

BLOCKCHAIN TECHNOLOGY AND AGRIBUSINESS SUPPLY CHAIN MANAGEMENT

PART 1



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Bentham Books

Blockchain Technology and Agribusiness Supply Chain Management

(Part 1)

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**Blockchain Technology and Agribusiness Supply Chain
Management (*Part 1*)**

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ISBN (Online): 979-8-89881-468-7

ISBN (Print): 979-8-89881-469-4

ISBN (Paperback): 979-8-89881-470-0

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First published in 2026.

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FOREWORD

It is with great pride that we present *Blockchain Technology and Agribusiness Supply Chain Management (Part 1)*, a comprehensive exploration of how blockchain is reshaping agricultural ecosystems. This volume thoughtfully examines the intersection of blockchain and agribusiness, beginning with foundational concepts and progressing toward real-world applications across supply chains, finance, insurance, and consumer markets.

The chapters systematically address traditional inefficiencies in agricultural supply chains, such as fragmentation, lack of transparency, fraud, post-harvest losses, and limited market access, and demonstrate how blockchain offers transformative solutions. From smart contracts and automated transactions to financial inclusion for smallholder farmers and blockchain-enabled agricultural insurance, this book presents both theoretical depth and practical insight. Importantly, it also highlights traceability systems, sustainability integration, and the psychological dimensions of consumer trust in transparent food systems.

By combining technology, policy, economics, and behavioral perspectives, this volume serves as a valuable resource for researchers, policymakers, agribusiness professionals, and students. It not only explains how blockchain operates but also illustrates its strategic role in building resilient, transparent, and sustainable agricultural supply chains for the future.

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PREFACE

Agriculture stands at a transformative crossroads where technological innovation meets the urgent need for transparency, sustainability, and resilience. Blockchain Technology and Agribusiness Supply Chain Management (Part 1) explores this critical intersection by presenting a comprehensive examination of how blockchain is reshaping agricultural supply chains from farm inputs to consumer delivery.

This volume begins by establishing the foundational principles of blockchain, its operational mechanisms, security architecture, and diverse models, including public, private, consortium, and hybrid systems. It then examines traditional supply chain inefficiencies—fragmentation, post-harvest losses, lack of traceability, and fraud—and demonstrates how blockchain-driven solutions enhance transparency, optimize logistics, and build trust among stakeholders.

Through detailed discussions on traceability systems, smart contracts, financial inclusion for smallholder farmers, blockchain-enabled insurance models, and consumer trust dynamics, this book bridges theory with practice. Real-world case studies across agriculture, food systems, and global supply chains provide practical insights into implementation challenges and emerging opportunities.

This part particularly emphasizes sustainability, risk management, financial empowerment, and the integration of technology with AI, IoT, and cloud systems. Designed for researchers, policymakers, agribusiness professionals, and technology innovators, this volume lays a strong conceptual and practical foundation for understanding blockchain's transformative potential in modern agribusiness ecosystems.

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CHAPTER 1

The Intersection of Blockchain and Agribusiness

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Abstract: Blockchain technology, initially developed to support secure digital transactions, has emerged as a key enabler of transparency, efficiency, and security across multiple industries, including agribusiness. The chapter provides a background on the basics of blockchain, including concepts of decentralisation, immutability, and transparency, and how blockchain is relevant in agriculture. Decentralised networks based on distributed ledger technology (DLT), which do not need intermediaries and transfer assets directly from one peer to another, lead to lower costs and offer agribusinesses more control over the supply chain. Blockchain has come a long way from its origins with Bitcoin, and not only serves cryptocurrency but is now applied to food traceability, supply chain processes, and financial inclusion. Blockchain enables food security in agriculture by tracking the path products take from farm to consumer, preserving quality, and removing fraud. Because it enables decentralised marketplaces that allow farmers to sell all sorts of products and bypass intermediaries, and because it enhances access to credit and facilitates digital payments, it can also empower farmers. It elaborates on the main types of blockchain and its use cases in agriculture, such as traceability, inventory management, and enhanced food safety. The chapter also mentions smart contracts, which allow automating transactions and minimising human involvement in supply chain processes. Even so, agribusiness adoption of these solutions faces a range of challenges, including technological hurdles, education, and regulatory hurdles. There are additional barriers, such as high costs and limited scalability (especially for smallholder farmers). There is a bright future for blockchain in agribusiness, particularly with mass adoption in the making as infrastructure becomes stronger and costs decrease. Case studies are conducted to explore the current influence of blockchain in agribusiness, with particular emphasis on supply chain optimisation, transparency, and farmers' empowerment to promote a resolution to an efficient and sustainable global agricultural system.

Keywords: Agribusiness, Blockchain, Distributed ledger technology, Food safety, Technology, Transparency.

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INTRODUCTION

Blockchain is an open, distributed ledger or database divided into segments of data called blocks, also known as Distributed Ledger Technology (DLT). All data is aggregated into blocks, and each block links to the previous one *via* cryptographic hashes, forming a chain that never ends. This construct lends to immutability and trustworthiness by assuring that once information is written to the block, it cannot be retroactively altered without additionally affecting the entirety of the following blocks. The structure of blockchain is depicted in Fig. (1) and described as follows [1, 2].

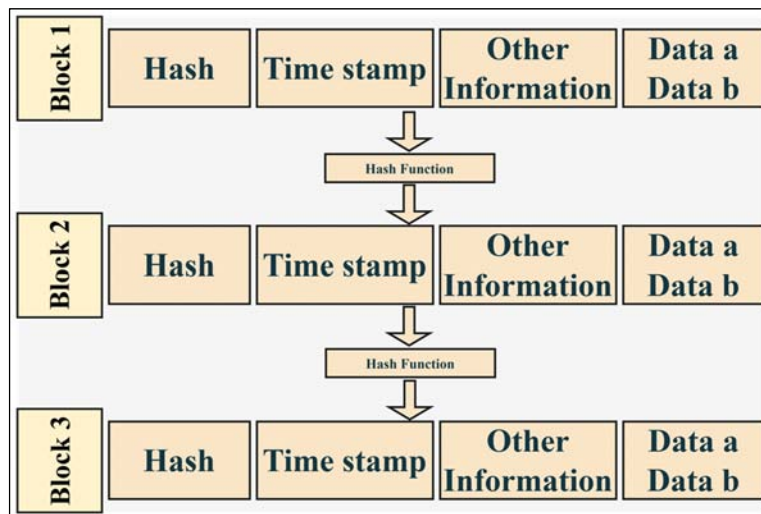


Fig. (1). Structure of blockchain.

Blockchain data storage depends on the service and application, utilising systems like IPFS for peer-to-peer storage, Apache Cassandra for distributed databases, and cloud storage solutions such as Storj, Ethereum Swarm, and Sia. This data serves various applications, including transaction recording, banking, contracting, and IoT. A crucial component of blockchain technology is the hash function, which generates a unique fixed-length output from any input, ensuring data integrity by drastically altering the hash if even a minor change occurs. This mechanism secures blocks by updating all ledger copies across the network, enhancing trust.

Merkle trees efficiently and securely store large data structures. A timestamp tells both the exact time a block was created and which particular document has been protected by this block. For businesses, this immutable historical record of change can be of increasing importance. The other elements of the blockchain include

digital signatures, nonce values, and nBits. Every user has a private and a public key, so when signing data, the private key encrypts it, but during decryption, the public key must be used to verify its authenticity. A nonce is a 4-byte value starting at zero, which increments with each hash calculation, and nBits determines the target threshold value for an allowable block hash.

The first blockchain-like protocol was suggested by cryptographer David Chaum in his 1982 dissertation called “Computer Systems Established, Maintained, and Trusted by Mutually Suspicious Groups”. In 1991, Stuart Haber and W. Scott Stornetta built upon these concepts to develop a solution for securely storing certificates of documents and ensuring tamper-proof document timestamps using cryptographically secure chains of blocks, and in 1992, they and Dave Bayer implemented Merkle trees for increased efficiency by allowing multiple document certificates to be bundled in one block. Their firm, Surety, has published hashes of the certificates of documents in “The New York Times” every week since 1995.

The first decentralised blockchain was conceptualised by Satoshi Nakamoto in 2008, introducing a Hashcash-like proof-of-work system to timestamp blocks without a trusted party and adding a difficulty parameter to stabilise block creation. This design was implemented in 2009 as the core of Bitcoin, serving as its public transaction ledger. By August 2014, the Bitcoin blockchain had grown to 20 GB, reaching nearly 30 GB by January 2015, 100 GB by January 2017, and surpassing 200 GB by early 2020.

The terms “block” and “chain” were initially used separately in Nakamoto’s whitepaper, but became widely known as “blockchain” by 2016. Accenture’s diffusion of innovations theory suggested blockchain achieved a 13.5% adoption rate in financial services by 2016, leading to the creation of the Global Blockchain Forum by industry trade groups under the Chamber of Digital Commerce. However, a 2018 Gartner survey found that only 1% of chief information officers (CIOs) had adopted blockchain, with 8% in early planning or experimentation. By 2019, only 5% considered it a game-changer for their business.

However, blockchain networks can be classified into three main types, public, private, and federated blockchains, based on the network management system used and the permissions provided. A private blockchain is a permissioned access platform; a public blockchain is a permissionless open data network where any user can append data in the form of a transaction, which is an identification data package in the system with accessible and copyable data. In contrast, a federated blockchain combines the functions of both private and public blockchains [3 - 5].

The agricultural industry grew rapidly to 3.5 trillion USD in the early years of the 21st century. However, there were also a lot of challenges. One of these is

CHAPTER 2

The Evolution of Blockchain in Supply Chain Optimization**Kumud Shukla^{1,*}, Jyoti Yadav¹, Vibhu Sahani², Akhil Sharma³ and Shaweta Sharma⁴**¹ *School of Agriculture, Galgotias University, Greater Noida-201301, India*² *LLRM Medical College, Meerut, India*³ *Department of Pharmacy, R.J College of Pharmacy, Raipur, Uttar Pradesh-202165, India*⁴ *School of Medical and Allied Sciences, Galgotias University, Greater Noida-201301, India*

Abstract: Blockchain technology is revolutionising supply chain management (SCM) by addressing persistent issues like opacity, inefficiencies, and fraud. This chapter describes how the general principles of blockchain (*e.g.*, decentralisation, immutability, smart contracts) can change supply chains, specifically agriculture and agribusiness. Starting with a description of traditional supply chain management, the chapter points out a number of inefficiencies, such as fragmented operations, post-harvest losses, and limited market access for small farmers. It then reviews the significant aspects of agricultural SCM, covering input supply, production, distribution, and retail. The chapter outlines the evolution of blockchain technology, from its inception as a tool for cryptocurrency to its adoption across the supply chain management space, highlighting its benefits such as increased traceability, security, and efficiency. The way blockchain has been leveraged in logistics, food safety, and ethical sourcing can be seen in case studies of industry pioneers like Walmart's IBM Food Trust, Maersk's TradeLens, and Everledger. Blockchain facilitates end-to-end tracking of produce in agriculture that provides proof of authenticity while adhering to fair-trade practices in the supply chains of coffee, cocoa, and tea. In the future, the combination of blockchain, IoT, and AI will have the potential to further optimise supply chain processes through concurrent data collection and predictive analytics. The emergence of decentralised finance (DeFi) also opens new opportunities for payments, financing, and insurance in SCM. Moreover, blockchain plays a significant role in sustainability tracking, promoting eco-friendly practices and ensuring regulatory compliance. As adoption expands from niche applications to widespread implementation across industries, blockchain continues to redefine supply chain management, fostering greater trust, efficiency, and resilience in global trade networks.

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Keywords: Agriculture industry, Decentralisation, Inventory management, Immutability, Logistics, Smart contracts, Stakeholder, Supply chain management, Transparency.

INTRODUCTION

A supply chain is a global network of organisations, people, activities, information, and resources that are engaged in delivering a product or service to a customer. The supply chain is the process of steps it takes to get a good product from raw materials to the consumer. Since SCM involves all these processes and activities, it can be defined as the management of these processes and activities to ensure that the final product is delivered in the correct quantity, at the right place, at the right time, at the right level of quality, and at the minimum possible cost. Everything related to planning, organisation, and control, as well as sourcing, production, logistics, inventory, and customer service, is integrated into a single pipeline with the goal of achieving end-to-end efficiency and cost minimisation while ensuring that customer needs are met or exceeded [1]. Fig. (1) summarises the typical supply chain used in the traditional model.



Fig. (1). The standard supply chain used in the traditional model.

Traditional supply chains suffer from several problems, including low transparency of processes, reliance on manual processes, poor demand forecasting and inventory controls, ineffective transportation logistics, poor responsiveness to market changes, in adequate visibility between supply chain partners. These inefficiencies lead to high supply chain costs, delays, stockouts, and the loss of

market opportunities – all of which can be prevented through better data integration and novel technology like automation and analytics [2].

Key Challenges Faced by Traditional Supply Chain

Many limitations exist in traditional supply chains to overcome such challenges that hinder efficiency, transparency, and adaptability. Visibility is the biggest issue — companies cannot track their stock, see how it moves, when it ships, or what disruptions occur in real time. As a result, businesses are forced to make decisions reactively, leading to operational inefficiencies and higher costs. In addition, traditional supply chains are prone to inaccuracies and inefficiencies, as errors, delays, and mismanagement are more common in manual processes and paper-based systems [3].

In the same vein, inaccurate demand forecasts can lead to high inventory costs from excess stock or stockouts, which negatively affect customer satisfaction and the ability to generate sales. Similarly, interrelated inefficiencies in inventory management, such as high carrying costs and slow-moving inventory, also compound the complexity in the supply chain. Transport and logistics difficulties worsen these problems, as supply chain costs increase and delivery delays are prolonged by inefficient route planning, unreliable delivery timetables, and expensive transport channels [4].

How Technology Addresses Traditional Supply Chain Challenges

However, to overcome these hurdles, modern supply chain management is relying on advanced technologies. By providing real-time insights, data analytics helps companies analyse demand trends, maintain stock levels, and determine the areas where bottlenecks can occur. As the Internet of Things (IoT) facilitates real-time tracking of shipments and inventory using Radio Frequency Identification (RFID) tags and Global Positioning System (GPS) sensors, logistics are improved and losses are reduced [5].

SCM software streamlines processes in a single system (order processing, tracking, and overseeing suppliers), allowing businesses to execute broad supply chain activities in a concentrated way. Cloud-based platforms enhance collaboration and enable companies to track supply chain activities without being present where the action takes place. Automation improves efficiency by removing redundancy in processes such as order processing, invoicing, and warehouse management, reducing the chance of human error and lowering operational costs.

CHAPTER 3**Trust Building: Transparency and Traceability within Agricultural Supply Chains with Blockchain Technology****Kumud Shukla^{1,*}, Priyank Sharma², Akhil Sharma³, Shaweta Sharma⁴ and Akanksha Sharma³**¹ *School of Agriculture, Galgotias University, Greater Noida-201301, India*² *AIHSR, Amity University, Noida-201303, India*³ *Department of Pharmacy, R.J College of Pharmacy, Raipur, Uttar Pradesh-202165, India*⁴ *School of Medical and Allied Sciences, Galgotias University, Greater Noida-201301, India*

Abstract: The need for transparency and the need to trace the source of agricultural raw materials are essential to building trust in agricultural supply chains and ensuring food safety, quality, and compliance with regulations. Traditional traceability systems encounter problems like inconsistent identification of products, data fragmentation, and lack of access to real-time information. The application of blockchain technology in food safety ensures decentralisation and tamper-proofing, improving visibility throughout the supply chain from farm to fork. This chapter discusses the basics of traceability in agriculture and outlines the motivation for blockchain to solve significant issues. This explains product identification mechanisms, in-chain data tracking in real time, and interoperability with existing Enterprise Resource Planning (ERP) systems. Through blockchain, stakeholders can facilitate easy product verification, mitigate fraud, and maintain compliance with global food safety standards. In addition, the chapter looks at real-world applications through case studies of Beef Ledger, which tracks beef cattle, Provenance, which tracks fisheries, HerdX, which monitors the health of hundreds of thousands of cattle, and an example of livestock registration in Vietnam (TE-FOOD). The following examples show how blockchain can improve the supply chain by enhancing accountability, reducing inefficiencies, and building trust with consumers. While the potential is excellent, there are still challenges to mass adoption of blockchain, especially for smallholder farmers in emerging economies. To encourage industry-wide adoption, obstacles such as high implementation costs, digital literacy gaps, and infrastructure constraints need to be addressed. In conclusion, this chapter will emphasise the impact of blockchain on transparent, secure, and optimal agricultural supply chains. Blending blockchain technology with traceability systems can help agriculture adopt innovative, sustainable mechanisms for a more trustworthy future.

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Keywords: Agricultural supply chains, Blockchain, Beef Ledger, HerdX, Transparency, Traceability, TE-FOOD.

INTRODUCTION

Modern agricultural supply chains require transparency and traceability to ensure food safety, ethical supply, and regulatory compliance. Transparency gives consumers insight into where agricultural products come from, how they are made, and how they travel, helping them choose ethical and informed products. In an age where consumers want sustainability and responsible sourcing, businesses need to embrace transparency across their supply chains to ensure they do not lose trust and competitive advantage [1].

Increased transparency creates a healthy atmosphere of accountability in which stakeholders like farmers, suppliers, and distributors work transparently, thereby minimising the chances of irresponsible labor use, environmental issues, and false information. It is also essential for international trade, given that numerous markets globally require traceability in order to promote equitable and sustainable agricultural systems. Novel markets are open to producers who are transparent about their practices, giving them more opportunities to grow [2].

Traceability provides a layer of transparency, allowing products to be tracked throughout the supply chain, all the way from farm to fork. One of its most significant advantages is control over quality, which allows contamination sources or quality problems to be easily traced, enabling recalls to be targeted and minimising the risk of broader food safety events. Apart from contributing to food safety, traceability also enables a more efficient supply chain by streamlining logistics, reducing wastage, and recognising operational bottlenecks. Having real-time visibility to observe the location of products in motion helps businesses optimise processes, reduce losses, and improve productivity [3].

Traceability is crucial to verifying sustainability claims, whether for organic certification, fair trade, or environmentally friendly production practices. A strong traceability system gives consumers confidence in the products they buy, a growing need as shoppers increasingly want to know that their purchase behaviour aligns with their values. Blockchain technology helps improve transparency and traceability in agricultural supply chains by providing secure, verified, and immutable records. This also enhances trust and accountability, as well as market access, regulatory compliance, and sustainability. As food production becomes increasingly reliant on ethical and sustainable methods, the uptake of innovative traceability solutions has gone from optional to compulsory in order to pave the way for the future of our food production systems [4].

Role of Blockchain in Enhancing Trust and Accountability

By increasing trust, transparency, and efficiency among every player in the supply chain, ground-breaking technology can completely revolutionise agricultural supply chains. The most important benefits are transparency and traceability. Each transaction and every movement of farm products is recorded on a blockchain in an immutable manner, thus all data concerning origin, quality, and distribution is stored securely [5].

This enables consumers, merchants, and regulators to trace products from the farm to the fork, reduces fraud, and enhances confidence in the authenticity of each commodity. Real-time information access guarantees full and equal access to data by all the parties in the supply chain, be it farmers, processors, distributors, or consumers, removing any asymmetry that makes a transparent and trustworthy supply chain possible. Moreover, blockchain assists in reducing fraudulent activities since it is nearly impossible to manipulate the records or present fake goods, which strengthens the credibility of agricultural trading [6].

With more transparency offered by blockchain, it also brings ease and cost savings to the supply chain. The traditional agriculture supply chain consists of multiple intermediaries, requires extensive paperwork, and is prone to inefficiencies and high costs. By removing intermediaries and automating processes, blockchain expedites transaction time. To further boost efficiency beyond the confidence derived from needing fewer third-party intermediaries, smart contracts provide the ability for self-executing agreements that guarantee timely and secure payments. Such contracts autonomously execute the predefined conditions in the coded issue, thus eliminating the existence of delays and disputes. In addition, better traceability also increases the identification of supply chain inefficiencies to be tackled, thereby decreasing waste and making better use of resources [7].

Blockchain supports trust and consumer confidence by providing information on the provenance of products; consumers can verify this information. It allows consumers to track their food from farm to table, guaranteeing its quality and safety. The system will help avoid farmers being exploited by intermediaries, while also promoting ethical and sustainable agricultural growth. Moreover, named food traceability powered by blockchain enables quick identification of contamination sources in instances of foodborne illnesses, thereby reducing food safety risks significantly and preventing widespread occurrences [8].

Smallholder farmers, who often face challenges in accessing markets and fair pricing, can also benefit from blockchain technology. By enabling direct transactions between farmers and retailers or consumers, blockchain eliminates

Leveraging Smart Contracts for Automated Transactions in Agribusinesses

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Abstract: The agri-food sector is an essential pillar of economies worldwide, playing a vital role in food security and safety, as well as the livelihoods of millions. However, it continues to tackle recurrent issues such as supply chain inefficiencies, lack of transparency, and simple food fraud. Smart contracts, a form of blockchain technology capable of executing programmable agreements between parties, are a promising remedy for these challenges. A smart contract is basically software that has contractual rules written into it. This chapter lays the foundation for smart contracts operating on a blockchain-based architecture, explains how they differ from regular contracts, and outlines the features that make them unique. In agribusiness, platforms like Ethereum and Hyperledger serve a crucial role in the implementation of smart contracts. Key applications include improving traceability, automating supplier-buyer interactions, and strengthening food safety and quality control. Real-world implementations illustrate their effectiveness in preventing fraud and ensuring compliance with industry standards. Despite their potential, the adoption of smart contracts in agribusiness is influenced by various factors, as analysed through Rogers' diffusion of innovation framework. Comparative advantage, compatibility, and complexity play pivotal roles in determining adoption rates. Case studies showcase successful implementations while shedding light on adoption challenges. Barriers to widespread use include technological constraints, regulatory uncertainties, infrastructure costs, and knowledge gaps, particularly among small-scale farmers. Additionally, data security and privacy concerns remain significant obstacles. Addressing these challenges is essential for harnessing the full potential of smart contracts in agribusiness. This chapter provides insights into overcoming these hurdles and fostering a more transparent and efficient agri-food ecosystem.

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Keywords: Agribusiness, Agri-food sector, Blockchain technology, Ethereum, Hyperledger, Smart contracts.

INTRODUCTION

Agri-food refers to the primary products of plants, forestry, animal husbandry, and fishery, specifically plants, animals, microorganisms, and their products from agricultural activities. Agri-food is a human survival need, which is associated with the life of the human community. With the recent global COVID-19 pandemic and the Russian-Ukrainian war, the quality and safety of agri-food are facing a global problem. Data from Statista states that between the years 2014 and 2020, the rate of severe food insecurity in Nigeria increased from 6.6% to 21.4%, where the reported incidence in 2020 was almost double that of 2019 [1]. Various industries of the agri-food sector are summarised in Fig. (1).



Fig. (1). Various industries of the agri-food sector.

Blockchain smart contracts can be interpreted as a new technology that runs in a particular blockchain environment and can pass, confirm, execute, and enforce the stipulations of an agreement automatically. Compared with traditional contracts, blockchain smart contracts are low-cost, highly automated, highly efficient, and highly secure. Blockchain smart contracts can also have self-censorship, which is not something that a traditional contract can possess [2].

In the agri-food industry, blockchain smart contracts are deployed first. Second, the relevant stakeholders of the whole supply chain are added to the chain. Finally, the smart contract is customised according to different needs. Realising that the transfer of all data in the blockchain can break through the data interaction barriers upstream and downstream of the agri-food supply chain, it can fundamentally solve the problems of falsification of agri-food data and difficult positioning [3].

Smart contracts possess highly automated characteristics that can help us maximise the control of the quality of the agri-food industry. Consequently, the research and application of blockchain smart contracts in the agri-food industry can further facilitate the digitalisation process. The agri-food industry is faced with this step of marketising data elements in the journey of digitisation. Blockchain smart contracts can provide solutions to specific issues in the agri-food sector, including data verification, credible regulatory oversight, and traceability of data. It can also enhance its service to the whole agri-food sector as well as related industries, regulatory bodies, and consumers [4].

With the development of research, there are currently three primary forms of smart contracts. The first is the traditional smart contract in Ethereum, which is mainly based on Solidity, Serpent, and Mutan programming languages, in which the operating environment is mostly EVM (Ethereum Virtual Machine). The second is the chain code in Hyperledger, with Golang and Java as the main programming languages, and the running environment is mostly Docker containers. Finally, the third is the quasi-smart contract, a blockchain information channel with the basic functions of a smart contract. In the agri-food industry, Ethereum and Hyperledger are the leading development platforms. Moreover, the main form is the development of an alliance chain. As an essential and powerful engine for the digital transformation of the agri-food industry, blockchain smart contracts have a unique definition and related role in the agri-food industry. However, the development of blockchain smart contracts in the agri-food industries is still in its infancy, and the overall situation of its development is relatively fragmented [5].

Current Challenges in the Agri-food Sector

The agrifood sector plays a critical role in sustaining global populations, but it suffers from various challenges that compromise food safety and security, including increased climate change, population growth, and inefficient agricultural practices, all of which tremendously affect food security in states. The solutions to these problems involve a mix of technological solutions, policy intervention, and sustainable agriculture practices [6].

Financial Inclusion and Blockchain for Smallholder Farmers

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Abstract: Smallholder farmers, who constitute a key element of global food security, require access to financial tools to support agricultural sustainability. Unfortunately, lack of collateral, higher transaction costs, and limited banking infrastructure in rural areas make it difficult for many of these farmers to access financial services. These people struggle to access the financial mechanisms that most of the world takes for granted, such as credit, insurance, and savings, restricting fiscal capacity to allocate toward productivity-enhancing technologies. Blockchain technology offers transformative potential to close these financial gaps due to its ability to allow secure, transparent, and efficient financial transactions. This chapter discusses how blockchain-based solutions like peer-to-peer lending, asset tokenisation, and microfinance based on smart contracts could provide credit access to people without traditional collateral. In addition to providing improved financial security for farmers through real-time remittances, transparent payment systems, and decentralised insurance models, blockchain also has sought-after properties. Smart insurance linked to weather and parametric payments is effectively limiting the climate variability financial risks by providing timely compensation. Outside of finance, blockchain is revolutionising agricultural supply chains with price transparency, less intermediary exploitation, and secured contract-based payments. Despite these advantages, there are persistent challenges to widespread adoption, such as digital illiteracy, infrastructure limitations, regulatory barriers, and scalability issues. Case studies of implementations of blockchain applications in smallholder agriculture present best practices. This chapter outlines policy suggestions to encourage blockchain use in rural finance and highlights how governments, financial institutions, and agritech startups can create an enabling ecosystem for adoption. Overall, public-private partnerships and targeted interventions could catalyse inclusive finance, helping smallholder farmers reap the benefits of the enormous potential of digital financial services. By conducting a thor-

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ough analysis, this chapter highlights both the potential of blockchain to transform agricultural finance and its limitations that will hinder long-term scalability.

Keywords: Agricultural supply chains, Blockchain technology, Decentralised finance, Financial inclusion, Smallholder farmers.

INTRODUCTION

Financial inclusion in agriculture is about making financial services available and affordable to everyone in the agricultural value chain, especially smallholder farmers, who are usually left behind. This includes the availability of services for credit, insurance, savings, and payment instruments that respond to the specific requirements of farm-based livelihoods. Traditional financial systems often neglect this sector as rural farming is considered high risk, along with high transaction costs. The core of good financial inclusion is to give farmers the capacity to invest in better inputs, manage risk, and coordinate more productive efforts [1].

They provide flexible, agricultural cycle-sensitive loan products, cheap insurance against crop failures, and secure savings facilities for future investment in their farming enterprises. Digital finance will be even more critical in reaching broader populations while lowering costs. Financial inclusion holds the potential to play a decisive role in enhancing the sustainability and resilience of agricultural systems and supporting food security and economic development at the community level. In the end, it is about providing farmers with holistic access to the financial ecosystem to allow for growth and stability [2].

Importance of Smallholder Farmers in Global Food Security

Smallholder farmers account for the vast majority of agricultural land in many developing countries and are the heart of global food security. They play a vital role, but they are rarely supported and work in arduous conditions and with scarce resources. These farmers grow much of the world's food supply and serve the food needs for local and national consumption. Adapted to local ecosystems, their varied farming practices are critical for biodiversity and sustainable agriculture. Supporting smallholder farmers is vital not only for food availability but also for ensuring food accessibility and affordability. They play a crucial role in reducing poverty and promoting rural development [3].

When empowered with access to resources, technology, and markets, smallholders can significantly increase their productivity and contribute to more resilient food systems. With food security increasingly threatened by climate change and other environmental pressures, supporting these farmers is more

critical than ever. To build sustainable, equitable food systems for the growing global population, investing in their capacity through better agricultural practices, information, and financial services is crucial. This means that their fates are inseparable from the health of the world's food supply [4].

Challenges Faced by Small Farmers in Accessing Financial Services

Smallholder farmers play a vital role in food systems at both the local and global levels, and yet, they are perennially neglected by traditional financial models. The core challenges include:

Lack of Tangible Collateral and Formal Credit History

Lenders typically demand physical assets like land titles, which are often absent in rural agrarian communities. The absence of documented financial transactions further impedes credit access, creating a cycle of exclusion [5].

Prohibitive Transaction Costs and Logistical Barriers

The dispersed nature of rural populations and the high cost of establishing and maintaining financial infrastructure in remote areas drive up transaction costs. This makes servicing smallholder farmers economically unviable for many formal lenders [6].

Inadequate Banking Infrastructure and Limited Financial Literacy

Banking branches and ATMs (Automated Teller Machines) are scarce in rural areas, which compels farmers to depend upon informal and high-interest credit sources. Adding to this problem is an almost complete lack of financial literacy, which prevents farmers from effectively using complicated financial products and services [7].

Vulnerability to Market Volatility and Climate-Induced Risks

The seasonal nature of agricultural income, coupled with exposure to unpredictable weather patterns and fluctuating market prices, creates substantial income volatility. This uncertainty raises the perceived risk of default, making lenders hesitant to extend credit. This volatility, combined with climate change-related risks, makes lending to small farmers even less attractive [8].

These financial inclusion challenges must be overcome gradually, as depicted in Fig. (1).

Insurance Innovations in Agricultural Sector Risk Management Using Blockchain

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Abstract: Farmers face a variety of challenges (e.g., climatic uncertainties, fluctuations in market conditions, pests, and diseases), hence the need for sound agricultural risk management, which is essential for food security and economic stability. Although traditional agricultural insurance mechanisms are helpful, many inefficiencies undermine their effectiveness, including delayed settlements, high operational costs, fraudulent claims, and limited access to high-quality insurance for smallholders. This necessitates innovative approaches to improve the effectiveness of agricultural risk management. However, blockchain is attractive in terms of decentralization, transparency, immutability, and efficiency, and has become a transformational solution in agricultural insurance. With the addition of smart contracts, blockchain brings claim settlements to the table in no time, and that too is fraud-resistant. Blockchain enables parametric insurance models that automatically trigger payouts when specified conditions are met, such as a specific weather event, thereby preventing disputes and processing delays. At the same time, these models reduce smallholder farmers' reliance on traditional insurers by providing low-cost, inclusive coverage through decentralized P2P insurance pools and microinsurance. Blockchain adoption can help overcome these challenges in agricultural insurance through transparency, fraud prevention, reduced transaction costs, and increased reach to underserved farmers. However, to realize its potential, challenges such as digital literacy, rural connectivity constraints, regulatory complexities, and data integration issues need to be addressed. This chapter discusses how blockchain can transform agricultural insurance, identifies case studies of successful applications, and demonstrates key learnings for best practices. The report also provides a roadmap for the future, underscoring the need for policy support, public-private partnerships, and agrotech innovations to build scalable, sustainable blockchain-based insurance solutions. By using blockchain, agricultural insurance can be more effective, fairer, and better able to withstand new threats.

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Keywords: Agriculture, Blockchain, Innovation, Internet of things, Insurance, Intelligence, Technology.

INTRODUCTION

There are a variety of risks that can disrupt agriculture, with consequential effects on production, profitability, and sustainability. These include climatic, market, pest, and disease risks. The variability of weather and extreme climatic events has a profound impact on agricultural productivity. Droughts, floods, storms, heatwaves, and out-of-season frost can reduce crop yields and livestock. Climate change has worsened these threats, making growing seasons more unpredictable and causing soil erosion and water shortages [1, 2].

Economic uncertainty for farmers stems from changes in market prices, input costs, and trade policies. Abrupt shifts in supply and demand, global trade restrictions, or rising inflation in fuel and fertilizer prices can impact profitability. Fluctuations in commodity prices, driven by global economic conditions, can leave farmers financially insecure. Insect infestations, like swarms of locusts and fall armyworms, can be fatal to crops. Pests can quickly spread across states, leading to significant agricultural losses. Constant use of chemical pesticides has led to the development of resistant pest populations by making it harder to control them. Integrated pest management (IPM) approaches can reduce these risks, but they need to be intentionally implemented [3, 4].

Diseases of plants and animals can ravage agricultural production. Fungal infections, bacterial blights, and viral outbreaks affect staple crops; meanwhile, livestock diseases, such as avian influenza or foot-and-mouth disease, cause economic losses and endanger food security. Diseases can break out due to a combination of climate change effects, inadequate biosecurity measures, and global trade patterns, all of which require tight surveillance, early detection and intervention strategies. Technological innovations, insurance mechanisms, and adaptive farming attributes may enhance resilience against these agricultural risks and ensure food security [5].

Importance of Risk Management in the Agricultural Sector

However, risk management is essential for the farmer, who must manage stochastic risks to stabilize production, sustain farming economies, and feed nations. With uncertainty around climate, market instability, pests, and diseases, farmers have to plan to minimize losses proactively. With farm risk management, farmers can be more organized, invest resources better, and ensure financial stability even in the face of multiple risk factors ranging from labor shortages to climate change [6].

Climate risks like droughts, floods, and extreme weather events can severely affect crop yields and livestock health. Further, market fluctuations in commodity prices, supply chain disruptions, and variations in input costs are other risks that threaten farmers' income. Critically, pests and diseases can proliferate quickly, causing devastating impacts to agricultural production. Farmers utilize several risk management strategies to mitigate these challenges, including diversification, precision farming, and technological innovations such as IoT (Internet of Things)-based monitoring systems and AI-driven predictive analytics. Government policies and support mechanisms, like subsidies and emergency relief funds, are also a key element of the equation [7].

Adaptive measures involved financial instruments, especially agricultural insurance, which acts as a cushion for farmers, allowing them to bounce back from a loss and remain in operation. Additionally, the introduction of analytical data and blockchain technology in risk evaluation automates claim processing. In the end, an appropriate risk management strategy helps maintain farmer resilience in order to limit any adverse impacts on food supply chains and global agricultural markets. Investing in risk mitigation strategies, however, makes agriculture more sustainable in the long term, continues to be profitable, and protects livelihoods [8].

Role of Agricultural Insurance in Mitigating Risks for Farmers

Agricultural insurance is an essential financial instrument that protects farmers against uncertainties and supports their recovery from losses due to climate disasters, pests, diseases, and fluctuations in the market. Agricultural insurance guarantees stability for farmers by offering financial compensation for losing crops and livestock or dealing with price fluctuations, which makes them less exposed to unforeseen circumstances [9].

Enhancing resilience is one of the advantages of agricultural insurance. Compensating farmers helps them reinvest for the next annual cycle without going into debt. This will help keep food production high while avoiding long-term economic pain in those rural communities that depend on those industries. Insurance also allows farmers to qualify for loans, as lending institutions will have more confidence in lending to farmers, as they are aware that there is a financial backup in place [10].

Crop insurance, livestock insurance, weather-based index insurance, and a variety of other agricultural insurance are provided by governments and private insurers. Weather-indexed insurance, for example, pays farmers based on specific weather events such as too little rainfall instead of actual physical damage to crops, reducing administrative costs and possibilities for fraud [11].

Consumer Trust and Risk Perception in Sustainable Agriculture: The Impact of Transparency on Buying Behavior

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Abstract: Development is a significant contributor to environmental challenges and economic viability. Perceptions of consumer trust and risk largely influence the decision to consider sustainable agricultural products. Trust is a psychological construct comprised of cognitive and emotional factors that are critical to address consumer uncertainties. This is built on transparency in labelling, ethical farming practices, third-party certifications, and social influence. Risk perception, or the subjective evaluation of risks of adverse events, influences consumer choices. Risk perception is influenced by factors such as financial concerns, authenticity skepticism, and cognitive biases (like availability heuristic, status quo bias). Confusion over sustainable farming claims may dissuade the eco-friendly consumer. Transparency is the bridge between consumers, who are increasingly valuing these ideas, and farmers, who are struggling to demonstrate what they are doing, building trust and reducing skepticism. The key to winning over consumers is establishing transparency mechanisms and certifications for brands, which go a long way toward building consumer trust. The cognitive and emotional dimensions are also critical, with consumer behavior being affected by feelings such as pride or guilt. Trust signals like sustainability logos and brand storytelling reassure consumers and alleviate perceived risks. There is a role of culture and societal norms in influencing sustainable consumer behavior. However, there are hurdles to widespread adoption, including greenwashing, high product costs, and knowledge gaps. Consumer education, behavioral nudges, and transparent marketing are some examples of practical approaches that can help build trust. Future research should explore the long-term effects of transparency and changing consumer trends in sustainable agriculture. Knowledge of psychological drivers will help develop better marketing strategies, encourage sustainable consumption, and assist in saving the planet on a global scale.

Keywords: Consumer trust, Sustainable agriculture, Status quo bias, Transparency, Third-party certifications.

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INTRODUCTION

Sustainable agriculture has become a vital solution to environmental, economic, and social problems caused by traditional agricultural methods. It embodies sustainable practices, fair trade sourcing, and resource-efficient technology to ensure future food security with minimal ecological cost. The increasing number of studies shows that consumers prefer to buy sustainably produced goods, but it still depends on factors such as trust and perceived risk regarding the product. The extent of transparency surrounding agricultural practices is fundamental in influencing consumer trust and ultimately their buying behavior [1, 2].

Multiple factors affect consumer trust in sustainable agriculture, including product quality, ethical values, and credibility of producer claims. As consumer awareness around food safety, environmental impact, and ethical sourcing continues to grow, buyers expect clear, verifiable information about the origin and sustainability of the products they purchase. This demand has led to increased transparency in the agricultural sector, which can be achieved through certifications, labeling, blockchain technology, and digital traceability systems. Hawkins covers why transparency, when appropriately executed, establishes trust, as it helps alleviate information asymmetry, which can provide reassurances to consumers about product authenticity and primary concerns around greenwashing, false or misleading sustainability claims [3].

Risk perception also plays a significant role in consumer decision-making. Many consumers weigh the potential risks of sustainable agricultural products, including concerns about price premiums, availability, and efficacy compared to conventional alternatives. Misconceptions about the reliability and affordability of sustainable farming practices can deter consumers from making environmentally conscious purchases. Additionally, the skepticism surrounding the actual impact of sustainability claims can further complicate consumer confidence. Therefore, clear communication and transparent supply chains are critical in alleviating such concerns and fostering a positive perception of sustainable agriculture [4].

The impact of transparency on buying behavior is profound. When consumers perceive a brand or producer as transparent, they are more likely to trust its claims and exhibit loyalty. Studies indicate that consumers are more inclined to purchase sustainable products if they have access to detailed, verifiable information regarding farming practices, sourcing methods, and environmental impact. The integration of digital tools, such as QR (Quick Response) codes, blockchain-based traceability systems, and third-party certifications, allows consumers to access real-time data on product origins, reinforcing their trust and influencing their purchasing decisions [5].

Moreover, companies that prioritize transparency in their sustainability efforts often experience enhanced brand reputation and competitive advantage. Transparent communication strategies, such as storytelling, social responsibility initiatives, and direct engagement with consumers, further strengthen consumer trust and commitment. By addressing consumer concerns, reducing uncertainty, and proving sustainability claims, transparency becomes a key driver in shaping consumer preferences and encouraging responsible consumption [6].

Multiple factors, including product quality, ethical issues, and producer claims of legitimacy, determine consumer trust in sustainable agriculture. As consumers become more aware of the implications of food safety guidelines, the environmental impact of agriculture, and the ethics of sourcing, buyers are now looking for information to support their purchase on the origin of food and product sustainability. Such demand has forced the agriculture sector to focus on transparency through certifications, labeling, blockchain, and digital traceability systems. Transparency works because it diminishes information asymmetry, thus increasing consumer confidence that products are what they are claimed to be and alleviating suspicions of greenwashing, false or misleading sustainability claims [7].

PSYCHOLOGY OF CONSUMER TRUST

Trust is a key psychological factor that influences many of the customer's decisions, especially in sustainable agriculture. Trust is the intangible connector between consumer hope and product performance, guiding consumers through the uncertainty and possibility of risk (both at an individual and systemic level) that come with opting for eco-friendly products. It is essential to understand the psychological elements of trust and what builds it in order to create consumer trust in sustainable use of agriculture [8].

The study assumes that trust is a construct with cognitive as well as emotional dimensions. This refers to a consumer's readiness to trust a product, company, or system based on integrity, reliability, and alignment with one's values. In the realm of sustainable agriculture, trust is crucial, as consumers cannot regularly verify the truth of sustainability claims themselves. Instead, they rely on more distant signals, such as certifications, labels, and brand reputation, to help them make decisions [9].

Sources of Trust

Trust in sustainable agriculture is cultivated through multiple channels that reinforce consumer confidence in the authenticity and quality of products.

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