A Trusted Ecosystem in Agri-Food Supply Chain with Traceability Potentials of Blockchain Technology

Ridwan Salahudeen, Abel Ajibesin, Mathias Fonkam,
Wasilah Sada and Aminat Yusuf

May 29, 2024

A Trusted Ecosystem in Agri-Food Supply Chain with traceability potentials of Blockchain Technology

Ridwan Salahudeen, Abel Ajibesin, Mathias Fonkam, Wasilah Sada and Aminat Yusuf

Abstract

The complexity in the Agri-Food Supply Chain (AFSC) has made the traceability of causes of disease very difficult in the supply chain. This is more evident when there is an outbreak or pandemic as a result of food consumption. Governmental and health organizations have been championing for food transparency standards in order to easily trace and adequately recall such contaminated product. Stakeholders in this supply chain have been adopting centralized systems of traceability that are prone to manipulations and single-point of attacks. But as advancement is rapidly driving Information and Communication Technologies (ICT), researchers have attempted applying the potentials of blockchain technology in the agri-food industry. Despite the huge tunes of researches already conducted in this area, there is still little to non-practical implementation in the industry. This paper investigates the phenomenon and proposes a conceptual framework to drive future practical researches in this field. An algorithm was also developed to address one of the conflict resolution challenges in the supply chain as it was identified to be one of the major challenges causing stakeholders' skepticism on the acceptability of blockchain technology in AFSC.

Keywords: Agri-food supply chain; smart contract; conflict resolution; traceability system; food safety; blockchain

1. Introduction

Food supply chain is a highly complex value chain consisting of multiple stakeholders at different points of the chain. This involves a collaboration on producing and distributing of food products to end consumers. The increasing world's population has equally made the demand for these food products overwhelming. In spite of the limited produce obtainable from farms, in addition to the uneven producing capacity of different part of the world due to differences in technological advancements. As a result, this has caused food insecurity and equally affecting food safety as well as endangering the global public health (Hofman, 2019).

In the past two decades, major food pandemics that are due to the insecurity in food production have been reported. Among the popular cases are: The foot-and-mouth disease that happened in Europe around 2001. The USA's *Escherichia coli* outbreak of spinach in 2006. The China's Sanlu milk scandal of 2008. Another version of *Escherichia coli* outbreak in Germany during the year 2011. The South African *listeriosis* outbreak between 2017-2018. Then the most current Covid-19 pandemic that broke out from Wuhan (Demestichas et al., 2020).

Attempts to prevent these dangerous health outbreaks have been made by Governments and Health Organizations by enacting laws and regulations to standardize food transparency and to ensure auditable supply chain. This is in order to achieve an efficient traceability and ease of recall in case of any outbreak. One practical case could be seen in the European Regulation No. 178/2002 that set out some basic principles of food law at all stages of food chain (production, processing and distribution) to protect human health and consumer's interest. Another instance is the Hazard Analysis and Critical Control Points (HACCP) principles meant to reduce hazards and risks in food production processes to the safest level. Similarly, regional law and regulations are being established globally in order to curb pandemics caused through agri-food supply chain (AFSC) negligence.

Due to these global regulations as well as the ever-growing concerns of consumers for food provenance and confidence for safety measures, stakeholders in the food industry are being compelled by these demands to adopt traceability techniques on their agri-food products and services. Unfortunately, most of the systems adopted are centralized and asynchronous to the various critical stages in the supply chain, making interoperability along the chain very difficult (Thejaswini & Ranjitha, 2020). This has given room for manipulations of the fragmented data produced by the various players in the chain just to fake the provenance of the food product to a consumer.

With the exponential growth in technological development and their perceived benefits to supply chain systems, many practitioners at both the industries and academia have attempted cutting-edge researches introducing digital traceability techniques to monitor the production, distribution and consumption of food products. The technologies mostly used are Radio Frequency Identification (RFID) sensors, Near Field Communication (NFC), Wireless Sensor Network (WSN), Internet of Things (IoT), Distributed Ledger Technology (DLT) such as the Blockchain Technology, among others. In this paper, attention is being focused on the Blockchain adoption due to the technology's strength in dealing with transparency and trust problems, based on the immutability and distributive properties of the technology in record keeping.

Conversely, the establishment of Industry 4.0 as the fourth industrial revolution aiming to create a holistic and connected ecosystem for supply chain management has further brought agri-food supply chain into active research spotlight (Kayikci et al., 2020). Even though a lot of researches have focused on blockchain application to the AFSC in order to achieve the desired healthy and trusted ecosystem, practical adoption of these great researches are still lacking.

After a careful analysis of the phenomenon with the inquisitive interest on understanding the reasons for the apparent gap between the huge researches already conducted in this area, and the little turn-on practical implementation in the industry, the authors noted the following discoveries:

1. The fundamental understanding of how blockchain techniques can be implemented in the agri-food products to achieve the desired traceability and provenance remained limited and very unclear (H.M. Kim & Laskowski, 2018; Yiannas, 2018).
2. The acceptability level of the technology by policy makers and the supply chain stakeholders is low, which is affecting collaboration and trust in the supply chain (Borrero, 2019).

This research seeks to investigate why the actual implementation of blockchain technology in agri-food traceability is so low despite the tremendous research outputs in this field and how to drive future researches toward more practical ideas in this field of research.

2. Problem Overview

The fraudulent act of manipulating AFSC information in order to fake food provenance has not only cost loss of lives and terminal diseases, but has also affected the industry with an increasing annual losses due to consumers decline in confidence and boycott of farm produce suspected to be contaminated (Kamath, 2018).

Many a times, players in the AFSC fabricate and replace food ingredients different from what is being reported in their ingredient's details, a common example of this fraudulent act is the deliberate replacement of beef with horsemeat in a food contents while specifying beef in the ingredient (Castle, 2013).

In the report of PricewaterhouseCoopers, safe and secure approaches in field environments published in 2016, The food industry was estimated to be losing around $40 billion annually on food damages resulting from low patronage of consumers mostly due to fear of poisoning (Newswire, 2018). For instance, in 2017 when there was the Salmonella outbreak and the Centre for Disease Control (CDC) gave a warning on papaya consumption in the United States after many death and hospitalization cases were reported. The impact of that warning had a huge global economic loss in agricultural industry and lasted for more than a year affecting all papaya's famers all over the globe even after the outbreak was already traced to Mexico.

Until recently, the methods of tracking and record keeping previously used in the AFSC are basically analog, with transaction validations happening individually between any two players within the chain. Each generated transaction activates one link up the chain, and a corresponding confirmation of a receipt of a product activate the link down the chain. This approach is highly inefficient in tracing infection/contamination of agri-food products when there is need to investigate a source of infection during an outbreak. This is because in many of the cases, the records are highly fragmented with missing or duplicate data challenging the effective analysis of the record collected and leading to delayed and unreliable reports from the investigations (Kamath, 2018).

Consequently, consumers are losing confidence on the food they consume on a daily basis and that is invariably affecting the patronage to non-essential farm produce. For this reason, this study seeks to explore ideas to influence an effective agri-food traceability and equally to boost consumers' confidence in the food products they consume.

3. Theoretical Background

In order to set the background straight for the objective of this research, the authors dedicated this section to elaborate on the fundamental concepts needed for the research. They are as follow:

3.1. Blockchain Technology

Blockchain is a digital method of record keeping as a ledger otherwise known as Distributed Ledger Technology (DLT) that require its records to be decentralised and duplicated across the entire network, making alteration or deletion of records kept on the network difficult or impossible. The blockchain innovation was based on the novel idea introduced by a pseudonymous name "Satoshi Nakamoto" in 2008, proposing a peer-to-peer electronic medium of value exchange without the need for a third party (Salahudeen & Fonkam, 2020). The popularity of the technology grew even faster with its adoption in the financial sector and gave birth to the first cryptocurrency called Bitcoin (Duan et al., 2020). The technical architecture of a blockchain network require each participating node to ensure a timestamped and cryptographically hashed records to be collected in blocks and all blocks linked together in a chain manner. In each blockchain platform, there are some special node referred to as miners that uses their computational powers to verify and validate the authenticity of each records that goes into the network before populating such record. Many miners race in the verification of these records with a single miner championing the race by providing a proof-of-work (PoW) for other miners to ascertain the verification (Saberi et al., 2019). The pull of records with their PoW are continuously populated into a block, each block is cryptographically stamped with a hash key to serve as its identifier. Blocks are chained to their immediate previous block in the chain by including the hash key of the previous block into a current block's hash key, this chaining architecture makes it difficult or impossible to delete or alter already stored records. Because the hash keys are cryptographically linked to form a chain and the entire records are synchronously duplicated into all the nodes in the network, any attempt to modify an already stored record will invalidate the hash key corresponding to the record's block, with a new timestamped cryptographic hash key being the only solution to validate the altered block. Suppose that the altered block can then be revalidated with the new hash key, then all blocks above the altered block will have to be revalidated as well. Due to this complexity and difficulty in modification, the architectural design of blockchain practically makes it impossible to manipulate records after storage.

3.2. Smart Contract

Smart contracts is a concept conceived around 1994 by Szabo predating the blockchain technology itself (Clack & Vanca, 2018). It started gaining interest immediately after the Bitcoin's implementation of blockchain became a recognized means of transacting electronically (Salahudeen & Fonkam, 2020). Just after that, the need for encoding agreements between transacting parties became an obvious requirement in achieving automatic third party devoid transactions. According to the definition provided by (Clack et al., 2016): "A smart contract is an automatable and enforceable agreement. Automatable by computer, although some parts may require human inputs and controls. Enforceable either by legal enforcement of rights and obligations or via tamper-proof execution of computer code." It is a means of achieving transparent implementation of agreements without the need of trusted third parties that would add additional cost and delay overheads to an electronic transaction (Tripoli & Schmidhuber, 2018).

3.3. Agri-Food Supply Chain

Generally, commodities are meant to be transferred from their point of production mostly with transportation media, passing through stages of intermediaries such as suppliers, distributors, retailers etc., before finally reaching the final consumers (Mondal et al., 2019). Similarly, this ideology was borrowed into the agricultural industry to describe the movements of agricultural (both crop and animal based) produce right from the farm to the point of consumption (also referred to as "farm-to-fork") (Esteso et al., 2018).

An agricultural economist first coined the term Agri-Food Supply Chain (Marsden et al., 2000; Salin, 1998). It has had and still having synonymic expression referring to the same idea. Some of the popular ones include phrases like, agricultural value chain, food value chain, supply chain in agriculture, food supply chain, among others.

Based on the ubiquitous of agricultural practices across the globe, different regions on the globe having different and sometimes irregular climatic patterns, AFSC is faced with a complex and dynamic decision making process. To achieve an efficient and effective decision-making in AFSC, this climate diversity together with cross-country laws and jurisdictions that could affect the chain of supply must be carefully looked at. The consideration of these factors have always rendered the decision making process of the AFSC highly complex and also the executing environment full of uncertainties for the stakeholders in the supply chain (Sharma et al., 2020). However, continuous advancements in technology particularly in Information Communication Technology (ICT) and Artificial Intelligence (AI) has assisted greatly in the manners in which this AFSC data can be collected, processed, visualized and analyzed to achieve a more desired and effective decision-making among the stakeholders (Shahid et al., 2020).

Additionally, because processed foods and edible products such as most pharmaceutical products are ingredients with these agricultural products. So in order to achieve the consumer's confidence and trust in the healthiness of the products that they consume on daily basis, a traceable means of verifying these ingredients making up the products need to be provided in the AFSC architecture (Wallace & Manning, 2020).

4. Proposed Methodology

This research work intends to adopt a Design Science Research methodology to address the research problem. In order to achieve these objectives, a framework on how to carry out the research was framed and depicted in a diagram shown on Figure 1.

After a detailed and comprehensive review into literatures, some key characteristics were identified to be inherent in an Agri-Food Supply Chain (AFSC) system such as the safety, quality and perishability of the food products that finally gets to the end consumer in the chain. So the individual stakeholders involved in the various stages of the supply chain consisting of the farming, processing, distributing and retailing are mostly conflicted on the heterogeneity of the ingredients making up the food product; or conflicting on cross-country and border jurisdictions; or uncertainties arising from product's shelf life, deterioration rate, market demands and/or prices.

With the identification of these inherent characteristics, an algorithm for resolving these conflicting factors was developed as depicted in Figure 2.

Although this paper dedicated a reasonable amount of time to develop a holistic conceptual framework to achieve the trusted ecosystem in an AFSC, efforts were also made to decompose the roadmap of the research into achievable components that can be built upon by other researches.

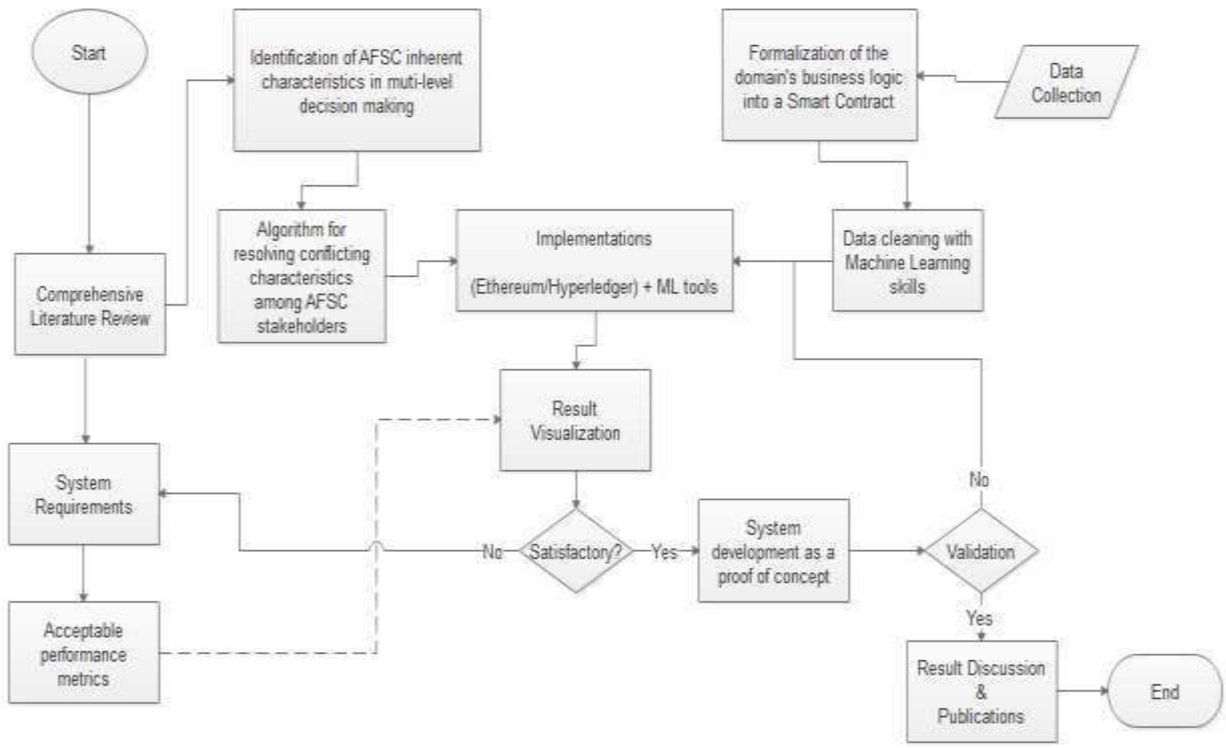

Figure 1: Proposed Conceptual Framework

Therefore, the singular aim of this paper is to address the conflict resolution dilemma in the supply chain. When this is achieved, future researches will look into other components with the sole aim of harmonizing all the findings into achieving a trusted ecosystem in the agri-food supply chain system.

```
Algorithm: ConflictResolution()

Input:
    X_C ← Complainant Statement
    X_D ← Defendant Statement

Output:
    C ← Source of Conflict
    S ← Consensus Solution

Procedure:
    Step 1: Accept complainant statement into X_C
    Step 2: Notify defendant about X_C
    Step 3: If defendant agrees on the terms in X_C, then S ← X_C
            Else, accept defendant statement into X_D
    Step 4: Compare X_C and X_D and extract the differences into
            C
    Step 5: Iterate through C,
            While both complainant and defendant have not reach
an agreement, Permutate X_C, X_D and C as P
                          P_i = X_C ∪ X_D ∪ C
    Step 6: If both complainant and defendant agrees on an P_i,
then S ← P_i
            Else, find optimal P as P_o and assign it to S
S ← P_i
    Step 7: Broadcast S to complainant and defendant End
```

Figure 2: AFSC Conflict Resolution Algorithm

In order to ensure the statements entered by each parties during the resolution processes are easily computable, a formal and well-structured method of language expression is needed. To this end, the types of statements that can be accepted by the algorithm are restricted to any of the following categories:

1. Issuing statement: A type of statement that introduce a new discussion or argument.
2. Supporting statement: A statement by same party (complainant or defendant), linking up to their previous statement(s)
3. Responding statement: A statement by an opponent party reacting to the other party's statement(s).

The issuing statement can be seen as the root of a conflict which requires supporting or responding statements from either the initiator of the argument (complainant) or the opponent (defendant) before it can be judged to be justified (if there is no valid defending response from the defendant) or unjustified (if there is no valid supporting evidence from the complainant).

When all the inputs of the algorithm in Figure 2 are restricted only to the identified categories above, then a good data structure can be achieved to process the arguments in the conflict in order to arrive at an optimal solution that would be favorable to all aggrieved parties. It is almost very glaring that a graph data structure would be very useful in this situation, where each issuing statement can easily be modelled as the root and the each supporting statements can be placed on the right node while the responding statements goes on the left or vice versa.

5. Literature Review and Related Works

Distributed Ledger Technology (DLT) particularly the blockchain technology has gained prominence in recent years and its adoption is prevalent in many disciplines. In most cases, the adoption usually cut across multiple discipline, hence making researches involving the blockchain technology highly multidisciplinary (Feng et al., 2020). As mentioned earlier, the initial traceability method used in the agricultural industry are basically centralized with challenges of interoperability and data manipulations. Of recent, there has been focuses of DLT and blockchain researches in the AFSC traceability vision. This section briefly highlights some of the notable researches as follow;

In 2016, a PhD research by (Tian, 2016) conceived and introduced an idea of tracking agric-food products in the Chinese food market by tagging the food items with Radio Frequency Identification (RFID) and recording their movements on a blockchain network. By doing so, their research was able to make an investigative enquiry on how to ascertain quality of agricultural produce that are mostly perishable such as vegetables and fruits and the safety of contaminable meats such as pork, beef and chicken meats in such a complex food market like Chinese's.

A follow-up research (Tian, 2017) was published by the same author in the following year, where the author additionally introduced the Hazard Analysis and Critical Control Points (HACCP) in his (Tian, 2016) work. The critical check pointing enabled the author to scale his initial system when challenged with voluminous streams of data during the traceability.

A similar conception was implemented by (Kumar & Iyengar, 2017) in the India's complex rice market to solve the difficult data manipulation the country's rice supply chain was faced with. They argued and attributed that the manipulating potentials of the supply chain player was due to the centralized method of keeping inventories of transactions in the supply chain. Their decentralized record keeping method of implementation with the aid of blockchain technology, was equally a radical solution that distributed the authorization of the record's custody to all the participating nodes in a network which is in contrast to the previous central manipulative authority.

(Henry M. Kim & Laskowski, 2018) gave an ontological representation to the agreements reached by the stakeholders in a supply chain to form what is popularly known as smart contracts. With their smart contract, food traceability could be achieved with provenance. Their work was particularly useful in tracking the ingredients of pharmaceutical products right from the planting/rearing stage to the processing stage and final distributions to the manufacturers. Their ontological representation of complex agreements among the stakeholders in the supply chain smart processes were translated into contract and was programmed in the Ethereum language of Solidity.

In (Tse et al., 2018) the factors limiting the blockchain and DLT adoption in the agricultural supply chain was extensively analyzed. In their findings, they term the limiting factors to be Political, Economic, Social and Technological (PEST), and specify ways of addressing each of these factors. In the same vein, (Kamilaris et al., 2019) canvassed for a need for frameworks to boost the acceptability of blockchain initiatives among farmers: technical operability, education and awareness, policies and regulations.

Similarly, (Corallo et al., 2018) proposed an agri-food data management framework for the Agriculture 4.0 context coined out from the Industry 4.0 framework. The adoption of Industry 4.0's analytical skills and IoT techniques were used to create what the authors termed "food democracy and citizenship".

(Leng et al., 2018) carried out a correlational analysis of the decentralized nature of agricultural practices compared with its fitness to the blockchain technology's decentralization architectures. The research revealed that the complex Chinese agricultural sector was a scattered and disordered industry that fits perfectly to the blockchain technology. The paper then proposed a dual-based blockchain architecture separating the user information and transaction information into two different chains. While the chain for user information was meant for recording only user details, the other chain was solely meant for transactional records. Their analysis showed a major improvement in the network resource matching, its efficiency and an enhanced credibility in terms of public service platforms. In a similar fashion, (Caro et al., 2018) implemented the agri-food supply chain on two different blockchain implementations of Ethereum and Hyperledger to present a fully decentralized solution named AgriBlockIoT.

The work of (Galvez et al., 2018) introduced an innovating idea of using chemical analysis of agric-food item and storing the data on a blockchain network in a chronological order, such that manipulation of already administered analysis would be very difficult.

Also, with the trending advances in the field of AI, researches such as (Mao et al., 2018) did provide fantastic idea of fusing blockchain with deep learning algorithms to analyze gathered credit evaluation text while (Kamble et al., 2020) added the concept of Big Data to the existing methods of IoT and Blockchain mostly adopted by most researches.

6. Conclusion

Agri-Food Supply Chain (AFSC) is a highly complex value chain that attracts numerous stakeholders. Its beauty cuts across different countries and regions on the globe. With the distinguishing laws and jurisdictions governing these stakeholders playing distinctive roles at different stages of the supply chain such as: farming, transporting, processing, distributing, retailing, etc. Many of the players consciously or unconsciously manipulate their product's information in order to fake the provenance of their product going through the chain. Because of the repeated difficulties faced by health and food regulatory bodies in tracking down sources of infection/contaminations during food related pandemics, many consumers had lost trust in the agri-food industry. This has resulted into interventions by various governments to compel the AFSC stakeholders to adopt tracking traceability mechanism in their products and services. Even though there are lots of researches already carried out in achieving traceability in AFSC using the blockchain technology due to the technology's acclaimed potentials in transparency and trust. This research work noted that there is still little-to-non practical implementation in the industry, this was attributed to the high skepticism among the stakeholder pertaining the technology's ability in resolving conflict among them. For that reason, this paper proposed a conceptual framework to drive future researches in this field into a more acceptable roadmap in achieving the trusted ecosystem in AFSC traceability. A conflict resolution algorithm was also developed to implement one of the key ideas conceived in the proposed framework.

References

Borrero, J. D. (2019). Agri-food supply chain traceability for fruit and vegetable cooperatives using Blockchain technology | Sistema de trazabilidad de la cadena de suministro agroalimentario para cooperativas de frutas y hortalizas basado en la tecnología Blockchain. *CIRIEC-Espana Revista de Economia Publica, Social y Cooperativa*, *95*, 71–94. https://doi.org/10.7203/CIRIEC-E.95.13123

Caro, M. P., Ali, M. S., Vecchio, M., & Giaffreda, R. (2018). Blockchain-based traceability in Agri-Food supply chain management: A practical implementation. *2018 IoT Vertical and Topical Summit on Agriculture - Tuscany, IOT Tuscany 2018*, 1–4. https://doi.org/10.1109/IOTTUSCANY.2018.8373021

Castle, S. (2013). Europe Says Tests Show Horse Meat Scandal Is 'Food Fraud.' *The New York Times*. https://www.nytimes.com/2013/04/17/business/global/european-study-affirms-role-of-fraudin-horsemeat-scandal.html

Clack, C. D., Bakshi, V. A., & Braine, L. (2016). *Smart Contract Templates: foundations, design landscape and research directions*. http://arxiv.org/abs/1608.00771

Clack, C. D., & Vanca, G. (2018). Temporal aspects of smart contracts for financial derivatives. *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, *11247 LNCS*, 339–355. https://doi.org/10.1007/978-3-03003427-6_26

Corallo, A., Latino, M. E., & Menegoli, M. (2018). From Industry 4.0 to Agriculture 4.0: A Framework to Manage Product Data in Agri-Food Supply Chain for Voluntary Traceability, A framework proposed. *International Journal of Nutrition and Food Engineering*, *12*(5), 126–130. https://www.internet4things.it/industry-4-0/effetto-industria-4-0-25-di-

Demestichas, K., Peppes, N., Alexakis, T., & Adamopoulou, E. (2020). Blockchain in agriculture traceability systems: A review. *Applied Sciences (Switzerland)*, *10*(12), 1–22. https://doi.org/10.3390/APP10124113

Duan, J., Zhang, C., Gong, Y., Brown, S., & Li, Z. (2020). A content-analysis based literature review in blockchain adoption within food supply chain. In *International Journal of Environmental Research and Public Health* (Vol. 17, Issue 5, p. 1784). MDPI AG. https://doi.org/10.3390/ijerph17051784

Esteso, A., Alemany, M. M. E., & Ortiz, A. (2018). Conceptual framework for designing agri-food supply chains under uncertainty by mathematical programming models. *International Journal of Production Research*, *56*(13), 4418–4446. https://doi.org/10.1080/00207543.2018.1447706

Feng, H., Wang, X., Duan, Y., Zhang, J., & Zhang, X. (2020). Applying blockchain technology to improve agri-food traceability: A review of development methods, benefits and challenges. *Journal of Cleaner Production*, *260*. https://doi.org/10.1016/j.jclepro.2020.121031

Galvez, J. F., Mejuto, J. C., & Simal-Gandara, J. (2018). Future challenges on the use of blockchain for food traceability analysis. In *TrAC - Trends in Analytical Chemistry* (Vol. 107, pp. 222–232). Elsevier B.V. https://doi.org/10.1016/j.trac.2018.08.011

Hofman, W. J. (2019). A Methodological Approach for Development and Deployment of Data Sharing in Complex Organizational Supply and Logistics Networks with Blockchain Technology. *IFACPapersOnLine*, *52*(3), 55–60. https://doi.org/10.1016/j.ifacol.2019.06.010

Kamath, R. (2018). Food Traceability on Blockchain: Walmart's Pork and Mango Pilots with IBM. *The Journal of the British Blockchain Association*, *1*(1), 1–12. https://doi.org/10.31585/jbba-1-1-

(10)2018

Kamble, S. S., Gunasekaran, A., & Gawankar, S. A. (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. https://doi.org/10.1016/j.ijpe.2019.05.022

Kamilaris, A., Fonts, A., & Prenafeta-Boldύ, F. X. (2019). The rise of blockchain technology in agriculture and food supply chains. *Trends in Food Science and Technology*, *91*, 640–652. https://doi.org/10.1016/j.tifs.2019.07.034

Kayikci, Y., Subramanian, N., Dora, M., & Bhatia, M. S. (2020). Food supply chain in the era of Industry 4.0: blockchain technology implementation opportunities and impediments from the perspective of people, process, performance, and technology. *Production Planning and Control*. https://doi.org/10.1080/09537287.2020.1810757

Kim, H.M., & Laskowski, M. (2018). Toward an ontology-driven blockchain design for supply-chain provenance. *Intelligent Systems in Accounting, Finance and Management*, *25*(1), 18–27. https://doi.org/10.1002/isaf.1424

Kim, Henry M., & Laskowski, M. (2018). Toward an ontology-driven blockchain design for supplychain provenance. *Intelligent Systems in Accounting, Finance and Management*, *25*(1), 18–27. https://doi.org/10.1002/isaf.1424

Kumar, M. V., & Iyengar, N. C. S. N. (2017). *A Framework for Blockchain Technology in Rice Supply Chain Management Plantation*. 125–130. https://doi.org/10.14257/astl.2017.146.22

Leng, K., Bi, Y., Jing, L., Fu, H. C., & Van Nieuwenhuyse, I. (2018). Research on agricultural supply chain system with double chain architecture based on blockchain technology. *Future Generation Computer Systems*, *86*, 641–649. https://doi.org/10.1016/j.future.2018.04.061

Mao, D., Wang, F., Hao, Z., & Li, H. (2018). Credit evaluation system based on blockchain for multiple stakeholders in the food supply chain. *International Journal of Environmental Research and Public Health*, *15*(8). https://doi.org/10.3390/ijerph15081627

Marsden, T., Banks, J., & Bristow, G. (2000). Food Supply Chain Approaches: Exploring their Role in Rural Development. *Sociologia Ruralis*, *40*(4), 424–438. https://doi.org/10.1111/14679523.00158

Mondal, S., Wijewardena, K. P., Karuppuswami, S., Kriti, N., Kumar, D., & Chahal, P. (2019). Blockchain inspired RFID-based information architecture for food supply chain. *IEEE Internet of Things Journal*, *6*(3), 5803–5813. https://doi.org/10.1109/JIOT.2019.2907658

Newswire, P. R. (2018). The blockchain in agriculture and food supply chain market is projected to grow at a CAGR of 47.8%. In *NY-REPORTLINKER*.

Saberi, S., Kouhizadeh, M., Sarkis, J., & Shen, L. (2019). Blockchain technology and its relationships to sustainable supply chain management. *International Journal of Production Research*, *57*(7), 2117–2135. https://doi.org/10.1080/00207543.2018.1533261

Salahudeen, R., & Fonkam, M. (2020). *Soft Computing Modelling for Blockchain Smart Contracts*. https://doi.org/10.22624/AIMS/iSTEAMS-2020/V23N1P1

Salin, V. (1998). Information technology in agri-food supply chains. *The International Food and Agribusiness Management Review*, *1*(3), 329–334. https://doi.org/10.1016/S10967508(99)80003-2

Shahid, A., Sarfraz, U., Malik, M. W., Iftikhar, M. S., Jamal, A., & Javaid, N. (2020). Blockchain-Based Reputation System in Agri-Food Supply Chain. In *Advances in Intelligent Systems and*

Computing: Vol. 1151 AISC. https://doi.org/10.1007/978-3-030-44041-1_2

Sharma, R., Kamble, S. S., Gunasekaran, A., Kumar, V., & Kumar, A. (2020). A systematic literature review on machine learning applications for sustainable agriculture supply chain performance. *Computers and Operations Research*, *119*. https://doi.org/10.1016/j.cor.2020.104926

Thejaswini, S., & Ranjitha, K. R. (2020). Blockchain in Agriculture by using Decentralized Peer to Peer Networks. *Proceedings of the 4th International Conference on Inventive Systems and Control, ICISC 2020*, 600–606. https://doi.org/10.1109/ICISC47916.2020.9171083

Tian, F. (2016). An agri-food supply chain traceability system for China based on RFID & blockchain technology. In *2016 13th International Conference on Service Systems and Service Management, ICSSSM 2016*. https://doi.org/10.1109/ICSSSM.2016.7538424

Tian, F. (2017, July 28). A supply chain traceability system for food safety based on HACCP, blockchain & Internet of things. *14th International Conference on Services Systems and Services Management, ICSSSM 2017 - Proceedings*. https://doi.org/10.1109/ICSSSM.2017.7996119

Tripoli, M., & Schmidhuber, J. (2018). Emerging Opportunities for the Application of Blockchain in the Agri-food Industry Agriculture. *Food and Agriculture Organization of the United Nations*, *August*, 21. http://www.fao.org/3/CA1335EN/ca1335en.pdf

Tse, D., Zhang, B., Yang, Y., Cheng, C., & Mu, H. (2018). Blockchain application in food supply information security. *IEEE International Conference on Industrial Engineering and Engineering Management*, *2017-Decem*, 1357–1361. https://doi.org/10.1109/IEEM.2017.8290114

Wallace, C. A., & Manning, L. (2020). Food provenance: Assuring product integrity and identity. *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources*, *15*(32). https://doi.org/10.1079/PAVSNNR202015032

Yiannas, F. (2018). A New Era of Food Transparency Powered by Blockchain. *Innovations: Technology, Governance, Globalization*, *12*(1–2), 46–56. https://doi.org/10.1162/inov_a_00266