Blockchain in Agri-Food Supply Chains

Subjects: Computer Science, Software Engineering
Contributor: Filisia Melissari , Andreas Papadakis , Dimitris Chatzitheodorou , Duc Tran , Joachim Schouteten , Georgia Athanasiou , Theodore Zahariadis

The involvement of multiple actors in the food industry and the prevalence of centralised systems, which are owned and controlled by single stakeholders, can raise concerns regarding data reliability. When traceability data are stored in centralised systems managed by single entities, they become more susceptible to unintentional errors, deliberate tampering, or potential attacks. Efforts have been made to replace these centralised systems with distributed platforms such as blockchain infrastructure, aimed at fostering trust among supply chain actors.

traceability blockchain food Ethereum Quorum smart contracts agriculture dairy

1. Blockchain

Blockchain, a distributed digital ledger (DLT), can store records of data/transactions that are confirmed by all participating nodes, leading to a highly tamper-resistant system. Depending on the access, blockchain networks can be (a) public/permissionless, where users can read/write data with examples including Bitcoin and Ethereum, (b) private (permissioned), where access is granted by a central entity to specific entities, and (c) hybrid (or consortium), which are controlled by a group of companies/participants that authorise the participation in the network along with the rights to access/modify the stored data [1]. The benefit of the public chains is the open access, while the private ones can control access due to their more centralised nature, and the consensus algorithms of private chains employed may offer better performance [2].

Ethereum, a pioneering blockchain platform, allows automated and computerised transactions, commonly referred to as ‘smart contracts’ [3]. Smart contracts are designed to execute specific actions automatically when predetermined conditions are met. Their computerised nature ensures direct execution without any delays or the need for external entities to take action [4]. Once registered in the blockchain system, smart contracts become immutable. This immutability instils confidence that the contract will be enforced as initially designed. Smart contracts can interact not only with human users but also with other smart contracts within the same blockchain ecosystem, making them valuable for automating various business processes. Blockchain systems can incorporate regulatory requirements by encoding them as computerised rules. These rules can be integrated into the blockchain and modified as needed [5]. This flexibility allows for compliance with changing regulations.

However, it is worth noting that smart contracts have limitations. They have a restriction on the volume of data they can handle efficiently. Additionally, smart contracts cannot independently verify the trustworthiness of the triggering event. This means that they rely on external sources to provide accurate information for execution [6]. As the concept of smart contracts becomes available on multiple blockchain platforms, the choice of platform typically depends on the specific requirements of the use case at hand.

The security and performance of a blockchain network are ensured by the consensus algorithm, which verifies the content of new blocks. Proof of work (PoW), proof of stake (PoS), and proof of authority (PoA) are some of the better-known categories of consensus algorithms. Vistro et al. (2021) investigates the usage of consensus protocols in different application domains [7].

- Proof of Work (PoW) is the first consensus algorithm. In PoW, participating nodes, often referred to as 'miners', are tasked with resolving intricate mathematical problems (mining). These nodes engage in competitive mining, with the objective of introducing a computational and energy cost to create a new candidate block. Successful miners are rewarded with cryptocurrency upon the successful assembly of a block. Nevertheless, it is noteworthy that PoW exacts a substantial toll in terms of time and energy resources.

- Proof of Stake (PoS): PoS addresses the inefficiencies inherent in PoW, including delays and the high consumption of energy resources. PoS introduces the concept of validators who "stake" cryptocurrency as collateral to validate new blocks. Nodes that stake larger quantities of cryptocurrency enjoy a higher likelihood of being selected to propose a new block, subsequently validating transactions and receiving a cryptocurrency reward. PoS exhibits greater energy efficiency and imposes less computational overhead in comparison to PoW. However, it is worth noting that PoS may potentially favour users with greater financial stakes.

- Proof of Authority (PoA): In PoA, validators are approved by a central authority following a rigorous screening process. These validators are subsequently randomly chosen to generate the next block that is added to the blockchain. PoA is typically deemed suitable for permissioned blockchain networks characterised by demanding throughput and low latency requirements. However, it relies upon the presence of a central authority, and the identities of validators are publicly disclosed.

- Raft is a distributed consensus algorithm by dividing participating nodes in three categories: leader, followers, and candidate (during leader election phase). The leader node manages the block addition and placement in the whole network [8].

- The Istanbul Byzantine Fault Tolerance (IBFT) consensus mechanism is a flavour of PoA algorithms involving a block-proposing node and a group of validating nodes, which approve, by two thirds, the addition of the block. The group consensus model employed is a variant of practical Byzantine fault tolerance [9].

While public blockchain networks are using PoW or PoS consensus algorithms, private networks are oriented towards PoA-type algorithms. PoA algorithms reduce time for block creation and insertion, offer operational effectiveness and flexibility, and can ensure security with the employment of trusted nodes and supermajority validation requirements.

2. Blockchain in Agri-Food Supply Chains

The involvement of multiple actors in the food industry and the prevalence of centralised systems, which are owned and controlled by single stakeholders, can raise concerns regarding data reliability. When traceability data are stored in centralised systems managed by single entities, they become more susceptible to unintentional errors, deliberate tampering, or potential attacks [10].

Efforts have been made to replace these centralised systems with distributed platforms such as blockchain infrastructure, aimed at fostering trust among supply chain actors [11][12]. The shift from centralised systems to decentralised systems involves adopting a collaborative and mutually trusted management model for both on-chain and off-chain data. In this regard, various distributed architectures for data management have been proposed, including systems such as the Electronic Product Code Information Service (EPCIS)-based distributed traceability system, which facilitates the sharing of information about physical and digital objects [13]. Among blockchain technologies, Ethereum has emerged as the most widely used, closely followed by Hyperledger Fabric [14].

Casella et al. (2023) and Kamilaris et al. (2019) corroborated that the utilisation of blockchain technology is on the rise within the domains of agri-food, logistics, and supply chain management [15][16]. In the case of agri-food supply chains, the input data for the blockchain systems can be intricate due to the diverse sources of raw materials and the complex mixing and transformation process to produce the final products [17]. For instance, Lucena et al. (2018) attempted to develop a quality assurance tracking system using blockchain technology that captures the physical, chemical, and biological conditions during the transformation of grains [18]. Most of the early blockchain projects in agri-food supply chains targeted non-processed food products such as beef or fruits, which does not require complex data input for tracing the product flow from raw materials [19]. To the best of the authors' knowledge, studies regarding blockchain-based traceability systems for processed dairy products such as cheese remain scant in the literature.

Blockchain-based traceability systems face some critical challenges, such as the storage pressure that hampers the system performance. In this regard, combining InterPlanetary File Storage System (IPFS) and blockchain [20][21] or storing traceability data off-chains and the Merkle keys on chains [21] appear to be promising solutions.

Even though blockchain provides immutability of the records of data, it does not ensure the verifications of actors' reliability or accountability of the transaction process. Shahid et al. (2020) proposed a reputation system that captures the reviews of supply chain actors in IPFS while their hashes are stored in blockchain. By doing this, the immutability and integrity of the reviews made by multiple actors can be ensured [16]. Li et al. (2022) took an extra measure in verifying the input data by using Electronic Product Code Information Service (EPCIS) to authenticate and authorise the Internet of Things (IoT) devices used for data collection [21]. As previously discussed, the advancement of blockchain applications within agri-food supply chains has garnered growing interest from both the academic and industry communities. Nonetheless, given that blockchain technology is still in its early stages of development, there is a pressing need for more practical projects to thoroughly explore and capitalise on its potential.

References

1. Chenchev, I. Classification of the DLT Consensus Algorithms with Focus on Blockchain. In Intelligent Sustainable Systems; Selected Papers of WorldS4 2022; Springer: Singapore, 2022; Volume 2, pp. 731–741.
2. Sivula, A.; Shamsuzzoha, A.; Helo, P. Requirements for blockchain technology in supply chain management: An exploratory case study. Oper. Supply Chain. Manag. 2021, 14, 39–50.
3. Buterin, V. A next-generation smart contract and decentralized application platform. White Pap. 2014, 3, 1–2.
4. Zheng, Z.; Xie, S.; Dai, H.-N.; Chen, W.; Chen, X.; Weng, J.; Imran, M. An overview on smart contracts: Challenges, advances and platforms. Futur. Gener. Comput. Syst. 2020, 105, 475–491.
5. De Filippi, P.; Hassan, S. Blockchain technology as a regulatory technology: From code is law to law is code. arXiv 2018, arXiv:1801.02507.
6. Köhler, S.; Pizzol, M. Technology assessment of blockchain-based technologies in the food supply chain. J. Clean. Prod. 2020, 269, 122193.
7. Vistro, D.M.; Farooq, M.S.; Rehman, A.U.; Malik, S. Smart application based blockchain consensus protocols: A systematic mapping study. In Proceedings of the 3rd International Conference on Integrated Intelligent Computing Communication & Security (ICIIC 2021), Bangalore, India, 6–7 August 2021; Atlantis Press: Dordrecht, The Netherlands, 2021; pp. 573–581.
8. Ongaro, D.; Ousterhout, J. In search of an understandable consensus algorithm. In Proceedings of the 2014 USENIX Annual Technical Conference (USENIX ATC 14), Philadelphia, PA, USA, 19–20 June 2014; pp. 305–319.
9. Castro, M.; Liskov, B. Practical byzantine fault tolerance. In Proceedings of the OsDI, New Orleans, LA, USA, 22–25 February 1999; Volume 99, pp. 173–186.
10. Zhao, G.; Liu, S.; Lopez, C.; Lu, H.; Elgueta, S.; Chen, H.; Boshkoska, B.M. Blockchain technology in agri-food value chain management: A synthesis of applications, challenges and future research directions. Comput. Ind. 2019, 109, 83–99.
11. Menon, S.; Jain, K. Blockchain technology for transparency in agri-food supply chain: Use cases, limitations, and future directions. IEEE Trans. Eng. Manag. 2021, 71, 106–120.

12. Latino, M.E.; Menegoli, M.; Lazoi, M.; Corallo, A. Voluntary traceability in food supply chain: A framework leading its implementation in Agriculture 4.0. Technol. Forecast. Soc. Change 2022, 178, 121564.
13. Lin, Q.; Wang, H.; Pei, X.; Wang, J. Food safety traceability system based on blockchain and EPCIS. IEEE Access 2019, 7, 20698–20707.
14. Sendros, A.; Drosatos, G.; Efraimidis, P.S.; Tsirliganis, N.C. Blockchain applications in agriculture: A scoping review. Appl. Sci. 2022, 12, 8061.
15. Casella, G.; Bigliardi, B.; Filippelli, S.; Bottani, E. Cases of application of blockchain on the supply chain: A literature review. Procedia Comput. Sci. 2023, 217, 1416–1426.
16. Kamilaris, A.; Fonts, A.; Prenafeta-Boldύ, F.X. The rise of blockchain technology in agriculture and food supply chains. Trends Food Sci. Technol. 2019, 91, 640–652.
17. Qian, J.; Fan, B.; Wu, X.; Han, S.; Liu, S.; Yang, X. Comprehensive and quantifiable granularity: A novel model to measure agro-food traceability. Food Control 2017, 74, 98–106.
18. Lucena, P.; Binotto, A.P.D.; Momo, F.d.S.; Kim, H. A case study for grain quality assurance tracking based on a Blockchain business network. arXiv 2018, arXiv:1803.07877.
19. Shahid, A.; Almogren, A.; Javaid, N.; Al-Zahrani, F.A.; Zuair, M.; Alam, M. Blockchain-based agri-food supply chain: A complete solution. IEEE Access 2020, 8, 69230–69243.
20. Yao, Q.; Zhang, H. Improving agricultural product traceability using blockchain. Sensors 2022, 22, 3388.
21. Li, L.; Qu, H.; Wang, H.; Wang, J.; Wang, B.; Wang, W.; Xu, J.; Wang, Z. A Blockchain-Based Product Traceability System with Off-Chain EPCIS and IoT Device Authentication. Sensors 2022, 22, 8680.