Blockchain technology for agricultural supply chains during the COVID-19 pandemic: Benefits and cleaner solutions

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ABSTRACT

This study aims to investigate blockchain technology for agricultural supply chains during the COVID-19 pandemic. Benefits and solutions are identified for the smooth conduction of agricultural supply chains during COVID-19 using blockchain. This study uses interviews with agricultural companies operating in Pakistan. The findings discover the seven most commonly shared benefits of applying blockchain technology, four major challenges, and promising solutions. About 100% of the respondents mentioned blockchain as a solution for tracking the shipment during COVID-19, data retrieval and data management, product and transaction frauds, and an Inflexible international supply chain. Roughly 75% of the respondents mentioned the challenge of lack of data retrieval and data management and the Inflexible international supply chain in COVID-19 besides their solutions. This study can expand existing knowledge related to agricultural supply chains. The experiences shared in this study can serve as lessons for practitioners to adopt the blockchain technology for performing agricultural supply chain during pandemic situations such as COVID-19.

1. Introduction

The value chain digitisation has changed agricultural business transactions (Kamilaris et al., 2019). The foremost effect is derived with barcodes, resulting in the tracking of items across the value chain (Rogerson and Parry, 2020). Mobile devices for data gathering, more sensible sensors that are affordable and used for tracking conditions, and the internet to change the link with new applications brought by consumers (Wang et al., 2019). Mobile phones are currently taking over numerous such roles. Radio-Frequency Identification (RFID) and Quick Response (QR) codes have successfully replaced the barcodes (Gurtu and Johny, 2019). These technologies automate the value chain process to make it more effective (Sari et al., 2021). However, product traceability and transparency in supply chain management are still challenges for organisations (Erol et al., 2020). Mainly when the database system handles transaction records separately, where the records are not open to other stakeholders in the chain (Morgan et al., 2018). This problem makes transactions a challenging task towards recording and verification (Rogerson and Parry, 2020). Even if data has been recorded in many circumstances, it cannot be guaranteed that these records are not deceptive as the database can be modified (Kalla et al., 2020).

Blockchain is an emerging technology that has the prospect of addressing the gaps mentioned above. The attention of agricultural businesses to blockchain technology is increasing rapidly (Gurtu and Johny, 2019). Businesses progressively differentiate how improved data management competence from evolving technology creates supply chain expertise and reduces bottlenecks in transactions (van Hoek, 2019). The agricultural area positions the value of technology to reduce transaction costs, improve logistics, increase traceability, and improve food safety practices (Erol et al., 2020). Blockchain technology signifies a stimulating opening to increase transaction-related efficiency, lower resistance, and advance traceability in agricultural supply chains globally (Kamilaris et al., 2019). Blockchain practice will continue to grow in agriculture (Kamilaris et al., 2019). The benefits of this technology are wide-ranging, and research on the topic is scarce, especially those related to environmental conservation (Goni et al., 2015).

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Blockchain-based tools that can help connect farmers to agricultural supply chains include the GrainChain application that rapidly transfers ownership of grain (GrainChain, 2020).

The ongoing COVID-19 pandemic has brought a significant crisis to many fields of human activity (Zeinalnezhad et al., 2020), such as energy supply chain and consumption (Klemeš et al., 2020a)Klemeš et al., 2020, plastic waste needed for PPE - Personal Protection Equipment (Klemeš et al., 2020b) and for the vaccination (Klemeš et al., 2021a), waste management supply chain (Fan et al., 2020), and global food supply (Lin et al., 2020) despite the many blockchain systems currently in the agricultural supply chain, particularly in Pakistan, a country with a very substantial population. During this period, shortages of basic necessities, such as rice, vegetables, wheat flour, and eggs, have prompted frights among suppliers and buyers due to the disruption of supply networks (Paul and Chowdhury, 2020). The limitations of native and transnational activities following the unique COVID-19 pandemic have resulted in instability in the food chain. This problem creates widespread economic distress and uncertainty that will predominantly affect the defenceless. In this pandemic situation, where people are socially distant, digital technologies such as blockchain are used worldwide to support food value chains while fulfilling public health measures and maintaining worker safety (Paul and Chowdhury, 2020).

From a theoretical perspective, research on blockchain technology for agricultural supply chains has significantly increased since 2018. The topic of the study varies from review paper, management framework, challenges, and opportunities. For instance, Bermeo-Almeida et al. (2018) provided a systematic literature review on blockchain technology in agricultural supply chains to discover the research topics and contributions. In another study, Kamilaris et al. (2019) discussed the impact and challenges in implementing blockchain technology for agricultural and food supply chains. Yadav and Singh (2020) investigated the barriers to blockchain technology adoption for agricultural supply chains in India.

Although the potential of blockchain technology is recognised throughout the industry, there are few publications or reports on the successful application of the technology, especially those related to agricultural supply chains. So far, very little research has gone beyond conceptual considerations of the benefits and solutions offered by blockchain technology for agricultural supply chains, particularly during the COVID-19 pandemic. This paper attempts to address the lack of theoretical insights in research by examining the benefits and solutions that blockchain technology provides for agricultural supply chains in Pakistan during the COVID-19 pandemic. The study explicitly addresses the following research questions:

RQ1: How blockchain can benefit agricultural supply chains during the COVID-19 pandemic?

RQ2: What solutions does blockchain provide for secure agricultural supply chains, especially in situations like COVID-19 and other similar pandemics?

This study uses the interview as a method to answer the research questions. Chief Executive Officers (CEO) from four agricultural companies involved in farming, importing, and exporting agricultural products in Pakistan are selected for the interview. The interviews results are then analysed using qualitative data analysis. The statements from the experts revealed a multitude of different benefits and solutions offered by blockchain technology to manage agricultural supply chains during the COVID-19 pandemic. The study provides new insights into how blockchain technology plays a vital role as global food supply chains proved brittle during the crisis. This investigation would be advantageous for practitioners in the agricultural industry to select blockchain technology as an appropriate solution to overcome some problems related to data transparency and traceability to facilitate trust among stakeholders.

2. Literature review

This section reports a literature review of blockchain technology and its contribution to agricultural supply chains, particularly in tackling the problems caused by COVID-19. Several related studies are examined for their ideas and contribution to the knowledge and to uncover research gaps and inconsistencies that could be addressed in future works.

2.1. Blockchain technology

A whitepaper, "Bitcoin: A Peer-to-Peer Electronic Cash System", mentioned the invention of Bitcoin was released decades ago (Nakamoto, 2008). It is the novel cryptocurrency attempt that endorsed trustworthy monetarist transactions deprived of a reliable principal authority (Tschorsch and Scheuermann, 2016). With the help of blockchain technology, Bitcoin resolves the imperfections associated with digital tokens as they can be easily replicated or created (van Hoek, 2019). Blockchain is a software engineering technology whose use is rapidly increasing, particularly in Pakistan, supporting smart city initiatives (Khan et al., 2020). Blockchain technology is currently integrated with other sophisticated information systems such as the Enterprise Resource Planning system (Chofreh et al., 2011) that can optimise the performance of internal data control, transactions, and operations (Chofreh et al., 2015). Blockchain technology is also used in project management for more accurate and transparent project control to support success in managing projects (Chofreh et al., 2019).

Blockchain is a ledger based on the concept of digital transactions supported by various machines that do not rely on reliable third parties (Erol et al., 2020). Separate files related to transaction data, known as blocks. These blocks are accomplished with the help of a particular software platform that sends, processes, stores, and displays data in a human-readable form (Wang et al., 2019). Separately each block encloses a header with a timestamp in the bitcoin setup. Data associated with transactions and links to the previous block and each block is hashed, grounded in its content, and then referenced in the next block title (Zhang et al., 2019).

Fig. 1 shows the blockchain encompassing n blocks. Each of the following blocks includes the preceding block's hash, a timestamp, information regarding the transaction, the information regarding the nonce number intended for the excavating process and any further specifications desired for the practice to work. The changes in a specific block will create a mismatch with the hashes of the subsequent blocks altogether.

In addition to cryptocurrency and financial transactions, the importance of Blockchain technology has been known since 2014 (Tayeb and Lago, 2018). It includes management of records, digital mode authentication, initiating smart contracts, electronic voting, the transmission of locally created items, and tracking items (Dujak and Sajter, 2019). Blockchain achieves accomplishment and demonstrates its usage in several cryptocurrencies, and numerous organisations aim at connecting its transparency and fault tolerance for solving complications in situations where various mistrustful actors are indulged in the distribution of resources (Manski, 2017).

2.2. Advantages of blockchain technology

Blockchain is a technology comprising a decentralised system that becomes its most significant benefit. With the help of this technology, the role of the third-party organisation is ended where no one intermediately is involved, and all participants make the decision. Blockchain technology has its own validity to ensure verified transactions. Every move is reported to the blockchain, where every participant of the blockchain is available with the data records. This available data cannot be modified or deleted. With the help of such a way of recording through blockchain, it results in immutability and transparency (Erol et al., 2020).
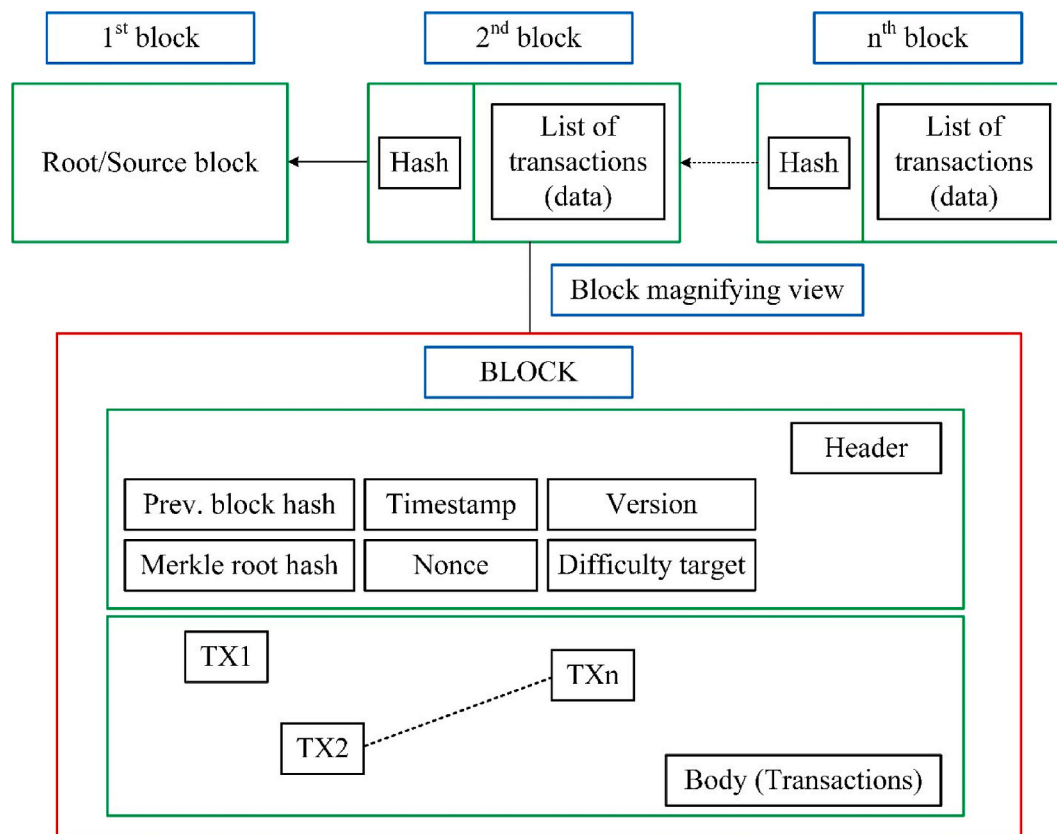
Fig. 1. A blockchain example, adapted from Kamilaris et al. (2019).

When the transaction is attached to the Blockchain, deletion or modification to it is not possible. It is due to the fact of decentralisation. In the case of a centralised system, the decisions are made by one person; the records can easily be changed or deleted. But in the case of a decentralised system (like in blockchain), each transaction linked with the blockchain is copied to all the networks (Erol et al., 2020). This creates blockchain technology not changeable and unbreakable. The design and working of blockchain are in such a manner that the problems at any point can easily babe highlighted and can easily be corrected. This results in another advantage of blockchain technology that is related to traceability.

Blockchain technology is highly secure due to the process through which any individual is connected with the network. Every individual is assigned a unique identity. Crypographic hash is another reason behind blockchain security. The hash value of any newly added block is calculated that includes the previous hash value also. The hash value of any block comprises the id of the block, previous hash value, the block's creation time, the Id of the user, and the detail of all previous transactions with their hashes. The hashes are automatically created, making it impossible to alter the hash value (Erol et al., 2020).

Another aspect acts as a challenge in the traditional way of working, where multiple ledgers are involved for record-keeping. This makes things difficult and complicated for the participants of the system. Blockchain technology easily overcomes this challenge, where all the transactions are included in one ledger. Faster processing is another advantage of blockchain. The traditional way of recording the transaction (processing and initialising in the bank) is time-consuming. With the help of blockchain technology, this processing and initialising time is reduced from days to minutes and seconds.

2.3. Blockchain in agriculture and food supply chain

Cleaner supply chain management refers to activities across all stages of the supply chain that significantly impact social well-being and the environment. Due to increased awareness, people are more concerned about food safety and demands sustainable compliances. Blockchain adoption has become a high priority to ensure such activities are in real practice. Supply chains are extensive storage places to store larger data in cleaner mode. With a cleaner supply chain through blockchain, the storing places are interconnected.

Organised data is necessary for an efficient and clean supply chain, which becomes harder if the data is disorganised. Blockchain is the solution as it is decentralised in nature. With the help of blockchain, information can easily be shared in a faster mode. It helps to remove inessential establishments from the supply chain. It improves the data journey by providing the customer with an opportunity for an enhanced experience. However, blockchain adoption is still immature (Zhao et al., 2019). There is a need to investigate the blockchain adoption benefits and solutions in agricultural supply chains. Identifying these benefits and solutions would facilitate the adoption rate of blockchain, particularly in Pakistan agricultural supply chains.

The domains of agriculture and the food supply chain are two significant and highly relevant domains (Dujak and Sajter, 2019). These two domains are interlinked as in distributed supply chains. The agriculture products are utilised as inputs, where consumers are often the ultimate clients (Maslova, 2017). It is evident that immediately after the emergence of blockchain technology, it began to be used in supply chain management (Wang et al., 2019). Reuters Events (2018) reported that in supply chain management, the use of blockchain would nurture 87% of yearly growth, increasing from $45 M in 2018 to $3314.6 M in 2023. As a popular example, the company AgriDigital in December 2016, implemented the first-ever payment on a blockchain for the grain sale (CTA, 2017). A cloud-based system is used to accomplish over 1300 users, in addition to the grain of 1.6 Mt. It includes $360 M in cultivator payments (Kalla et al., 2020). The triumph of AgriDigital aided as motivation for the prospective consumption of blockchain in the supply

chain for agricultural products. The company is presently targeting to construct reliable and effective supply chains through blockchain. Louis Dreyfus Co (LDC), is another recent example, who is the principal foodstuffs trader, collaborated with banks of France and Netherlands through blockchain for the foremost agriculture product trade (such as a shipment of soybeans) (Hoffman and Munsterman, 2018). Fig. 2 shows the use of blockchain for the digitisation of the food supply chain. As shown in the figure, there are three layers: the top layer (showing the physical flow), the middle layer (showing the digital flow), and the bottom layer (showing the blockchain layer).

Under the top layer, a digital flow layer consists of numerous digital technologies. The connecting infrastructure is Internet/Web servers. Each accomplished action, sanctioned with the help of the above-mentioned digital technologies, is logged to the bottom layer. This process supports unchallengeable ways to stock information, acknowledged by all contributors. The information captured during each transaction is validated by business companions, forming consent among all accomplices (Rogerson and Parry, 2020). Once the blocks are validated, they are added to the transaction chain at the individual level, becoming an eternal process record. As shown in Fig. 2, diverse information is transcribed to the blockchain at the individual phase of the food line. The phases in the food supply chain system are defined as follows.

  i. Provider: At this stage, the information related to crops, using pesticides and fertilisers, the machinery involved is provided. These transactions are logged.
  ii. Producer: At this phase, the information related to the farm and the practices related to farming is employed. Further information related to the process for cultivating the crop and conditions of weather is recorded.
  iii. Processing: The detail related to the place of work and its apparatus, the used processing approaches is employed. Business transactions occurring with the producers besides with the suppliers are also logged.
  iv. Distribution: This phase deals with the details related to shipping, details related to the followed trajectories, storage settings, time in shipment at every transportation way. Entire transactions related to the suppliers and the traders are transcribed on the blockchain.
  v. Retailer: At this phase, the details related to the food article, the food article quality and the quantity of food item, date of ending the food item usage, storage settings and shelf time are listed.
  vi. Consumer: This is a concluding stage. At this stage, the purchaser, with the help of a mobile phone, can scan the food item through its QR code and get the in-depth facts related to it from the producer and supplier until it reaches the retailer.

Blockchain technology innovation has apprehended the imagination and provided both academics and practitioners with challenges and opportunities. Tian (2016) advocated in combination with RFID for the

use of blockchain for food security. Tian (2017) developed an agricultural supply chain traceability system using blockchain and the Internet of Things. A comprehensive literature review of blockchain-based applications in agricultural supply chains was carried out by Zhao et al. (2019). The research findings depict the blockchain framework for traceability, sustainable water management, agri-food and information security in agricultural supply chains. Yadav and Singh (2019a,b) conducted an agricultural application research survey. The authors concluded that adoption of blockchain remained an immature stage and categorised current research centred on blockchain in four dimensions: traceability, design, informational and other diverse applications. A platform for addressing selective farmer issues in the Indian environment with a blockchain-based mobile application was proposed by Yadav and Singh (2019a,b).

Kamilaris et al. (2019) examined blockchain patterns in agricultural supply chains and addressed some of their implementation challenges. These problems include a lack of government oversight, confusion about regularity, and lack of training programmes. Kamble et al. (2019) addressed the Indian foodstuff retail supply chain through the blockchain traceability process, while Galvez et al. (2018) explored different problems in using blockchain for food traceability. Since the blockchain-based system lacks control of the sensor from which data is transmitted to the blockchain system, it is difficult to capture such fraudulent sensors if such sensors are manipulated. Failure to regulate the system's storage speed, capacity and latency, scalability, privacy, and high costs are also problems in terms of blockchain acceptance of farmers' supply chains (Zhao et al., 2019).

The concept of land registration in the Indian sense was explored in Thakur et al. (2020). The authors agree that such a system is genuine, manipulative, and gives absolute property rights. They addressed numerous challenges in implementing blockchain-based mechanisms, including high initial investment, confusion about regularity, and security concerns.

Even though blockchain has advanced considerably in recent years, there is a big gap regarding conceptual considerations of the benefits and solutions offered by blockchain technology for agricultural supply chains. The review of blockchain showed an interesting increase in the number of published papers, mainly in 2018 and 2019. However, studies contemplating the interplay of blockchain and agricultural supply chains remain at their developing stages. Based on the literature, blockchain has lots of potential to bring reformation in agricultural supply chains.

2.4. Blockchain for e-agriculture and supply chain during COVID-19

While the COVID-19 pandemic discloses, substantial consideration has focused on the resiliency of food supply chains in a phase of the crisis (van Remko, 2020). Food supply chains are defenceless long before the coronavirus pandemic. A rapid food supply chain adjustment is required for demanding side shocks (van Remko, 2020). It includes panic buying,
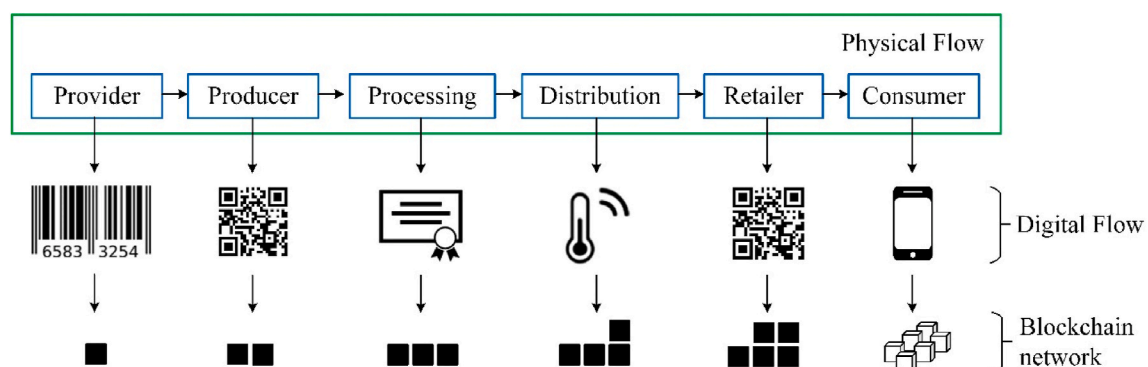

Fig. 2. Food supply chain system, adapted from Kamilaris et al. (2019).

fluctuations in food buying patterns, in addition to the plot for any supply-side interferences because of possible labour lacks and disruptions to transportation and supply networks (Hobbs, 2020).

The ongoing COVID-19 pandemic has carried a vast crisis on the global food supply (Lin et al., 2020) regardless of numerous present blockchain systems in the agricultural supply chain. Throughout this period, scarcity of necessary food, such as rice, vegetables, flour, and eggs, has triggered frights between suppliers and shoppers due to interruptions in supply networks. Producers, manufacturers, and distributors have inadequate information due to abrupt changes in customers' shopping behaviours. It requires weeks, or even months, to regulate resource allocation to recover the food products supply operations to an average level. Limitations to local and international movements following the unique COVID-19 epidemic are producing disturbances to the food chain globally (de Sousa Jabbour et al., 2020). This process is creating extensive economic suffering and uncertainty that will mainly affect the defenceless.

The COVID-19 crisis has sharply depreciated development economies' exchange rates, product, and energy prices (Chofreh et al., 2020). With rising capital costs, the effect is felt in the agricultural operations of capital intensity. World trade in commodities is expected to decline between 13 and 32% by 2020 (World Trade Organization, 2020). With globally increasingly diverse food supply chains, risk reduction strategies have to be productive for the successful agricultural supply chain management. There is a risk of supply chain coordination or instability in the supply chain. de Paulo Farias and dos Santos Gomes (2020) emphasised that COVID-19 has put people in the agricultural supply chain at health risks, and agricultural supply chain relationships in the handling and feeding agricultural supply chains and disease transmission must be vigilant. The numerous supply-side threats in food supply chains during the COVID-19 pandemics and the demand-side have been studied by Hobbs (2020). Galanakis (2020) emphasised different risks during COVID-19 that hinder sustainable food production and consumption. The agricultural supply chain disturbances and their impact on food security are highlighted in Torero (2020). Stephens et al. (2020) have provided a small scale to identify ideal domestic substitutes in the short term. Still, they should encourage less reliance on global agri-food value chains because of trust and transparency issues. Hailu (2020) found shocks in the food manufacturing supply and demand due to the border closures and trade constraints that resulted from a sudden decrease in the demand for processed foods. Brewin (2020) examined the potential labour shortages in oilseed processors, leading to possible bottlenecks between crushers and millers that impede retail and distribution in agricultural supply chains. Stockford (2020) illustrated the effect of COVID-19 on storage and transportation, thereby increasing procurement cost, resulting in possible delays within the agricultural supply chain. Gray (2020) investigated various risks caused by COVID-19, such as labour issues, reduced movement of sea containers, and regulation of transportation closures. Haley et al. (2020) provided the prevention of various risks posed by migrant workers involved in agricultural supply chains.

According to Lin et al. (2020), there are at least three significant lessons that can be learned from COVID-19 related global food supply troubles:

(i) The need for real-time precise, and accurate information for all the involved parties. It is reported that when it is panic buying, precise information is lacking by the supply network to imitate the purchase behaviours, thus making quick responses impossible.
(ii) The need for productive coordination between parties at a global level for generating early and suitable real-time responses.
(iii) The need for an efficient process for reducing time in bureaucratic actions.

World Bank is capitalising on digital technology that can encourage food safety, guarantee food security, and protect farmers' livings (World Bank, 2019). Quayson et al. (2020) mentioned that blockchain is a promising digital technology that can improve agricultural supply chain activities. Additional development of blockchain-based supply chain systems is needed for mitigating the problems during the crisis (van Remko, 2020).

Kalla et al. (2020) mentioned that the technology of blockchain would provide agility in practical solutions. Smart contract based automation can substitute paper-based and long-term agreements with a digital market, where the transactions can be done quickly without compromising ownership. Since blockchain enables two parties to transact directly, producers may procure raw material from farmers. It will assist farmers in getting better prices for their goods and reducing food products' overall prices. Blockchain technology can help poor people remotely and safely purchase free or subsidised food from local suppliers. More contributors will contribute to good causes as both accountability and anonymity are provided by blockchain-based systems.

Blockchain plays a significant role in eliminating intermediaries, disruptions and allowing smallholders to communicate directly to consumers and end-users, thereby reducing corruption (Aiken, 2020). Blockchains can enable smart contracts for the automated delivery and payment of agricultural products contracts. These features can reduce the time and severity of problems the global supply chain's smallholder farmers face. In the context of the profound and devastating effects on smallholder farmers that would enable players, particularly smallholder farmers, to emerge stronger and more resilient in the revolutionary changes in the supply chain.

Pakistan is among more than 180 countries fighting the COVID-19 pandemic. There are strong warnings of a global economic slump as labours remain sick and factories remain shut. Mitigating the economic damage will not be easy for Pakistan. This country is currently experiencing economic stabilisation and is below the world average in the maximum human development indicator (Malik et al., 2019). With the COVID-19 pandemic in Pakistan, the effect on health and economy is realised, and it became observable when farmers demolished surplus produce. The pandemic has shattered the small-scale farmers already struggling because of changes in the climate. They cannot even pay for taking their products to the marketplace due to a lack of labours and vehicles.

Sana Jameel (1982) mentioned that Pakistan is one of the world's top rice producers, wheat, cotton, sugar cane, mango, and oranges. Pakistan produces approximately 1.7 Mt of mangoes per annum, distributed to more than 50 countries, mainly to the United Arab Emirates and Saudi Arabia. Agriculture is the backbone of Pakistan's economy, contributing 19% to the country's GDP and paying 39% of the labour force. Key crops (cotton, wheat, rice, maise and sugar cane) add 4%, and minor crops contribute 2% to GDP, whereas livestock area adds 11% GDP.

In the new socially distanced settings, digital technologies are used worldwide to help food value chains while fulfilling public health actions and protecting workers' safety (van Remko, 2020). Like in China, 'Pinduoduo' (the e-commerce platform) is used to help farmers for selling excess products. It also helps in collaborating with academia to propose agricultural e-extension services. The United Nations (UN) Development Programme is used by JUMIA (in Uganda) to connect market vendors and weak food producers with consumers via online mode (JUMIA, 2020). In the same way, Ninjacart in India and AgriChain in Australia are rationalising supply chain methods to decrease incompetence and risk and bring fresh food from farmers to buyers. Indigo Transport permits grain cultivators to demand transport for their crops in the USA. In France, Connecting Food with the help of blockchain is performing traceability for the whole product.

In Pakistan, the government takes various steps to support the agriculture sector. Still, the pandemic is revealing the gaps and obsolete practices in the agriculture sector resulting in the loss. It is observed that COVID-19 has exposed Pakistan's poorly accomplished food supply

chain resulting in wastage of food and prices reduction that ultimately affects the poor farmers. However, the pandemic has been a huge challenge, as this has been facilitating innovation waves (Klemeš et al., 2021b). The evolution of innovation can be seen in Fig. 3, where the global crisis triggers the majority of the emerging technologies.

Experts consider that COVID-19 is an opening for Pakistan to change the agriculture sector to a sustainable agricultural model to increase production. It is recommended to connect the agricultural industry with technology such as blockchain to get a multitude of benefits. Through this, the government can certify food security and control prices. Directly purchasing from farmers and removing middlemen from the equation will eliminate barriers and prevent hoarding and dishonesty (Jamal, 2020).

The review of blockchain showed an interesting increase in the number of published papers, mainly in 2018 and 2019. However, blockchain and agricultural supply chains remain at their developing stages. Based on the literature, it is found that blockchain has lots of potentials to bring reformation in agricultural supply chains. Blockchain can help the individuals of the agriculture supply chain for better and secure transactions. The advantages of blockchain are evident and are not conditioned to any specific situation (pandemic or no pandemic). Blockchain is the need of today's world. This need became necessary when the whole world went into a pandemic. The lessons learned from the countermeasures adopted during COVID 19 pandemic, when the whole world went into a lockdown, are significant. The world has seen the prohibition of all non-essential activities. The maximum population stayed at their own homes. Blockchain has played a significant role in managing the pandemic. It is growing as a prominent technological way of dealing with the novel needs as a result of this crisis, such as faster intervention, trackable, trustworthy, and less costly means towards quality decision-making.

2.5. Related research on blockchain for the agricultural supply chain during COVID-19

Blockchain is one of the fastest emerging and developing technologies in today's world, and research is only just starting on this distributed technology. Blockchain technology can transform the agricultural industry in several focuses, such as supporting peer-to-peer agricultural

transactions, a smart contract platform to help the intricate transaction process, and transparent digital agricultural supply chains. However, there has been little research focused on blockchain technology related to the agricultural sector and food supply chains during the COVID-19 pandemic from a theoretical perspective. This section discusses the related studies on blockchain technology for the agricultural supply chains during the COVID-19 epidemic. Table 1 summarises the studies to identify the domain and contribution of the existing studies useful for analysing the literature's knowledge gaps and inconsistencies.

Quayson et al. (2020) published an article on digital inclusion for the agricultural supply chain during COVID-19. The researchers illustrated some learnt lessons for building resilient COVID-19 supply chains in developed and developing countries. The study specifically focused on smallholder farmers who are working in the global value chain. Discussions regarding the digital inclusion of smallholder farmers are reported highlighting its benefit towards preventing significant disturbances that can happen from destructing the source of revenue of society's most exposed.

Another study on blockchain for COVID-19 is conducted by Kalla et al. (2020). This study investigated the effect of the COVID-19 pandemic on almost all parts of human life, business, and the world. The researchers mentioned the actual situation where the human activities ceased for months and are now started again but with specific protocols to avoid pandemic spread. It is observed that technological advancements can benefit from safeguarding humanity. In this study, the researchers have identified various challenges related to COVID-19 and considered blockchain a technical solution for this pandemic. The study has successfully reported the agriculture-related challenges during COVID-19; however, they are not explicitly investigated how blockchain can benefit the agricultural supply chain during COVID-19 or similar pandemics.

The most relevant study is conducted by Lin et al. (2020). According to the researchers, it is crucial to attaining an ideal trade-off among productivity and truthfulness of the agricultural management systems due to several untrusted stakeholders, such as small-scale farmers, food producers, distributors, retailers and associated logistic companies. The authors surveyed investigating techniques and implementing blockchain technology specific to the agriculture domain in their research. The study managed to examine and identify the technical elements of
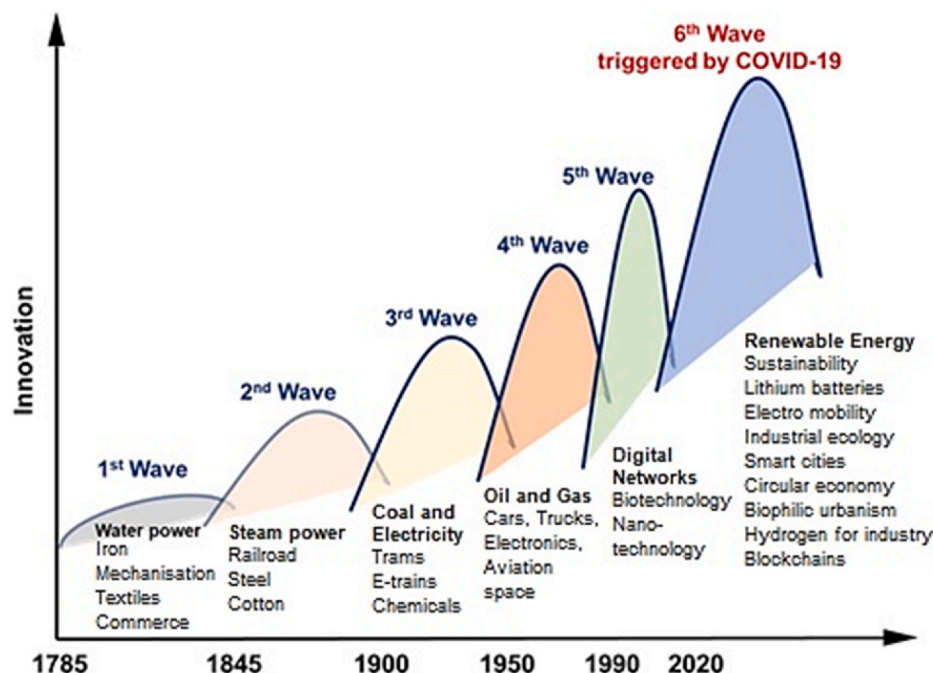

Fig. 3. Waves of innovation through industrial history and into the future, adapted from Klemeš et al. (2021b) and the first version from Newman (2020).

Table 1

Related researches on blockchain for agricultural supply chain during COVID-19.

Reference	Title	Domain	Key contribution
Kalla et al. (2020)	The role of blockchain to fight against COVID-19	Blockchain against COVID-19 in the general scope.	The study discusses general challenges during the COVID-19 pandemic. The blockchain application is discussed as a critical technology to treat COVID-19.
Lin et al. (2020)	Blockchain technology in current agricultural systems: From techniques to applications	Blockchain technology for agricultural supply chain during COVID-19.	Conducted an enhanced food supply chain investigation in the COVID-19 pandemic economy as an illustration to demonstrate the effective use of blockchain technology.
Quayson et al. (2020)	Digital inclusion for resilient post-COVID-19 supply chains: Smallholder farmer perspectives	Agricultural supply chain through digital technologies during COVID-19.	It was reported about the need for digital transformations to construct a robust post-COVID-19 agricultural supply chain to progress the livelihood. The study also provided some success stories using digitalisation during COVID-19 for successfully running their businesses when everything is locked down.
Galanakis (2020)	Innovations and technology disruptions in the food sector within the COVID-19 pandemic and post-lockdown era	Industry 4.0 technology applications to help agricultural supply chains during the COVID-19 crisis.	Internet and Communication Technologies (IoT), blockchain, and other Industry 4.0 technology applications are the potential innovations to solve related issues and improve the agricultural supply chains during and post-COVID-19 period.

blockchain besides the existing blockchain applications. The significant challenges towards the agriculture sector are reported, and their overcoming solutions are discussed.

The aforementioned research characterises blockchain as a significant ingredient towards successful agricultural supply chains during COVID-19 and similar pandemics. It is found that there are very scarce studies conducted on COVID-19, in particular, to use blockchain technology for the agricultural supply chain. This study is a novel attempt to investigate the benefits of blockchain technology to solve issues in the agricultural supply chain and improve it during and after the COVID-19 pandemic. In this regard, a case study in Pakistan, where the economy's stability mainly depends on agriculture, is selected.

3. Research methodology

Interview sessions are conducted to answer the research questions with the CEOs of Pakistan's four agriculture and farming companies involved in farming, importing, and exporting agricultural products (fruit, rice, and corps). It is a conversational interview, where no pre-arranged questions are asked to stay as open and adaptable as possible to the nature and priorities of the interviewees.

This research conducted online interviews using synchronous communication through videoconference and Voice-Over Internet Protocol (VOIP). The participants were connected through a computer or mobile device. For VOIP, the questions and their responses were gathered using live audio, whereas, in videoconferencing, the researchers could see the participants during the conversation. Online interviews are used to get indigenous data using the internet to generate new substantiation in association with a particular research question (Hewson, 2017).

The online interviews are conducted with four agribusiness companies in Pakistan. All these four companies practise blockchain for the agricultural supply chain. The chosen companies and respondents fit the problem scope in terms of the various problems faced by the companies during the COVID-19 pandemic and their adoption of blockchain technology for overcoming the agribusiness challenges of COVID-19. As blockchain technology is new to agribusiness companies in Pakistan, very scarce companies have started using blockchain technology for their agribusiness. This act as a strong reason behind the small sample size of companies. In qualitative research, the sample size ranges from 4 to 87 samples (Chofreh et al., 2016). The present study manages to get four samples as blockchain technology is new, and there are very few agribusiness companies that are adopting blockchain technology for their daily businesses. Fig. 4a shows the six-stage process of data collection and data analysis.

The current study uses qualitative data analysis that converts the raw data collected from experts into a novel theory. The qualitative data analysis process comprises of three activities: data reduction (code, categorise, and conceptualisation), data display, and drawing conclusions (Chofreh et al., 2016). As shown in Fig. 4a, after explaining the purpose of the interview, the interviewer shares the terms with the interviewees. The interviewer mentioned to them who would access their answers and how they would be analysed. The interview with the CEO of the companies was related to two aspects: the benefits of using blockchain in situations like COVID-19 for the agricultural supply chain and the prominent solutions they managed to get after they used blockchain technology during COVID-19 for their businesses. The interview sessions were recorded for analysis purposes.

After the interview, the tape recorder was verified to ensure the recordings of the session. The interviewer also made written notes throughout the interview that comprise the interviewee opinion and any observations notified during the session. The gathered data was then analysed by codifying, categorising and conceptualisation. Then, the conceptually raised data were synthesised, and the conclusion was drawn.

4. Analysis

The analysis of the data gathered through interviews is reported in the subsequent section. This section also describes the data collection and data analysis process to describe, condense, recap, and evaluate data. Data analysis commences by data reduction, which comprises coding, categorisation, and conceptualisation. Sekaran and Bougie (2020) defined coding to index the text in the transcript to progress a thematic model. This study generates codes manually. These codes were then inserted into the Atlas.ti software, a qualitative data analysis software (Friese, 2019), to generate the codes' relationships. Fig. 5 displays the generated codes for the benefits of using blockchain technology for the agricultural supply chain during COVID-19 and its promising solutions.

The above-mentioned codes are then transformed into network views. Fig. 6a and Fig. 6b show the network view of the generated codes.

The data analysis process is then continued by considering the code and doing categorisation of the text. These codes are manually allocated to the correct citations in the interview transcript. The Atlas.ti software enables the user to envision the categorisation method. Data conceptualisation is the last activity of the data reduction process. It deals
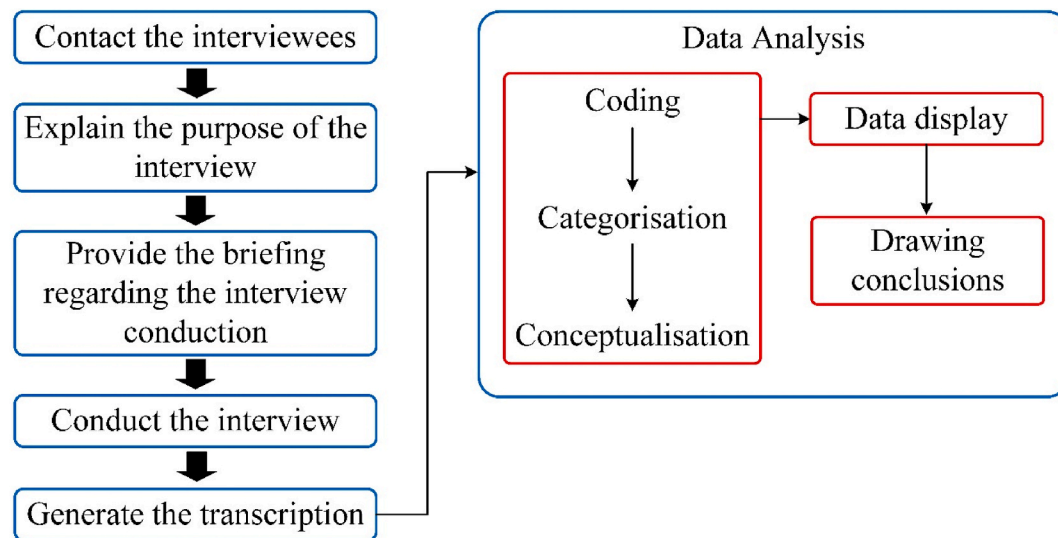
Fig. 4. Steps to conduct the conversational interview, adapted from Chofreh et al. (2016).

Fig. 5. Generated codes.

with converting the categories into concepts. It comprises three essential steps: an 'initial memo', 'sorting and investigating scrap beginnings', and 'memo memos'. In the initial memo stage, an explanation about the codes is given.

Data analysis conclusions give meaning to the data. This process results in the development of novel ideas and concepts in a study. Huberman et al. (2014) stated that the conclusion illustration and verification procedure are accomplished by observing patterns and clarifications. Through following up practice, conclusions are confirmed and verified. The findings are resent to the interviewees to confirm the research findings.

5. Results and discussion

This section provides the shared benefits of the blockchain technology application for the agricultural supply chain during COVID-19 and the solutions that the blockchain technology provides for secure agricultural supply chains, especially in pandemic situations like COVID-19. The results and discussion section is deliberated in the following sub-

sections.

5.1. How can blockchain technology benefit the agricultural supply chain during the COVID-19 pandemic?

The farming (agriculture) companies in Pakistan reported the benefits of using the agricultural supply chain during COVID-19 through interviews. Fig. 7 demonstrates some of the benefits that the experts have confirmed. The CEO of the rice exporter company mentioned the fact related to COVID-19 that it had exposed overall problems related to lack, traceability, connectivity, exchange of data, and transparency in existing systems. That person stated that "*even in the age of 5G and IoT (Internet of Things), there is no competent and transparent system to track their shipments*". He considered this one reason why pandemic fetched various sectors, including the agricultural supply chain, to its knees. He further shared the company's experience about the benefits of using blockchain for the rice supply chain during COVID-19. He mentioned that " *…. In this pandemic, the transactions related to rice import/export is easily done by us by using blockchain. Besides, at any stage, it is easier for me and my client to track the rice throughout the time from field to market …. ".* The CEO of the company further shared the problems that have been addressed with the help of blockchain technology. He pointed that "*… it is the blockchain that has made us perform and receive the payments directly without involving the bank channels. Blockchain helped us streamline the whole process by cutting out all third parties and long processes. Here I want to mention one thing related to tracking rice as an agriproduct. After we started using blockchain technology, things became very transparent to us (tracing from field to shelf). We can track the product for any possible detail …*"

The multiline international import and export company involved in fresh fruits farming mentioned the crises and a clear need to develop their business network conferring to modern practices. The company's CEO mentioned the blockchain development solutions that are strong enough to fight the COVID-19 crisis. He stated that "*… blockchain technology help us in the data retrieval process. I tag blockchain as a 'preventer' for COVID-19 as well as future pandemics. Through blockchain, my company has successfully managed to obtain data related to the fruits right from the provenance to the retail store.*

Furthermore, it also helped us in the data management aspect …". The interviewee also revealed the impact of data management and recovery through blockchain technology on the agricultural supply chain. He argued that "*… I observed that due to having blockchain technology, my company has managed to streamline our inventory management, ultimately*
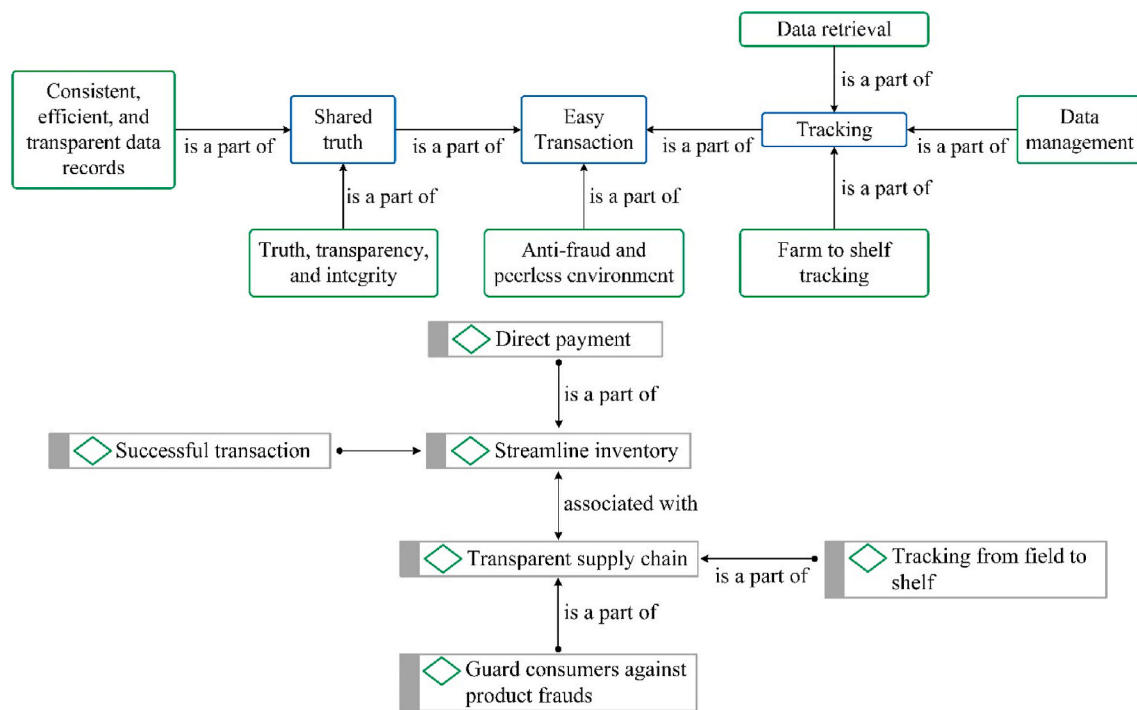
Fig. 6. a. Network view of codes for benefits
Fig. 6b. Network view of codes for solutions.

resulting in a transparent supply chain …. " The Senior Executive of the company also shared his experience related to the upright traceability feature of blockchain and guarding product scams. He claimed that "… *blockchain authorises agricultural merchandises and food components to be traced all over the supply chain. The blockchain technology can also guard consumers against product frauds due to farm to shelf tracing characteristic of blockchain …".* The CEO of the company shared an experience where the production workers became sick. Even then, the earlier parts of the supply chain were reconfigured easily.

Another company dealing with crop farming export and import was contacted, and the CEO of the company shared his views regarding the benefits of blockchain technology for the agricultural supply chain during COVID-19. He emphasised that " …. *the agriculture industry needs to emphasise on data management as data is a necessary strength to fight counter to pandemics. With the help of blockchain solutions, we can access to data about what, where, How, When, Who …. Leading to better control over the businesses even in the pandemic …. "* According to the respondent, blockchain solutions become "… *the reason for consistent, efficient, and transparent data records. I can feel the significance of blockchain towards businesses in data analysis".* It is further shared by the CEO of the company, who stated that "… *with blockchain technology, automated data collection takes place that goes to a ledger which keeps our data counter to unauthorised access, thus preserving privacy and resulting in a transparent supply chain."*

The CEO of the rice exporter company shared some critical issues caused by the COVID-19 globally related to trading and the need for the flexibility of international supply chains. According to the interviewee, " …. *the resilience in supply chains can only be achieved when there will be trust, transparency and integrity …"* He shared his views about "… *improving resilience through the utilisation of blockchain technology deals with shared truth concept …. "* The CEO of the company also shared his opinions related to transactions. He mentioned that "… *we found blockchain technology an easier way for performing transactions safely and instantly in COVID-19 …"* He further tagged blockchain as "… *the anti-fraud and peerless environment where we successfully managed to perform the transactions even in the complete COVID-19 lockdown …".* Fig. 8 shows

the benefits of blockchain experienced towards the agricultural supply chain during COVID-19. Blockchain can get a vast number of resolutions to agriculture in normal situations and critical cases like COVID-19.

5.2. Promising solutions by blockchain for the agricultural supply chain during COVID-19

This study obtained several solutions from the interviews that have been conducted. Interviewees suggested solutions by using blockchain technology for agricultural supply chains during the COVID-19 pandemic. Fig. 9 shows promising solutions for the agricultural supply chain during the COVID-19 pandemic because of the many benefits it brings by using blockchain technology.

(1) *Tracing from farm to shelf.* Blockchain technology helps farmers to deliver seeds to market. Also, retailers and consumers have become able to authenticate the validity of each supply easily during COVID-19. With the help of blockchain technology, food producers can provide comprehensive information to consumers about where these products come from. This technology acts as an irreversible online technology to record information that is the basis of cryptocurrencies like bitcoin. In this era of technological advancement, some manufacturers are adopting blockchain technology, but many are still slow in adopting it.

(2) *Transparent supply chains.* Blockchain technology helps disseminate various agricultural companies' information from cultivation to shipping recorded in an unmatched ledger. Blockchain can significantly advance the supply chain by enabling a faster and more cost-effective supply of products, increasing product traceability, improving coordination among partners, and helping go into financing. When blockchain is used to record information, assets such as loans, bills, inventory elements, and orders are assigned with a unique identifier, which functions as a digital token. Each actor on the blockchain is assigned a unique identifier, which is also called a digital signature. Interviewees use this identifier to sign the blocks they add to the blockchain. Each stage
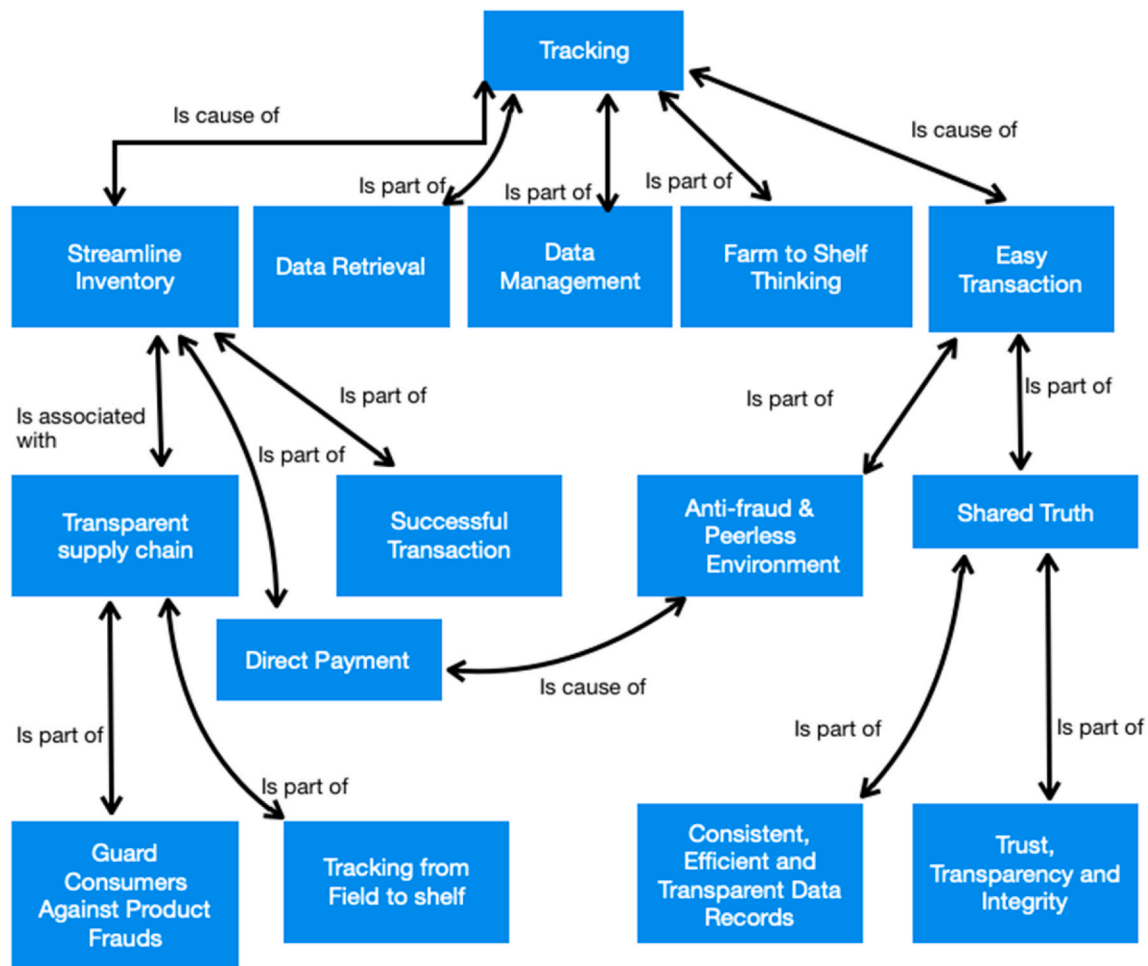
Fig. 7. Data displaying the relationship between benefits and solutions.
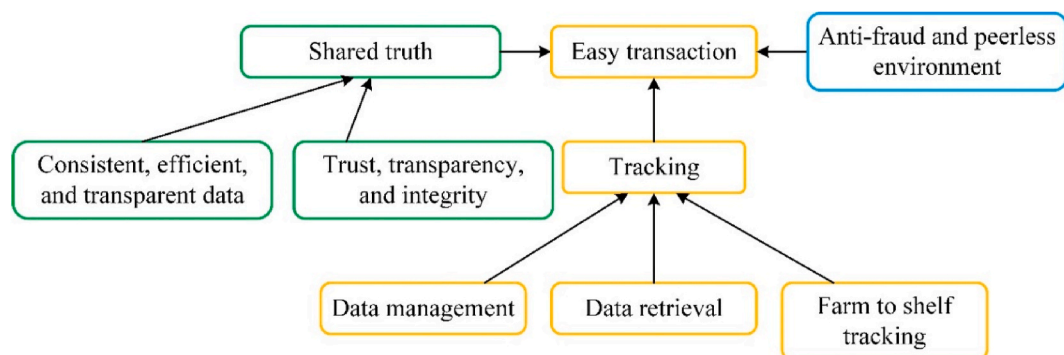

Fig. 8. Blockchain-related benefits to agricultural supply chains during COVID-19.

of the transaction is then recorded on the blockchain, matching the token from one actor to another.

(3) *Direct transactions or payment.* With the help of blockchain technology, payments are made in an anti-fraud environment where transactions are cryptographically encrypted, and the entire network validates them. The company found that the private blockchain they created had significantly decreased transaction fees. Keeping records of current transactions is an essential operation in the agricultural business. These records help companies to track their past actions and performance and guide them for the future. With the help of these records, companies can see how they are working internally and externally with outside organisations. The company has a master ledger that includes all activities. Others can access it, which helps the company automatically verify whether the assets are owned by the respective companies and can be transferred. No mediator is required to be a guarantor regarding assets because transaction records pass through the organisation through the main leader where the records are not updated personally.

(4) *Efficient or streamlined inventory management.* Blockchain technology can help manage inventory efficiently and control every asset in-store with the help of a digital identity system, where counterfeiting is becoming a challenging endeavour. Every transaction that goes into the blockchain is unmatched and
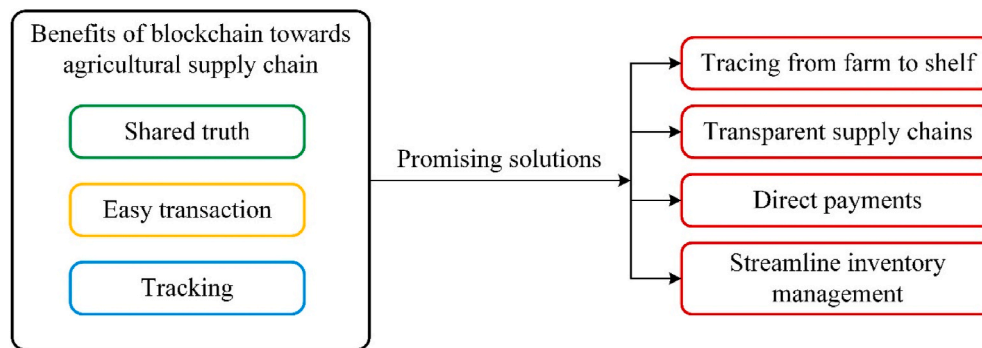
Fig. 9. Promising solutions for agricultural supply chains during COVID-19.

without fraud. The distributed record system creates transparent networks so that the people involved in managing the inventory can work honestly. With the blockchain, total transparency in the network is achieved, generating trust among the people involved and helping them trace the specific path of the item with details of origin. By monitoring everything in real-time, it is much easier for company employees to deal with excess inventory, clean stock, and help reduce employee errors. With the help of efficient inventory via blockchain, companies easily calculate inaccuracies by helping them reduce costs and maximise profits.

5.3. Blockchain benefits to provide solutions for agricultural supply chain during COVID-19

Global food supply chains became rigid throughout the COVID-19 pandemic, generating the need to uplift the flexibility of agricultural supply chains with the help of enhanced efficiency in agriculture product manufacturing, dispensation, and consumption. Now the question arises: how can blockchain, where data is directly provided to the relevant person (producer, distributor, and consumer), plays its part in providing a solution?

It is found that the agriculture companies of Pakistan used blockchain technologies for consolidating the information related to the seed quality, for tracking the information regarding the growth of the crop, and for accounting for the journey after it departs from the farm. It is further experienced that by laying out unchangeable records from manufacturing to consumption, the information through blockchain has increased the supply chain transparency. With the help of such data, the transfer of information is facilitated throughout the supply chain process. Based on the interviews' views, it is concluded that through comprehensive validation of blockchain technology, a wide range of illegal and unethical ways of production and distribution can be prevented, ultimately ensuring sustainability and supply chain security. The interviewee shared their opinion about the benefits of blockchain that acted as a solution provider for them and helped them resolve the various agricultural supply chain challenges during the COVID-19 pandemic. Table 2 shows the real-world agricultural supply chain challenges, the solutions provided by blockchain during the COVID-19 pandemic, and the response frequency for the reported solutions by the CEOs of the companies.

As shown in Table 2, blockchain technology helped organisations build their agricultural supply chain capabilities in situations like COVID-19 pandemics. Through blockchain, the organisations managed to overcome the crucial challenges that emerged during the crisis. It is seen that all 4 CEOs mentioned the challenge of tracking the shipment in COVID-19 and product/transaction frauds. 100% of the respondents mentioned blockchain as a solution for these challenges. 75% of the respondents mentioned the challenge of lack of data retrieval and data management and the Inflexible international supply chain in COVID-19 besides their solutions.

Table 2
The benefits and solutions provided by blockchain to handle the agricultural supply chain challenges during COVID-19.

Real-world agricultural supply chain challenge	Solution	Response Percentage
No competent and transparent system to track the shipment during COVID-19	Through the blockchain traceability feature, payments are formed and received directly without any third party and lengthy process involved. Hence tracking from field to shelf become convenient	100%
Lack of data retrieval and data management	Through blockchain data traceability feature, data/ information can easily be obtained related to supply chain from provenance to shelf	75%
Product and transaction frauds	Through blockchain, farm to shelf tracking characteristics, anti-fraud and peerless environment is successfully managed to perform the transactions during the COVID-19 situation.	100%
Inflexible international supply chain	Through the blockchain characteristics of trust, transparency and integrity resilience is improved.	75%

Table 3 shows three significant organisational and technological capabilities built using blockchain technology for the agricultural supply chain management. The reported capabilities are transparent supply chain, anti-fraud environment, and flexible international supply chain. With such capabilities, the supply chain industry will strengthen its operations even during situations like COVID-19 and similar.

6. Conclusions

This study reports on the benefits of using blockchain technology for agricultural supply chains and the promising solutions experienced by farmers during the COVID-19 pandemic. The research results show that successful agricultural business enterprises can carry out their duties effectively and efficiently through blockchain technology. This result is due to blockchain technology providing many benefits such as secure transactions, prevention of product fraud, trustworthiness, transparency and integrity, easy data retrieval, and traceability. Blockchain technology supports supply chain management can offer data transparency in the recycling process. Multiple entities in the supply chain can access similar data and information even if they are not actively sharing tracking systems. With the solution in place, recyclers can track waste as it moves through the chain, and major stakeholders in the agricultural supply chain can compare their recycling efforts. The significant novelty of the study is defined as follows:

Table 3
Organisation capabilities provided by blockchain to handle the agricultural supply chain challenges during COVID-19.

Real-world agricultural supply chain challenge	Solution	Organisational, technological capabilities
No competent and transparent system to track the shipment during COVID-19	Through the blockchain traceability feature, payments are formed and received directly without any third party and lengthy process involved. Hence tracking from field to shelf become convenient	Transparent supply chain
Lack of data retrieval and data management	Through blockchain data traceability feature, data/information can easily be obtained related to supply chain from provenance to shelf	
Product and transaction frauds	Through blockchain, farm to shelf tracking characteristics, anti-fraud and peerless environment is successfully managed to perform the transactions during the COVID-19 situation.	Anti-fraud environment
Inflexible international supply chain	Through the blockchain characteristics of trust, transparency, and integrity, resilience is improved.	Flexible international supply chain

- This study is a novel attempt to investigate the benefits of blockchain technology application for the agricultural supply chain during the COVID-19.
- It provides solutions to the issues in the agricultural supply chain and improves them.
- This new investigation might contribute to the scientific progress of research in blockchain technology, particularly in the boundary of agricultural supply chains.

This study investigated the benefits and solutions of blockchain technology applications used for cleaner and more sustainable agricultural supply chains. It makes several significant contributions to knowledge and practice. From a scientific point of view, this study would enhance research growth in blockchain implementation for agricultural supply chains. The study could give an advanced understanding of blockchain technology applications in the agricultural industry. It can revolutionise the industry by solving the existing problem of agri-product fraud, its traceability, price manipulation, and lack of customer trust in the product.

The study could motivate the agricultural business sector to use blockchain technology. In conclusion, blockchain technology can effectively solve agricultural business enterprises during the COVID-19 pandemic, where everything is locked down. The COVID-19 crisis has given a decisive boost to the innovation of processes in the agricultural supply chain, especially customer interactions. Building trust between trading partners, providing end-to-end visibility, streamlining processes, and resolving issues faster with blockchain add to stronger, more resilient supply chains and better business relationships. Participants can act sooner in the event of disruptions. Blockchain can help ensure food safety and freshness in the food industry and reduce waste. In case of contamination, food can be traced back to its source in seconds rather than days. According to recent statistics, 23% of respondents cited value chains and new business models as the main reasons they adopted blockchain. Another 23% claimed they would do so for a higher degree of security (Petrov, 2021).

This study has several limitations, which are reported here. Researchers conducted conventional interviews, which took longer (for hours). It is difficult to check the flow of answers to the interviewee because the discussion provided has become too broad. Additionally, this study had fewer interviews due to the limited number of agricultural companies practising blockchain. It would be better for future studies to add the sample size to the survey to produce a more comprehensive analysis.

This study can be extended in the future by considering the following research directions. The findings of this research work are based on feedback from one agriculture-based country (Pakistan). This study can be extended in the future by involving other countries which rely on agriculture as their economic strength. Comparative studies can be carried out to compare views on the implementation of blockchain technology in agriculture for normal and pandemic situations. Another study could also propose a framework that guides farmers on overcoming the challenges of successfully implementing blockchain technology in agricultural supply chains by offering strategic solutions.

CRediT authorship contribution statement

Huma Hayat Khan: Conceptualisation. **Muhammad Noman Malik:** Data curation, Formal analysis, Writing – original draft. **Zdeňka Konečná:** Writing – review & editing. **Abdoulmohammad Gholamzadeh Chofreh:** Formal analysis, Data curation, Writing – review & editing. **Feybi Ariani Goni:** Formal analysis, Data curation, Writing – review & editing. **Jiří Jaromír Klemeš:** Formal analysis, Methodology, Resources, Project administration, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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