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Enabling affordances of blockchain in agri-food supply chains: a value-driver framework using the Q-methodology

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Abstract

The application of blockchain beyond cryptocurrencies has received increasing attention from industry and scholars alike. Given predicted looming food crises, some of the most impactful deployments of blockchains are likely to concern food supply chains. This study outlined how blockchain adoption can result in positive affordances in the food supply chain. Using Q methodology, this study explored the current status of the agri-food supply chain and how blockchain technology could be useful in addressing existing challenges. This theorization leads to the proposition of the 3TIC value-driver framework for determining the enabling affordances of blockchain that would increase shared value for stakeholders. First, we propose a framework based on the most promising features of blockchain technology to overcome current challenges in the agri-food industry. Our value-driver framework is driven by the Q-study findings of respondents closely associated with the agri-food supply chain. This framework can provide supply chain stakeholders with a clear perception of blockchain affordances and serve as a guideline for utilizing appropriate features of technology that match organizations' capabilities, core competencies, goals, and limitations. Therefore, it could assist top-level decision-makers in systematically evaluating parts of the organization to focus on and improve the infrastructure for successful blockchain implementation along the agri-food supply chain. We conclude by noting certain significant challenges that must be carefully addressed to successfully adopt blockchain technology.

Keywords*:* Blockchain technology, Agricultural food supply chain, Framework, Adoption, Value-driver, Q-methodology

1. Introduction

This study investigates the potential of blockchain technology in the agri-food supply chain context. The focus is on identifying the challenges and opportunities for implementing blockchain technology to enhance supply chain traceability and transparency. Moreover, we explore the factors that affect the adoption of blockchain technology and the barriers to its implementation.

Over the last decade, the rise of emerging technologies has shown the potential to revolutionize the industrial world, and thus interest in blockchain technology and its applications is growing. Currently, it is well known for the excitement it has aroused regarding today's financial markets and digital currencies, particularly Bitcoin. However, blockchain technology has other functions far beyond cryptocurrencies (Angelis and da Silva, 2019; Bhushan et al., 2021). The variety of applications of this technology in different fields, such as supply chain management, healthcare information systems, e-government, voting systems, smart contracts, and digital signatures, has attracted the attention of early adopters (Laaper et al., 2017; Ølnes et al., 2017; Roehrs et al., 2017; Sullivan and Burger, 2017).

In agri-food supply chains (ASC), in which many players collaborate throughout different stages from farms to supermarkets, some common factors are important (Lin et al., 2017; Tripoli and Schmidhuber, 2018). A large number of members interacting along a supply chain (SC) increases its complexity, leading to a lack of sufficient transparency and subsequent problems (Casey and Wong, 2017). In the agri-food supply chain, the need for more transparent information has intensified owing to food crises and safety scandals that have occurred in recent years, such as trench oil, contaminated milk powder, genetically changed food, and mad cow illnesses (Aung and Chang, 2014). Specifically, after the COVID-19 global pandemic, the need for effective mechanisms to protect food safety and ensure COVID-19-free supply chains has been accentuated (Iftekhar and Cui, 2021). In addition, sustainability concerns are increasing every day, resulting in consumers demanding higher quality and safety. All of these lead to new challenges for companies that need to take effective action through technological integration (Yadav et al., 2020).

We believe that blockchain technology can solve these challenges. Blockchain allows all subscribers of a specific network at any supply chain point to have full access to a transparent ledger that stores complete records of the chain (Korpela et al., 2017). There has been a trend to adopt this technology because it marks a fundamental shift in the mechanisms that can generate reliable, trust-based, and integral infrastructure (Hughes et al., 2019).

The blockchain can manage all supply chain activities in a decentralized independent shared network based on blockchain integrity. Therefore, it eliminates the need to collaborate with other third-party organizations or systems to support communication (Hackius and Petersen, 2017; Secinaro et al., 2021). In addition, blockchain systems can pinpoint the exact location of an item at each point while providing a full record of previous transactions (Sadouskaya, 2016). The consensus capability is another significant feature of blockchains. This implies that if more than half of the network members participate in the authentication of the record process, it is almost impossible to change or tamper with the input data in the network (Apte and Petrovsky, 2016). This guarantees companies a high level of authentication regarding the origins of their products. It also significantly reduces the time and expenses required to detect errors and misconduct while providing organizations with safe and correct data (Bocek et al., 2017).

Considering the increasing complexity of today's food supply chains and the urgent need to increase transparency, blockchain, through its immutable and distributed nature, brings to bear various capabilities to resolve the challenges arising along the entire supply chain lifecycle. Blockchain can directly link different actors in the food supply chain, such as suppliers, producers, processors, distributors, retailers, and consumers. All these supply chain members have unique procedures and applications, and this interoperability and integration, thanks to blockchain technology, can create a traceable and transparent value chain (Lee et al., 2017). All actors in the supply chain can benefit from blockchain's costless verification by eliminating or reducing the costs associated with ingredient certification and product certification (dos Santos et al., 2019).

In some research cases, blockchain has benefitted supply chains and addressed certain issues, such as information inequality and inefficient food recall procedures(Queiroz et al., 2019; Petersen et al., 2018; Zhao et al., 2019). The Food and Agricultural Organization (FAO) estimated that 1.3 billion tons (almost one-third of the produced human food) of edible food is discarded every year as a result of food recalls and spoilage across the entire supply chain (Ishangulyyev et al., 2019). Yiannas (2018) reported that the cost of product recalls can exceed $93 billion if outbreaks cannot be traced back to their root causes. By using blockchain technology, food supply chains can operate more efficiently and recall food with greater precision. A blockchain environment that updates product information in near real-time gives stakeholders better monitoring of product flows and enables them to react to situations more quickly. For example, Walmart discovered that imported fresh products such as mangoes often need to be checked at the border for up to four days (Yiannas, 2018). Rayes and Salam (2017) concluded that compared to traditional ASC, this technique is highly efficient, undergirds high transmission speeds, reduces costs, and significantly improves quality.

However, there are problems associated with the adoption of blockchain technology. Some agri-food supply chain companies may be satisfied with existing legacy systems or deem blockchain services unnecessary. Dominant ASC players are still unclear about the enabling and constraining affordances of blockchain platforms to alter the current supply chain settings and modify the status of technology transition, substantial efforts must be made to fulfil the required criteria and eliminate roadblocks and hardships toward adoption (Gonczol et al., 2020).

Gaps in the research literature suggest that while a number of successful use-cases in development and pilot testing have been reported, fewer application cases on implementing blockchain information systems for the agri-food supply chain have been published. For example, Baralla et al. (2019) proposed a generic traceability system based on blockchain technology for agri-food supply chains that could implement the current "farm-to-fork" (F2F) model and integrate current traceability rules and processes in the European Union. To ensure the origin and provenance of food items in a Smart Tourism Region, Baralla et al. (2021) developed a blockchain-based platform based on agile development and applied software engineering practices to support a general blockchain system. In collaboration with Walmart, IBM developed a Blockchain-as-a-Service (BaaS) food traceability framework, and pilots tested pork and mango traceability in China and the Americas, respectively (Kamath, 2018). The Walmart blockchain solution enhanced visibility throughout Walmart's food supply chain, in addition to reducing the time to track mango origins from 7 days to 2.2 seconds using a farm-to-table approach (Yiannas, 2018).

Darwin, the famous naturalist and evolutionary theorist, and his disciple Huxley (2003) asserted that life forms that have the greatest capacity for environmental adaptation will endure and procreate, whereas species with less capacity for environmental adaptation will eventually become extinct. This understanding of life's evolution and its relationship with modern business demonstrates the necessity for firms to continuously adapt to the shifting preferences and needs of their clients, shareholders, and other stakeholders. To live, they must strike a balance between what they can provide and what the ecosystem needs (Carlisle and McMillan, 2006). This theory is also applicable to the realm of information technology. Technologies would not survive without continuous research, improvements, and training to adapt to changes in the environment and satisfy the ever-changing requirements of stakeholders and customers. This highlights the importance of studying the subjectivity of user experiences in the design of information systems to enhance adaptability. Even the most innovative and high-level technologies would become impractical if their users did not adopt them adequately, despite their hype and promises (Mathieson, 1991). Moreover, to provide insight into the sustainable use of a system for a particular context and user, researchers must identify the subjective requirements of the technological environment (Calvo and Peters, 2014). Thus, the organization can select the system design, evaluate the implemented system design solutions, and improve the solutions (Pawlowski et al., 2015).

A significant portion of IS behavioral research is descriptive, looking for regular patterns in user and IS staff activities. Such descriptive modelling is useful for exploratory studies that result in the development of theories and later hypothesis testing (Bariff and Ginzberg, 1982). Hevner and Chatterjee (2010) suggested a corresponding relationship model between design and behavioral science to address the significant challenges encountered while developing effective information systems**Error! Reference source not found.**. According to the authors, the behavioral science paradigm originates from approaches in natural science research. Behavioral science in the IS paradigm is concerned with developing and validating theories that describe or anticipate organizational behavior and people's reactions to the examination, design, execution, and use of information systems. Finally, these theories let scholars and experts know how communication between humans, technology, and companies should be handled to allow an information system to reach its proposed goals, such as enhancing efficacy and effectiveness within an organization.

Many studies have been conducted on the design, development, and deployment of blockchain-based solutions in agri-food supply chains. However, we believe that the subjective opinions of prospective users have not been appropriately addressed to fully grasp the opportunities and challenges in implementing such systems. Therefore, as a behavioral science study in information systems (IS), this study does not aim to design a blockchain system that works in practice. According to the definition of Bariff and Ginzberg (1982) , Information systems behavioural research tends to be descriptive, searching for systematic relationships among observations of user and IS personnel behaviour. In the field of information systems, the behavioral approach is a growing trend that does not ignore technology but develops non-technical strategies aimed at changing attitudes, management policies, and organizational behaviors related to technology (Laudon and Laudon, 2018).

Overall, this review aims to contribute to a better understanding of the potential benefits and challenges of using blockchain technology in agri-food supply chains and provide insights for practitioners and policymakers considering the adoption of blockchain in their organizations. Our research also shows that the adoption of blockchain technology in agri-food supply chains is not fully mature despite the recent publicity, and the expected values, applications, challenges, and future trends are still under study. Hence, in this study, we propose the following research questions to address the gap:

1. What are the current attitudes toward blockchain adoption for overcoming agri-food supply chain challenges?

2. How could blockchain integrated with IoT potentially enhance the shared value across agri-food supply chain?

3. What are the main challenges that need to be addressed for the successful adoption of blockchain in the agri-food supply chain?

To find an appropriate solution for our research, we performed a meta-analysis of the data reported by Croxson et al. (2019) . In this study, we explore the current state of agri-food supply chains from a new perspective and investigate how blockchain can benefit the agri-food supply chain using Q-methodology; we then use the results to propose our value-driver framework. In other words, this study provides guidelines to improve blockchain technology adoption within different parts of agri-food supply chains from a value-driver framework perspective, driven by our Q-study factor analysis and interpretations and the relevant literature. Our Q-study explored industry experts' attitudes regarding the current status of the agri-food industry, blockchain potential, and the hurdles preventing blockchain adoption within the agri-food industry. Practitioners' beliefs were deemed a proxy for the associated attitude toward the subject of the study.

The remainder of this paper is organized as follows. Section 2 provides a brief overview of blockchain technology and reviews the literature on its application to the agri-food supply chain. Section 3 provides details of our Q-methodology research, including the design of the instruments and data collection procedures. Section 4 discusses the results of the Q-study and analyses the factors affecting the adoption of blockchain technology in the agri-food supply chain. Section 5 uses a value-driver framework to discuss the opportunities and challenges of implementing blockchain technology in agri-food supply chains. Section 6 summarizes the main findings and adducees implications for future research.

2. Review of blockchain adoption

Given its inherent features and ability to revolutionize today's companies' business models, blockchain has been described as a technology that can address various business problems in general. Gonzalo et al. (2020) suggested several advantages of adopting blockchain technology across supply chains. Reducing paperwork and tracking the routes of goods, which stem from the streamlined and transparent characteristics of the technology, are the two main advantages of blockchain technology. Beyond these two well-known advantages, Hackius and Petersen (2017) discussed blockchain's capabilities in facilitating the employment of IoTs by connecting sensors and other digital gadgets at different stages of the supply chain to detect fraud and counterfeit goods. According to Korpela et al. (2017) , the integration capability of blockchain technology has more functional advantages, including tracking alterations or adjustments along the chain, controlling and monitoring all services across the chain via device interoperability, cloud service protection, stable real-time connections and secure access, exchange of information with collaborators, and partner identity control.

The adoption of blockchain technology in the agri-food industry enables affordances emphasized by Kamilaris et al.(2019) , including (i) public access and effective management of the supply chain, leading to reduced costs associated with controlling and maintaining the current supply chain, eventually resulting in price adjustments and offering fair-priced products throughout the whole market; (ii) enabling more support, security, and services for farmers, producers, and small businesses; and (iii) providing transparent digital services and secure transactions and facilitating fair trade around the world, especially in developing countries. The environmental advantages and sustainability issues of implementing the technology such as waste management have attracted the attention of eco-friendly organizations. For example, Kouhizadeh and Sarkis (2018) explored the possibility of turning supply chains greener and explained the multiple factors that lead to process facilitation. Lam and Zhibin (2019) discussed how blockchain's special characteristics can be used to reduce greenhouse gas emissions through greater supply chain transparency during the textile production process. Bottoni et al.(2020) [44] highlighted trust and coordination as being among the main challenges of supply chains, which they strive to address by proposing Intelligent Smart Contracts. According to the authors, fully automated supply chains supported by intelligent smart contacts can significantly increase profitability.

Although blockchain has significant capabilities in optimizing operations and reducing transaction costs, major concerns must be addressed and roadblocks must be removed before executives and top-level decision makers can widely accept this technology. Angelis and da Silva (2019) discussed the managerial concerns regarding technology adoption. They then presented a framework for determining the proper adoption of blockchain by professionals, which discusses the generation of unique values related to particular organizational objectives. Alternatively, using the Design Science Research method, Jahanbin et al. (2019) designed an artifact to address the most vital trust-related requirements and priorities at any point in the agri-food supply chain. We believe that this could help improve the adoption of blockchain-based information systems for real-time food tracking.

Recent studies have identified common problems associated with the adoption of technology. Abeyratne and Monfared (2016) found that a blockchain must be in operation with any actor in the supply chain with a particular IT infrastructure, which may be impossible in distant areas. Korpela et al. (2017) also pointed to the paucity of existing norms for data and digital supply chain record layouts in the supply chain because blockchain is a modern system. Therefore, accepting and conforming to these requirements is essential. At the same time, this adds another degree of difficulty and even inability to adopt for potential users already concerned about implementing new technologies. Furthermore, Sadouskaya (2017) explained that organizations devote years to designing, developing, and improving their supply chains, but the difficulties that inevitably affect them offset the future gains of blockchain. Croxson et al. (2019) noted that while industry analysts agree that blockchain adoption is imminent and will remedy existing challenges, factors such as high setup costs and technical complexities inhibit blockchain adoption.

Some studies have also focused on investigating the expected value, applications, challenges, and future blockchain technology trends in supply chain operations. For example, Zhao et al. (2019) reviewed blockchain technology from a holistic perspective, demonstrating its recent advancements, main applications in agri-food value chains, and challenges, and then outlined some initial blockchain solutions for the agri-food value chain. In another study using thematic analysis, Chen et al. (2021) investigated blockchain technology adoption in food supply chains and conducted a qualitative thematic analysis to identify adoption benefits and challenges. Dutta et al. (2020) examined 178 articles related to blockchain incorporation in supply chain operations and highlighted how blockchain comes into play in SCs, how it can be applied to various SC operations and functions, and its social impact. In a similar study, Jabbar et al. (2021) reviewed state-of-the-art use cases and startups in the blockchain-based supply chain domain and analyzed the challenges and future directions of blockchain applications in supply chain management.

The following section discusses the potential of blockchain technology to improve the agri-food supply chain.

2.1 Blockchain adoption in ASCs

Presently, blockchain affordances continue to attract tremendous interest; however, large-scale implementation is still under development. However, the focus has mainly been on the blockchain technology itself, instead of incorporation, adoption, and implementation issues [1]. Moreover, business decision-makers must find a way to match the requirements of their companies with the services that a blockchain system provides as a solution for enhancing the level of creativity in their services and products and eventually creating much more value.

There are great opportunities and capabilities for blockchain-based solutions that can revolutionize the agri-food supply chain, but their adoption in real-world practice requires more time to reach maturity (Zhao et al., 2019; Ge et al., 2017). Thus far, blockchain technology has not been completely recognized owing to its immaturity, and the desire to use it for tracking and tracing goods in supply chains in conjunction with IoT devices is still in its infancy (Francisco and Swanson, 2018). Using a thematic analysis approach, Menon and Jain (2021) investigated 25 blockchain use cases in the conceptual, proof-of-concept, and commercial stages, arguing that even though blockchain has tremendous potential in the agri-goods supply chain, many enterprises are still developing proof-of-concept or experimenting with the deployment and implementation of technology. Research on the constraining affordances of blockchain technology is ongoing.

However, despite the enthusiasm for and promises of technologies, we cannot expect successful implementation in practice unless it is appropriately adopted by end users (Mathieson, 1991). According to Rogers's theoretical framework of "Attributes of Innovation Framework," which is one of the most commonly used frameworks for the adoption and dissemination of new technologies (Rogers, 2010), "relative advantage" is an essential factor that impacts innovation adoption. "Relative advantage "is the level of awareness at which the idea would surpass the existing systems. Therefore, in the next section, we review the main features of blockchain-augmented information systems that can provide such superiority over traditional systems.

2.2 Benefits of blockchain adaption in agri-food supply chains

We classify blockchain advantages based on the five main features of this technology: traceability, transparency, tamper-evidence, immutability, and compliance (3TIC), and elaborate on each feature's capabilities to generate value in agri-food SC. Legacy supply chains often suffer from a lack of integration of the various systems that constitute the supply chain, which may lead to reductions in transparency, overall efficiency, and, ultimately, supply chain profitability. The following section discusses how the agri-food supply chain can benefit from the 3TIC features of blockchain technology to create value.

2.2.1 Blockchain traceability in agri-food supply chain

Blockchain can decrease the workload and guarantee traceability. It can record the history of all transactions over time, reconstruct records in a straightforward manner, and detect the source of a product. Pizzuti and Mirabelli (2015) believed that blockchain can completely handle traceability frameworks by recording the history of the entire transaction, instantly reconstructing records, and detecting the source of a product. It is helpful to apply blockchain as a traceability solution because it rapidly detects and recognizes a particular item. Although the same outcome can be accomplished in centralized traceability systems, the speed of traceability operations in a blockchain is significantly higher. This speed becomes more imperative when dealing with food products, especially if the food needs to be verified before consumption and the origin needs to be detected quickly. In the case of origin detection, especially in managing contaminated food, the reputation of the business brand could also be preserved (Mejia et al., 2010), and adverse media effects would be diminished (Dabbene and Gay, 2011).

2.2.2 Blockchain transparency in agri-food supply chains

Beske-Janssen et al. (2015) argue that transparency is essential for evaluating supply chain performance. All members cooperating in a supply chain, such as retailers, warehouses, and individual stores, can thereby participate in blockchain transparency benefits. For example, stores can identify information about a freight arrival and make preparations to collect it. In addition, the blockchain, as a distributed ledger, can display information about the land, production unit, shipment number, and storage conditions. Disclosing information in centralized systems is one way to easily achieve transparency. However, in this case, blockchain capabilities in terms of data transparency are more extensive than in centralized systems. According to Martin and Leurent (2017) , the main goal of blockchain is to facilitate information exchange, build a ledger for the data and its workflow, and authenticate food quality standards as it travels throughout the supply chain. These objectives are achieved by letting each party share declarations, proof, and mutual assessments of others' declarations about food. The data stored in the blockchain ledger are visible and accessible to every authorized member.

Blockchain can show who is carrying out what activities in a supply chain where and when. Thus, blockchain can be very helpful in addressing social and environmental concerns owing to its support for traceability and transparency, which can be reinforced by incorporating smart contracts.

2.2.3 Blockchain tamper-evidence in agri-food supply chains

The *Oxford English Dictionary* defines the word *tamper* as "to meddle or interfere with (a thing); to misuse, alter, corrupt, or distort it." Tampering may occur at any stage of a product's life cycle: the producing, processing, logistics, or retail stages (Li, 2013). Tamper-resistant or tamper-evident approaches are employed to protect against tampering (Toreini, 2018). Consequently, Caro et al. (2018) argued that tamper-proofing and data privacy concerns in food traceability have become top priorities for farmers, cold chain managers, government agencies, and consumers. According to Caro et al. (2018) , tamper-proof records are crucial to maintaining trust and reliability across the entire supply chain in the agri-food industry.

Cao et al. (2019) stated that blockchain guarantees truthfulness through proof-of-work, whereby the public blockchain system operates as a transparent, decentralized, and tamper-evident ledger that accounts for the ownership of value tokens. Blockchain ensures that data cannot be distorted or tampered with. The data are instantly accessible to all parties in a reliable and distributed manner and are not controlled by mediators (Salah et al., 2019). Due to blockchain anti-tamper properties, Helo and Hao (2019) and Zhao et al. (2019) stated that blockchain technology provides an effective solution to counterfeiting and quality tracing in agri-food products. In other words, the blockchain offers a new mechanism for stakeholders. For instance, in the farm-to-fork connection, blockchain can help view and update the tamper-proof history of transactions about an agri-food product, resulting in high-quality food, improved fair trade, and quicker fake product detection (Dooley et al., 2018). Because all transactional information related to all parties in the supply chain is recorded in the block and cannot be altered or deleted, researchers believe that it has gained widespread acceptance as a method for solving trust and security problems in information transparency and prevention of data tampering (Ølnes et al., 2017; Galvez et al., 2018; Andoni et al., 2019; Sikorski et al., 2017).

2.2.4 Blockchain immutability in agri-food supply chains

Blockchain immutability is relevant to agri-food products, because agricultural product transactions are exposed to a variety of information management problems. Blockchain technology makes transactions permanently immutable and provides decentralized data, which can smooth data exchange and reduce the possibility of manipulation and corruption (Francisco and Swanson, 2018).

Ahmed and Broek (2017) argued that immutable food data and transaction registers could help protect producers and distributors from fraud, identify sources of foodborne illnesses, and facilitate data sharing between entities. Furthermore, Yadav et al. (2021) assumed that because blockchain is a decentralized and immutable database, it could also work well as a settlement platform in agri-food supply chains via smart contracts. Furthermore, the immutability of data in blockchain prevents paperwork forgery and improves its accessibility. It contributes to the traceability, provenance, and certification of agri-food products (Yadav et al., 2021). In addition, according to Lin et al. (2017) , integration of blockchain with agricultural and environmental monitoring data stored on a distributed cloud enables sustainable agrarian development that is secure and trustworthy.

Kamble et al. (2020) investigated the capabilities of blockchain-enabled traceability in agri-food supply chains, finding immutability, provenance, traceability, and suitability to be among the most outstanding blockchain technology features of agri-food SC. Motta et al. (2020) analyzed six case studies in the agri-food domain and compared them to identify standard and discrepant features. They concluded that trust, immutability, and redundancy were the most frequently cited characteristics of blockchain technology in academic and industrial reports. Furthermore, all the case studies linked blockchain to cryptography, immutability, and redundancy.

2.2.5 Blockchain compliance in agri-food supply chain products

Using "smart contract" blockchain technology can allow certain activities to automatically run according to predefined regulations. The speed of the process is increased by assigning runtime executions to smart contracts rather than to the entire system. Simultaneously, blockchain technology enables compliance in a straightforward manner by allowing the safe and secure sharing of private data. Blockchain technology can support regulators and guarantee the execution of regulatory standards. This is realized through blockchain's contribution to the compliance process progress, as blockchain can support compliance experts in controlling the appropriate implementation of intricate regulations (Elkaim, 2019). Javaid et al. (2019) stated that blockchain technology enables straightforward compliance by allowing private data distribution using a safe and protected method. Blockchain automation can also facilitate Industry 4.0. According to Yu and Schweisfurth (2020), Industry 4.0 adoption is also more likely to occur in companies with high levels of process automation and a variety of products.

In an agri-food supply chain, blockchain technology creates transparency and stores data for all production and processing activities. Simultaneously, it guarantees compliance with agri-food product standards and improvements in sustainability. Benefits of blockchain will accrue to companies and governments by allowing them to trace and control noncompliance with international standards, enabling them to monitor farm and animal health status to sustain disease-free status. Furthermore, competent central authorities must issue and export certifications easily, rapidly, and assertively. Nearly all the required information about the products is recorded in the distributed ledger, and certificates can be issued automatically (Tripoli and Schmidhuber, 2018).

Despite the promising capabilities of this technology, its use of blockchain technology in the agri-food supply chain is still in its early stages and it is thus considered a developing technology (Araballi and Devaki, 2022). Although there have been several pilot and proof-of-concept projects, the implementation of blockchain in the agri-food industry remains limited. The most recent research shows that blockchain technology implementation in agri-food supply chains faces challenges. We point out a few major challenges. Menon and Jain (2021) revealed that technology is still in the exploratory and testing phases, with several enterprises still developing proof-of-concept or experimenting with deployment and implementation, while there is ongoing research on challenges that impede blockchain technology implantation. In addition, research shows that there is still ongoing research on the possibilities, potential values, limitations, and challenges of blockchain implementation in the supply chain.

3. The research methodology

In this study, the Q-methodology is used to identify a spectrum of distinct perspectives among the study participants. Q-studies use participants to provide measurements about the concourse structure, just as an R study collects variables to understand the population. In Q-studies, there is a population of statements against which people are measured. Factor analysis is then performed to identify variables that cluster together. This population is measured using these variables to identify individuals who could effectively measure these factors. In the same way that researchers perform factor analysis in R studies, Q-studies identify the variables of interest. In other words, in Q-methodology, the concourse is the population, and people are variables that model aspects of the concourse (Watts and Stenner, 2005).

Given the nature of our research questions, we adopted a grounded theory approach to investigate this relatively unknown topic. We believe that the Q-methodology is an appropriate method to employ because it is well suited for providing information on an initial set of noteworthy issues in applying blockchain in agri-food supply chains. The Q-methodology's central principle allows investigators to explore the spectrum of human subjectivity to reveal the structure of discovered thoughts and perceptions about the subject of the concourse (Dennis, 1986). Q-methodology can identify people's viewpoints and their influence on incentives, aims, drivers, and decisions, which cannot be discovered using other research approaches (Exel and Graaf, 2005). This section aims to discover the perspectives of agri-food industry experts on blockchain adoption. Using this method, we can concentrate on participants' subjective notions about issues regarding blockchain adoption in agri-food supply chain companies and develop preliminary theories.

Our study of the body of literature points to the need for a comprehensive theoretical framework that connects blockchain features to their potential benefits and consequently contributes to the representation of blockchain capabilities in the agri-food value chain. Furthermore, advancements in experimenting with deployments and implementations or developing novel blockchain-enabled systems in agri-food supply chains open new avenues for illuminating the potential and capabilities of improving associated operations. We believe that focusing on blockchain advantages that maximize shared values will help agri-food supply chain stakeholders better understand the opportunities for adoption.

3.1 The Q-study concourse and Q-statements

This step in Q-methodology is concerned with defining the concourse in a blockchain-enabled agri-food SC. "Concourse" refers to the communicability flow surrounding a specific subject and involves all possible participants' feelings and views regarding the subject (Brown, 1993). In this study, a concourse is defined as the values and challenges in a blockchain-enabled agri-food supply chain. Subsequently, the research concourse was used to develop our Q-statements, which were categorized into four groups: (i) the existing situation of supply chains in the agri-food industry, (ii) blockchain usefulness across agri-food supply chains, (iii) challenges of blockchain adoption in agri-food supply chains, and iv) opinions on blockchains from the agri-food industry point of view. The Q-statements were then refined, selected, and classified within these groups to create a functional framework to meet two goals: engaging the respondents in the concourse by means of their operations with the Q-sorts, and helping us explain the extracted factors according to our theoretical definition of the concourse.

3.2 Q-study implementation

An online tool, "Qsortware," was used to collect data. The participants in this Q-study needed to satisfy a few conditions to qualify for participation in the survey: They must have worked in the agri-food industry for at least six months and be at least 18 years old. The process of identifying potential individuals and inviting them to participate in the survey was conducted using two channels: first, by sending survey invitation emails to agri-food companies across New Zealand, and second, by presenting the research in agricultural e-business forums. Table 1 displays the demographic data of the 27 participants regarding their knowledge of blockchain technology, job titles, age, and experience in the agri-food supply chain. We used the PQ-method software to analyze the Q-sort data. The PQ-method software was primarily developed to implement the process of Q-study data analyses and is favored by many Q-methodology researchers owing to its comprehensive tools for analyzing factors and its ability to help with the interpretation and explanation of Q-sorts (Exel, N.J.A. and G. Graaf, 2005; Klaus et al., 2010).

3.3 Q-study factor analysis and interpretations

In our Q-study analysis, a correlation matrix was initially generated by measuring the intercorrelation between each Q-sort and other Q-sorts. Using the Kaiser-Guttman principle, Centroid Factor Analysis (CFA) extracted seven factors from the correlation matrix that retained seven factors with eigenvalues greater than 1. Then, to determine the appropriate number of factors in the CFA solution, we applied two additional parameters proposed by Brown (1980). The first factor includes certain variables that yield at least two significant factor loadings after factor extraction. The second parameter is Humphrey's rule (Brown, 1980), which advises retaining a factor only if twice its standard error is less than the cross-product of its two highest loadings (ignoring sign). Finally, five factors meeting the aforementioned parameters were obtained. However, running a five-factor solution with CFA in the PQ method resulted in no Q-sorts loading on the fifth factor. Hence, we adopted a four-factor solution that showed at least three exemplars for each factor.

Table 1 - Respondent Demographics

	Freq	% of total
Experience in Agriculture Industry		
6 months–2 years	9	33.33%
2–10 years	7	25.93%
Over 10 years	11	40.74%
Job title		
Agri-business owner/executive	4	14.81%
Agri-sector research, development, or education	5	18.52%
Agri-sector consultant/specialist	7	25.93%
Agri-sector manager	3	11.11%
Agri-sector professional otherwise not mentioned	8	29.63%
Perceived knowledge on blockchain technology		
Low	11	40.74%
Medium/low	7	25.93%
Medium	7	25.93%
Medium/high	2	7.41%
High	0	0.00%
Age		
18-30	8	29.63%
31-45	10	37.04%
46-60	6	22.22%
61+	3	11.11%

Table 2 – Statements and Factor Arrays

No.	Category	Statement	Factor 1	Factor 2	Factor 3	Factor 4
1	The current state in agri-food SCs	Provide sufficient transparency	−2	−1	0	−1
2		Provide sufficient traceability	−1	0	0	1
3		Are cost effective	2	2	−1	−1
4		Can provide consumers with their required level of proof	0	−1	2	0
5		Can meet current certifications/audit requirements	2	3	1	2
6		Is not vulnerable to human error	3	1	0	2
7	Benefits of blockchain adoption in agri-food SCs	Helping to meet certification requirement compliance	3	0	3	2
8		Lowering administration costs through automation compliance	3	1	−1	−2
9		Removing issues of third-party compliance	−2	−2	−2	−2
10		Providing accurate and real-time tracking of goods traceability	1	3	3	1
11		Immutable transactions provide consumers immutability and tamper-evidence with a higher level of proof	−1	2	1	3
12		The benefit is worth the risk: Providing a competitive advantage over other businesses	−1	−2	−1	0
13	Hurdles in blockchain adoption in agri-food SCs	It seems too complicated	0	0	2	3
14		There are not enough other organizations using it	−2	2	3	1
15		Involves excessive set-up costs	1	3	1	2
16		Will still be open to manual data entry errors	3	−2	1	0
17		Will create too many extra problems	−1	0	−1	−2
18		Will not be able to meet compliance/audit concerns	2	−1	−2	−2
19	The personal opinion on blockchain implementation in agri-food SCs	Blockchain implementation in the industry is inevitable	1	2	2	−1
20		Blockchain technology excites me	0	−1	2	3
21		Blockchain technology is talked about often within the industry	1	−2	0	3
22		I have a good understanding of how blockchain works	0	1	−2	1
23		I would encourage my company to adopt blockchain technology	−2	1	−2	0
24		Agri-food industry is generally open to new technology and systems	2	3	3	−2

Next, we applied Varimax rotation, followed by judgmental hand rotation. Finally, the PQ method created a factor array for each factor. In a factor array, the significantly loading sorts are merged into one single "average" Q-sort that is representative of the shared perspectives of the study participants, for in fact a factor array is a single Q-sort generated to represent the perspective of a specific factor (Watts and Stenner, 2012). In this study, we used the factor arrays created by CFA for factor interpretation (Table 2). The shaded cells represent the top four ranked statements for each factor.

Q-methodology interpretation entails the development of a set of short explanations that clarify and help to better understand the point of view stated by each factor (Watts and Stenner, 2005). In this step of the research, we present the results of the analysis of the research factors (also recognized as "types" in the Q-methodology context) obtained through the former step. In this section, we develop theoretical explanations for these factors using abductive logic by referring where appropriate to the four theoretical categories used to develop the Q-set (Table 2, Column 2). Abductive reasoning suggests the most probable theory that explains a phenomenon, which is the inference informed by the factors discovered through Q-sort factor analysis in the domain of our Q-study. Abduction is a subjective way of reasoning about things that may be intuitively true but cannot be demonstrated or disproven by experiments or observation (Wingreen et al., 2020). According to Stephenson, factor analysis performs the same function as Peirce's logic of abduction, which allows the generation of new hypotheses through experimentation (Brown, 1980).

3.3.1 Factor 1: Regulation-centered

Factor 1 consists of four exemplars that make up 10% of the study variance. Table 2 displays the high-ranking statements for this factor. The rankings indicate that people with this factor believe that current food supply chains are not vulnerable to human error. In addition, the most important benefit of blockchain adoption in the agri-food SC is in helping meet certification requirements compliance and lowering administration costs through automation compliance. This ranking indicates the importance of facilitating administrative tasks and improving certificate authentication. Individuals with this perspective also believe that the most important factor preventing blockchain adoption is that it remains open to manual data entry errors. However, we speculate that people with a Factor 1 attitude may not be aware of blockchain's potential in integrating IoT devices and smart contracts to enhance automation accuracy. Generally, this factor reflects how, for many people, blockchain technology's regulation and compliance-driven prospects are the most influential factors in its adoption.

We theorize that Factor 1 potentially demonstrates practitioners' views of agri-food SC companies that trade with markets beyond national borders; thus, fulfilling international standards and authorizing certifications is essential in their global market. These companies are aware of the environmental, financial, and social side effects of the supply chain and concentrate on meeting standards to acquire a competitive advantage. Although this group supports automation compliance, its Q-sorts reveal that they are not confident in the capabilities of blockchain technology to eliminate intermediaries and inherit their duties. Individuals with this perspective are unlikely to be pioneers. They tend to be averse to the risk of implementing blockchain unless it is widely used and has proven its functionality.

3.3.2 Factor 2: Cost-effective solution seekers

Factor 2 makes up 12% of the research variance and includes seven exemplars. The top priorities for this factor indicate that its exemplars believe that the current state of the agri-food SC is good enough to deal with certifications/audit requirements, while the most important benefit of blockchain adoption in the agri-food SC is the ability to provide precise and real-time tracking and traceability of products. This observation emphasizes the importance of the traceability and transparency features of blockchain technology for people with Factor 2 perspectives in the food supply chain. In addition, while they admit that the entire agri-food industry is open to new technology and systems, they believe that the current state of the agri-food SC is cost-effective and consider the high set-up costs of blockchain a roadblock that needs to be seriously addressed to pave the way for its adoption. We argue that while those with this factor perspective appreciate the improved traceability and trackability capabilities of blockchain, users may not be willing to undertake the high risks and expenses of technology deployment. Hence, they seek more cost-effective measures that enable trustworthy authentication of agri-food product provenance.

We may theorize that Factor 2 pertains to Small and Medium Enterprises (SMEs) with a limited budget for technological investment, for whom the technology would constitute a significant investment to keep up with cutting-edge technology that does not fit their strategic plans. Price and ease of use are the two primary factors for technology acquisitions (due to restrictions on capital expenses and having less experienced IT staff, respectively). Additionally, these companies would prefer to enjoy the pay-as-you-go subscription model for IT services. Therefore, decision makers with this attitude are often inclined to concentrate on cost reduction and ease of use of the solution, providing traceability and transparency across the supply chain. These companies' concerns can be addressed through workshops and training programs for the followers of pioneering enterprises in blockchain deployment.

3.3.3 Factor 3: Collaborative controllers

Factor 3 is the most dominant factor in this study, accounting for the highest common variance (18 %), represented by 10 Q-sorts. We can see in Table 2 that the top priorities for this type point to the ability of blockchain to help meet certification requirement compliance, as well as accurate and real-time tracking and traceability of goods. This leads to the integration of compliance, traceability, and transparency as primary value drivers that play the most crucial role in blockchain adoption in the food supply chain. However, individuals with this factor perspective believe that current organizations in the food supply chain are optimistic about blockchain potential and are inclined to improve and update their current traditional systems and technologies. However, they may also believe that a lack of a sufficient number of organizations integrated into blockchain systems is one of the most significant hurdles to adopting this technology. This interpretation of people with the Factor 3 perspective implies that among the most critical challenges in adopting large-scale blockchain solutions are stakeholder management and the need to gather unlikely collaborators and competitors together to jointly tackle challenges.

According to this factor, the lack of transparency and traceability is the major challenge encountered by supply chains. People with this perspective were also the most knowledgeable of all the groups in this study on blockchain technology. They also agreed that blockchain's compliance-based ability to help meet certification requirements would be the most significant potential benefit. It is theorized that individuals with the Factor 3 perspective reveal the ambition of larger enterprises that have already started to learn about blockchain, thinking of creating architecture, developing proofs of concept, or experimenting with deployment and implementation.

People with the Factor 3 perspective also believe that involving many third parties in authorizing certifications and standards increases the complexity of the system and diminishes data transparency, thereby threatening the accuracy and integrity of shared data. This observation reflects the absence of trust in existing certification authorization measures. Blockchain can be a solution to control the fraud and corruption present in current systems. Therefore, in their view, eliminating the human workforce and replacing it with technology might be a suitable solution to prevent malicious manipulation of data, besides enhancing tracking and tracing capabilities. It also reduces the costs of administrative tasks and paperwork. Overall, we hypothesize that the Factor 3 group consists of people belonging to influential organizations whose mission is to become market leaders by employing cutting-edge technologies. They possess sufficient budgets and facilities to invest in emergent technologies and create competitive advantages in the market.

3.3.4 Factor 4: Food data security improver

Factor 4 had three exemplars and explained 10% of the variance. This factor exclusively had the highest priority for immutability and tamper-evidence features; in other words, the security-enhancing capabilities of blockchain technology that improve blockchain adoption in agri-food SC. People with this attitude may believe that the immutability of transactions provides a higher level of proof of consumers' immutability and tamper-evidence needs. Additionally, they may be concerned about counterfeit agri-food products that can tarnish a brand's image and break consumer trust, in which regard blockchain immutability and tamper-evidence solutions may be effective. However, they argue that blockchain is too complicated for small-to-medium-sized companies. This complexity may account for the technology and knowledge required for implementation and use. This factor suggests that the excitement and focus of businesspeople's everyday discussions might be the key to unlocking the potential benefits of blockchain in agri-food SCs.

People with a Factor 4 perspective are interested in and enthusiastic about how blockchain deployment works in the agricultural food industry. However, they are not as risk-tolerant as the pioneers in this regard. While they are concerned with providing their customers with the required level of proof to enhance information trustworthiness, their conservative approach leads them to prefer to follow peers who successfully implement the technology. In addition, regarding the lack of inclination to innovate in the agricultural industry (Table 2, statement 24), there was a considerable difference between this group's opinions and the beliefs of the other three groups. This study has not clarified this problem, which may affect the future adoption of blockchain and other disruptive technologies for people with this factor perspective.

3.4 Summary discussion of the factor types

Overall, the results of our analysis demonstrate that senior managers and decision makers confirm that the current challenges of the agri-food industry can be tackled by incorporating blockchain technology. According to practitioners and top-level decision-makers, blockchain may be a solution to the current challenges of the agri-food industry. Despite the advantage of providing transparency, the business case for blockchain deployment is not always evident, considering the huge costs and demanding skillsets involved. Furthermore, the Q-study results demonstrate how few organizations are currently inclined toward the risk of blockchain adoption, given the high cost of infrastructure and implementation, vague benefits, and the relative immaturity of blockchain solutions to agri-SC problems. Nevertheless, these factors indicate a positive attitude toward blockchain adoption, implying that many companies are optimistic and open to upgrading traditional systems and migrating to blockchain-based collaborative solutions.

The high rating of "not enough other organizations using blockchain" was a consistent theme among all four groups and was considered an issue that could hinder adoption. Another roadblock to adoption was the high setup cost, which was highly prioritized across the different groups. Cooperation between different players in the industry as a collaborative blockchain partnership is a possible solution for coping with these challenges. This collaboration aims to decrease setup costs and reduce the possibility of other companies rejecting the technology. In addition, our study reveals that the average level of blockchain knowledge in agri-food organizations is minimal. The reason might be that business expertise and blockchain knowledge are rarely found jointly within organizations. This suggests the possibility of an industry-wide service or consulting market for these professionals that would make it possible to merge knowledge bases and encourage the involvement of smaller enterprises and individuals with lower technological expertise.

All the factor groups disagreed almost equally with the removal of third-party compliance from current systems. We should seek the roots of this argument in their hesitation regarding blockchain technology's ability to take over the responsibilities of intermediaries and assign duties to smart contracts to be executed faultlessly. This lack of confidence is entirely reasonable because the current grasp of blockchain and knowledge about its potential are limited for most agri-food industry experts, and blockchain deployment in the industry is not yet fully mature. It is also possible that people in the agri-food industry have become accustomed to the services provided by intermediaries or acknowledge that their intermediaries provide value, and are therefore reluctant to implement blockchain if it will result in disintermediation of the supply chain.

The results of our Q-study explored four major factors or mainstreams of thought, and all factors emphasized one or more 3TIC value-driver components for blockchain adoption in agri-food SC. For example, Factor 1 was associated more with blockchain compliance, and people with Factors 2 and 3 perspectives mainly emphasized real-time product traceability and information transparency. Factor 4 attitudes are primarily related to enhanced information immutability and tamper-evidence for enhanced food safety and security.

Our empirical evidence confirms that the issues of insufficient financial and human capital and knowledge resources pose challenges in adopting blockchain. However, the vast majority of agri-food industry experts admit that keeping up with technological advances is inevitable to maintain competitive advantages, even though many supply chain actors might show resistance toward the changes in their traditional information systems. One reason for this resistance could be the lack of awareness and clarity regarding the potential benefits of blockchain as an emerging technology. In addition, enterprises experimenting with deployments and implementations or developing proofs-of-concept have not yet disclosed information about their experiences.

Thus, as a result of the analysis of the empirical data and relevant literature, it is hypothesized that (i) the lack of knowledge about blockchain-driven benefits and inappropriate matching between benefits and organizations' needs, capabilities, and limitations increase the possibility of failure in adoption. (ii) In addition, besides recognition of its advantages and opportunities, the successful adoption of blockchain is subject to the precise consideration and scrutinization of implementation challenges and barriers.

Therefore, clarifying blockchain capabilities in the agri-food supply chain to show how it restrict opportunistic behaviors and improves cooperation to meet mutual interests would be helpful in blockchain adoption. Furthermore, to make blockchain adoption for agri-food supply chain applications more successful, there must be a critical evaluation of both technical and non-technical challenges. Therefore, in the next section, we present a value-driver framework to highlight the benefits of blockchain adoption in agri-food SC based on the 3TIC components emphasized in the four factors revealed by the factor analysis. This framework is followed by a discussion of the most significant technical and non-technical roadblocks that must be carefully addressed before blockchain implementation.

4. Value-driver framework for blockchain adoption in ASCs

A value-driver framework is a tool used to identify and prioritize the key drivers that determine the value of a particular technology or innovation in a specific context. For blockchain adoption in the food supply chain, our value-driver framework aims to identify the key factors determining the potential benefits and challenges of using blockchain in this context. Our Q-method results support the proposal of a value-driver framework for adopting blockchain in the food supply chain by allowing us to identify the subjective perspectives of different stakeholders involved in the food supply chain. By gathering the viewpoints of a diverse group of stakeholders, including producers, distributors, retailers, and consumers, the Q-method helped us identify the key factors that drive value for each stakeholder group (research factors). Once the rankings were collected, statistical techniques were used to analyze the data and identify the key factors that drive the value for each stakeholder group. This information is then used to develop a value-driver framework that prioritizes the key factors determining the potential benefits and challenges of adopting blockchain in the food supply chain.

The results of our Q-study support our postulate that the significant enabling affordances of blockchain technology are centered around the 3TIC features. Considering the primary services of blockchain technology, which can be useful in resolving existing challenges in agri-food supply chains, we observed that the five most promising features of this technology were traceability, transparency, tamper-evidence, immutability, and compliance (3TIC). Moreover, the results of our Q-study demonstrate that many benefits of blockchain technology adoption in agri-food SC could be driven by 3TIC features. Nevertheless, the lack of knowledge and clarity regarding blockchain's benefits has raised uncertainties regarding the goals of blockchain adoption. Thus, to tackle this problem, we integrated the findings of the Q-study with academic and industrial literature to develop a value-driver framework based on the 3TIC features of blockchain technology (Table 3).

Table 3. Blockchain-based value-driver framework for agri-food SC

3TIC feature	Value-driver	Reference
Transparency	1. Assuring information quality (accuracy, adequacy, credibility, and timeliness).	Helo and Hao (2019); Sander et al. (2018); Tse et al. (2017); Yang et al. (2017); Liu and Ye (2021)
	2. Improving information sharing and coordination.	Nakasumi (2013; van Engelenburg et al. (2018); Casado-Vara et al. (2018); Zheng et al. (2021); Kramer et al. (2021)
	3. Providing more accurate demand forecasts.	van Engelenburg et al. (2018); Perboli et al. (2018); Ghode et al. (2021)
	4. Improving information transparency market orientation.	Leong et al. (2018); Khaqqi et al. (2018)
	5. Increasing accountability of supply chain participants (Who has done what, and when?).	Tripoli and Schmidhuber(2018); Tse et al.(2017); Nakasumi (2017)
Traceability	6. The ability of real-time tracking and tracing of products (quantity, origin, destination, dispatch date, etc.).	Iftekhar and Cui (2021); Salah et al. (2019); Casado-Vara et al. (2018); Abelseth et al. (2018); Kshetri (2018); Boehm et al. (2017); Tian (2016); Helo and Shamsuzzoha (2020)
	7. The ability to track and trace shipping and transporting means.	Kshetri (2018); Tian (2016); Baygin et al. (2022)
	8. Verifying the details of sales, purchases, and the ownership of products.	Casado-Vara et al. (2018); Khaqqi et al. (2018); Chinaka (2016); Vivaldini (2021)
	9. Verifying order time, lead time, and delivery time.	Yoon et al. (2020); Helo, P. and A. Shamsuzzoha (2020); Ara et al. (2021)
	10. Verifying environmental variables (temperature, storage condition, etc.).	Bocek et al. (2017) ; Kamilaris et al. (2019); George et al. (2019); Alonso et a;. (2020); Pranto et al. (2021)
	11. Verifying information about product shelf life and expiration date.	Leong et al. (2018); Carbone et al. (2018); Menon et al. (2021)
	12. Identifying and monitoring contaminated products to limit the spread of diseases in the case of an outbreak.	Kamilaris et al. (2019); Galvin (2017); Tian (2017); Xu et al. (2022)
	13. The ability to verify product descriptions, recipes, and ingredient data.	Kamilaris et al. (2019); Verhoeven et al. (2018); Hellani et al. (2021)
	14. Verifying information about involved machinery and operations in the previous stages.	Kshetri (2018); Tian (2016,2017); Ahmad et al. (2021)
	15. Transferring customer and consumer expectations and feedback to supply chain actors.	Kamath (2018); Carbone et al. (2018); Carboni (2015); Mazzù et al. (2021)
Tamper-evidence / Immutability	16. Providing a secure, decentralized, platform that protects data against tampering.	Iftekhar and Cui (2021); Hackius and Petersen (2017); Kshetri (2018); Mylrea and Gourisetti (2018); Iansiti and Lakhani (2017)
	17. Preventing product misrepresentation and detecting counterfeit (fake) products.	Perboli et al. (2018); Kshetri (2018); Antonucci et al. (2019); Jayaprasanna et al. (2021)
	18. Facilitating the use of sensors and "Internet of Things" devices to enable automated data capture.	Caro et al. (2018); Kshetri (2018); Tian (2016); Alonso et al.(2020);Tian (2014); Kim et al. (2018);Zheng et al.(2018)
	19. The ability to trade directly between supply chain parties and eliminate third-party intermediaries.	Secinaro et al. (2021); Zhao et al. (2019); Salah et al. (2019); Helo and Hao (2019); Casado-Vara et al. (2018); Zheng et al. (2018)
Compliance	20. Automated enforcement of global rules, business processes, and terms & conditions of an agreement.	Tripoli and Schmidhuber (2018); Kamilaris et al. (2019); Rožman et al. (2019); Khan et al. (2021)
	21. Assuring regulatory support for preventing environmental degradation such as deforestation, air pollution, and CO_2.	Leong et al. (2018); Kshetri (2018); Nikolakis et al. (2018); Badzar (2016)
	22. Protecting workers' rights (child labour, temporary agreement, payment, and taxation).	Gonczol et al. (2020); Abeyratne and Monfared (2016); Kshetri (2018); Venkatesh et al. (2020); Christ and Helliar (2021)
	23. Assuring the implementation of regulations, standards, and Standard Operating Procedures (SOPs).	Kamath (2018); Liu and Ye (2021); Abelseth (2018); Kim et al. (2018); Lucena et al. (2018); Iftekhar et al. (2020)
	24. Assuring food safety and quality standards.	Kamath (2018); Sander et al. (2018); Tse et al. (2017); Carbone et al. (2018); Iftekhar et al. (2020); Tian (2018)
	25. Decreasing transaction fees and reducing processing time, bureaucracy, and paperwork.	Kshetri (2018); Bai and Sarkis (2020)
	26. Eliminating cash and replacing the current banking system with digital currencies.	Caro et al. (2018); Chinaka (2016)
	27. Fairer pricing and trade by connecting members directly to each other and improving information transparency in the marketplace.	Gonczol et al. (2020); Kamilaris et al. (2019); Tönnissen and Teuteberg (2019); Bingzhang, L. and V. Zirianov (2021)

	(“organic,” “fair trade,” “sustainability,” “Halal,” etc.) are genuine.	Nikolakis et al. (2018); Shew et al. (2022)
	29. Facilitating the whole process of integrating new partners in a collaborating network	Pal (2020); Rejeb et al. (2021); Hastig, G.M. and M.S. Sodhi (2020)
	30. Improving automation and decreasing human delay and error.	Jabbar et al.(2021); Habib et al.(2020); Swan (2015); Collomb and Sok (2016); Ciotta et al. (2021)

In this framework, based on the existing literature, we classified potential applications of blockchain adoption based on the 3TIC features and presented blockchain capabilities that can be utilized in various stages of agri-food supply chains to enhance shared value. This framework was developed by incorporating the IoT into blockchain-based solutions and applying blockchain to verify entities and the identities of assets along the agri-food supply chain from production to consumption. The findings in the literature support the ability of blockchains to foster trust and create shared value through increased transparency, traceability, security, and smart contract automation. We may conjecture that blockchain 3TIC features create enabling affordances for reducing distrust, and restricting opportunistic human behavior, arbitrary judgment, and mistakes without relying on trusted third parties.

This 3TIC framework relies on the relevant literature and provides an explicit representation of blockchain capabilities and opportunities for supply chain strategists, which can be used as a guideline for utilizing the most appropriate features of the technology. Hence, this framework can assist senior decision-makers in the agri-food industry to successfully adopt and deploy blockchain-based information systems. Furthermore, using this framework, they can systematically evaluate parts of the organization to focus on and improve their capabilities for adoption. However, the goal of the 3TIC value driver framework is not only to improve the quality of processes involved in the ASC, but also to frame the blockchain 3TIC features in a structured format to help prospective stakeholders achieve the best value chain goals through increased trust, quality, efficiency, and reduced costs and risks. Hence, blockchain technology would be more attractive to stakeholders and collaborators if it operates to reduce existing agri-food supply chain costs in addition to enhancing the effectiveness of its processes.

For example, the trackability-based capabilities proposed in our framework can be employed to identify where fast actions must be planned and, in cases of food failure, to ensure quick recalls and cost savings by preventing further contamination. To maintain the value chain and eliminate product failures, the food supply chain must be more efficient and partner collaboration must be closer(Duan et al., 2020). Moreover, it is crucial to know who has done what, where, and when in the food supply chain, as every step and supplier affects the final product. Therefore, the blockchain-based supply chain enhances cost efficiency through its traceability and security functions(Benton et al.,2018).

Moreover, the effective communication and transparency-based features presented in the 3TIC framework can facilitate inventory level optimization and demand forecasting; thus, one of the most common causes of waste can be avoided (Peña et al., 2019). Excess inventory increases the company’s economic burden, and a loss of sales costs is incurred when inventory is insufficient to meet demand (Perboli et al., 2018). Similarly, in an agri-food supply chain, this framework could be useful for introducing blockchain value drivers that reduce exploitation, bounded rationality, and information asymmetry. Therefore, by improving transparency, the supply chain can become more efficient and unnecessary waste avoided (Duan et al., 2020).

The improved blockchain data security measures presented in the framework could also operate as a guideline for enhancing trust in light of the fact that all transactional information related to all parties in the supply chain cannot be tampered with or misrepresented. In the midst of underlying trust and security issues in information transparency and the prevention of falsified information, blockchain data security has been widely accepted by scholars as a solution (Feng et al., 2020). Therefore, the successful adoption of blockchain immutability and tamper-evident measures should prevent the breaking of trust and decrease the risk of tarnishing the reputation of parties and organizations. By establishing trust, it inherently reduces opportunism and perceived danger, thus reducing monitoring and transaction costs. Trust can thus reduce transaction costs associated with asset specificity, defective information, and bargaining (Kshetri, 2018).

Furthermore, the compliance-based value drivers represented in the framework can provide guidelines for blockchain-enabled ASC systems to increase trust and reduce transaction costs by being decentralized and governed jointly without a single authority. Catalini and Gans (2020) found that eliminating a centrally coordinating entity in an ASC decentralized network can significantly reduce transaction costs and increase the effectiveness of the network. We also believe that successful blockchain adoption will lead to reduced regulatory compliance costs. This framework would thus also be helpful in redesigning the process in a blockchain-enabled ASC. In this way, it would result in reducing third-party costs and risks, simplifying the supply chain management process. Consequently, the digitalization of physical processes can increase speed, reduce interactions and communication, and increase efficiency (Kshetri, 2018). Moreover, reduction in quality verification costs, business process distortions, and ownership transfers among supply chain partners is possible through the successful adoption of blockchain smart contract solutions in the supply chain (Ashley, M.J. and M.S. Johnson, 2018).

In the next section of this paper, we elaborate on some existing challenges confronting the adoption of blockchain technology in agri-food supply chain.

5. Analysis of blockchain challenges in ASCs

A general misconception of blockchain's possibilities inaccurately presents the technology as a silver bullet (Blanchard, 2019). While blockchain technology implementation in the agri-food supply chain may be promising, significant challenges must be considered and aligned with organizational capabilities and potential before implementation. The following are some key technical and non-technical constraining affordances of blockchain discussed in the literature:

5.1 Nascence

Blockchain is a technology with the potential to revolutionize global supply chains; however, a few challenges must be overcome before it can be widely adopted. Initially, as blockchain is still a nascent technology, it is accompanied by many uncertainties and open questions, which means that it has been slow to gain enterprise acceptance (Scully and Höbig, 2019). According to Hughes et al. (2019) , although the blockchain technology has attracted considerable research attention, its adoption in supply chains has been slow in most countries. Furthermore, in the current nascent stage of blockchain development, supply chain decision makers lack clear guidelines for ensuring that unintended consequences are taken into account appropriately and risks are minimized (Hewett et al., 2019).

5.2 Infrastructure and resources

Digitalizing processes are prerequisites for adopting blockchain-based solutions to optimize a company's supply chain efficiency (Köhler and Pizzol, 2020). Supply chains must be fully digitized before blockchain technology can fulfill its potential (Rogerson and Parry, 2020). Consequently, parts of the world that are still developing and lack the necessary infrastructure face problems in implementing blockchain-based solutions (Kshetri, 2018). In the absence of reliable data, there are gaps in the supply chain, allowing questions to be raised about the reliability of all information provided to the end user (Rogerson and Parry, 2020). Moreover, in developing countries, the adoption of blockchain technology is more difficult owing to inadequate digital infrastructure, defective standards, and high labor costs (Astill et al., 2019; Dora et al., 2022), and infrastructural, technological, and economic developments determine the extent to which blockchain deployment in SCs yield benefits (Kshetri, 2021).

Some studies have focused on high investment in blockchain-based solutions. For example, every engaged supplier must use a digital device to record their manufacturing information, which is one of the prerequisites for implementing blockchain technology, while some small suppliers still use pen and paper to keep track of data. However, replacing paper and pens with digital gadgets and providing related training are costly and time-consuming (Chen et al., 2021). In addition, financial support and infrastructure investments are required to integrate all the companies into the blockchain system (Menon, 2018).

5.3 Privacy and security

Privacy concerns relate to the anonymity of counterparts and whether certain information can be shared with certain entities (Scott, 2004). Excessive information openness in decentralized systems may compromise privacy protection (He et al., 2019). There is a risk of user identities being revealed in the blockchain, giving rise to concerns about anonymity and privacy. For example, sensitive information such as production methods may be disclosed in agricultural products. Consequently, striking a balance between confidentiality and transparency can be challenging (Menon, 2018). Moreover, denial-of-service (DoS), spoofing attacks, security threats, Sybil attacks, and double-spending attacks may negatively affect the performance of blockchain and distributed ledger technology networks (Gervais et al. 2016; Kaloudi et al., 2018). Designers and developers must consider the most acceptable security and privacy policies as inherent components in designing and implementing industrial blockchain applications (Etemadi et al., 2021).

5.4 Policy and regulation

The lack of clarity in regulatory standards has been cited as one of the primary impediments to blockchain implementation (Rauchs et al., 2018; Davies and Vermeulen, 2018). Currently, there are no rules governing blockchain technology, and there is a lack of appropriate standards (Chen et al., 2021). Global supply chains function in a complicated global context. As a result, a variety of laws, rules, and organizations are involved. The development of blockchain-related legislation and regulations is complicated by overlapping and competing requests from various national authorities worldwide (Galvez et al., 2018). Therefore, the adoption of blockchain technology for agri-food traceability must be governed by legal and regulatory frameworks for compliance (Feng et al., 2020).

5.5 Interoperability and standardization

Another significant issue is the absence of compatibility with the databases of other businesses, which exposes diverse blockchain systems to various risks of errors and failures. It is difficult to transfer these many data formats from the enterprise system to the blockchain (Nash, 2018a,2018b). Over 6,500 projects are using a variety of blockchain platforms and solutions, most of which are independent, with diverse protocols, code languages, consensus methods, and privacy options (De Meijer, 2020).

Thus, additional work is needed to allow the interoperability of novel blockchain and distributed ledger technologies with older systems, and to make them compatible with existing IT systems(Etemadi, 2021). In addition, many businesses are establishing their own blockchain-based procedures, which lack interoperability because there are currently no standardized integration options (Uddin et al., 2021). It is also crucial that ledger types (e.g., public and private ledgers) be interoperable and standardized. The development of blockchain architecture standards for collaborative trust and data security will enable interoperability among the latest technological solutions (Feng et al., 2020).

5.6 Collaboration

Blockchain technology has been extensively proposed to tackle existing agri-food supply chain challenges that impact trust. However, research shows that human barriers remain among the key obstacles to blockchain adoption, because collaboration with other parties and creating new cross-industry partnerships are essential to realizing the full benefits of blockchain technology. Therefore, all participants in a supply chain must cooperate; this is considered one of the most significant roadblocks to the success of blockchain technology. Moreover, among the most critical challenges for adopting large-scale blockchain solutions is stakeholder management and the resultant necessity to gather unlikely collaborators and competitors to work together to tackle these challenges(Deloitte, 2019).

5.7 Human barriers

Obtaining the staff necessary to adopt blockchain technology is a difficult task for businesses. Users face certain issues because blockchain platforms operate under standards that differ from traditional systems (Yli-Huumo et al., 2016). To better grasp blockchain technology and its deployment, knowledge of business models, technical features, and governance of the technology is required (Toufaily et al., 2021). Although blockchain is a top priority for many businesses, some industry leaders are not familiar with the technology, which might delay its adoption (Jabbar et al., 2020). It is notoriously difficult, for example, to persuade farmers to embrace new technologies because they are primarily risk-averse and resistant to disruptive modern technologies (Whitehead, 2019).

5.8 Scalability

With the widespread adoption of blockchain systems, their scalability becomes a critical issue. Blockchain systems are prone to performance degradation as the number of users increases. Blockchain networks that support food supply chains may need to handle a large volume of transactions, and problems of scalability can be challenging to overcome (Toufaily et al., 2021). For example, the Bitcoin blockchain can process only a few transactions per second, whereas the VISA network can process thousands per second. This scalability problem is particularly acute for public blockchains that are open to anyone, as they are often slow and expensive. Scalability can also be an issue for private blockchains, which are limited by the number of nodes in the network and the computing power of those nodes (Jabbar et al., 2020).

5.9 Environmental impacts

Blockchain technology has the potential to reduce supply chain waste significantly and increase sustainability by reducing inefficiencies and increasing transparency. However, this technology also has an environmental impact owing to its energy consumption. The addition of new blocks to a blockchain requires a significant amount of computing power, which translates into high energy costs. For example, the energy consumption of the Bitcoin blockchain is estimated to be equivalent to that of a mid-sized US town (Bashir, 2017). As blockchain technology becomes more widely adopted, its environmental impact must be considered and minimized.

In short, blockchain technology has the potential to transform agri-food supply chains by increasing their transparency, traceability, and efficiency. However, significant challenges must be overcome before this technology can be widely adopted. These challenges include the nascent state of the technology, infrastructure and resource constraints, privacy and security concerns, policy and regulatory challenges, interoperability and standardization issues, collaboration barriers, human factors, scalability, and environmental impacts. Organizations considering implementing blockchain technology must carefully evaluate these challenges and align their capabilities and potential before implementation.

Therefore, for blockchain to be more effective, users' subjective experiences must be addressed during the system design phase, as well as their acceptance during blockchain deployment. In addition, organizations that do not have sufficient qualified and skilled staff may not be able to reap the full benefits of blockchain technology implementation (Bashir, 2017). Hence, increasing stakeholder knowledge and comprehension of blockchain technology through ongoing professional training programs could be key to improving supply chain adoption (Etemadi, 2021).

6. Concluding remarks

In a digitized agri-food supply chain, it is essential for companies to deliver value, and understanding the value-proposing capabilities of emerging technologies such as blockchain and IoT-based systems can help mitigate the pressure to do so. To this end, our data analysis highlights the need for a continuous exploration and understanding of the status of agri-food supply chain systems from a human perspective. This knowledge should be used to address the challenges faced by the agri-food industry through the adoption of emerging technologies.

The primary aim of our research is to provide new practical knowledge to assist in the design, development, and rollout of strategies and applied projects in the agri-food supply chain. We propose a decision-making framework and support tool that leverages the key features of blockchain technology integrated with the IoT to increase value creation and capture along agri-food supply chains, ultimately improving blockchain adoption. Intuitively, it is reasonable to assume that these principles apply to other domains and use-cases (Kshetri, 2022).

Through a Q-study, we identified four main factors (groups) in the opinions of agri-food industry experts regarding the benefits of blockchain adoption. We then developed the theory that a lack of knowledge and clarification about the technology's promising advantages is one of the main factors preventing blockchain adoption. This theory led to the development of a value-driver framework that can guide the evaluation of the suitability of blockchain technology for the agri-food industry.

Our framework can also be used to support policymakers and CEOs in assessing the necessary improvements for successful blockchain adoption and deployment in agri-food supply chains. However, challenges such as technical and nontechnical roadblocks must be overcome before blockchain can be implemented.

While the disruptive potential of blockchain technology is widely recognized, it is essential to consider its enabling and constraining affordances, particularly in different socioeconomic contexts. This can be explored further by investigating the enabling and constraining affordances of blockchain in agri-food supply chains in developing markets.

The goal of the Q-methodology is to study the structure of the concourse rather than the characteristics of a population. Although this study explored and interpreted four distinct perspectives of agri-food supply chain practitioners, the insights gained from a Q-study are not generalizable to the broader population because the results are based on the opinions and attitudes of a specific group of participants, which may not be representative of the broader population. Regarding the perspectives observed in this study, although we can say which are the most probable among our group of participants, we cannot generalize the findings to all types of agri-food products or to a larger population. Future research should focus on solutions to tackle the challenges associated with blockchain adoption in agri-food supply chains and investigate new avenues for utilizing blockchain capabilities. We acknowledge that blockchain is a rapidly developing technology, which might have affected the timeliness of our results. However, blockchain adoption is not widespread (Menon and Jain, 2021; Araballi and Devaki, 2022). Therefore, we believe that this threat is only a minor issue.

In conclusion, our study provides valuable insights into the potential of blockchain technology to improve agri-food supply chains. However, further research is needed to explore its applicability in different socioeconomic contexts and to confirm the findings more precisely.

Declaration of Conflicting Interests

The authors declare no conflict of interest.

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