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Sustainable Agriculture and Food Supply Chain Through Digital Transformation

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ABSTRACT

With the increase in demand due to the increase in the world population, the deterioration of the physical conditions of the world, and the decrease in natural resources, the problem of meeting our food needs has reached the point where it cannot be ignored, especially due to the Covid-19 pandemic. The agriculture and food sector is of great importance in meeting humanity's basic nutritional needs because nutritional needs cannot be postponed or replaced by something else. There is no doubt that technology has had an impact on every industry in recent years. Particularly, in the agriculture sector, digitalization has touched lives, from the manufacturer to the consumer, and has made our life easier, especially since the Covid-19 Pandemic. This actively demonstrates that digitization supports sustainability goals in industries. Numerous digital innovations in these sectors have the potential to contribute to sustainable food production, improve animal welfare, combat climate change, improve global food security, and support biodiversity. With rapidly developing technology, it is possible to prevent disruptions in the supply chain from the producer to the consumer by ensuring that the members of the supply chain exchange information simultaneously and accurately. Using technology for this purpose makes the food supply chain transparent, enables traceability, ensures food safety, and maintains food quality. Thus, in this paper, the impact of digitalization on the food sector value chain, food security, provide sustainability in the food sector were discussed in the light literature findings.

INTRODUCTION

It is known that one of the most important factors in the development of humanity and civilizations is the agricultural revolution. The rapid increase in the world population in recent years brings along the problem of nutrition and agricultural production should be increased to reduce this problem. However, the inadequacy of traditional farming methods; causes problems such as environmental pollution caused by agricultural production, destruction of forests, overgrazing, unbalanced fertilizer use, and soil erosion. At the same time, with the expansion of the trade network in agriculture, it has become difficult to maintain food safety and quality with food supply chain management and to ensure the sustainability of the product and information flow along the chain from producer to consumer without any problems. To reduce uncertainties and

negativities in agriculture and the food supply chain, and to increase product quality and efficiency, digital transformation is rapidly increasing its effectiveness in these areas.

In the world, smart agriculture and practices that increase productivity are intensified. Some of these applications facilitate the continuous monitoring of issues such as the development stages of the plant, the minerals needed by the plants and irrigation, how much and what kind of fertilizer should be given to which areas, weather conditions, soil condition, and pest control. Sustainability of production and estimated harvest time are facilitated in detail and in real-time, aiming to maximize efficiency by minimizing the problems encountered in traditional methods. (ERTAŞ, B., 2020). Monitoring and verifying the food supply chain to ensure food safety is critical to identifying and addressing disruptions in the food supply chain worldwide. The way to solve traceability problems and ensure transparency is to use blockchain technology. It is possible to prevent problems such as counterfeit food, as the product information is recorded in the blockchain and this information is not changeable (Gerdan, D., et al., 2020).

Today, the meaning of “Sustainable agriculture and food supply chain through digitalization” is the process of integrating advanced digital technologies. Artificial Intelligence, big data, robotics, unmanned aviation systems, sensors, and blockchain are all connected through the Internet of Things (IoT) to the farm production system. While sustainable agriculture and food systems aim to meet the food and fiber needs of society and also aim not to harm the environment. At this point, the major term is "sustainability". The use of technology and the digital transformation of agriculture and the food supply chain have been effective in the emergence of terms such as *Agriculture 4.0* and *Agri-Food 4.0*. Thus, in this study, the applications, and systems, that are being used to provide sustainability in these sectors, have been explained in light of the literature findings.

SUSTAINABILITY IN AGRICULTURE: SMART AGRICULTURE (4.0)

Regarding, Oliver Wyman Report (2019), rapid growth in the world's population means more people, and more demand and that demand requires more output. The Food and Agriculture Organization of the United Nations suggested that farmers should increase their food production by 70 percent by 2050. This food must adapt to the needs of the growing urban population, a factor spanning the entire agricultural value chain. The four main developments that are putting pressure on agriculture to meet the demands of the future are demography, scarcity of natural resources, climate change, and food waste. (De Clercq, M., Vats, A., & Biel, A. 2018). According to the UN's 2019 Food Security and Nutrition Report, more than 820 million people are currently at risk of starvation, while 670 million adults and 120 million children struggle with obesity. With this unequal distribution, it is well known that about one-third of all food produced is lost or wasted for various reasons from the beginning of production to consumption. Due to climate change, portable and arable land water resources are decreasing, while natural disasters increase the loss of arable land. Desertification has

become one of the most important environmental problems today and its effects are resource-depleting climate change, unsustainable freshwater use, and land management (KIRKAYA, A., 2020).

Agriculture is one of the main producers of greenhouse gases and accounts for the largest share of global methane and nitrous oxide emissions. It is estimated that crop and animal production and deforestation cause 21% of total global GHGs emissions directly. Estimates are that the increase will continue until 2050. A side effect of climate change is increased precipitation variability, causing an increased frequency of droughts and floods, which tend to lower crop yields. In addition, climate change will exacerbate existing long-term environmental problems such as groundwater depletion and soil degradation, which will affect food and agricultural production systems. The impact of climate change on global food security is not only about food availability, but also about food quality, access, and use (De Clercq, M., et al., 2018; Araújo, S. O., et al., 2021).

The traditional approach in the food industry is undergoing a radical transformation in the face of digitalization and a new term called *''Agriculture 4.0''* or *''Digital Agriculture''* is encountered. Agriculture 4.0 is considered the evolution of agricultural engineering based on *precision farm production systems* and its main purpose is to automate sustainable production in agriculture. Precision agriculture enables agricultural guidance, monitoring, and control of agricultural areas with the *Global Positioning System (GPS).* The vehicles used at every stage of agricultural production are equipped with sensors so that the machines are in communication with each other during the entire production. With agricultural tools and fields equipped with sensors, it is aimed that the farmers can obtain detailed information on the fields and what kind of fertilizer they should use weather conditions, the amount of mineral and irrigation needed by the plant, the condition of the soil, and the estimated harvest time to maximize the yield. In this way, producers have the opportunity to manage and monitor the entire planting area with smart technology devices, minimizing labor power and production input costs, and enabling them to obtain high-quality and high-quantity products. (KILAVUZ, E., & Erdem, İ., 2019).

Smart Agriculture Technologies

To improve product quality, various arrangements for agricultural procedures such as planting, harvesting, irrigation, fertilization of existing plants, seed selection, usage of multiple types, product diversification, and new management methods should be developed. It is feasible to save methodically and location-based data collected from channels such as satellite photos, ground-based optical sensors, and aerial images using digital monitoring technologies. Various algorithms can be used to assess the data's relationships with one another, and the results can be delivered to the user in seconds (KIRKAYA, A., 2020).

Key developments in Agriculture 4.0 include low-cost and advanced sensors, low-cost microprocessors, high-bandwidth mobile communications and cloud-based ICT systems, and big data analytics. With

Agriculture 4.0, a traceable agriculture system has been introduced as a result of the widespread application of information and communication technologies. Thus, digitalization in agriculture has improved control mechanisms and assisted in maximizing agriculture productivity (KILAVUZ, E., & Erdem, İ., 2019).

The main focus of smart agriculture is to increase agricultural productivity and incomes and make them sustainable in the long term. With smart agricultural practices, productivity, sustainability, and economy are aimed by collecting data from crop yield, fertilizer applications, soil mapping, weather effects, and many other similar phenomena and using expertise (shown in Figure 1). When applied together with all its components, it will undoubtedly provide great benefits to living life and environmental problems such as greenhouse gas, through more efficient use of water or optimization of processes and inputs. With the future growth in the global population, it will be possible to create solutions for the issues with nutrition and resource efficiency that will occur. (DUMAN, B., & ÖZSOY, K., 2019)

Figure 3 Sustainable Smart Farming Applications (DUMAN, B., & ÖZSOY, K., 2019)

Produce Differently

Hydroponics is a hydroponic method of growing plants using mineral fertilizer solutions in a water solvent, which is a subset of hydroculture. ***Algae*** grown in aquaculture areas can be used to substitute raw materials and fishmeal, resulting in significant cost savings. When compared to fishmeal, which costs around $1,700 per ton, cultivating algae costs between $400 and $600 per metric ton in most places. Algae are also a more consistent source of raw materials because they are not dependent on catching fish. Reduced risk in aquaculture operations allows producers more control over expenses and the capacity to estimate future investments or financial returns (De Clercq, M., et al., 2018).

Increasing Efficiencies in Producing

One way to sustainably produce high-quality food is through ***Vertical Farming*** (shown in Figure 2)**.** To produce food in difficult locations where sufficient land is not accessible, vertical farming involves growing food in layers that are stacked vertically. It is related to urban farming and uses soil, hydroponic, or aeroponic growing methods. The method increases output while using 95% less water, less fertilizer, fewer dietary supplements, and no pesticides (De Clercq, M., et al., 2018).

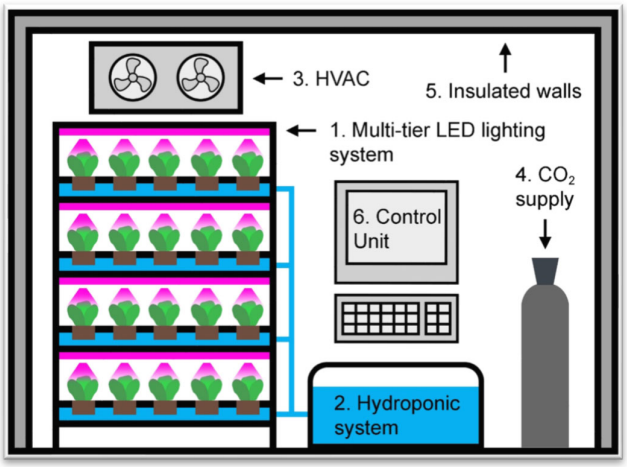

Figure 4 Vertical Farming (Van Gerrewey, T., et al., 2021)

Regarding, Oliver Wyman Report (2019), AeroFarms, based in the US, has been developing, owning, and managing indoor vertical farms since 2004 to provide healthy food. It is a global leader in high-tech, data-driven, large-scale vertical farming. Since its farms can produce throughout the year, they have the potential to produce 390 times more than a regular farm of the same size. Extreme weather conditions and seasonal shifts have no impact on production. Fruits and vegetables last longer since they are grown locally rather than imported (De Clercq, M., et al., 2018). Another investment example is that in 2017, IKEA and local investors collaborated on vertical farming in Dubai, and KKR signed projects worth $100 million for desert agriculture (Odası, Z. M., 2020).

However, it is still a relatively new technology, and its cost-effectiveness, scalability, and environmental sustainability cannot currently surpass traditional farming practices, according to experts. There are many challenges as well as opportunities in terms of economic, environmental, social, and political (Van Gerrewey, T., et al., 2021). Vertical farming needs reasonably priced electricity, nevertheless, to be profitable. Governments might encourage the implementation of these farms by providing tax reductions or power subsidies. Eventually, countries with a population that is highly educated, low energy prices, and a government open to (Public-private partnership) PPPs will take the lead in this field (De Clercq, M., et al., 2018).

TECHNOLOGIES & APPLICATIONS IN AGRICULTURE AND FOOD SECTOR

Agriculture 4.0 has enabled the development of remote sensing, image processing, GPS technology, sensor IoT technologies, and data collection methodologies. Farms are becoming more profitable, productive, safe, and environmentally friendly as a result of agriculture, smart devices, robotic systems, and precision agriculture with the effect of digitalization.

Digital transformation is turning the agricultural world upside down. There is a growing use of new technologies, such as ***The Internet of Things (IoT),*** that have a significant impact on supply chain

sustainability. It is an internet-based network system where smart devices connected via sensors can use this data to activate various actions. Due to its real-time, highly accurate flow of digital information and its advantages in process and service management, IoT is rapidly gaining popularity in many industries when integrated with other technologies. When ***machine learning*** is applied to sensor or drone data on IoT platforms like IBM's Watson, management systems become true artificial intelligence systems. Moreover, IoT and the use of sensor technologies reduce the demand-supply gap and improve food quality and security. It is estimated that 20 billion devices are connected in many areas including smart cities, housing, energy systems, communications, logistics, agriculture, health, and industry. It is thought to be combined with blockchain technology to combat security issues. (KIRKAYA, A., 2020; De Clercq, M., et al., 2018; Saetta, S., 2020).

The hands-on, experienced management style of farming can be replaced by a ***data-driven farming*** strategy thanks to digitization. Farmers can make better judgments by analyzing and evaluating data on the weather, different seed varieties, soil quality, disease risk, historical data, market trends, and prices (De Clercq, M., et al., 2018). Data is essential to the future of any business. New technologies have a big influence on uncertainty reduction because they enable exact data to be collected in real time, which, when combined with autonomous and intelligent decision-making capabilities, will assist boost efficiency, sustainability, flexibility, agility, and efficiency. It provides flexibility throughout the entire supply chain from field to fork (Lezoche, M., et al., 2020). There are many definitions of ***Artificial Intelligence (AI).*** It is a method that helps automate tasks and processes by simulating cognitive functions that are similar to those of humans. Applications of artificial intelligence are anticipated in the most significant agricultural research areas of the present and the foreseeable future due to their ability to facilitate agricultural operations and create alternate solutions to issues that require resolution or improvement. Agricultural robots, crop and soil monitoring, and predictive analytics are the three main areas of AI in agriculture. As there is better planning and inventory management, AI in the case of fresh produce helps predict shelf life, minimizing guessing and lowering food waste (Dadi, V., et al., 2021; Terzi, İ., et al., 2019)

Application areas for AI in the food sector include food item segmentation, guaranteeing FSC stability, and enhancing food delivery. The standard for AI is the human level in terms of thinking, speech, and vision. Machine learning, deep learning, and neural networks all aid in the solution of complicated issues. The idea behind machine learning, an AI-based application, is that computers should have access to data and be permitted to learn on their own utilizing structured historical data. Due to their capacity for learning and ability to spot patterns in data, machine learning models may be utilized for corporate decision-making by anticipating demand and predicting product backorders with more flexibility, process clarity, and accuracy. Other uses of AI include multi-agent systems, the semantic web, autonomous systems, natural language comprehension, and decision-making (Dadi, V., et al., 2021)

Drone tech has regularly been listed among smart farming methods in recent years. Soil structure, plant nutrition content, illness, and insect activity in plants can all be identified, especially with drone-based hyperspectral imaging technology. It is even possible to spray plants against recognized diseases and pests using additional apparatus attached to drones. The application of plant nutrients and pesticides when needed, in the required dose and area, would both minimize input costs and avoid excessive chemical application, which causes soil and environmental contamination. Integration of productivity in crop production, particularly economic efficiency and smart farming systems; first, is critical for reducing input costs, and secondly, and maybe most crucially, for limiting environmental pollution in terms of sustainable agriculture (Odası, Z. M., 2020). ***Geographical Information Systems (GIS)*** is defined as a set of location-based data management systems. Lots of data could be associated simply and give a more in-depth view and insights through maps that depicted data with GIS, which includes location-based data gathering, management, and analysis (KIRKAYA, A., 2020).

Precision farming offers significant possibilities for using ***Nanotechnology***. It is simple to create nanoparticles with distinctive features from various biological sources and use them in agriculture. This "green synthesis" method is safe for the environment, simple to carry out, and can be done without special equipment at room temperature. Nanotechnology-based nanoparticle distribution has given encouraging results for plant disease resistance, enhanced plant growth, and nutrition through site-specific delivery of fertilizers and other critical nutrients. By enabling improved penetration and a prolonged release of the active components over time, nanoencapsulation can also enhance the application of herbicides. Agriculture is considered as having a bright future in the next era of agricultural mechanization. Faster and more accurate diagnostic tools offer a big and bright future for contemporary agricultural applications, such as the precise distribution of nutrients and fertilizers, with the use of biotechnological advancements and nanomaterials (Duhan, J. S., et al., 2017).

These technologies make it possible for the agriculture and food supply chain to develop into a data-driven, intelligent, adaptable, and autonomously networked system. Active technology will automatically include each agricultural process' activities into the food chain, all the right up to the final consumer (Lezoche, M., et al., 2020).

SUSTAINABILITY IN FOOD SUPPLY CHAIN: AGRI-FOOD (4.0)

The agri-food industry is considered one of the most important and complex industries since food safety plays a significant role in people's lives. Furthermore, this sector is confronted with societal difficulties such as increasing food demand, food safety management, trade margins, climate change, environmental protection, and regulation by the growing population. As a result, the Agri-food business has been heavily impacted by technology applications in the industrial sector, which is presently referred to as "Industry 4.0." The phrase

"Agri-Food 4.0" is derived from the term "Agriculture 4.0." (Miranda, J., et al., 2019; Lezoche, M., et al., 2020).

Digital innovation has always been a part of the agriculture industry. A significant digital shift in agriculture and food has been enabled, particularly by developments in Precision Agriculture, remote sensing, robotics, farm management information systems, and (agronomic) decision support systems. Recent advancements in Big Data, Blockchain, Robotics, Artificial Intelligence, Cloud Computing, and the Internet of Things allow for the merging of previously unconnected fields of research into intelligent, interconnected systems of systems. With the use of these technologies, agriculture will develop into an integrated, data-driven, intelligent, agile, and autonomous system of systems. Active technology will automatically integrate each agricultural process' activities into the food chain up to the final consumer. It is among the expectations of Agri-Food 4.0 to increase the income of agri-food supply chain stakeholders and to minimize the negative effects that may occur due to difficult and complex external factors such as weather conditions and market behavior, thus reducing the pressures, ensuring sustainability in the sector and identifying the problems promptly and taking action (Lezoche, M., et al., 2020).

Food safety is a fundamental issue today. Food supply chain management; aims to protect food safety and quality, and ensures the sustainability of product and information flow throughout the chain. To ensure safety, monitoring and verifying the food supply chain are critical in predicting the disruptions that may occur in the food supply chain around the world, identifying and addressing the disruptions, and providing immediate solutions. It is necessary to solve traceability problems and ensure transparency to ensure safety and minimize the problems that may occur in the food supply chain. Thus blockchain technology provides helps to reduce the uncertainties in the sectors. (Gerdan, D., et al., 2020; KELEŞ, B., & Gülden, O. V. A., 2020)

Blockchain Tech

Blockchain is a technology that provides digital traceability and authentication of food products throughout the entire supply chain, from suppliers to store shelves and finally to final consumers (shown in Figure 3), by recording data encrypted by approved users in a network environment in an immutable distributed database (Gülden, O. V. A., 2020; Dadi, V., et al., 2021).

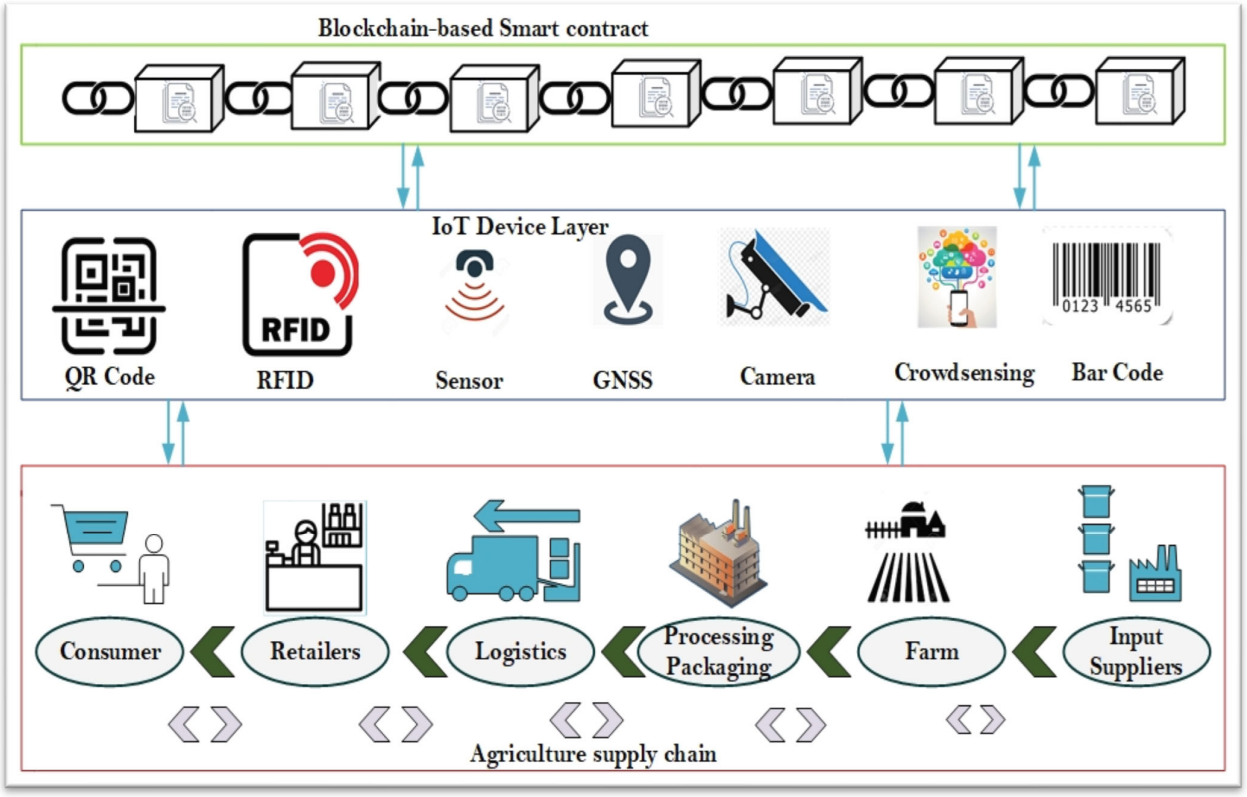

Figure 5 The blockchain Process for Agriculture (Bhat, S. A., et al., 2021)

The use of blockchain technology allows manufacturers to transparently share product information with consumers, thereby establishing a relationship of trust. As it provides consumers with the opportunity to interact with producers, they have the chance to understand the food production process more comfortably and in more detail. Thus, fraud and low-quality product suppliers will not only make it difficult to stay in the market but also will force them to maintain and increase the quality of their products. It helps consumers to tighten their relations with the producer by removing the barriers in the exchange of goods, thus strengthening the consumer's trust and belief in food safety. (Xiong, H., et al., 2020).

Blockchain applications in agriculture improve various aspects of agricultural systems, especially supply chain and internet of things (IoTs) based systems. These include food safety, food quality monitoring, and control, traceability for waste reduction, reliable operational data analysis, and efficient contract exchanges and transactions to reduce economic costs. The design and operation of the blockchain are created in such a way that problems at any point can be easily found and easily fixed. (Khan, H. H., et al., 2022; Lin, W., et al., 2020; Koç, E., 2020).

Achieving important supply chain management goals including quality, dependability, speed, affordability, risk reduction, sustainability, and flexibility is made possible by the blockchain's structure. The creation of blockchain-based infrastructures and applications by software companies, the construction of

blockchain research labs, efforts by prominent corporations to standardize blockchain, the provision of technical and strategic support by consulting firms to businesses wishing to adopt the technology, and so on, can all be viewed as signs that this technology will be used widely. (Keleş, B., & Gülden, O. V. A., 2020)

CONCLUSION

The agricultural sector plays an important role in humanity. In response to the increasing population, it is important to raise sufficient food on time and deliver it to the consumer. However, this process may quite long and difficult. With the rapid development of technology as a necessity of the 21st century, every sector has had to go digital to a certain extent. There have been digital developments in agriculture and the food supply chain, and as a result, the terms "Agriculture 4.0" and "Agri-Food" have been coined. Agriculture 4.0 refers to the new generation of digital agriculture. By moving away from traditional methods, it is possible to increase production and efficiency in agriculture, reduce costs as much as possible, and assure environmental sensitivity with artificial intelligence and sensors, etc. Food safety is important for the welfare of society. Agri-food 4.0, ensures that the process of reaching the product from the field to the fork is transparent and traceable, especially by using blockchain technology. Undoubtedly, the innovations that digitalization brings, not only minimize the problems that may occur in an important sector such as agriculture but also eliminates uncertainties. Needless to say, using technology actively can be costly, but it can be considered a long-term investment since digitalization is described as the future.

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