Nanotechnology Perceptions
ISSN 1660-6795
www.nano-*ntp.com*

Blockchain Based Agri-Food Supply Chain- Principles, Architecture And Challenges

Haris Manzoor Qazi

Assistant Professor, University of Kashmir North Campus, J&K;
haris@uok.edu.in
Corresponding author: Haris Manzoor Qazi

Agriculture forms an integral part of a nation's economy since it helps feed the entire population. The global body, International Monetary Fund (IMF), predicts a 70% increase in the production of food through agriculture by the year 2050 in order to meet the demand posed by ever growing population. The food we consume reaches us through a well-defined process that starts right in the fields where it is grown. Recently, a technology known as blockchain, has impacted a large number of social and economic domains. In particular, the influence of blockchain on the food supply chain has been remarkable. In this article, the role of blockchain technology on ensuring the authenticity and genuineness of food items is analyzed. The article explains the agri-food supply chain and reviews the architecture of blockchain. It also highlights the role of IoT on food chain as realized as an integrated service. The article culminates with a discussion of various challenges of blockchain in agriculture alongwith a mention of some real life agri-blockchain services.

Keywords: Agri-food supply chain, Farm-to-fork, Blockchain, Ledger, IoT.

Introduction

Agriculture forms a big part of the economy of any country because it helps feed the entire population. Agricultural food production is projected to be 70% higher by 2050 than it is today. Due to rapid population growth, there is high pressure on agriculture to increase food production sustainably. Not only does agriculture face a decline in production, but it also faces limitations in data collection, storing, securing, and sharing, climate change, increases in input prices, traditional food supply chain systems where there is no direct connection between the farmer and the buyer, and limitations on energy use [1]. As a result, policymakers, development agencies, civil society organizations, and private enterprises are investigating the role of food and farm markets in the development of sustainable agriculture [2]. Sustainable food and agricultural production cannot be accomplished by the conventional agriculture systems that have led to substantial deforestation, water scarcity, or soil erosion. Thus, advanced systems must be used which conserve and reinforce the basis of natural resources and increase production.

Smart Agriculture

Smart agriculture, also known as precision agriculture or agri-tech, refers to the use of technology to enhance agricultural productivity, efficiency, and sustainability. The idea of smart agriculture was first introduced in 2009 and revived through the involvement and input of many stakeholders involved in design and implementation. Smart agriculture aims to address the challenges facing modern agriculture, such as climate change, resource scarcity, and population growth, by leveraging technology to make farming more efficient, sustainable, and resilient. Smart agriculture uses advanced technologies such as the Internet of Things (IoT), big data, and cloud computing to monitor the field environment, analyze crop growth, and provide information to the farmer for decision-making [1]. Many modern farms make use of cutting-edge technology and scientific ideas [3]. An information-based management cycle for smart agriculture is presented in Figure 1.

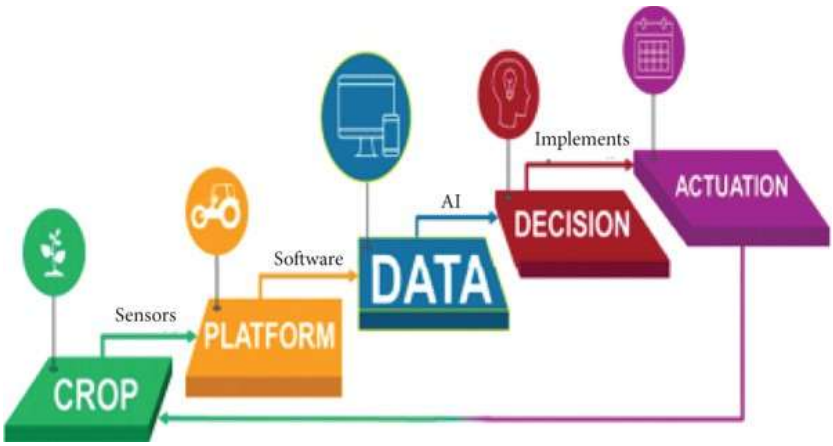

Fig. 1 Smart Agriculture Cycle [1]

In smart agriculture, IoT provides a wide range of applications such as soil and plant tracking, crop growth observation and selection, assistance for irrigation assessment, and monitoring of the agriculture environment. A variety of field sensors such as soil moisture sensors, humidity sensors, leaf moisture sensors, solar radiation sensors, infrared light sensors, and rainfall predictors can be installed in a variety of locations, including greenhouses, seed banks, cold rooms, agricultural machinery, transportation systems, and livestock, and the data collected can be processed in the cloud for monitoring and control [4]. The implementation of IoT has increased the productivity and effectiveness of farmers. Farmers can also figure out which crops are most suited for which conditions and can rotate crop accordingly [5]. The figure below shows a typical three layer IoT architecture that can be deployed in smart agriculture [6].

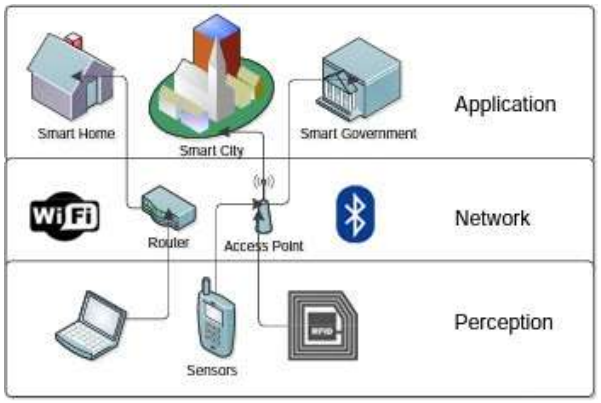

Fig. 2: Three-layer IoT architecture [6]

Agri-food supply chain- From farm-to-fork

A supply chain may be defined as the integration of all activities related to the transformation of products from raw materials to end-user goods, as well as the associated information flows, in order to achieve a sustainable competitive advantage. It is also referred to as a sequence of events involving a transformation, movement, or distribution that adds value [7]. Food supply chain management is a process that explains how food from an agricultural field ends up on our tables, i.e, from production to consumption [8]. Thus supply chain management deals with production, refining, delivery, selling consumption, and disposal [9]. The process of the supply chain is depicted in Figure 3.

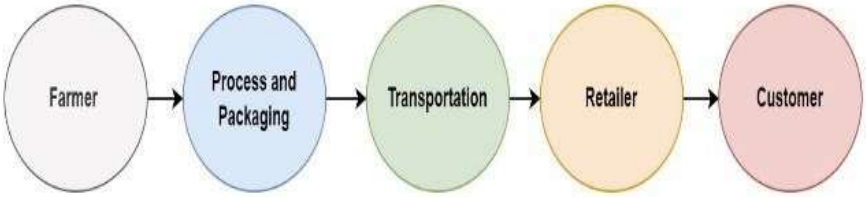

Fig. 3: The Agri-Food Supply Chain [10]

As has been already said, agriculture, when carried out using IoT technologies, is known as smart agriculture. The agri-food supply chain system corresponding to such a scenario can be depicted in figure 4. This classical food traceability scenario, sometimes termed "from-farm-to-fork", fosters traceability of food along the whole supply chain, e.g., from agricultural production (the farm side) to consumption (the fork-side) [11].

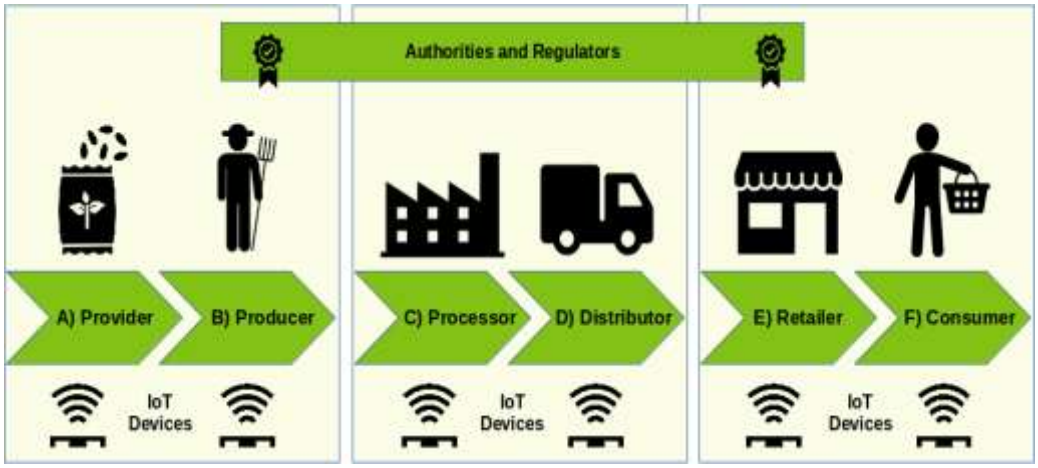

Fig. 4: IoT based smart agriculture supply chain system [11]

As is seen in the above figure, the food supply chain comprises of the following players:
Provider: providers of raw materials, such as seeds and nutrients, but also pesticides, chemicals, etc. Producer: usually the farmer e.g., the responsible of the actions from seeding/planting to harvesting.
Processor: this actor may perform various actions, from simple packaging to more complex processes (e.g., pressing of the olives).

Distributor: this actor is responsible of moving the output of the processor (e.g., the product) from processor's site to the retailers.

Retailer: this actor is responsible of selling the products in either small local stores or big supermarkets.

Consumer: forms the final element of the chain.

Problems in agri-food supply chain
Today, the vast majority of traditional logistic information systems in agri-food supply chains merely track and store orders and deliveries, without providing features such as transparency, traceability and auditability [11]. The food supply chain faces several challenges such as the need for confidence among stakeholders, credibility and traceability required by the end-users, risk management, delays, disruptions, and insufficient or lacking information [12]. Another major bottleneck is that farmers use chemical fertilizers, insecticides, and other materials to increase crop production, especially vegetable growers often use harmful pesticides to spray vegetables to improve their profitability, and consumers buy the same vegetables to eat which is a major health hazard. Further, food frauds and data alteration are also big challenges for supply chain stakeholders. In addition,

IoT based supply chains present many challenges due to their centralized client/server model. These include traffic congestion when the server couldn't support the large number of requests from clients. Moreover, when the server is down, client request cannot be met [6]. Thus, the problems in agri-food supply chain can be summarized as under:

Centralized

Most of the IoT systems are built based on a client/ server (centralized) platform. The client/ server model would not be able to sustain the IoT system in near future due to the increase in the number of IoT devices [6]. Therefore, there is a need to move from a centralized platform to a decentralized platform.

Lack of transparency and trust

More and more food products and beverages are branded and accompanied by a variety of certification schemes with an increasing risk of fraud (selling unqualified product with high-quality labels or claims) and adulteration, thereby weakening customers' trust in the authenticity of food products. Further, the lack of transparency in supply chains delays the identification of contamination sources and the root causes of product problems [13].

Lack of traceability

The inability to track the food product through all stages of the supply chain is a major cause of concern.

Lack of security

IoT devices are more vulnerable to security attacks, resulting in tampered data.

Inefficient & fraud prone

Much of the compliance data and information is audited by trusted third parties and stored either on paper or in a centralised database. These approaches are known to suffer from problems such as high cost and inefficiency of paper-based processes and fraud, corruption and error both on paper and in IT systems.

Blockchain technology and blockchain based supply chain

The term blockchain was coined by Satoshi Nakamoto in 2008 to serve as the public distributed ledger for bitcoin cryptocurrency transactions **[**14]. Blockchain is a distributed database where data can be recorded and shared via a decentralized computing network while also providing security and privacy. Since the data is spread, only the owner who has the private key can make transactions. The other machines or computers on the network serve as validators. It safely records transactions between nodes in a public ledger without the need for a trusted third party [15]. When a sender node makes a transaction, it distributes it to the other nodes on the network. The receiving nodes verify the transaction and have proof of work. The node that succeeds in the proof of work will broadcast it to all the other nodes and connect the block to the chain. The transaction shall contain the public key of the recipient and shall be signed by the sender. Therefore, any other node will verify the validity

of the transaction. Blockchain's impact extends beyond the digital currency for which it was originally designed, offering potential benefits in various sectors including finance, healthcare, education, and supply chain management [16].

Architecture

Blockchain systems are based on a peer-to-peer (P2P) architecture, which consists of nodes that are connected directly to each other via the Internet without a central element of coordination and control [7]. The data are recorded in a sequential chain of hash-linked blocks that facilitate the data distribution to be more manageable than other traditional data storage formats. Each block includes the hash of the block history, hash of the current block, date, other details, and transactions for the block. The blocks are verified and uploaded into the chain-like system by selected nodes via an agreed consensus protocol. This consensus mechanism allows all the parties to engage in the monitoring process when adding data flow. In addition, the duplicates of these data are stored in all involved nodes to ensure no tampering.

The application of blockchain in the food industry enhances traceability and safety. This can enhance food safety by quickly pinpointing any tainted products, reducing the risk of foodborne illnesses. This increased transparency allows consumers to make more informed decisions about the products they buy, leading to a stronger bond of trust between consumers and food producers. In agriculture, blockchain provides similar benefits by streamlining supply chain processes, reducing costs, and ensuring the authenticity of agricultural products. Farmers can use blockchain to directly connect with buyers, improving profit margins and reducing the power asymmetry often seen in traditional agricultural supply chains. These improvements not only enhance operational efficiency but also promote sustainability within the agricultural sector by supporting fair trade practices and reducing waste [17]. Figure 5 shows the structure of a blockchain based food supply chain.

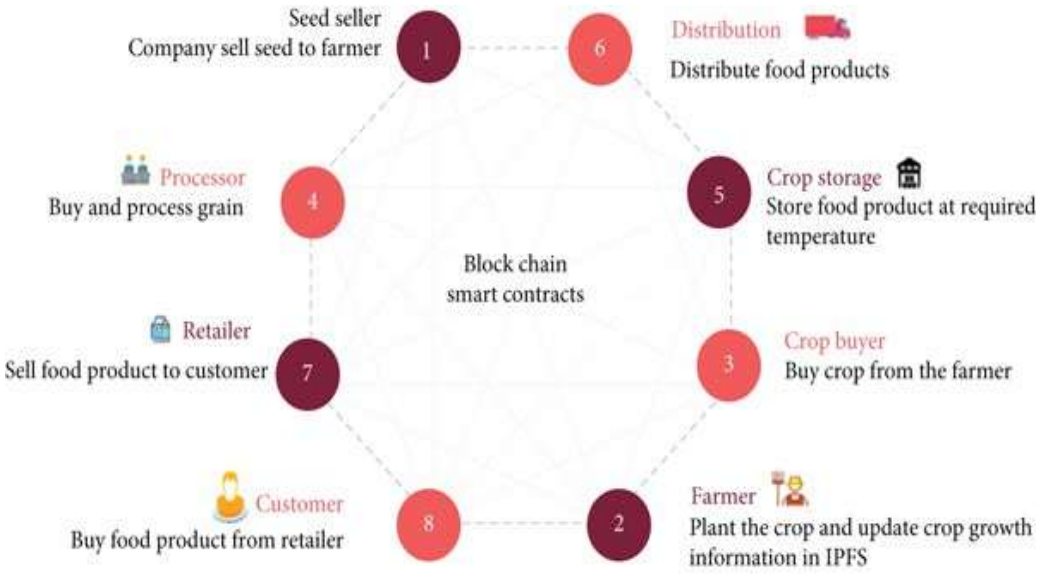

Fig. 5: Blockchain based food supply chain [1]

Advantages

Blockchain technology benefits the food supply chain in a number of ways:
Traceability and transparency

Blockchain technology offers a comprehensive view of the entire product life cycle, from the point of initial production to the point of final retail delivery. This ensures that data regarding the origin, handling, processing, and distribution of agricultural products is readily available and verifiable, fostering trust among consumers and compliance with regulations. Such a process enables all stakeholders within the supply chain, inclusive of consumers, to meticulously track the provenance of goods and authenticate assertions put forth by manufacturers and distributors regarding the calibre and durability of the products [18].

Enhanced efficiency

The decentralized nature of blockchain simplifies complex supply chain logistics, removing unnecessary intermediaries, and reducing costs. It also accelerates transactions and enhances the responsiveness of supply chain management to market changes. This shift towards more agile supply chains is crucial for meeting both retailer and consumer demands more effectively [19].

Improved sustainability

Blockchain supports sustainable agricultural practices by enabling better monitoring and compliance with environmental and social standards. Corporate entities bear the responsibility of guaranteeing transparency and compliance in their supply chain operations, consequently cultivating an ethical culture across the entire firm. This alignment with global sustainability goals is increasingly important as consumers and regulatory bodies demand higher standards [20].

Smart contracts

Smart contracts are a self-executing computer code, enabling the exchange of assets between participants without the need for an intermediary. It specifies all the terms of the transaction and if the participants fulfill them, they automatically receive what is needed. The automation of contracts and supply chain operations via smart contracts ensures that transactions are executed only when agreed conditions are met. Such contracts can automatically manage payments and certifications without human intervention, streamlining operations and reducing the likelihood of errors, conflicts and fraud [21]. Smart contracts are designed with rules and actions that apply to all parties participating in the transaction [11]. Further, growers can enter into smart contracts with sellers to ensure consistent revenue throughout the year. For example, a coffee shop owner can directly order his coffee beans from a grower located at a distant place. He can either pay the entire amount at once, or only pay for the supply of coffee beans and the rest when he receives the shipment. This process frees-up growers from the chain of intermediaries.

Consumer empowerment

Through the provision of reliable and verifiable information regarding their purchased products, blockchain technology enables consumers to make well-informed decisions. This can drive consumer decisions towards products that are ethically sourced and produced, influencing market trends and encouraging producers to adopt sustainable and transparent practices [22].

Compliance and safety

Blockchain enables the adherence to health and safety regulations by offering a dependable and immutable system for documenting information like pesticide application, crop cycling, and additional agricultural methodologies [23].

Fraud reduction

The immutability of blockchain reduces the risk of fraud throughout the agricultural supply chain. With blockchain, once data is entered into the ledger, it cannot be altered without consensus from all parties involved, making it extremely difficult to manipulate transaction records or product information, which enhances the integrity of the supply chain [24].

Market access

Blockchain can potentially open up new markets for farmers by proving the authenticity and quality of their products. With verified data available on a blockchain, small-scale farmers can access global markets more easily, increasing their potential customer base and improving their profitability [25].

Decentralization

The decentralized nature of blockchain mirrors the decentralized nature of agricultural production, particularly in less developed countries where agriculture is widespread across rural areas. Blockchain technology can link these small-scale producers directly with consumers and retailers, reducing the dependency on centralized systems that can be inefficient or corrupt [26].

Innovation and development

As blockchain technology matures, its potential for innovation in agricultural supply chains continues to grow. This includes the development of new forms of agricultural finance, insurance, and even consumer-driven agriculture initiatives, which could further transform the industry [27]. Integration of blockchain with technologies like IoT, big data and machine learning is also being explored.

Integrating blockchain with IoT- The way forward in agriculture

As we already know, IoT devices such as sensors have the ability to acquire/collect surrounding environmental data, send the data to a server through Internet and later with the support of decision- making tools the data can be used to make a critical decision such as turn on the valve for irrigation [6]. The integration of IoT with blockchain technology increases the productivity in agriculture sector and improves the overall visibility of food

products across the supply chain. In other words, it provides consumers with complete history of the food they are buying. The only pre-condition is that all the participants (so including the IoT devices) are registered users of the underlying blockchain, meaning that they have the correct public/private key-pairs to digitally sign each operation on the distributed ledger [11]. Additionally, combining blockchain with IoT devices allows real-time monitoring of food storage and transportation conditions, ensuring products are kept in safe environments and decreasing the chances of spoilage and contamination [28]. Figure 6 shows the five-layer architecture of IoT with blockchain.

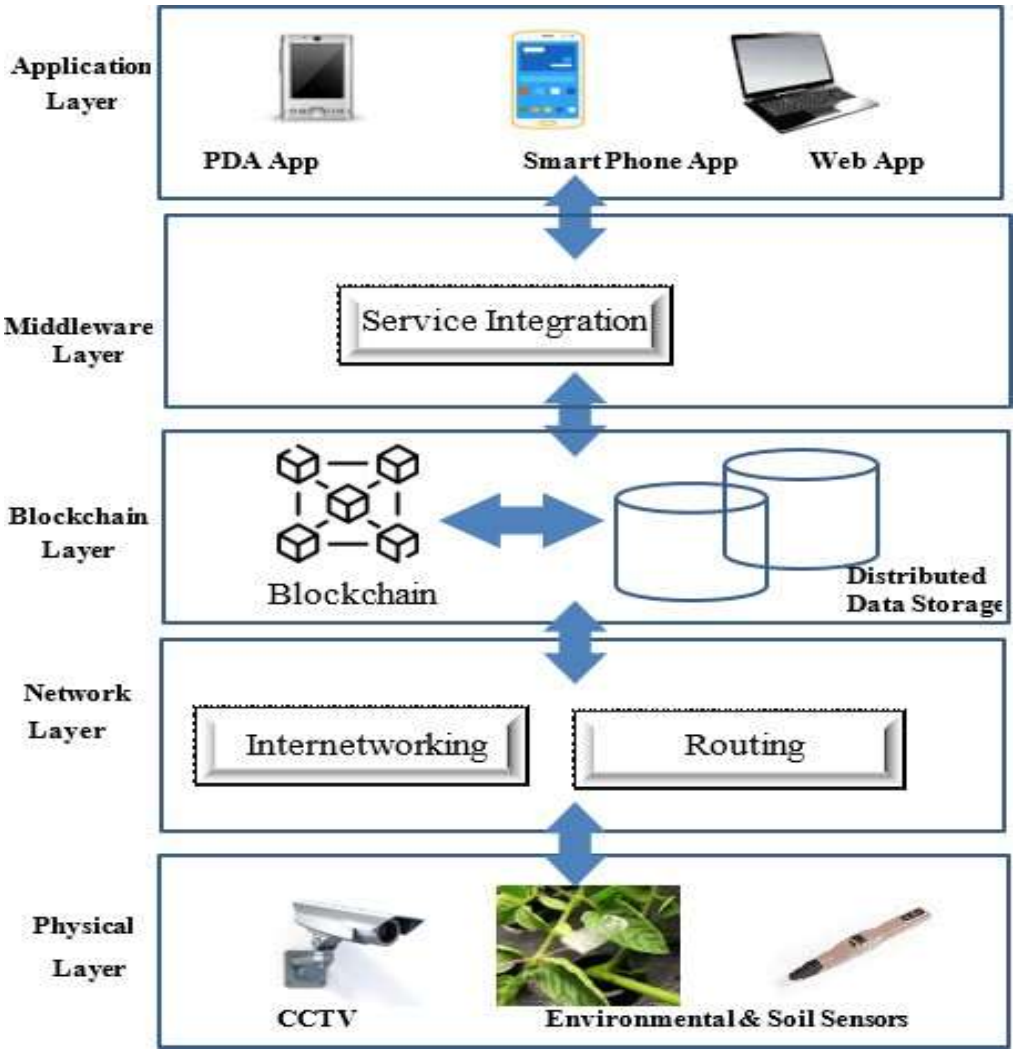

Fig. 6: IoT-Blockchain architecture [6].

Challenges

There are many advantages of integrating blockchain with IoT. However, at the same time, new challenges are introduced as enumerated below [6]:

Scalability

Blockchain scales poorly as the number of nodes in the network increases. In the existing blockchain implementations, only few transactions can be accomplished per second. This is a bottleneck and inefficient for IoT systems, where gigabytes (GB) of data can be generated by IoT sensors every second. Big IoT systems are still reluctant to integrate with blockchain due to scalability issues.

Processing

IoT systems are diverse with different computing capabilities, and as such all of them cannot run the same encryption algorithms at the required speed. This makes the processing of high volumes of IoT data complicated and time consuming in the blockchain.

Storage

One of the main benefits of blockchain is that it uses the decentralized model and removes the central server concept. However, the ledger has to be stored on the nodes themselves. As such, the number of nodes in the network will increase over time with an increase in the distributed ledger.

Digital to physical interface

Connecting blockchain applications with precision agriculture, big data, sensors and IoT platforms, connecting to electronic readable labels (identifiers of physical goods) such as RFID, barcode or 2D grid codes pose a substantial challenge.

Skills

Blockchain technology is still at infant stage in terms of using it in IoT applications. Therefore, a majority of people lack knowledge and skills. For example, farmers are generally only focused on farming and reluctant to accept change that involves the use of technology.

Cost

Many steps are involved in a transaction processing, including defining heavy security and storing it across multiple participants. Furthermore, these steps consume large amount of computing power. As such, it becomes difficult to meet the expenses.

Standardization

Currently there is no standardization for the operation of blockchain. This can create major incompatibility issue with regards to interoperability.

Affordability

Larger farms are more likely to employ blockchain technology and leverage its benefits. This can indirectly create a gap between big-time farmers and small holders.

Blockchain organizations

A number of companies offer solutions based on blockchain technology to enhance the agri-food supply chain. A few of them are mentioned hereunder:

IBM Blockchain

IBM generated the IBM Food Trust to help bring transparency and efficiency to food supply chains. The company has several products that measure food safety and freshness and assist to reduce waste. Real-time certifications, test data, and temperature data ensure that proper food handling protocols are met. A shared ledger that is upgraded and validated in real-time with each network participant allows equal visibility of activities and reveals where an asset is at any point in time, who owns it, and what condition it's in.

Ripe.io

Ripe.io uses blockchain to improve transparency in the food supply chain. The Ripe.io blockchain ecosystem has a variety of tools to track the food journey, as well as supply chain tracking, bran quality verification, secure data aggregation, and sensor and IoT integration. Farmers will be able to leverage IoT and sensors to automate processes and efficiently accomplish market demand for high-quality, sustainable products. Distributors will be able to transparently track food products to offer real-time data on food safety and delivery. Customers will receive trusted, certified information on the journey of their food, creating a new standard of food quality.

Agri Digital

AgriDigital is a blockchain-based and integrated commodity management solution for the global grains industry. The platform offers seamless solutions to complex commodity, logistical, risk, and customer management issues. By the applied blockchain technologies, distributed ledgers, and smart contracts, AgriDigital offers real-time payment to growers, increased efficiencies for brokers, a flexible supply chain for buyers and financiers, and paddock to plate transparency for consumers.

Food Coin

The FoodCoin ecosystem deals will take place with the use of smart contracts, while the transactions will accept a proper cryptocurrency named FoodCoin (FOOD). An extensive selection of tools, such as a proper "smart" wallet, a remote user identification system, flexibly

configurable smart contracts, corroboration of the origin of food, and a proper crypto payment processor, will customize the essential platform parameters to overcome current expenses. The special crypto fund will be founded with this aim of view.

TE-FOOD

TE-FOOD is a farm-to-table detectability solution, covering all logistics and food quality activities and data management of the supply chain. It offers cost-effective software and identification tools to make livestock and fresh food supply information transparent.

References

[1] Awan S, Ahmad S, Ullah F et al (2021) IoT with blockchain: A futuristic approach in agriculture & food supply chain. Wireless Communications & Mobile Computing. Wiley 2021.doi:10.1155/2021/5580179

[2] Movilla-Pateiro L, Mahou-Lago XM, Doval MI, Simal-Gandara J (2021) Toward a sustainable metric and indicators for the goal of sustainability in agricultural and food production. Critical Reviews in Food Science and Nutrition. PubMed 61(7): 1108–1129.doi: 10.1080/10408398.2020.1754161

[3] Mane AE, Chihab Y, Tatane K, Korchiyne R (2022) Agriculture supply chain management based on blockchain architecture and smart contracts. Applied Computational Intelligence and Soft Computing. Wiley 2022. doi: 10.1155/2022/8011525

[4] Mahalakshmi J, Kuppusamy K, Chinnakkaruppan, Maheswari P (2020) IoT sensor-based smart agricultural system. Emerging Technologies for Agriculture and Environment. Springer 2020: 39–52. doi: 10.1007/978-981-13-7968-0_4

[5] Mentsiev AU, Isaev AR, Supaeva KS et al (2019) Advancement of mechanical automation in the agriculture sector and overview of IoT. Journal of Physics: Conference Series 1399 (4).doi: 10.1088/1742-6596/1399/4/044042

[6] Kassim MRM (2022) Applications of IoT and blockchain in smart agriculture: Architectures and challenges. IEEE International Conference on Computing (ICOCO) 2022: 253-258.doi: 978-1-6654-8996-6/22

[7] Krasteva I, Glushkova T, Stoyanova-Doycheva A et al (2021) Blockchain-based approach to supply chain modeling in a smart farming system. Big Data, Knowledge and Control Systems Engineering. IEEE 2021. doi: 10.1109/BDKCSE53180.2021.9627309

[8] TongKe F (2013) Smart agriculture based on cloud computing and IoT. Journal of Convergence Information Technology 8(2)

[9] Kamble SS, Gunasekaran A, Gawankar SA (2020) Achieving sustainable performance in a data-driven agriculture supply chain: A review for research and applications. International Journal of Production Economics. 219: 179–194

[10] Kumar D, Dwivedi RK (2023) Blockchain and IoT based smart agriculture and food supply chain system. International Conference on Intelligent and Innovative Technologies in Computing, Electrical and Electronics (IITCEE). IEEE 2023 : 755-761. doi: 10.1109/IITCEE57236.2023.10090897

[11] Caro MP, Ali MS, Vecchio M, Giaffreda R (2018) Blockchain-based traceability in agri- food supply chain management: A practical implementation. IoT Vertical and Topical Summit on Agriculture - Tuscany (IOT Tuscany). IEEE 2018

[12] Kittipanya-Ngam P, Tan KH (2020) A framework for food supply chain digitalization: Lessons from Thailand. Production Planning & Control. 31(2-3): 158–172

[13] www.supplychainbeyond.com

[14] Nakamoto, S. (2008). Bitcoin: A Peer-to-Peer Electronic Cash System. Retrieved from https://bitcoin.org/bitcoin.pdf
[15] Pavithran D, Shaalan K, Al-Karaki JN, Gawanmeh A (2020) Towards building a blockchain framework for IoT. Cluster Computing. 23(3): 2089–2103
[16] Bolfing, A. (2020). Introduction to Blockchain Technology. In Cryptographic Primitives in Blockchain Technology
[17] Wang, A.-P. (2021). Blockchain Technology and Its Applications. Encyclopedia of Organizational Knowledge, Administration, and Technology
[18] Babu E, Ritvik K, Sainath LVA, Sai MT (2023) Blockchain-driven agricultural product traceability and supply chain management. 5th International Conference on Inventive Research in Computing Applications (ICIRCA). doi: 10.1109/ICIRCA57980.2023.10220840
[19] Rana S (2020) Blockchain-based traceability and transparency in agricultural supply chains: Challenges and opportunities. Turkish Journal of Computer and Mathematics Education (TURCOMAT). 11(3): 13591. doi: 10.17762/turcomat
[20] Mukherjee AA, Singh R, Mishra R, Bag S (2021) Application of blockchain technology for sustainability development in agricultural supply chain: Justification framework. Operations Management Research. 15: 46-61. doi: 10.1007/s12063-021-00180-5
[21] Nagariya R, Mukherjee S, Baral MM, et al (2022) The challenges of blockchain technology adoption in the agro-based industries. International Journal of Mathematical, Engineering and Management Sciences. doi: 10.33889/ijmems.2022.7.6.059
[22] Saberi S, Kouhizadeh M, et al (2018) Blockchain technology and its relationships to sustainable supply chain management. International Journal of Production Research. 57: 2117-2135. doi: 10.1080/00207543.2018.1533261
[23] Song L, Wang X, Wei P, et al (2021) Blockchain-based flexible double-chain architecture and performance optimization for better sustainability in agriculture. Computers, Materials & Continua. https://doi.org/10.32604/CMC.2021.016954.
[24] Vidhate A, Saraf CR, Wani MA (2020) Applying blockchain security for agricultural supply chain management. Int. J. Appl. Evol. Comput. 11: 28-37. doi: 10.4018/ijaec.2020100103
[25] Atre S (2023) Blockchain technology in agriculture: Enhancing transparency, traceability, and efficiency. International Research Journal of Modernization in Engineering Technology and Science. doi: 10.56726/irjmets47072
[26] Acharya DK, Shrivastava M, Padhi P (2023) AgriBlock: A Blockchain based framework for agricultural supply chain management. International Journal on Recent and Innovation Trends in Computing and Communication. doi: 10.17762/ijritcc.v11i10s.7625
[27] Kamilaris A, Fonts A, Prenafeta-Boldú F (2019) The rise of blockchain technology in agriculture and food supply chains. ArXiv. doi: 10.1016/j.tifs.2019.07.034
[28] Balamurugan S, Ayyasamy A, Joseph KS (2021) IoT-Blockchain driven traceability techniques for improved safety measures in food supply chain. International Journal of Information Technology. 14(4): 1087-1098. doi: 10.1007/s41870-020-00581-y