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BLOCKCHAIN TECHNOLOGY FOR THE TRACEABILITY AND FRAUD DETECTION OF FOOD - AN OVERVIEW

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Abstract

The present paper aims to review the use of blockchain technology to improve traceability and prevent fraud in the food supply chain. With the growing complexity of global food systems, traditional traceability methods are often insufficient to guarantee transparency and data reliability. The main objective of this work is to analyze how blockchain can enhance information accuracy, strengthen consumer trust, and support food safety management across different stages of the supply chain. Blockchain provides a decentralized and secure structure for recording transactions, offering verified information accessible to all stakeholders. The integration with technologies such as IoT, RFID, and Big Data enables real-time monitoring of products from production to retail. Although its large-scale implementation still faces technical and regulatory challenges, the technology has strong potential to support a safer, more transparent, and sustainable food system.

Key words: *supply chain, food traceability, food safety, transparency, blockchain.*

INTRODUCTION

The increasing globalization of food supply chains has amplified the complexity of production, distribution, and information exchange, raising new challenges in ensuring food quality, safety, and transparency (Behnke and Janssen, 2019). Traditional systems of data management and coordination among supply chain partners often struggle to guarantee full traceability and reliability, particularly in cross-border trade (Alfaro and Rabade, 2009, Charlebois et al., 2014). As a result, the demand for more transparent and verifiable information sharing has grown substantially in recent years.

Food traceability plays a central role in this context, enabling the systematic collection and transfer of information throughout the supply chain to ensure product authenticity, quality, and safety (EC 178/2002). The concept has gained prominence following a series of food crises that eroded consumer trust and led to stricter regulatory requirements worldwide (Hsu and Liao, 2019). Traceability is now considered an essential component of modern food logistics, benefiting consumers, producers, retailers, and regulatory authorities alike (Grunow and Piramuthu, 2013).

Among the emerging technologies proposed to strengthen the traceability systems, blockchain has attracted significant attention due to its decentralized and tamper-resistant architecture (Kelepouris et al., 2007). By providing immutable records of transactions and enabling real-time access to trusted information, blockchain can enhance transparency, facilitate product tracking, and improve the overall integrity of food supply chains (Sarac et al., 2010).

The aim of this article was to summarize the current state of research on the application of blockchain technology in food traceability and food fraud detection, highlighting its principles, potential benefits, challenges, and prospects for integration into global food systems. This research article was conducted using a systematic literature review methodology.

BLOCKCHAIN TECHNOLOGY

Blockchain technology, defined as a distributed and tamper-resistant digital ledger, organizes information into sequentially connected data blocks that are managed collectively by a decentralized network. Each block stores records of digital events or transactions among participants, whose integrity and immutability are ensured through cryptographic hashing mechanisms (Gavina et al., 2019). Within this network, nodes share equal authority and maintain identical copies of the data, relying on consensus protocols capable of tolerating Byzantine faults, which enable secure peer-to-peer exchanges without the need for intermediaries (Son et al., 2021). This technology offers several advantages, including transparency, security, operational efficiency, accessibility, and the promotion of collaborative participation among stakeholders (Treiblmaier et al., 2020). Initially developed to support Bitcoin transactions (Nakamoto, 2008), blockchain has since demonstrated broad applicability in different sectors (medical, financial and food) (Iansiti and Lakhani, 2017). In the medical field, it facilitates the secure management of patient records and improves pharmaceutical traceability (Kshetri, 2018), while in marketing and digital identity management, it enhances data authenticity and strengthens consumer trust (Crosby et al., 2016). A particularly promising field of application is the food supply chain, where blockchain supports transparency, product traceability, and safety assurance (Pilkington, 2015; Iansiti and Lakhani, 2017). The concept of supply chain management (SCM) through blockchain was first developed and implemented by Walmart, which employs the technology to trace contamination events, identify bacterial sources, and minimize the scale of product recalls (Nofer et al., 2017). These same principles now underpin global initiatives designed to ensure food integrity, combat fraud, and reinforce consumer confidence.

BLOCKCHAIN IMPLEMENTATION IN COMPANIES

The integration of blockchain technology into companies is attracting growing interest, as it offers a way to enhance transparency, traceability, and trust in business processes. The main internal and external benefits of blockchain implementation in companies are summarized in Table 1. These benefits collectively highlight blockchain's potential to enhance both operational efficiency and consumer trust within supply chains.

Three main categories of blockchain system users have been identified: professional users (producers, distributors, transporters, and retailers), software and smart contract managers (Christidis and Devetsikiotis, 2016), and final consumers (Tian, 2017). Figure 1 provides an overview of the specific roles associated with each user category.

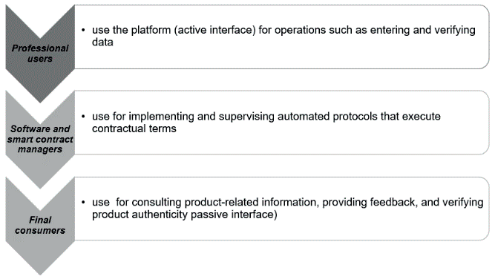

Figure 1. The role of blockchain system users

TECHNOLOGIES SUPPORTING BLOCKCHAIN TRACEABILITY IN THE FOOD SUPPLY CHAIN

Blockchain traceability in the food sector is enhanced by several complementary technologies that improve monitoring, data recording, and verification. RFID (Radio Frequency Identification) tags make it possible to track animals or products automatically, offering real-time insights while reducing the potential for human error (Tian, 2017). Barcodes and QR codes serve as a bridge between physical goods and digital records, allowing items to be scanned at various stages of the supply chain and enabling both forward and backward tracking (Treiblmaier, 2018). Through IoT (Internet of Things) devices, environmental conditions such as temperature and humidity can be continuously monitored, helping maintain food quality and ensuring adherence to safety standards (Rejeb et al., 2020). The use of Big Data analytics allows organizations to analyze large datasets from supply chains, facilitating better risk assessment and informed decision-making (Francisco & Swanson, 2018). Furthermore, 3D printing can be applied to create tamper-evident packaging and secure labels that integrate directly with blockchain records, guaranteeing product authenticity (Kim and Laskowski, 2018).

Table 1. Internal and external benefits of blockchain implementation in companies

Type	Benefit	Description/Effect	Source
Internal	Process optimization	Avoids document duplication, standardizes data formats, and unifies databases, leading to more efficient information flow.	Treiblmaier, 2018
	Real-time stock monitoring	Enables better replenishment planning, faster product recalls, and automated quality control via smart contracts.	
	Traceability improvement	Streamlines product tracking along the supply chain and integrates various communication and documentation tools.	
	Data centralization	Provides a single, comprehensive data source for economic, technical, and managerial analysis, reducing operational risks.	Francisco and Swanson, 2018
External	Intellectual property protection	Prevents counterfeiting and reduces black-market activities by securing product information.	Kim and Laskowski, 2018
	Transparency and trust	Enhances corporate image and consumer loyalty through verifiable data transparency.	
	Ethical and sustainable reputation	Demonstrates responsible business practices, improving the company's public perception.	

By linking these technologies, blockchain forms the core of a robust traceability framework that spans the full supply chain from production and processing to distribution and consumption enhancing transparency, accountability, and consumer confidence while minimizing the risk of fraud.

BLOCKCHAIN TECHNOLOGY IN THE AGRI-FOOD SECTOR

In the agri-food sector, traceability and effective food fraud detection are vital not only for safeguarding food safety but also for restoring consumer confidence. From a food safety perspective, traceability allows every stage of the supply chain from production and processing to distribution to be monitored, thus reducing the risk of contaminated, adulterated, or mislabelled products reaching the market. Effective fraud detection helps identify intentional or accidental manipulation of food, such as substitution, dilution, or misrepresentation, which can pose serious health risks (Spink et al., 2019). From the consumer standpoint, reliable traceability and robust fraud controls build trust in the integrity of food products, ensuring that claims about origin, quality, and authenticity are accurate.

Between 2020 and 2024, 2,734 food fraud incidents were reported (EC 2020-2024). Grey-market cases accounted for the largest share, representing 43%, primarily affecting alcoholic beverages (spirits and other products, excluding wine) as well as staple foods like cereals, meat, and seafood. These incidents often involve cross-border movement outside official channels, such as unauthorized meat processing or illegal fishing, reflecting the economic incentives driving covert trade and regulatory evasion (EC, 2018). Adulteration was the second most common type, comprising 22% of cases, frequently targeting dairy products, oils, and spices, where products are diluted or substituted to increase profit margins. Document fraud accounted for over 26% of incidents, particularly in meat and seafood supply chains, where mislabelling of origin, species, or quality undermines market value and consumer trust. Counterfeiting, though less frequent at 8%, mainly affected branded or protected products, including alcoholic beverages and high-value foods. The high number of reported incidents may reflect improved detection capabilities, driven by advances in analytical methods and data sharing, rather than a sudden increase in fraudulent activity. Enhanced monitoring tends to correlate with higher reported incidence, whereas limited oversight often results in underreporting (Brooks et al., 2021). Conversely, under-detection remains a concern in regions lacking robust control systems (EC, 2018). In the current decade, global supply chains have become longer and more complex, making them harder to trace and creating additional opportunities for fraud. Ingredients and products now cross multiple borders, widening the gap between producers and consumers and increasing the likelihood of undetected fraudulent activity. Economic pressures, particularly during recessions or market instability, further exacerbate the problem, as fraudsters exploit cost-cutting measures and supply shortages. In response, technological innovations for detecting food fraud have advanced rapidly, offering tools to mitigate risks. Within the food supply chain, blockchain improves traceability and transparency, supports fair trade practices, and helps reduce the risk of food fraud.

Blockchain in Agriculture Sector

In the agribusiness sector, the supply chain integrates a complex set of operations that encompass the entire process from agricultural production on farms to the stages of industrialization, distribution, and commercialization, culminating with the delivery of products to the final consumer (da S.R. Rocha et al., 2021).

Blockchain technology has multiple applications throughout the agricultural supply chain, providing transparency, traceability, and data integrity at each stage of production.

Table 2 summarizes the key stages, recorded data, and associated benefits reported in recent studies.

Table 2. Blockchain application in agriculture sector

Supply chain stage	Blockchain application	Type of recorded data	Main benefits	References
Seed sourcing	Recording seed origin and certification	Certified seed vendors, batch numbers, genetic provenance	Ensures authenticity and prevents seed fraud	Mao et al., 2018
Crop management	Documentation of pesticide use and field activities	Pesticide type, application date, dosage	Supports traceability and compliance with regulations; promotes sustainable practices	Lin et al., 2021
Harvesting and processing	Logging of harvesting, handling, and processing events	Harvest dates, handling procedures, processing data	Improves transparency and quality monitoring	Hasan et al., 2019
Storage and distribution	Monitoring environmental parameters through IoT integration	Temperature, humidity, storage time	Maintains product quality and reduces spoilage	
Transportation and logistics	Tracking logistics operations and vehicle data	Vehicle identifiers, routes, time stamps	Enables continuous chain of custody (“farm to fork”)	Kumar et al., 2022
Safety and traceability	Rapid identification of contamination sources	Time-stamped, immutable records	Accelerates recall procedures and minimizes food waste	Tian, 2017; Rejeb et al., 2020
Quality assurance and certification	Verification of compliance with standards	HACCP, ISO 22000 documentation	Promotes accountability and consumer trust	Tripoli and Schmidhuber, 2018

Blockchain in Meat Processing Sector

Meat supply chains are vulnerable to hazards including the presence of residues from veterinary treatments harmful microorganisms, and intentional or accidental food adulteration.

Blockchain technology has been increasingly applied in meat processing to enhance traceability, ensure product authenticity, monitor quality parameters, and streamline supply chain operations.

Table 3 summarizes key applications and use cases observed in the sector.

Blockchain in Dairy Supply

The dairy industry faces persistent challenges in maintaining traceability, authenticity, and quality control, largely because milk is highly perishable and moves through complex supply networks.

Blockchain technology provides a decentralized and transparent way to record each step of milk production from collection on farms to its arrival in stores creating verifiable records that can be shared across all partners in the chain (Hasan et al., 2019).

When combined with IoT sensors, RFID tags, and QR codes, blockchain allows continuous monitoring of factors such as temperature, hygiene, and transport conditions, all of which are critical for safety and quality (Tian, 2017; Rejeb et al., 2020). This integration makes it easier to detect adulteration, contamination, or mislabeling, problems that have long affected dairy products (Akram et al., 2024). Advanced tools like Big Data analytics and artificial intelligence can further enhance predictive control and rapid intervention during safety incidents, strengthening both regulatory compliance and consumer trust (Francisco and Swanson, 2018).

Table 3. Blockchain application in meat processing sector

Stage	Description	Key data recorded	References
Animal registration	Animal is received on the farm; passport data entered into traceability platform. Each animal receives a unique ID.	Animal ID, mother's ID, birth country, origin country, supplier name, farm ID, birth date, entry date, breed, sex, weight, health status	Treiblmaier, 2018; Mao et al., 2018
Rearing / growth phase	Records welfare and growth information during stay at farm; daily inspections ensure compliance.	Health (vaccinations, diseases, treatments), feeding type and quantity, growth method, weight at exit, exit date	Lin et al., 2021
Slaughter stage	Transport, arrival at abattoir, humane slaughter.	Abattoir ID, slaughter date, pre-slaughter weight, transport authorization, health certificate, vehicle ID, arrival date	Tripoli and Schmidhuber, 2018
Product processing	Processed or semi-processed products prepared.	Product type, lot number, processing date, facility ID	Francisco and Swanson, 2018
Packaging, distribution, product recall	Products packaged per EU regulations; transported via refrigerated trucks; unique barcodes enable upstream/downstream traceability.	Packaging compliance, date, expiry, weight, destination store, barcode ID, distribution route, storage temperature	Kim and Laskowski, 2018
Consumer-level traceability	Consumers scan QR/barcode to track product origin and supply chain journey.	Product ID, origin, supply chain path, processing and packaging details	Tian, 2017; Rejeb et al., 2020

Moreover, blockchain has shown potential in safeguarding geographical indications and origin designations key elements for authentic cheeses like Feta, Parmigiano Reggiano, or Roquefort. Recording production data such as farm location, milk composition, and certification details on secure digital ledgers helps confirm authenticity and ensure adherence to EU and national standards (Mao et al., 2018; Kim and Laskowski, 2018). By linking digital records with smart tags and scannable codes, consumers and authorities can instantly verify product origin and integrity (Rejeb et al., 2020). These applications not only deter counterfeiting but also help preserve cultural value and consumer confidence in traditional, high-quality dairy products (Bai et al., 2022).

Blockchain in Fish and Seafood Industry

The fish and seafood sector is highly exposed to fraud, including species substitution, false labeling of origin, and products obtained from illegal or unreported fishing. Blockchain technology can address these challenges by providing an immutable record of every transaction and movement in the supply chain, starting from the catch location to the point of sale (Brooks et al., 2021). When combined with IoT devices, satellite tracking, and RFID tags, blockchain systems can record where and when fish were caught, by which vessel, and under which fishing license, ensuring compliance with legal and sustainability standards (Tripoli and Schmidhuber, 2018; Hasan et al., 2019). These records can also verify whether seafood originated from certified aquaculture farms or wild capture fisheries, helping to prevent fraudulent mixing or mislabeling of species. In processing and retail, scannable QR codes linked to blockchain ledgers allow consumers and authorities to confirm the authenticity and legality of seafood products (Rejeb et al., 2020).

This transparent approach reduces opportu-nities for illegal trade, protects honest producers, and strengthens consumer confidence in sustainably sourced seafood.

CONCLUSIONS

The present study highlights the growing potential of blockchain technology to enhance transparency, traceability, and trust within the food supply chain. By enabling secure and immutable data exchange, blockchain strengthens food safety management and fosters greater accountability among supply chain partners.

Evidence from recent implementations indicates that food companies increasingly adopt blockchain-based systems to verify product origin, ensure quality compliance, and improve consumer confidence. Applications have been reported across diverse sectors of the food industry, including primary production, processing, logistics, and retail.

The combination of blockchain with complementary technologies such as IoT, artificial intelligence, and cloud systems further expands its capabilities for real-time monitoring and data-driven decision-making. Nevertheless, widespread adoption is still limited by interoperability issues, high costs, and the lack of standardized frameworks.

Overall, blockchain offers a promising pathway toward a more transparent and sustainable food system, provided that future efforts focus on technological integration, scalability, and regulatory harmonization.

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