Food Supply Chain Enchanced by Industry 5.0 Technologies

Subjects: Agricultural Engineering
Contributor: Selvakumar Guruswamy, Milica Pojić, Jayashree Subramanian, Jasna Mastilović, Sohail Sarang, Arumugam Subbanagounder, Goran Stojanović, Varun Jeoti

The consequences of a crisis for a society depend on the level of society preparedness for the crisis, infrastructure in place, and training and skills of people engaged. The technologies (e.g., IoE, CC, blockchain, AI, DT, and 6G) of Industry 5.0 are yet to be fully explored and exploited in ensuring the resilience and sustainability of food systems. Therefore, this research sketches out a complete concept of a food system using Industry 5.0 technologies, and the main focus has been given to the use of 6G, AI, blockchain, and digital twin (DT) at different processes from production to distribution and retail to help optimize the food supply chain and thwart any possible disruption thereof.

Keywords: food security ; ICT ; Industry 5.0 ; blockchain ; IoE

1. Internet of Everything, 6G, and AI

The IoE extends the concept of the IoT; according to Bouzembrak et al. [1], when it comes to the Internet of Things (IoT) assisted applications, food supply chains top the chart. Monitoring of quality, safety, and traceability of the food products in collaboration with humans and supports of AI are the primary areas of concern that can be addressed by the IoE, especially when food is transported through longer supply chains. It is proposed to use the IoT to link the front-end activities of the food supply chain such as logistics, retail management, whole-sale operations, and warehouse management, which involve both humans and devices, to the back-end activities including food production, which is monitored using IoT tools. The integration of the IoT and humans with process- and data-driven new opportunities in the food supply chain arose. For instance, IoT sensors collect data such as soil, warehouse temperature, trace-and-track data from production, food processing and distribution, and retail units. Then, the gathered data are forwarded to a gateway and then to a remote server using wireless communication technologies e.g., WiFi, Bluetooth, LoRa, and 4G/5G. In the future, 6G is also expected to enhance the capabilities of existing communication technologies to achieve more reliable, fast, and larger connectivity that can help in increasing productivity in the industrial processes. For example, 6G enables the collection of data using nanonodes and the sending of the data to a nanorouter using terahertz (THz) communication; then the data are forwarded to a gateway using a nano–micro interface. The gateway is responsible for sending data over a 6G network following backhaul connectivity and then data analytics as given in **Figure 1** [2].

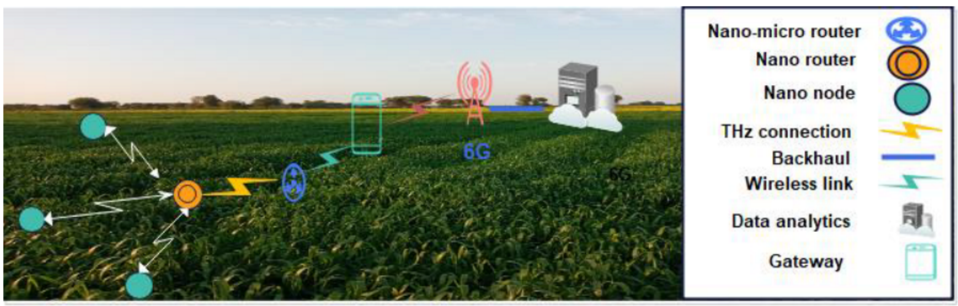

Figure 1. Envisioned smart production architecture using 6G.

Furthermore, technologies such as RFID technology, infrared (IR) sensors, global positioning systems (GPS), satellites, laser scanners, unmanned aerial vehicles (UAVs), cobots, and others enable timely delivery; locate the food items in transport; and monitor the quality of food during storage and transport to ensure that food-safety standards (HACCP, ISO 22000) are maintained, continuously monitor food conditions, and allow timely interventions to remove spoiled items before reaching the customer [3]. However, these devices collect a large quantity of data, which requires proper data processing to store and extract the important information. The rapid growth in cloud computing and AI applications motivates the utilization of these tools for data storage and predicting trends using historical data to enhance the supply management and decision-making process. The data analytics involves AI and ML such as computer vision, convolutional neural networks (CNNs), artificial neural networks (ANNs), fuzzy logic, neuro-fuzzy logic, expert systems, and other methodologies, which aim to feed machines with data from past experiences and statistical data, which enable the execution of the assigned task and solving a particular problem [4]. In addition, the huge data collection capabilities provided by the IoE will require new schemes to ensure trust and traceability in the food system.

The growing popularity of smart mobile phones and the advances in digital platforms have led to the development of e-commerce conducted via both traditional online websites and mobile apps [5]. In [6], mobile-based pork quality and safety tracing system has been developed to monitor the traceability of pork from pig breeding, purchase, sale, and slaughter services to table. In addition, digital technologies, e-commerce, and mobile apps are changing consumer experiences as well, enabling personalized offers in line with the diet, specific nutrition, or health needs of the consumer [7]. Food delivery applications have been widely adopted by catering businesses and customers, being extremely relevant during the recent COVID-19 crisis. Thus, the COVID-19 crisis has been turned into an opportunity to evolve social media into social marketing platforms allowing users direct contact with the food producers, choice of the payment mechanism, and pickup place. Zhao and Bacao [8] conducted a study to determine the users' intention to use food delivery apps during the COVID-19 crisis and concluded that it has been determined by users' satisfaction, perceived task-technology fitness, trust, performance expectancy, and social influence. The last mile delivery is the critical section of the supply-chain management. The threats to food security due to the COVID-19 crisis have been lively discussed lately [9]. Drones appeared to be a good alternative to support the delivery process, especially in terms of transportation cost, CO_2 emissions, and congestion so that several big companies, such as Amazon, Google, UPS, DHL, and Domino's Pizza, have started to use them for deliveries [10][11]. Food drone delivery in combination with mobile phone applications enables the scheduling and solving missed delivery problems, enables flexible delivery time, reduces the cost of transportation, and allows more sustainable delivery process [11]. Furthermore, blockchain has been suggested as a tool with a high potential to increase transparency, traceability, and sustainability in food supply chains, and hence decrease fraud and product falsification [12][13].

2. Trace and Track Using Blockchain Technology

The blockchain plays a key role in Industry 5.0 and is gaining significant attention in both the industry and academia [14]. The food supply chain involves different actors to ensure food safety and quality. However, food traceability also plays an important role in making the food supply chain more efficient. Thus, different track-and-trace technologies and software tools are used to ensure that the necessary checking and steps have been performed as required through all processes of production, postharvest operation and processing, and distribution and retail in the food system to improve food traceability. Traditionally, RFIDs and barcodes are the most common track-and-trace technologies in the food system.

The rapid growth of Industry 5.0 technologies drives the development of distributed trace-and-track systems that can avoid the risk of single-point failure in the system and can ensure integrity in the food supply chain. This motivates the use of blockchain technology that supports a robust information system and can help to improve traceability and transparency in the supply chain from production to distribution and retail. **Figure 2** illustrates the proposed blockchain-based food supply chain, where data gathered from each process are shared and stored in a distributed ledger, which is immutable [15].

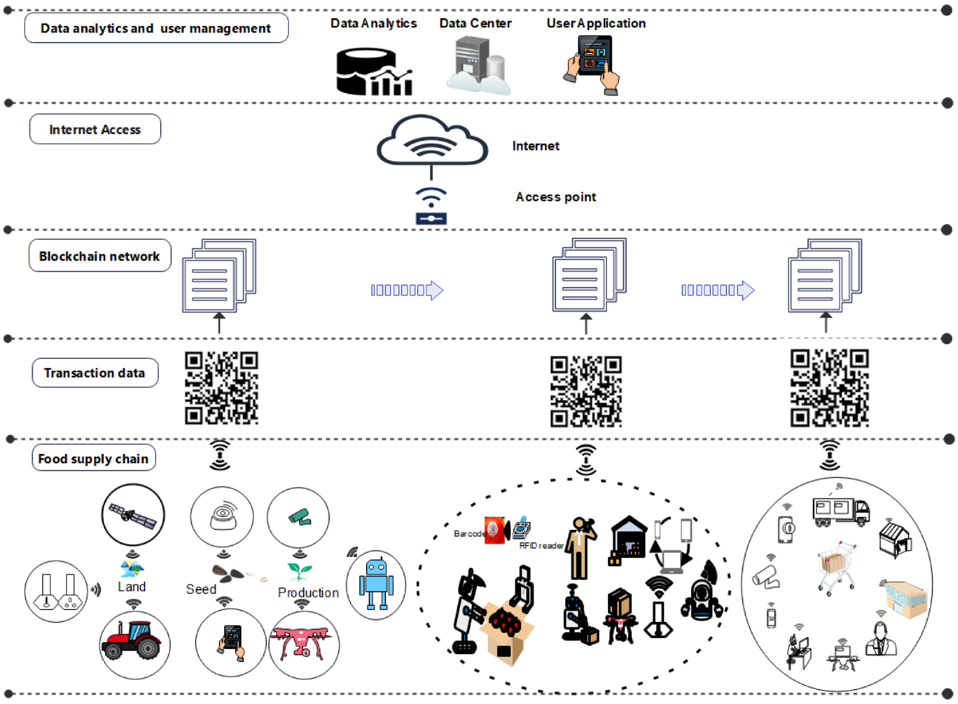

Figure 2. Blockchain in food supply chain.

Blockchain technology verifies transactions via multiple nodes in the blockchain network; all transactions are secured, records of transactions are stored in blocks, and the blocks of data are stored in a chain, which create the blockchain [13], which employs smart contracts to automate the agreement process and allows the secure peer-to-peer exchange of data. Each block generates a hash code from its content, and it is referred to in the next block. Blockchain provides a mechanism in which every participant of the blockchain can verify if a block has been genuinely added or any unauthorized manipulation happened. It makes the data available in blockchain immutable and, thus, safe. It enables financial transactions among the untrusted parties without the requirement of intermediaries or centralized systems [16]. It has no intermediary or centralized authority to administer or control the transactions. The impact of blockchain technology has been examined by Kamilaris et al. [17] who indicated that blockchain can enable a transparent supply chain. The transparency and fault tolerance features of blockchain can solve problems in scenarios where numerous untrusted players participate [12]. Especially in food safety management in the agri-food supply chains, in accordance to food safety standards, the application of blockchain technology can ensure the trust among the participants [18][19], which is very critical in this domain. The common requirement during crisis is to backtrack the supply-chain operations to find out the source of the outbreak such as food contamination or any other factor that has gone against the regulation. Similarly, the systems that can identify those irregularities and make notifications to the authorities should be built [20]. Likewise, Kouhizadeh et al. [21] emphasized the technological, organizational, and environmental barriers for wider blockchain technology adoption for supply-chain management. Apart from that, several companies have started using blockchain in the food supply chain. The European retailer Carrefour is using blockchain to verify standards and trace food origins in various categories (e.g., meat, fish, fruits, vegetables, and dairy products) [22]. Walmart, Nestle, Bumble Bee foods, the Chinese e-commerce giant JD.com, and the Dutch supermarket chain Albert Heijn are the other big players that have also started using blockchain. Regarding traceability, the blockchain-based systems are more homogenous and enable interoperability among different entities involved in the food supply chain, as well as between diverse supply chains, bringing thus to a higher level the issues of traceability and abilities of food withdrawal from the market in accordance to food safety standards [23].

3. Digital Twin

Food processing involves different stages and actors from food production and storage to distribution and exploits low-cost sensors to monitor the food supply chain. This results in a significant amount of data being gathered, which brings new challenges on how to utilize the stored data in a more intelligent way to remotely optimize the production and supply-chain process. Nowadays, the digital twin is gaining strong consideration, which represents the virtual replica of a device or process including both of its elements and dimensions and how it works throughout its lifecycle in the virtual space [24]. DT is expected to enhance food production and to support in identifying failures and their causes during the supply chain, as well as to optimize decision-making while reducing food loss and maintenance time.

A proposed digital twin for food supply chain consists of three main elements. First, the physical element consists of multiple sensors to measure different parameters from the production site or agriculture farm growing vegetables or fruits. These sensors collect data near the farm such as temperature, soil, climate, and irrigation conditions, as well as product freshness and horticultural maturity, and use available wireless links, e.g., WiFi and LoRaWAN, to transfer the data to the cloud for further analysis. In some scenarios, these sensors can also be mounted on other devices such as robots and drones to gather the data from the production field. Second, the virtual or digital element contains all necessary information about the physical product gathered from sensors (physical element) including weather conditions, product features, and its components, and the processes involved such as logistics and marketing, retailers, and consumers. Using the above details, DT will incorporate different data analytics, optimization approaches, and simulation platforms including software and AI techniques to identify and forecast potential problems in food processing that degrade food quality and induce food loss. Moreover, it will provide feedback to improve process performance and product quality, and actionable data, e.g., remaining shelf life, to facilitate the decision-making process. Finally, the connection is a foundation for the DT that provides the interaction of the physical object (i.e., deployed sensors) with the virtual object (i.e., cloud-based data storage). It plays a significant role by facilitating the data transfer collected using sensors and then accordingly updating the virtual state. Furthermore, it depends on different factors such as geographical conditions, the volume of data generated, data transmission rate, wireless technology, and delay requirements. **Figure 3** proposes a general framework of DT in food processing from production to food consumers, which involves different steps, technologies, and techniques.

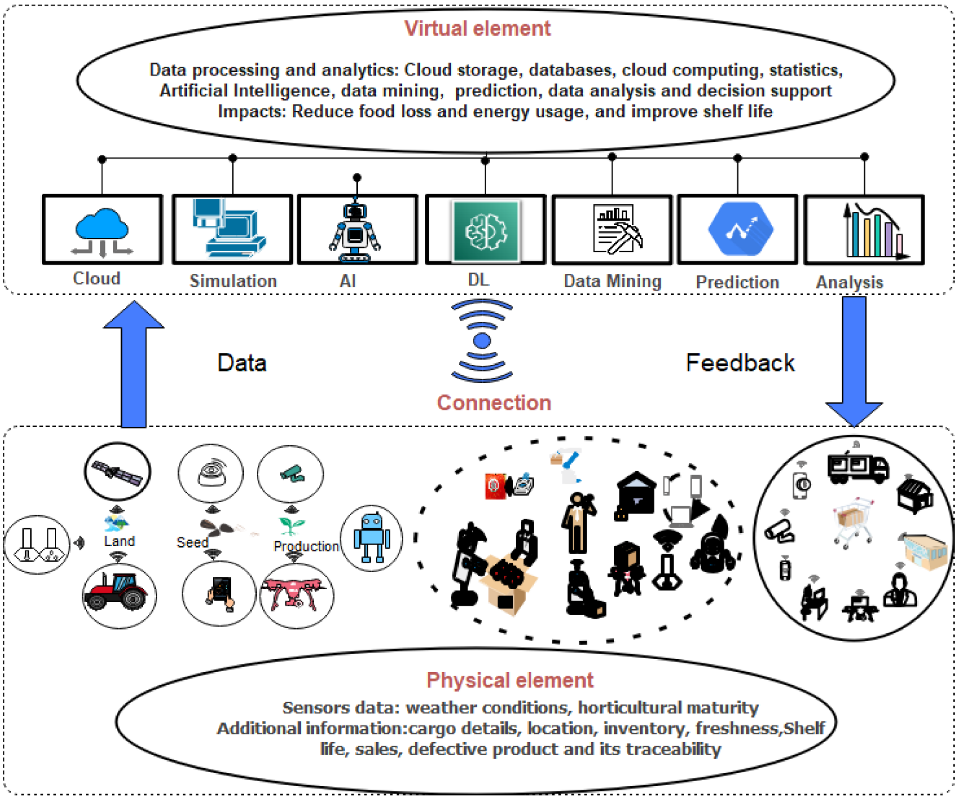

Figure 3. Digital twin for food supply chain.

DT can give a better understanding of the interrelations involved in food processing by analyzing continuous and real-time data gathered using sensors and then implementing data analysis and optimization approaches to support actors in the decision-making process, predict future trends and financial losses, improve the user's experience, and prevent the problems in the supply chain.

4. Cobots

Various technologies that feed into collaborative robots have been in existence, such as the IoT, robotics, augmented reality, and avatar. What is new is this concept of use of robots in a collaborative mode. It requires reimagining roles of both robots and humans. To begin with, one needs to accept that humans and robots are a hindrance to each other. That prepares the ground for leveraging strengths of each other—the creativity of human beings and accurate and fast repeatability of robots [25]. Lately, robots are no longer only large robots working from within safe cages. They are increasingly being built with small footprint, movability, and varying degrees of adaptability from one purpose to another. Therefore, one can imagine robots being deployed and redeployed with minimal planning and costs and help achieve critical goals of making a working environment safe, increasing productivity, and making profits. Thus, employees in various food sectors are now presented with a unique opportunity to work alongside robots—proving an adage that people should work with robots, not like robots. Imagine what it would mean to a person with disability to work as efficiently as an able person.

Today, the use of cobots in sustainable food production, storage, and distribution is being constructively reimagined, and this is an open academic research area drawing up ideas from Industry-5.0-driven smart manufacturing and logistics [26].

References

1. Bouzembrak, Y.; Klüche, M.; Gavai, A.; Marvin, H.J. Internet of Things in food safety: Literature review and a bibliometric analysis. Trends Food Sci. Technol. 2019, 94, 54–64.
2. Usman, M.; Ansari, S.; Taha, A.; Zahid, A.; Abbasi, Q.H.; Imran, M.A. Terahertz-Based Joint Communication and Sensing for Precision Agriculture: A 6G Use-Case. Front. Commun. Networks 2022, 3, 836506.
3. Leng, K.; Jin, L.; Shi, W.; Van Nieuwenhuyse, I. Research on agricultural products supply chain inspection system based on internet of things. Clust. Comput. 2019, 22, 8919–8927.
4. Jha, K.; Doshi, A.; Patel, P.; Shah, M. A comprehensive review on automation in agriculture using artificial intelligence. Artif. Intell. Agric. 2019, 2, 1–12.
5. Choi, T.-M. Mobile-App-Online-Website Dual Channel Strategies: Privacy Concerns, E-Payment Convenience, Channel Relationship, and Coordination. IEEE Trans. Syst. Man. Cybern. Syst. 2020, 51, 7008–7016.
6. Chen, T.; Ding, K.; Hao, S.; Li, G.; Qu, J. Batch-based traceability for pork: A mobile solution with 2D barcode technology. Food Control 2020, 107, 106770.
7. Kosior, K. Digital Transformation in the Agri-Food Sector–Opportunities and Challenges. Ann. Pol. Assoc. Agric. Agribus. Econ. 2018, XX, 98–104.
8. Zhao, Y.; Bacao, F. What factors determining customer continuingly using food delivery apps during 2019 novel coronavirus pandemic period? Int. J. Hosp. Manag. 2020, 91, 102683.
9. Cullen, M. COVID-19 and the Risk to Food Supply Chains: How to Respond. 2020. Available online: http://www.Fao.Org/3/Ca8388en/CA8388EN.Pdf (accessed on 24 October 2022).
10. Bamburry, D. Drones: Designed for Product Delivery, Revisited. Des. Manag. Rev. 2015, 26, 40–48.
11. Pugliese, L.D.P.; Guerriero, F.; Macrina, G. Using drones for parcels delivery process. Procedia Manuf. 2020, 42, 488–497.
12. Pearson, S.; May, D.; Leontidis, G.; Swainson, M.; Brewer, S.; Bidaut, L.; Frey, J.G.; Parr, G.; Maull, R.; Zisman, A. Are distributed ledger technologies the panacea for food traceability? Glob. Food Secur. 2019, 20, 145–149.
13. Astill, J.; Dara, R.A.; Campbell, M.; Farber, J.M.; Fraser, E.D.; Sharif, S.; Yada, R.Y. Transparency in food supply chains: A review of enabling technology solutions. Trends Food Sci. Technol. 2019, 91, 240–247.
14. Zhao, S.; Li, S.; Yao, Y. Blockchain Enabled Industrial Internet of Things Technology. IEEE Trans. Comput. Soc. Syst. 2019, 6, 1442–1453.
15. Azizi, N.; Malekzadeh, H.; Akhavan, P.; Haass, O.; Saremi, S.; Mirjalili, S. IoT–Blockchain: Harnessing the Power of Internet of Thing and Blockchain for Smart Supply Chain. Sensors 2021, 21, 6048.
16. Selvakumar, G.; Hemalatha, S. A study on integrating IoT Applications with Blockchain. In Proceedings of the 2019 International Conference on Computer Communication and Informatics (ICCCI), Coimbatore, India, 23–25 January 2019.
17. 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.
18. Leng, K.; Bi, Y.; Jing, L.; Fu, H.-C.; Van Nieuwenhuyse, I. Research on agricultural supply chain system with double chain architecture based on blockchain technology. Futur. Gener. Comput. Syst. 2018, 86, 641–649.
19. Demestichas, K.; Peppes, N.; Alexakis, T.; Adamopoulou, E. Blockchain in Agriculture Traceability Systems: A Review. Appl. Sci. 2020, 10, 4113.
20. Maslova, A. Growing the Garden: How to Use Blockchain in Agriculture. Available online: https://cointelegraph.com/news/growing-the-garden-how-to-use-blockchain-in-agriculture (accessed on 24 October 2022).
21. Kouhizadeh, M.; Saberi, S.; Sarkis, J. Blockchain technology and the sustainable supply chain: Theoretically exploring adoption barriers. Int. J. Prod. Econ. 2021, 231, 107831.
22. Carrefour. The Food Blockchain. Available online: https://www.carrefour.com/en/group/food-transition/food-blockchain (accessed on 24 October 2022).

23. Olsen, P.; Borit, M.; Syed, S. Applications, Limitations, Costs, and Benefits Related to the Use of Blockchain Technology in the Food Industry. Nofima Rapp. 2019. Available online: https://nofima.brage.unit.no/nofima-xmlui/handle/11250/2586121 (accessed on 24 October 2022).
24. Botín-Sanabria, D.M.; Mihaita, A.-S.; Peimbert-García, R.E.; Ramírez-Moreno, M.A.; Ramírez-Mendoza, R.A.; Lozoya-Santos, J.d.J. Digital twin rechnology challenges and applications: A comprehensive review. Remote Sens. 2022, 14, 1335.
25. Maddikunta, P.K.R.; Pham, Q.-V.; Prabadevi, B.; Deepa, N.; Dev, K.; Gadekallu, T.R.; Ruby, R.; Liyanage, M. Industry 5.0: A survey on enabling technologies and potential applications. J. Ind. Inf. Integr. 2021, 26, 100257.
26. Grobbelaar, W.; Verma, A.; Shukla, V.K. Analyzing Human Robotic Interaction in the Food Industry. J. Physics Conf. Ser. 2021, 1714, 012032.