

Unlocking Potential: Blockchain Technology and its Impact on Agricultural Supply Chains in Pakistan

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ABSTRACT

This review article explores the potential of blockchain technology in revolutionizing agricultural supply chains in Pakistan. In light of growing evidence, this is a new and emerging connection with great scope for agricultural development globally. The case of Pakistan is particularly interesting since its agriculture sector serves as the backbone of the nation's economy with agriculture significantly contributing to economic growth. However, sectoral and supply chain challenges allow for technology adoption to emerge as a transformative solution. Against this backdrop, the article reviews how blockchain technology, with its decentralized architecture and consensus algorithms, addresses key issues within agricultural supply chains particularly. The article highlights the global and local contexts, emphasizing blockchain technology as a solution to ensuring security in data sharing, permanence in record-keeping, and transparency end-to-end in the supply chain. Examining applications from developing countries, including India, Vietnam, Malaysia, Nigeria, and keeping a focus on specific evidence and learnings derived for Pakistan, the review provides a cross-country analysis, aiding understanding of this emerging technology and its applications. The global evidence identified in the article aid the development of key learnings for Pakistan, emphasizing the potential for improved data management, transparency, and reduced reliance on intermediaries. The article concludes with a futuristic outlook for Pakistan, proposing the effectiveness of blockchain-based frameworks for the agricultural supply chain and highlighting the role of the government that makes optimizing agricultural processes and fostering sector-wide transformation possible.

Introduction

Agriculture stands at the core of Pakistan, evidence being the significant contribution to the nation's economic prowess by constituting approximately 19% of the total GDP and providing employment for nearly 42% of the labor force (Sajid & Ur Rahman, 2021). Thus, the significance of agriculture in the context of Pakistan is accentuated by the extensive resource utilization in the sector and its subsequent substantial impact on the country's economic dimensions. This impact goes beyond economic indicators and resonates across the socio-economic dynamic as well which is evident through agricultural food supply chains. Agricultural supply chains, from end-to-end, go beyond providing market access and connect essential stakeholders such as agribusinesses, governments and farmers. Despite the extensive reliance on the large agricultural sector which also translates into driving economic growth, the sector is faced with challenges ranging from logistical inefficiencies to an imperative need for greater traceability and transparency in supply chains (Khan, et al., 2022). A substantial challenge in Pakistan's agricultural landscape also is the slow-moving performance of existing practices, attributed to a variety of factors. Among these, is the slow pace of technological innovation and the limited adoption of progressive farming techniques (Naseer, et al., 2019).

Parallel to the existing challenges that have encompassed Pakistan's agricultural sector and the growing need for innovation strategies, research is largely focusing on integrating technology with agriculture. In

this domain, blockchain technology in agriculture and the food supply chain is gaining importance. It is meaningful to unravel what this technology is. Blockchain technology comprises a combination of technologies which include essential components such as distributed databases, decentralized processing, consensus algorithms and more. Through this technology the larger goal of achieving consistency across the database and ensuring the integrity even in a decentralized database is achieved with adequate effect (Ge, Brewster, Spek, Smeenck, & Top, 2017).

What is the connection between blockchain and agricultural supply chains? Given existing challenges in agricultural food supply chains as observed briefly from the case of Pakistan, blockchain technology addresses several needs and emerges as a solution to contemporary agricultural supply chain challenges. Among the challenges highlighted, there are also issues of information reliability, consumer trust, transparency in the supply chain, quality, logistics, environmental impact, personal data, fraud, and food safety. These stand to be a variety of categories that have elicited a demand for greater transparency in the end-to-end process. Globally observed, there is a greater communication gap between consumers and producers, which is further exacerbated by reliance on third-party audits and centralized databases that pose problems like high costs, inefficiency, fraud, and data integrity issues. Such challenges pose significant threats to food safety, quality, and sustainability. Blockchain technology ensures permanence of records and enables secure data sharing among different stakeholders within a supply chain. Successful application would allow for greater trust and transparency. Specifically in the agricultural sector, the value of blockchain technology is becoming increasingly recognized for its characteristics of fostering transparency and trust in complex supply chains given its ability to resolve prevalent challenges, contributing to process optimization, addressing environmental concerns and beyond (Ge, Brewster, Spek, Smeenck, & Top, 2017). The application and value of blockchain technology in agriculture became even more important during the COVID-19 pandemic which caused global food supply chain disruptions. This hints at the constraints traditional systems posed which were thoroughly tested through this external shock. With blockchain's ability to enhance efficiency and maintain resilience of agricultural supply chains in the face of external shocks, the need for innovation and transformative change becomes even more highlighted (Khan, et al., 2022).

It is also meaningful to delve into some specifics that provide information on how blockchain technology could be integrated into the supply chain. One application of blockchain technology is its ability to digitize the agricultural supply chain. Within this application, blockchain technology can be integrated in the physical flow which is the movement of food as well as the digital flow which would enable use of QR codes, digital signatures, sensors, and the use of mobile phones through the internet infrastructure. Through the supply chain, information is stored in the blockchain layer which records every action taking place in the supply chain. It is validated and so each transaction turns into a permanent block of the chain. This effectively and comprehensively captures the entire supply chain process. An observed application would begin with the first step: recording transactions occurring with farmers. At this step, details of crops, fertilizers, machinery inputs and pesticides would be recorded. As a next step, there would be relevant information regarding the farm, farming practices, animal welfare, and crop cultivation. Within the chain, distribution records such as shipping information, storage conditions, transactions between middlemen and transactional information would also be noted. The chain also captures retailer information on quality, quantity, expiration, storage conditions and shelf life. At the end of the chain are consumers who are also empowered through for instance QR codes attributed to food items. Although a general overview, this end-to-end chain allows for transparency and traceability in the application of blockchain. This allows for greater accountability as well as reliability (Kamilaris, Fonts, & Prenafeta-Boldu, 2019).

Applications of Blockchain Technology in Agriculture

As observed, the application of blockchain technology in agricultural supply chains exposes it to benefits, end-to-end. This nuanced effect can more closely be observed through qualitative cross-country analysis from the developing world. Furthermore, these learnings can then be applied to Pakistan to support Pakistan's uptake. Some evidence from developing countries suggests that it supports small farmers, allowing for finance and insurance of rural farmers in particular to be transformed. Small farmers contribute about 80% of the production of goods in developing countries but largely lack essential support in finance and insurance. Blockchain helps in this aspect particularly by dealing with corruption, fostering regulation, and empowering disadvantaged segments as a consequence and because of its unique applications. Additionally, in developing countries where transactions are mostly based on cash, there is a lack of traceability which produces its own perils. This has the potential to impede upward growth of small and medium enterprises within developing countries by constraining them in terms of accessing credit, finding potential of growth and exploring new markets. Through blockchain technology, the gap is bridged by mitigating the uncertainty and "disintermediating" value exchange by making the process transparent and decentralized. This has the ability to present the technology as a pillar promoting trust and reducing costs (Kamilaris, Fonts, & Prenafeta-Boldu, 2019).

Global applications and their learnings for Pakistan in addition to specific evidence from Pakistan will allow for a holistic picture to be drawn where learnings and practice can be observed, and next steps can be paved.

Applications from the Developing World

Blockchain technology has gained significant popularity overtime specifically in farming businesses with positive outcomes and feedback (Gurtu and Johny, 2019). Overtime, as businesses discover solutions, the integration of technology for improved data management is growing in parallel. This allows for the supply chain to be understood end-to-end and issues such as those pertaining to transactions to be minimized (van Hoek, 2019). The agricultural sector at length recognizes the importance of technology in food safety, production as well as distribution. (Erol et al., 2020). Agricultural supply chains can be tied closely with blockchain technology to produce favorable outcomes on a number of different levels. According to Kamilaris et al., (2019) blockchain technology fosters the potential to speed up transactions, minimize issues, and enhance transparency. Blockchain technology is most commonly applied in supply networks through food supply chains and researchers show the core focus of approximately over 60% of the case studies is on agriculture and food production (Xia et al., 2023). This furthers the need for investigation into the applicability of technological innovation, in specific blockchain technology, in dealing with agricultural landscapes.

The applications of blockchain technology are also increasingly evident in South American agriculture and food sectors. The technology largely facilitates the manner in which these supply chains are organized and monitored (Bai et al., 2022). Brazil particularly leads the way in this realm, as backed by numerous studies, demonstrating its ability to enhance agricultural practices. A case study by South American researchers revealed that the utilization of blockchain technology greatly influences the field of farming. This signals towards the great potential of blockchain technology in relaying benefits to the transportation side of agricultural goods (da Silveira et al., 2023). Brazil's success can be attributed to the growing use of technologies, including blockchain, smart contracts, and NFTs, which have enabled the country to verify the legal and genuine nature of wine harvests. This increases customer satisfaction and trust by providing the assurance that the wine purchased is reliable (Kshetri, 2021). Studies also note the particular effects on small farmers. According to a study in Colombia, Blockchain is able to assist small coffee farmers which widens the applications down to the grass-root. Flexibility and adaptability are crucial for the well-being of all individuals which is largely facilitated by this technology (Treiblmaier, 2019). Research from Chile suggests that the benefits of blockchain in capacity of data and cyber security is particularly meaningful. The technology is frequently utilized to monitor the movement of items from one location to another. In research conducted in Peru, blockchain and smart contracts help

largely on grounds of guaranteeing the safety and traceability of food in a digital farming dynamic (Saberri et al., 2019).

Agri-Wallet Project of India

India's efforts are note-worthy. The country is leveraging blockchain technology to hone efficiency of its agricultural supply chain. The Indian company Agri 10x and similar companies are keenly implementing blockchain technology to link farmers with potential buyers for their goods. By breaking the middlemen cycle, this allows farmers to bypass middlemen and receive higher prices for their products which were earlier absorbed by the middlemen. Thus, the technology is able to increase income for farmers by connecting them with buyers. Agri-Wallet, another Indian company, also utilizes blockchain technology to assist farmers in receiving direct payments from their customers. The technology expedites the process and eliminates intermediaries which cause lag. Additionally, in India where access to credit is a crucial obstacle particularly in agriculture, blockchain makes it easier for farmers to access loans (Jahanbin et al., 2023). In terms of communication, blockchain also provides facilitatory grounds to farmers. Farmers can utilize blockchain technology in order to communicate with other stakeholders in the agriculture sector, such as suppliers, customers, and sellers. This allows for sale transactions to be made in an expedited and effortless manner while reaping higher incomes. Evidence from the Indian agricultural sector also suggests that utilizing blockchain technology can track the origins of food to ensure its safety and high quality, trace the source as well as the distribution of food items (L.B, 2022).

TE-Food Traceability System of Vietnam

Vietnam produces meaningful insights particularly stemming from the initiation of a new venture named TE-Food. This technology enables the tracking of food sources, with a specific focus on pig-related products. The origins and destinations of pork products can be uncovered through the use of blockchain. The application and desirability of such an initiative is multifold. It assists in fostering trust in the supply chain and in increasing people's understanding of the production process. Using unique codes, TE-Food is able to trace and track down the very source of food products. There are other key goals that TE-Food is also able to achieve through the integration of blockchain technology in the supply chain process. Transaction recording is one of them which opens doors to greater transparency and reliability specifically when compared against traditional methods of record keeping. In particular Blockchain's security and transparency are maintained through its decentralized storage of data, preventing any unauthorized changes. This set of information is known as the Trust Chain (Bambridge Sutton, 2023). Such an application significantly increases customer confidence in the product and processes, farmer confidence and reduces grounds for corruption or unfairness in the treatment of any stakeholder.

Blockchain in Malaysian Palm Oil Supply Chain

Although Malaysia is on track to becoming a high-income, developed country, its current application is meaningful to study. The implementation of Blockchain technology in Malaysia's palm oil industry ensures a highly secure and reliable supply chain. There are various types of aspects that fosters better the likes of equitable and lawful treatment of workers and valuable insights into crop cultivation on plantations. The blockchain technology allows for traceability down to the origin and uncovering the entire supply chain and processes along the way until it arrives at the purchaser (Kursehi Falgenti et al., 2022). The process also very neatly allows to retain track of where sustainable palm oil is made, focusing keenly on environmental rules and policies. In terms of data visibility, the data is available to see for all stakeholders including the purchases who duly remain informed through the process. This integration specifically means highly to the case of Malaysia because palm oil is a highly common ingredient in cosmetics and also is one of the major exports of Malaysia. Hence, keeping a vision of ensuring eco-friendly production of palm oil, the utility of blockchain technology in Malaysia has proven to reap great benefits (Muhammad Shabir Shaharudin et al., 2022).

Nigerian Focus on Blockchain Technology

There is great scope of successful application in the case of Nigeria. Although there are no extensive initiatives working for Nigeria, there is great transformative power of integrating blockchain technology studied within the country. Nigeria's supply chain can greatly be honed by provision of better visibility of product origins, destinations and facilitation of expedited operations. Given that the Nigerian economy is also reliant on farming, the application of blockchain can potentially enhance operations and eliminate dishonesty from within the supply chain. This allows Nigerian farmers to benefit from increasing production, getting better rates and having a more extensive access to customers and markets to be able to sell their products (Taofeek Tunde Okanlawon et al., 2023).

Evidence from Pakistan

Stemming from the learning that agriculture contributes largely to Pakistan's economy, there is great scope for positive benefits to be reaped through blockchain technology. According to Khalil Ur Rehman et al., (2023) farming has reaped benefits of digitization alone through the advent of technology. The advent of agri-tech businesses in Pakistan is also a recent but emerging phenomenon. "Telenor Velocity" has established a new agri-tech company in Pakistan that functions on three main aspects: Good Earth for the exchange of farm machinery and tractors, Pak Agri Market for a digital agriculture directory, and Pak ZarZameen for satellite images of farmland (Shahid, 2023). In addition to Pakistan's local demand contributing to the economy's GDP, Pakistan also has a strong export base that exports to major countries like the United Arab Emirates and Saudi Arabia (Khan et al., 2022). Post-COVID, the concept of physical distancing has exacerbated the utility of digital technologies, especially after the run-up during COVID-19 that furthered reliance on them (van Remko, 2020).

The application of other components such as Internet of Things (IoT) coupled with blockchain technology in agriculture, specifically sustainable forms the likes of Precision Agriculture, has grown in importance. From initial processes where farmers work in the field, there is great benefit that comes through the use of guiding systems and proper fertilizer application for farmers when planting and tending to their crops. Blockchain technology offers numerous advantages, including the capability to identify inferior food products and relay accurate information to customers. Currently in Pakistan, Zauq Group is the single agri-tech company that is working on tracking the provenance of food (Shahid, 2023). Pakistan's economy also relies on exporting a large quantity of mangoes to foreign nations but faces challenges such as inconsistent quality and difficulty in monitoring their transportation. As a result, Pakistan's access to international markets is largely hindered due to these problems and more. In order to resolve this issue, Pakistan's government teamed up with VeChain to establish a tracking system for the export destinations of mangoes which indicates the government's focus on taking initiative. Thus, in this case, an individual code is given to every mango, allowing consumers to scan and discover its origin, quality, and distribution path. By virtue of larger access to markets, this has reportedly increased international sales and hence the export bill of the country (Alobid et al., 2022).

Learnings for Pakistan from Global Evidence

Learnings from global case studies allows for valuable insights to be generated for Pakistan. Developments reported from South America, India, Malaysia, and introductory steps in Nigeria effectively convey the efficiency gains to agricultural supply chains from blockchain technology. Takeaways from current global projects suggest that there is proof of improvement in data management and greater transparency which appear as meaningful outcomes for a developing country like Pakistan which is also largely cash-based, specifically in the agricultural sector. Thus, the integration of blockchain technology with agricultural operations in Pakistan relays positive impacts on several levels. The Agri-Wallet project running in India and the TE-Food project in Vietnam specifically have valuable lessons for transparency in supply chains. For Pakistan, this elicits potential

for consumer trust through blockchain technology adoption and end-to-end visibility of actions and processes. Being a developing country, Pakistan has several different priorities and challenges. The case of Malaysia has key learnings for Pakistan in terms of adhering to environmental standards and enhancing security by ensuring equitable treatment for farmers. In terms of spotting an opportunity, learnings from Nigeria prove to be motivational next steps by underscoring the potential of farmers' income increasing by directing farmers to buyers. While there is reduced reliance on intermediaries which happens to be a key component of the agricultural landscape of Pakistan (Asad & Gondal, 2024), there are also hints towards greater benefits to farmers given the uptake of technology.

Future Scope for Pakistan

The future scope of Pakistan in terms of revolutionizing the agricultural sector using blockchain can be simply collapsed into a clear path. Pakistan is heavily reliant on its agricultural sector, faces pertinent challenges and explores solutions in the technological realm. In Pakistan, within agriculture, the wheat crop addresses about a third of the food demand, which is massive. The existing agriculture supply chain faces significant challenges including the lack of transparency, security, reliability, and traceability in this sector. This has translated to inefficiencies, artificial shortages, and high cost selling of crops to consumers. To address these issues, extensive research is being carried out on areas of improvement. A recent study proposes a blockchain-based framework which is specifically designed for the wheat crop supply chain. This proposed system introduces a crypto token that is named "wheat coin" (WC) to carefully track transactions among stakeholders within the wheat supply chain. This framework allows for traceability and transparency of wheat crop transactions. Additionally, a smart contract-based transaction system is implemented under the framework to address transparency. Other aspects within the framework such as the introduction of the Interplanetary File System (IPFS) adds robustness to the framework by improving data availability, security, and transparency. The storage system is decentralized which allows for private data of farmers, merchants and businesses to be kept private through encryption. Experimental results indicate that this proposed framework substantially outperforms existing solutions in the wheat crop supply chain, particularly in terms of transactions per minute, average gas charges for transactions, as well as transaction verification time. The study underscores the potential of blockchain technology to significantly enhance the efficiency and reliability of the wheat crop supply chain in Pakistan (Farooq, et al., 2024). There is great evidence on how effective the incorporation of blockchain technology in Pakistan's agricultural domain is. There is some direct evidence of incorporations through agri-tech businesses and some key learnings from similar backgrounds. The positive note extracted is that there is scope with experimental and real potential and regional learnings only increase the scope of application within the country. The government also appears to be focusing on the agricultural sector, honing its current capacity.

Based on a research report by the FAO, the greatest barriers to blockchain technology's adoption include regulatory uncertainty, lack of trust, inability to scale the technology, intellectual property concern and audit concerns (FAO, 2019). The government of Pakistan takes various steps to support the agricultural sector however faces challenges of food security as well as price hikes. The technology integration allows for food security to be certified as well as prices to be controlled – the greatest lessons of resilience stemming from the COVID-19 pandemic. Through appropriate government intervention via training programmes, regulatory frameworks and adequate overseeing can preemptively deal with several of the challenges. Existing technology is new hence there is limited evidence from Pakistan, thus building a framework from cross-country learnings proposed can put Pakistan on a higher pedestal in terms of learning trajectory and application (Khan, et al., 2022). Effective collaboration among key stakeholders such as government bodies would allow for the deployment of proposed frameworks to optimize agricultural supply chain processes and revolutionize the sector. Thus, the success of blockchain in agriculture is clear in Pakistan and can be guaranteed with prior planning, support, and extensive research.

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