਵੀਆਂ ਤਰੱਕੀ ਦੀ ਵਰਤੋਂ ਕਰਨ ਵਿਚ ਤੁਹਾਡੀ ਮਦਦ ਕਰਨ ਲਈ ਇਕ ਹੈਲਪਲਾਈਨ ਸੰਸਥਾ ਹੈ	1 | 2 | 3 | 4 | 5
III.ਬਲਾਕਚੇਨ ਤਕਨਾਲੋਜੀ ਖੇਤੀ-ਖੁਰਾਕ ਸਪਲਾਈ ਚੇਨ ਨੂੰ ਟਰੈਕ ਕਰਨ ਲਈ ਕਿਸੇ ਵੀ ਹੋਰ ਤਕਨਾਲੋਜੀ ਦੇ ਮੁਕਾਬਲੇ ਅਨੁਕੂਲ ਹੈ	1 | 2 | 3 | 4 | 5
IV.ਲੋਕ ਉਤਪਾਦਾਂ ਦੀ ਮਾਰਕੀਟਿੰਗ ਲਈ ਉਪਲਬਧ ਨਵੇਂ ਪਲੇਟਫਾਰਮ ਦੀ ਵਰਤੋਂ ਕਰਨ ਵੱਲ ਧਿਆਨ ਦੇਣਗੇ	1 | 2 | 3 | 4 | 5
V.ਲੋਕ ਪ੍ਰਣਾਲੀ ਅਤੇ ਤਕਨਾਲੋਜੀ ਵਿੱਚ ਪੂੰਜੀ ਨਿਵੇਸ਼ ਦਾ ਸਮਰਥਨ ਕਰਦੇ ਹਨ	1 | 2 | 3 | 4 | 5
ਬੀ4. ਕੋਸ਼ਿਸ਼ ਦੀ ਉਮੀਦ (ਈਈ) ਤਕਨਾਲੋਜੀ ਦੀ ਵਰਤੋਂ ਵਿਚ ਅਸਾਨਤਾ ਅਤੇ ਕੋਸ਼ਿਸ਼ ਦੀ ਡਿਗਰੀ ਨੂੰ ਦਰਸਾਉਂਦੀ ਹੈ	
I.ਬਲਾਕਚੇਨ ਤਕਨਾਲੋਜੀ ਦੀ ਵਰਤੋਂ ਕਿਵੇਂ ਕਰਨੀ ਹੈ ਇਸ ਬਾਰੇ ਸਿੱਖਣਾ ਆਸਾਨ ਹੈ	1 | 2 | 3 | 4 | 5
II.ਇਹ ਕਾਬਲ ਬਣਨ ਲਈ ਬਲਾਕਚੈਨ ਦੀ ਵਰਤੋਂ ਕਰਨਾ ਕਿਸਾਨਾਂ ਲਈ ਮਦਦਗਾਰ ਹੈ	1 | 2 | 3 | 4 | 5
III.ਬਲਾਕਚੇਨ ਟੈਕਨੋਲੋਜੀ ਐਗਰੀ-ਫੂਡ ਸਪਲਾਈ ਚੇਨ ਦੀ ਸਾਰੀ ਜਾਣਕਾਰੀ ਤੱਕ ਪਹੁੰਚ ਪ੍ਰਾਪਤ ਕਰਨ ਵਿੱਚ ਸਹਾਇਤਾ ਕਰਦੀ ਹੈ	1 | 2 | 3 | 4 | 5
IV.ਸਿਖਲਾਈ ਪ੍ਰੋਗਰਾਮ ਬਲਾਕਚੇਨ ਟੈਕਨੋਲੋਜੀ ਦੀ ਵਰਤੋਂ ਸਿੱਖਣ ਵਿਚ ਸਹਾਇਤਾ ਕਰਨਗੇ	1 | 2 | 3 | 4 | 5
V.ਇਹ ਭੋਜਨ ਸਪਲਾਈ ਲੜੀ ਦੀਆਂ ਗਲਤੀਆਂ ਜਾਂ ਨੁਕਸ ਦੂਰ ਕਰਨ ਵਿੱਚ ਸਹਾਇਤਾ ਕਰਦਾ ਹੈ	1 | 2 | 3 | 4 | 5
ਬੀ5. ਪਾਰਦਰਸ਼ਤਾ (ਟੀ)	
I.ਬਲਾਕਚੇਨ ਟੈਕਨੋਲੋਜੀ ਖੇਤੀ-ਭੋਜਨ ਸਪਲਾਈ ਲੜੀ ਵਿਚ ਦਿੱਖ ਨੂੰ ਬਿਹਤਰ ਬਣਾਉਣ ਵਿਚ ਸਹਾਇਤਾ ਕਰਦੀ ਹੈ	1 | 2 | 3 | 4 | 5
II.ਬਲਾਕਚੇਨ ਤਕਨਾਲੋਜੀ ਸਪਲਾਈ ਚੇਨ ਵਿਚਲੀਆਂ ਧੋਖਾਧੜੀ ਨੂੰ ਅਸਾਨੀ ਨਾਲ ਲੱਭ ਸਕਦੀ ਹੈ	1 | 2 | 3 | 4 | 5
III.ਵੱਖ ਵੱਖ ਸੰਸਥਾਵਾਂ ਸੁਤੰਤਰ ਅਤੇ ਪਾਰਦਰਸ਼ੀ otherੰਗ ਨਾਲ ਦੂਜੀ ਸੰਸਥਾ ਨਾਲ ਨਜਿੱਠ ਸਕਦੀਆਂ ਹਨ	1 | 2 | 3 | 4 | 5

IV.ਸਪਲਾਈ ਲੜੀ ਦੇ ਵੱਖ ਵੱਖ ਹਿੱਸੇਦਾਰ ਅੰਤ ਤੋਂ ਅੰਤ ਤੱਕ ਸਾਰੀ ਜਾਣਕਾਰੀ ਨੂੰ ਟਰੈਕ ਕਰਨਗੇ	1 2 3 4 5
ਬੀ6. ਇੰਟਰ ਫਰਮ ਟਰੱਸਟ (ਆਈ ਟੀ) ਇਕ ਵਿਸ਼ੇਸ਼ਤਾ ਹੈ ਜੋ ਦਰਸਾਉਂਦੀ ਹੈ ਕਿ ਕਿਵੇਂ ਲੋਕ ਤਕਨਾਲੋਜੀ ਦੀ ਵਰਤੋਂ ਕਰਨ ਵਿਚ ਵਿਸ਼ਵਾਸ ਕਰਦੇ ਹਨ	
I.ਬਲਾਕਚੇਨ ਟੈਕਨੋਲੋਜੀ ਹੋਰਨਾਂ ਫਰਮਾਂ ਨਾਲ ਸੰਚਾਰ ਵਧਾਉਣ ਵਿੱਚ ਸਹਾਇਤਾ ਕਰਦੀ ਹੈ	1 2 3 4 5
II.ਬੀ ਲਾਕਚੈਨ ਤਕਨਾਲੋਜੀ ਭਰੋਸੇਯੋਗ ਹੈ	1 2 3 4 5
III.ਬਲਾਕਚੇਨ ਤਕਨਾਲੋਜੀ ਜਾਣਕਾਰੀ ਦੀ ਸੁਰੱਖਿਆ ਅਤੇ ਗੋਪਨੀਯਤਾ ਨੂੰ ਸੁਰੱਖਿਅਤ ਰੱਖਣ ਵਿੱਚ ਸਹਾਇਤਾ ਕਰਦੀ ਹੈ	1 2 3 4 5
IV.ਐਗਰੀ-ਫੂਡ ਸਪਲਾਈ ਚੇਨ ਦੇ ਨਾਲ ਬਲਾਕਚੈਨ ਟੈਕਨੋਲੋਜੀ ਦਾ ਏਕੀਕਰਣ ਵੱਖ-ਵੱਖ ਪਾਰਟੀਆਂ ਦੇ ਵਿਚਕਾਰ ਜਾਣਕਾਰੀ ਦੇ ਪ੍ਰਵਾਹ ਨੂੰ ਵਧਾ ਸਕਦਾ ਹੈ	1 2 3 4 5
ਬੀ7. ਵਿਵਹਾਰਕ ਤਵੱਜੋ (ਬੀ ਆਈ) ਇਸ ਹੱਦ ਨੂੰ ਦਰਸਾਉਂਦੀ ਹੈ ਕਿ ਲੋਕ ਕਿਸ ਤਰ੍ਹਾਂ ਬਲਾਕਚੈਨ ਤਕਨਾਲੋਜੀ ਨੂੰ ਅਪਣਾਉਣਗੇ	
I.ਲੋਕ ਖੇਤੀਬਾੜੀ ਸਪਲਾਈ ਚੇਨ ਮੈਨੇਜਮੈਂਟ ਵਿੱਚ ਬਲਾਕਚੈਨ ਦਾ ਸਵਾਗਤ ਕਰਨਗੇ	1 2 3 4 5
II.ਉਤਪਾਦਨ ਦੀ ਮਾਰਕੀਟਿੰਗ ਨੂੰ ਵਧਾਉਣ ਲਈ ਤੁਸੀਂ ਬਲਾਕਚੇਨ ਤਕਨਾਲੋਜੀ ਦੀ ਵਰਤੋਂ ਕਰਨਾ ਚਾਹੋਗੇ	1 2 3 4 5
III.ਤੁਸੀਂ ਆਉਣ ਵਾਲੇ ਸਾਲਾਂ ਵਿੱਚ ਬਲਾਕਚੈਨ ਤਕਨਾਲੋਜੀਆਂ ਦੀ ਵਰਤੋਂ ਕਰਨ ਦੀ ਸੰਭਾਵਨਾ ਕਰੋਗੇ	1 2 3 4 5
IV.ਤੁਸੀਂ ਫੂਡ ਸਪਲਾਈ ਚੇਨ ਵਿਚ ਬਲਾਕਚੇਨ ਟੈਕਨੋਲੋਜੀ ਦੀ ਵਰਤੋਂ ਕਰਨ ਦੀ ਯੋਜਨਾ ਬਣਾਓਗੇ	1 2 3 4 5
V.ਬਹੁਤ ਸਾਰੇ ਵਿਦੇਸ਼ੀ ਦੇਸ਼ ਆਪਣੇ ਉਤਪਾਦਾਂ ਨੂੰ ਕੰਪਨੀਆਂ ਨੂੰ ਵੇਚਣ ਵਿੱਚ ਬਲਾਕਚੈਨ ਹੱਲ ਵਰਤ ਰਹੇ ਹਨ , ਇਸ ਤਰ੍ਹਾਂ ਤੁਸੀਂ ਵੀ ਇਸ ਨਵੀਂ ਤਕਨੀਕ ਨੂੰ ਅਪਣਾਉਣ ਲਈ ਤਿਆਰ ਹੋ	1 2 3 4 5