# 3. DIGITALISATION IN AGRI-FOOD SECTOR

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**Abstract**

The progress of the Fourth Industrial Revolution (called Industry 4.0) is driven by the development of cutting-edge digital technologies. Digital transformation is changing not only the manner of production, but also the definition of quality and the manner of quality management. The idea of Quality 4.0 refers both to the development of new technologies for quality assurance and control, as well as to changes in the culture of quality management. Industry 4.0 technologies are increasingly used in food production, leading to the development of Agri-food 4.0. They serve, for example, to control and implement production using automatic machines and robots. Invasive or remote sensors are used to monitor the environment, crops, farming conditions, processing operations and products throughout the entire supply chain. The use of the Internet of Things, artificial intelligence, big data and cloud computing enables advanced planning, control and optimisation of production. The use of digital technologies in the agri-food industry positively affects the quality and safety of food and has a positive impact on the efficiency of enterprises. At the same time, digital transformation is an opportunity to develop sustainable practices throughout the food supply chain. In this chapter, we present the idea of Industry 4.0 and Quality 4.0 as well as examples of the use of digital technologies in the agri-food sector.

**Keywords:** Industry 4.0, Quality 4.0, Agri-food 4.0, digitalisation, quality management.

**JEL codes:** O14, Q01, Q16.

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## Introduction

The modern food industry is a very competitive and dynamically developing environment in which consumer demands are growing towards better quality, safety and durability of food, greater variety of products and adoption of sustainable production. Therefore, in order to meet the ever-increasing consumer demand for high-quality food products, food researchers and the food industry should constantly look for more advanced solutions and technologies, including innovative processing and analytical techniques.

In the food industry, the ongoing Industry 4.0 era is characterised by high interconnectivity and the growing use of new technologies, especially digital innovations. The European Union countries have adopted Industry 4.0 technologies in very different ways. Due to their Industry 4.0 infrastructure and big data maturity, the Netherlands and Finland are leading in the implementation of Industry 4.0, while Hungary, Bulgaria and Poland come last (Castelo-Branco et al., 2019).

Advanced technologies have accelerated digitalisation and automation in almost all sectors, including the agriculture and food industry (Hassoun, Aït-Kaddour et al., 2022). Food producers can use technological approaches to solve problems such as food safety and quality, production optimisation, traceability, shelf-life control and other related issues in the context of food production. The integration of digital technologies in the food supply chain supports sustainable development in the agri-food sector.

The application of digital technologies in agriculture and food production sectors has been referred to using terms such as Agriculture 4.0, Digital Agriculture, Smart Agriculture 4.0, Smart Farming 4.0, Smart Farming (Calafat-Marzal et al., 2023). The term Agri-food 4.0 usually refers to the entire food production chain, from agricultural practices to food consumption (Calafat-Marzal et al., 2023). Smart Agriculture is defined as a management concept that directs actions to protect or increase agricultural productivity and food security in the face of changing physical and chemical constraints, changing climate and increasing requirements or expectations for transparency towards all actors in the agri-food chain (Baerdemaeker, 2023).

Recently, Hassoun et al. (2022) provided a general overview of key Industry 4.0 principles and their application in food production. According to Demartini et al. (2018), Hassoun, Jagtap, Garcia-Garcia et al. (2023), the number of publications and citations related to digitalisation or automation in the agri-food sector has increased tremendously in the last decade, and it is still rising; these issues have been presented in several reports (Baerdemaeker, 2023; FAO, 2022; McFadden et al., 2022).

This chapter briefly presents the idea of Industry 4.0 and Quality 4.0 as well as the examples of applications of cutting-edge digital technologies in the agri-food sector.

## 3.1. Digital transformation and evolution of quality concept

The Fourth Industrial Revolution is a modern idea that leads organisations into a new era of robotisation and digitalisation through optimal control of all production processes. The Industry 4.0 concept is currently one of the most-discussed topics among practitioners and scientists, making it a priority for many research institutions and enterprises (Bigliardi et al., 2023). In Industry 4.0, the manufacturing operations systems are increasingly deeply integrated with communication, information and intelligence technologies. These technologies can be categorised into physical and digital. Physical technologies mostly refer to manufacturing technologies such as: additive manufacturing, sensors and drones, while the digital ones refer to modern information and communication systems, such as: cloud computing, blockchain and big data (Bai et al., 2020). Various industrial sectors, including the food industry, are increasingly adopting the Industry 4.0 technologies (Hassoun, Jagtap, Trollman et al., 2023).

Past industrial revolutions not only changed the way products were made, but also affected the way their safety and quality were evaluated. Figure 3.1 presents the transformation from Quality 1.0 to Quality 4.0.

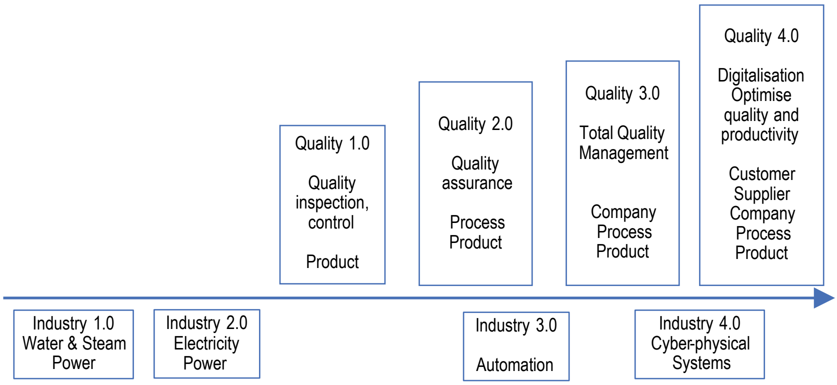


**Figure 3.1. Evolution from Quality 1.0 to Quality 4.0**
Source: based on (Liu et al., 2023; Zulqarnain et al., 2022).

As shown in Figure 3.1, companies have changed their approach to quality over time. Initially, manufacturers focused on plant productivity without focusing on losses. Product quality was a secondary issue that was assessed by time-consuming measurements.

In the Quality 2.0 era, this approach changed, and manufacturers began to pay attention to the waste generated. Labour productivity also became an important issue, which manufacturers sought to optimise. However, maximising production was still the most important issue of the era (Zulqarnain et al., 2022).

The next period called Quality 3.0 was a period in which quality was a key aspect of the business. During that era, organisations emphasised meeting customer requirements so that they were satisfied with the goods they purchased. Companies strived for continuous improvement, increasing productivity through appropriate labour and production standards (ISO standards) and involved all employees in activities that affected quality. In that era companies adapted Total Quality Management (TQM) to better manage quality strategies. Those activities reduced company costs resulting from advertised goods and production errors (Broday, 2022).

The solutions emerging from the Fourth Industrial Revolution have forced the transformation to Quality 4.0. There are various definitions given by different authors of Quality 4.0 which were presented by Broday (2022). Based on Carvalho et al. (2021), the term Quality 4.0 can be characterised as "the digitalisation of TQM and its effect on quality technology, processes and individuals". In the past, total quality management (TQM) and statistical control charts were used to enhance processes and inspect products for flaws. Quality 4.0 is the digitisation of quality management, fusing the new capabilities of Industry 4.0 with the established techniques of quality control. As a result, businesses need to modify their corporate cultures to put more emphasis on design, safety and service quality (Broday, 2022). Quality 4.0 technologies enable manufacturers to control quality throughout the production process. Based on Li et al. (2019), the real-time quality assurance with detailed documentation is available to organisations at every step of the process. According to Hyun Park et al. (2017), new industrial 4.0 technologies can help achieve quality excellence. Robertsone and Lapiņa (2021) explored how digital transformation changes quality management practices adopted by organisations. The scientists point out that there are several tasks and goals for the quality management, which organisations should take care of. In their study, the authors found that certain quality management practices become essential as prerequisites for digitalisation and for successful digital transformation, while other practices are influenced and affected by digitalisation.

Furthermore, artificial intelligence and big data analytics can be used to manage quality in companies. However, projects based on these technologies are not widely implemented in practice, and quality leaders do not use solutions based on the idea of Quality 4.0. Escobar et al. (2021) proposed a novel seven-step problem-solving strategy that includes the following steps: identify, acsensorise, discover, learn, predict, redesign and relearn. According to the authors, such a comprehensive approach increases the likelihood of successful implementation of the Quality 4.0 initiative.

## 3.2. Digitalisation and sustainability opportunities

Sustainable growth has become an important issue for companies in recent years. Additionally, there is a growing interest in the scientific literature concerning the impact of Industry 4.0 technologies on sustainable management and production (Ejsmont et al., 2020). Industry 4.0 has a great potential to increase resource efficiency while achieving sustainable value creation across social, economic and environmental dimensions (Calafat-Marzal et al., 2023; Carmela Annosi et al., 2020; Ghobakhloo, 2019; R. Sharma et al., 2021).

Based on Stock and Seliger (2016), there are some opportunities of sustainable manufacturing for the micro and macro perspectives of Industry 4.0. For the macro perspective, there are two main opportunities of sustainable manufacturing:

- selling the functionality and accessibility of products rather than just the tangible products,
- effective coordination of product, material, energy and water flows throughout product life cycles as well as between different factories.

For the micro perspective, there are five main opportunities of sustainable manufacturing:

- upgrading existing equipment to implement production monitoring sensors which will control, for example, energy efficiency,
- new skills of workers and better human performance,
- efficient use of resources, including water, energy and goods,
- designing suitable production process chains,
- adding new services to the product in order to improve customer satisfaction.

According to Bai et al. (2020), there are three main dimensions where Industry 4.0 technologies improve sustainability. The first one is the economic dimension, where organisations can reduce set-up times, labour and material costs, and increase productivity. The second dimension is the ecological point of view, where technologies can help in reducing energy, $CO_2$ emissions and waste. The third dimension is focusing on social sustainability. Employees are supported by smart and autonomous production systems to achieve better performance, higher satisfaction and motivation.

## 3.3. Digital technologies used in agri-food sector

Digital transformation in the agri-food industry is based on the adoptation of Industry 4.0 technologies. Enabling and high-impact applied technologies such as automation, autonomous robots, the Internet of Things (IoT), radio frequency identification (RFID), smart sensors, big data, artificial intelligence (AI), machine learning (ML), cloud computing and blockchain are increasingly used in food production (Hassoun, Jagtap, Garcia-Garcia et al., 2023) (Figure 3.2).

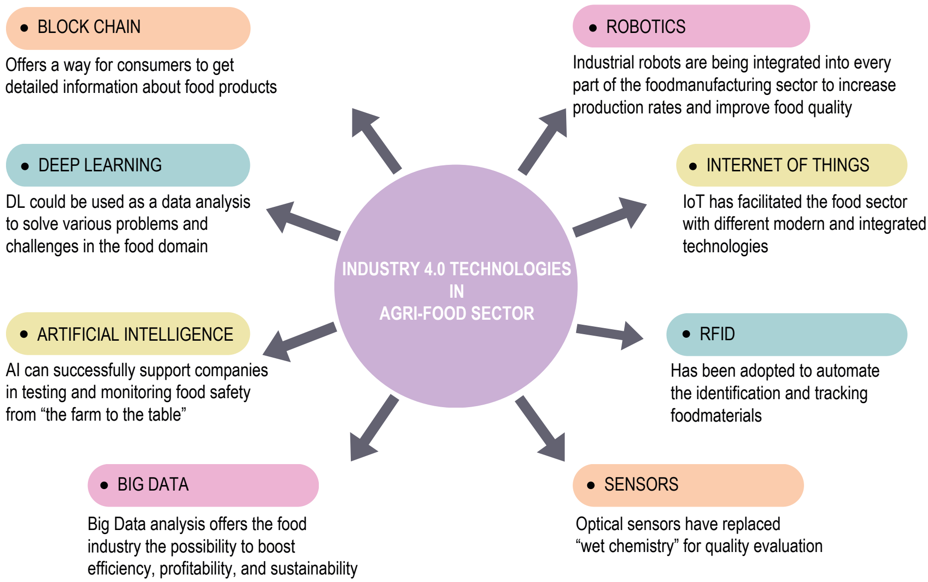


**Figure 3.2. Diagram of digital technologies used in agri-food sector**
Source: based on (Hassoun, Jagtap, Garcia-Garcia et al., 2023).

Nowadays robotics has started to make its way into almost every link in the food supply chain, "from farm to table" (Wang & Wang, 2021). On the farm, robots are used to help farmers plant, identify and sort seeds. They also monitor seedling growth and spray water. Autonomous vehicles (tractors) and drones are used for harvesting, monitoring and analysing crops (Wakchaure et al., 2023). In food manufacturing, robotics is used in primary and secondary processing—raw food is washed, sorted, transported, sliced and blended, while ingredients are combined to create new food products through cooking, baking, mixing, etc. (Iqbal et al., 2017). Robotics is also used in food packaging as pick-and-place robots (Mahalik & Nambiar, 2010). In the three final stages: delivery, serving and cooking, robots are still under development and need improvement (Iqbal et al., 2017).

The Internet of Things is another key 4.0 technology. IoT has facilitated the food sector with different modern and integrated technologies, such as: smart sensors, RFID, communication technologies and Internet protocols (Shah & Yaqoob, 2016). Due to the complexity of current technologies, smart sensors based on wireless technologies have been under rapid development in recent years and play a significant role in data acquisition and process automation in food industry

(Miranda et al., 2019). To improve the control in food processing, sensors are implemented in various stages of processing lines. Such solutions enable better process management, which consequently reduces the loss of food quality and production costs (Franceschelli et al., 2021).

The Radio Frequency Identification (RFID) has been adopted in the food supply chain as to automate the identification and tracking of food materials (Ilie-Zudor et al., 2011). According to Noor Hasnan & Yusoff (2018), a great example of the RFID application could be chicken meat, where the system is applied through a complete chain from the farm, through a slaughterhouse and processing factory, to the retailer.

One of the most important areas is the digitalisation of food quality control. To ensure that food products are safe for consumers and have the required organoleptic characteristics, quality control is key in the food sector. Quality is defined by several attributes, including the nutritional value, physicochemical properties, safety, sensory characteristics and shelf life. Originally, food quality was assessed using a variety of destructive and laborious techniques with limited analytical performance. Automated instrumental techniques have replaced "wet chemistry" in recent years. Based on Misra et al. (2022), food quality can be assessed by spectroscopic sensors and hyperspectral cameras, which are used more commonly nowadays for food quality and safety monitoring. To meet the demands of the food sector, smaller and faster devices (sensors) are being developed, allowing manufacturers to use them more efficiently throughout the production process. Relevant datasets from sensors can be grouped in the cloud and explored to help regulate quality standards as part of Industry 4.0 (Misra et al., 2022).

The food industry has huge potential for applying big data solutions to improve their businesses. In farming, a lot of data is generated by sensors which are analysed by farmers to help them make the right decisions (Wolfert et al., 2017). According to Jin et al. (2020), satellite imagery data can be used to detect crop growth, harvest prediction and improve agriculture monitoring systems, thereby helping to improve the quality of agriculture products. Big data is also useful in food logistics where obtained information are used for planning routes and choosing the best method of transportation (Jagtap et al., 2021). Furthermore, Big data can be also used to provide food safety solutions (Sadiku et al., 2020).

The next digital technology which is becoming crucial in recent years in food industry is artificial intelligence (AI). Based on Kler et al. (2022), the data management for food safety and quality may be changed with the use of machine learning and AI which may streamline the entire process. According to Bai et al. (2020), to effectively manage the whole supply chain and the associated human activities, all stakeholders must concur on the data to be recorded in a blockchain, from raw materials to final products. Yang et al. (2022) showed that the machine vision technology integrated with AI can be used for sorting apples according to their characteristics. This technology not only improves the sorting efficiency but also reduces damage to apples. In the supply chain management, AI can successfully support companies in testing and monitoring food safety from "the farm to the table" (Chacón Ramírez et al., 2020). According to Di Vaio et al. (2020), artificial intelligence has great potential to reduce waste and improve process efficiency to create more sustainable food production.

Deep learning (DL) could be used as a data analysis tool to solve various problems and challenges in the food domain. Zhu et al. (2021) presented in their paper how traditional machine learning and deep learning methods could be applied to the fields of food processing. Zhou et al. (2019) demonstrated that DL could be used for food traceability, calorie estimation, quality assessment of fruit, vegetables and meat. Following the authors, DL has been successfully applied for detecting food fraud and contamination.

The traceability of food is an important factor that indicates its quality (Yu et al., 2022). To ensure a new, higher level of food traceability, it is predicted that blockchain technology will be integrated with AI and big data as well as cloud computing to provide consumers with transparent information about the product's origin (Hassoun, Jagtap, Garcia-Garcia et al., 2023). In food packaging, AI solutions can help reduce the environmental impact of food packaging by optimising the design of packaging materials (Hassoun, Jagtap, Garcia-Garcia et al., 2023).

## 3.4. Challenges of digital transformation

Digital technologies could be incorporated into the agri-food sector to digitalise it and improve process stability, productivity and product customisation. However, there are still some challenges that companies (not only in the food industry) have to face in order to implement these new technologies (Carmela Annosi et al., 2020; Sharma et al., 2023).

The main challenges are the following.

a. Technical and technological challenges: complexity and technical challenges are the biggest barriers for companies that want to undergo digital transformation of their facilities (Microsoft, 2021). Current machines are not network-ready, which requires them to be adjusted or replaced accordingly.
b. Lack of budget and knowledge: most companies complain that a lack of budget and well-skilled staff have stopped the digital implementation in their organisations. Digitisation and the associated changes in machines, software as well as training for employees generate costs (up-front investments and recurring maintenance expenses) that many organisations are not prepared for (McFadden et al., 2022).

c. Information security and data protection: one of the main Industry 4.0 adoption barriers is corporate concerns about information security and privacy. Nearly a third (29%) of organisations believe that security risks associated with the implementation of IoT outweigh any potential benefits (Cisco, 2016).
d. Standardisation issues: the most significant concerns about data created in the supply chain are connected with issues of data justice, data quality and a lack of standardisation (Jin et al., 2020).

In order to remove barriers and support the implementation of digital technologies in the agri-food sector, it is necessary to take appropriate measures, e.g., informing people about their benefits, including intangible benefits, related to improving the quality of life and reducing the negative impact of food production on the climate. It is important to invest in human capital and strengthen the sector with well-trained professionals who are proficient in disruptive technologies, as well as to introduce the right incentives for innovation. Public and private policies should foster knowledge and data sharing to strengthen inclusive, secure and representative data ecosystems and promote competitive markets (Calafat-Marzal et al., 2023; McFadden et al., 2022).

## Conclusions

The implementation of Industry 4.0 technologies could lead to huge time and cost savings compared to traditional processes. The topic of digital transformation of the agri-food industry is of great interest nowadays. Various types of robots are used in the food industry to improve production and reduce labour. For instance, smart spectroscopic-based sensors have been developed to enhance food quality. The food processing sector is also becoming more familiar with the IoT and other associated technologies to reduce waste and costs. Furthermore, big data also offers many benefits, including food traceability and safety. Undoubtedly, there are still numerous challenges that companies need to face, but in the end, the implementation of new Industry 4.0 technologies offers an interesting and sustainable approach to enhance food production from “farm to fork”.

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