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Chapter 5

Improving Traceability in the Food Supply Chain Management System

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ABSTRACT

Recent food crises and disruptions in the food supply chain because of the COVID-19 pandemic demand extensive commitment, transparency, authenticity, and traceability from food chain stakeholders. Traceability is a key tool for the management of food safety, quality, and consumer satisfaction. Traditional traceability systems are based on centralized management of information which raises concerns regarding data tampering and real time monitoring of product life cycle. However, disruptions in the supply chain due to the pandemic, consumer concerns and changes in purchasing protocols have urged the food industry to adopt a decentralized traceability system to ensure reliability and sustainability in the food chain. The recent improvements in food traceability systems are centered around decentralized systems such as blockchain integrated with the internet of things (IOTs), radio frequency identification (RFID), etc. Although the adoption of these improvements is challenging for the food industry, the

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digitalization of the supply chain and integrated smart traceability systems are the solution for pandemic induced disruptions and future hurdles of the food supply chain.

1. Introduction

Globalization of food production and trade has led to various challenges in the food supply chain. Global food access leads to supply over a large distance, complexity, safety concerns, and track and trace challenges (Kayikci et al. 2020). Traceability is a key tool for the management of food safety and quality. The introduction of modern techniques and digitalization is essential to improve the status of traceability in food supply chain management (SCM). Consumer demand and satisfaction for safe, healthy, and sustainable food have urged the food industries to improve food traceability (Kittipanya-Ngam and Tan 2020). This scenario is of more concern in developing countries where several middlemen are involved in food SCM. The sustainable food SCM requires the tracking and tracing of all events involved in food processing from farm to fork (Feng et al. 2020). Digitalization of food SCM can be achieved by using the traditional internet of things (IOT) for each step of production, processing, distribution, and consumption. IOT can provide valuable information about food traceability by using various tools in combination such as radio frequency identification (RFID), near field communication (NFC), etc. (Anal et al. 2017). However, the accessibility of information based on these IOTs relies on a single central point for storing, transmitting and sharing information, which makes it difficult to access all the events in the food product life cycle by the consumers (Banerjee et al. 2018, Khan and Salah 2018). Traditional methods of food traceability are not very effective in building trust among all the participants of food SCM. However, the current traceability status can be improved by adopting methods or strategies in food SCM which can improve traceability, transparency, and integrity (Feng et al. 2019). An improved food traceability system with data privacy and temper free platform can be achieved by the incorporation of blockchain technology in food SCM. Blockchain is decentralized technology in which information cannot be altered solely by a member to food SCM, rather time stamped blocks are interlinked to ensure the security and accessibility of information (Andoni et al. 2019, Yong et al. 2020).

Blockchain technology in combination with RFID, NFC, and IOTs can help to improve the overall status of traceability by ensuring the safety and transparency of information throughout the food chain (Feng et al. 2020). The novel coronavirus (COVID-19) was found to spread through the food supply chain such as China detected the virus in imported frozen meat products. Such a food crisis demands an improved traceability system such as blockchain technology as a decentralized source of information

that can overcome the problems of IOTs, being a centrally controlled source of information (Iftekhar and Cui 2021).

Food SCM is considerably different from other supply chains in the perspective that food SCM is associated with food quality, safety, freshness, storage, and various other real time factors. Currently, food SCM faces many challenges such as obstacles to sharing transparent information and a lack of decision-making models (Zhong et al. 2017). For the implementation of strategic models, the adoption of information technology and IOTs are key factors. However, improving traceability status by incorporating IOTs, blockchain and strategic modelling demand the participation of all food SCM participants from farmer to consumer, in terms of commitment and cost.

This chapter summarizes the current strategies which can be adopted into food SCM to improve the overall status of traceability and the role of blockchain and IOTs in combination with other tools (RFID, NFC, etc.) in advancing food traceability systems.

2. Challenges in the Implementation of Traceability System in Food SCM

Due to the globalization of food and agriculture commodities, food safety and quality are of great concern for all the participants involved in the food SCM. The failure to incorporate an appropriate trace and track technology may lead to serious food safety issues and reputation defame for the food processors or industries (Aung and Chang 2014). The lack of authenticity and complete product information may lead to the consumer's interest to the products of alternative brands, which creates a decline in sales (Kayikci et al. 2020). The maintenance of food safety, quality, and consumer satisfaction are major challenges in food SCM. In comparison to other supply chains, the food chain has a major issue of change in product quality at any stage from farm to fork. This can only be managed by transparent, complete, and fair information transfer to all the stakeholders of food SCM from food origin to the ultimate point of consumption. In many developed and developing countries, paper-based traceability systems are in practice which can be easily tampered with, on the other hand, digitalization of traceability within food SCM would require commitment in terms of cost and skilled personnel (Karippacheril et al. 2017). For small scale industries, implementation of traceability would lead to additional investments, which might be difficult to manage for producers without any external support. The traceability, reliability, and transparency in food SCM can only be achieved uniformly by the implementation of cost effective systems (Aung and Chang 2014).

The implementation of a traceability system in food SCM is extremely challenging due to the diversity in the nature of foods and the involvement

of extensive information within the processing of every food product. The implementation of a traceability system in food SCM refers to the integration of a traceability system with the food chain to facilitate the collection, processing, and transport of information in a standardized format among different stakeholders of food SCM. By the combination of advanced information and communication technologies, an effective traceability system can provide precise and transparent information at any step of the food chain (Haleem et al. 2019).

3. A Shift from Traditional to Improved Traceability Systems

The quality and safety of food within a food SCM can be assured by incorporating an advanced traceability system. Due to drastic changes associated with the pandemic COVID-19, strategies for food marketing and consumer purchasing are changing to online which demands more commitment to real time detection of food product track and trace route (Yu et al. 2020). The improvements in current traceability systems are being ensured by the incorporation of food logistic models, IOTs, and blockchain technology and combining these in various combinations to develop smart traceability systems. The technological advancements in traceability system demand changes in marketing, selling, and purchasing protocols to provide real time information on high quality and perishable food products delivered to the consumer's place of order. Various strategies have been incorporated into food SCM to improve traceability systems, including digitalization and logistic models in combination with various IOTs. A shift in the current traceability system from centralized information management to a decentralized information management system is presented in Figure 1.

Food Supply Chain Digitalization

The challenges and problems associated with food SCM have been greatly improved by the advancements of digital technology and its capability to handle big data associated with food product life. Integration of events in food product life by digital platform leads to a cost-effective, transparent, less laborious, and mistake free food SCM (Kittipanya-Ngam and Tan 2020). The merging digitalization technologies which can improve the current traceability system are artificial intelligence (AI), IOTs, blockchain, three-dimensional (3-D) printing, drones, and augmented and virtual reality (Eckert et al. 2016). AI was reported to use in precision agriculture farming, food product quality control assessment, sale and promotion assessment, and food simulation. IOTs were found helpful in developing smart devises for weather and animal monitoring and prediction of food

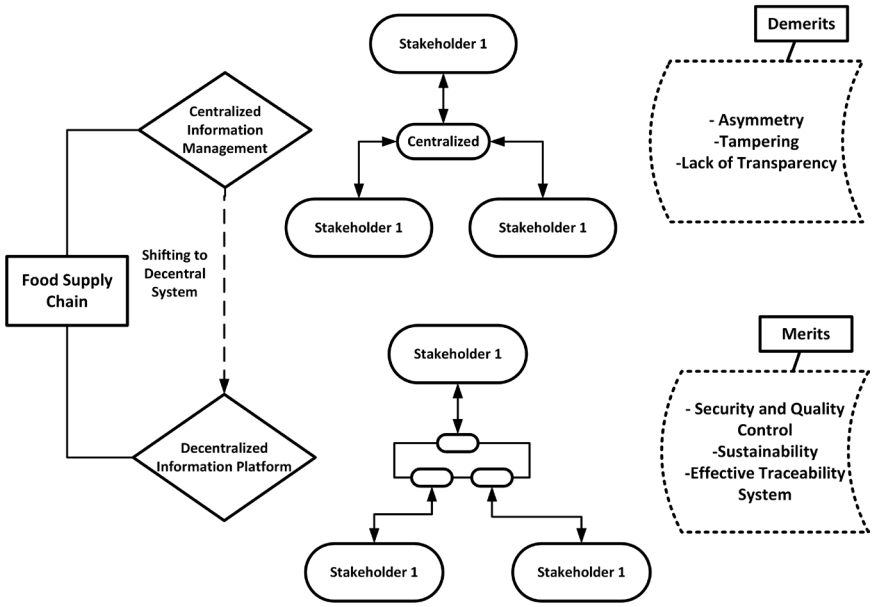

Figure 1. A shift in the food traceability system from a centralized information management to an advanced decentralized platform (Adopted and modified from Feng et al. 2020).

processing (Wehberg et al. 2017). The incorporation of blockchain in food SCM was found helpful in the prevention of food fraud by providing real-time food product information.

4. Role of IOTs in Improving Food Traceability

The real-time product life cycle tracking and decision-making regarding product processing, sale, and marketing have been optimized by using IOTs such as QR codes and RFID technologies. The integration of QR codes and RFID in developing food traceability systems was reported to be cost effective. QR code is effective in managing food SCM due to its fast readability, extensive data storage, cost effectiveness, and relatively easy implementation (Li et al. 2017). An integrated model based on QR code and web service technology was used in the implementation of a traceability system for fresh vegetables (Qiao et al. 2013). Gao (2013) applied QR based traceability system for farm product tracking and tracing, in which a QR code was used for product information transfer within SCM.

Recent improvements in RFID technology facilitated its application in food traceability systems. RFID is a contactless automated identification system for products and live animals associated with tags. RFID technology stores the data in tags and RFID readers are used to read this tag/memory

information and transfer it to the database for remote accessibility (Alfian et al. 2020).

5. Role of Blockchain in Improving Food Traceability System

Blockchain is a transparent, authentic, and tamper less digital ledger to monitor all events in the product life cycle (Kamble et al. 2019). Blockchain technology can provide a secure shared network among different stakeholders of food SCM without the involvement of any mediators (Calatayud et al. 2018). Unlike IOTs, blockchain does not require central data monitoring or processing, rather it removes the need of intermediates and facilitates a fast, reliable, and transparent trace of every event in product life (Pilk-ington 2016). All members involved in food SCM can always access the information at any stage of product processing.

The pandemic crisis and its influence on food SCM can be tackled by AI, machine learning, and blockchain technology. Blockchain based traceability systems are comprised of 3 main elements (data block, distributed ledger, and consensus algorithm). Data block is a sequence of interconnected blocks in which new blocks are connected to the origin to make an interconnected continuous secure chain of blocks, which prevents tampering and provide complete information of each stage in the product life cycle. Distributed ledger is a simultaneously shared digital database among all parties, which collects and stores the transaction information originated by any participant in the chain. Each transaction is assigned a cryptographic signature and time stamp. Consensus is mutual agreement among all participants of the chain for the validation of each block of information which is managed by algorithms (Marbouh et al. 2020, Zheng et al. 2017).

Blockchain is associated with programmable protocols to store and share sensitive data among different parties based on prior agreements to secure the data (Ahlmann 2018). The agreements, contracts, and check points are made visible to all participants of food SCM (Marques et al. 2020). Blockchain is at a developing stage and its implementation in SCM is proving to be very effective in improving the traceability, quality, and safety of product information (Calatayud et al. 2018).

The food chains are made accessible even with cell phones to customers by blockchain technology due their ability to provide traceability at each stage of the food product life cycle. Food SCM is very much different in comparison to other SCMs, as it demands the verification and tracking of product from its origin to ultimate consumption, tracing foodborne outbreaks, religious beliefs associated with a product such as kosher or halal, organic status, allergen free, and transparency (Galvez et al. 2018). When blockchain is applied to a food SCM, the product information on

the origin, processing, batch, and expiry details are digitally connected at each step (Charlebois 2017). All members of food SCM can access the product information without any alteration. The product data created by the blockchain at each step is essential in decision making such as management of shelf life and authenticity. The presentation of superior product quality to consumers, is the main driving force for all the stakeholders in food SCM to share the complete food product information. The blockchain concept provides the benefits of transparency, efficiency, security, and safety in the food life cycle (Galvez et al. 2018).

Blockchain based traceability systems are still in the developing stage, however, only very few examples of blockchain based food traceability have been observed at a pilot scale. The tuna fish supply chain was digitalized with blockchain technology from farm to fork level by Provenance (Saberi et al. 2019, Tripoli and Schmidhuber 2018). Later, a consortium was developed by Walmart, Nestle, and Unilever in association with IBM to apply blockchain in food SCM for transparency and traceability to ensure food safety (Barnard 2017).

6. Need for Smart Traceability System

In food SCM, blockchain can be a solution to tackle the traceability crisis encountered during COVID-19 pandemics, however, blockchain integration with IOTs (Figure 2), will make the food SCM more reliable, effective and transparent for consumers and all other stakeholders (Haroon et al. 2019). The COVID-19 pandemic has driven the change in buying and selling model of food products and the introduction of blockchain technology and IOTs into food logistics can serve as an effective tool to improve the traceability and reliability of a food SCM. A smart traceability system can provide complete, transparent, and reliable information about each step in the life cycle of a food product. A smart traceability system involves various components such as data collection, data processing, data storage, and sharing (Yu et al. 2020). This complete information can help in food recalls, maintaining food safety and quality, and preventing food waste/loss, food adulteration, and theft. The diversity of data and association of large data within food SCM require technological advancements in the formulation of smart traceability systems which are lacking in current traceability practices (Scholten et al. 2016).

The current traceability status of food SCM can be improved by portable devices for the detection and data storage related to food safety, quality, adulteration, and authenticity of food such as portable spectroscopy, array sensors, smart food packaging indicators, and wireless based detection technologies.

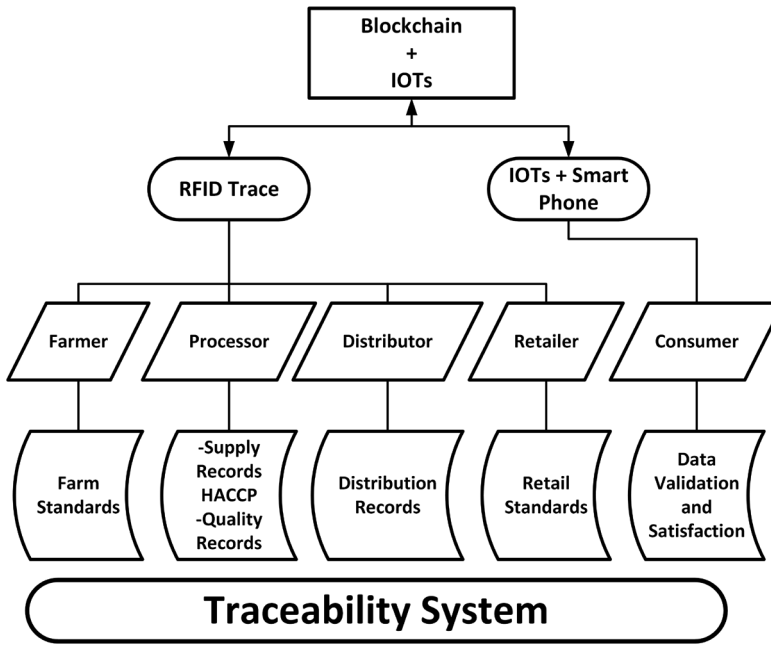

Figure 2. Blockchain and IOTs based integrated food traceability system (adopted and modified from Kayikci et al. 2020).

Improvements in Food Traceability System in Response to COVID-19 Pandemic

The possible transmission of the COVID-19 virus from animals to humans has raised consumers' food safety concerns and consumers are willing to pay an additional cost for authentic, safe, and traceable food items (Xiao et al. 2020). COVID has raised various food safety concerns, disruptions, and challenges in food SCM. Various countries such as China have issued guidelines at both private and government sectors to improve the fair trade and transparency in the food chain to prevent the further spread of the pandemic (Galanakis 2020, Iftekhar and Cui 2021). A model for a smart food traceability system is presented in Figure 3.

The improvements in traceability systems are brought by the integration of information systems and logistics. Various models have been proposed for the improvements in food chain traceability, such as the technology acceptance model, information system success model, and expectation confirmation model. Mixed model approaches have been recently proposed to address the issues or disruptions in food SCM as a result of COVID-19 (Tseng et al. 2022).

Various strategies have been proposed to improve food SCM traceability and transparency in response to disruptions and hurdles

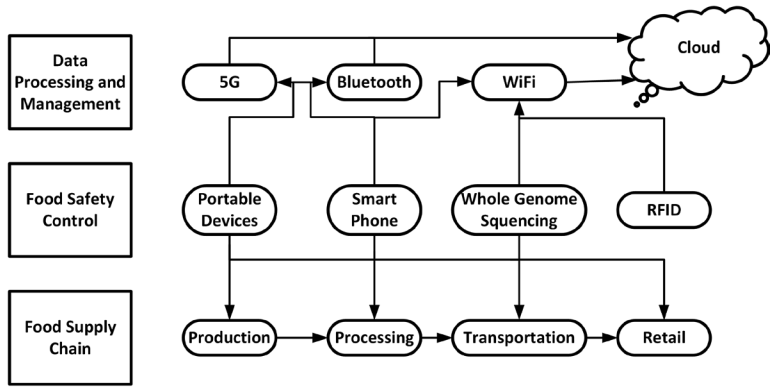

Figure 3. Schematic overview of a smart traceability system (Adopted and modified from Yu et al. 2020).

encountered in COVID-19 (Dania et al. 2018, Kumar and Kumar Singh 2021).

1. Improvements in supply chain responsiveness as strategy to tackle any disruption or change in food SCM. A rompt and effective response is a direct evaluation of the traceability system and product management (Stranieri et al. 2021).
2. Improvements in coordination among food SCM stakeholders to minimize the risks and ambiguity (Amjath-Babu et al. 2020). The incorporation of IT tools has been effective in improving coordination in food SCM (Singh et al. 2019).
3. Building trust, commitment, and confidence to collaborate among food SCM stakeholders.
4. Effective management of information collection, storage, and sharing among stakeholders.
5. Improvements in supply chain collaboration which brings harmonization in SCM, minimizes conflicts and suppresses individual interests.
6. Resource sharing (skills, assets, technology) among food SCM stakeholders. Resource sharing is challenging during the pandemic as there is a lack of appropriate financial support from government agencies which may discourage the private sector.
7. Ensuring safety measures and consumer confidence, particularly during a pandemic.
8. Digitalization of food SCM, which will assist stakeholders to connect directly without intermediaries. Blockchain, IOTs, and industry 4.0

technologies are used in the digitalization of food SCM in response to the pandemic.

9. Collective decision making, risk and reward sharing by involving all food SCM stakeholders to ensure continuous improvements in the food chain.
10. Operational flexibility and adaptation to changes in goals, strategies, and work plans in case of uncertainties such as COVID.

7. Industry 4.0 Important Concepts in the Improvement of Traceability

The industry 4.0 revolutions proposed various strategies and technologies to improve the supply chain authenticity and traceability (Hassoun et al. 2022). Machine learning (ML) is a collection of methods and algorithms to sort, classify and predict data. AI imitates human intelligence by learning, sensing and describing (Andersen et al. 2018). AI facilitates the conversion of data and predictions into solutions, decision making, and problem sorting. Cloud is a nascent digital platform for the storage of data at multiple servers. Due to the association of large data in food SCM cloud system is becoming an integral part of food SCM in data management (Jagtap et al. 2021). ML and AI are becoming an important part of food SCM in advanced process control and statistical process control for ensuring product safety and quality. By using analytical data, AI and ML can help to authenticate food products, prevent food fraud, and develop prompt problem predicting (Deng et al. 2021).

Nano sensors, biosensors, and smart sensors have been used throughout the food SCM for real time monitoring of all product life events (farm to folk). These sensors can be used to collect and process the data of food processing. Both spectral and non-spectral sensors have been proposed in the food chain. Significant changes have been brought by IOTs, blockchain, and cybersecurity in food SCM in response to pandemic induced disruptions. A traceability system based on IOT integrated with RFID was employed in the traceability of perishable food products to monitor humidity, temperature, and product movement (Alfian et al. 2020). Blockchain integration with IOTs can be used to develop an effective traceability system for real time monitoring and prevention of pandemic induced disruptions to the food chain. The Industrial 4.0 revolution described cybersecurity as an important element in the security of information. The food chain involves multiple stakeholders and data sharing, which makes it prone to cyberattacks (Jagtap et al. 2021). Therefore, implementation of cybersecurity is of main concern to prevent data theft and tampering in food logistics.

8. Conclusion

Digitalization and implementation of integrated smart traceability systems are solutions for the current and future problems of the food supply chain. The traditional systems based on a central information control platform are associated with various concerns such as data tampering, lack of real time monitoring, and complete data of product life cycle. A decentralized system such as blockchain integrated with IOTs and RFID can be used to device a smart traceability system. However, the development and implementation of smart traceability systems demand a lot of commitment from food SCM stakeholders. The adoption of such an improved or smart traceability system should be an integral part of the supply chain to respond to pandemic induced disruptions and any future hurdles.

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