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# Agri-Food 4.0 and Innovations: Revamping the Supply Chain Operations

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**Abstract**
The agri-food sector contributes significantly to economic and social advancements globally despite numerous challenges such as food safety and security, demand and supply gaps, product quality, traceability, etc. Digital technologies offer effective and sustainable ways to these challenges through reduced human interference and improved data-accuracy. Innovations led by digital transformations in the agri-food supply chains (AFSCs) are the main aim of 'Agri-Food 4.0'. This brings significant transformations in the agri-food sector by reducing food wastage, real-time product monitoring, reducing scalability issues, etc. This paper presents a systematic review of the innovations in the agri-food for digital technologies such as internet-of-things, artificial intelligence, big data, RFID, robotics, blockchain technology, etc. The employment of these technologies from the 'farm to fork' along AFSC emphasizes a review of 159 articles solicited from different sources. This paper also highlights digitization in developing smart, sensible, and sustainable agri-food supply chain systems.

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## 1. Introduction

Agri-food is a complex sector that consists of a varied range of operations and roles worldwide. It is an area of prominence, making it critical to successfully apply advanced internet technologies to ensure an efficient agri-food supply chain. It is the leading provider of sustainable, sufficient, affordable, and safe food, feed, fiber, and fuel to the end-user. The pressure is being created on different stakeholders associated with agri-food supply chains due to free trade strategies and globalization, besides the safe, hygienic, and quality foods. Socioeconomic and ecological factors play a vital role in achieving a thriving supply chain (Bhat and Jõudu, 2019). Innovative solutions are needed as supply chains are mostly inefficient, with increasing constraints and demand. The stakeholders related to the Agri-food sectors, such as manufacturers, producers, retailers, government, and policymakers, are linked intrinsically to solve critical challenges. Technology plays a vital role in defining and implementing key solutions and in the due process of decision-making (Panetto et al., 2020; Mor et al., 2018b). After the industrial revolution in the nineteenth century, there has been a rapid growth in the Agri-food industry where there were system mechanization and steam engine usage, which laid a base for the food processing industry. This period is specified as 'Agri-Food 1.0'. In the 1950s, commonly called 'Agri-Food 2.0', there has been increased use of electrical machines leading to improved production facilities. Robotics and automation were the main pillars of 'Agri-Food 3.0', which emerged in the 20th century. These led to the usage of specialized machinery to sow and harvest operations that complete work cycles in separated tasks. This era also led to remarkable progress in crop techniques (Miranda et al., 2019). 'Industry 4.0' influences the agri-food industry through various techniques, technologies, strategies, and methods. Cyber-physical systems (CPS) are the main benefits in this era with applications in precision production systems and open food production systems. Some CPS involved intelligent greenhouses, smart sensors, robots, vertical farms, drones, wireless sensor networks (WSN), etc. There was a particular emphasis on environmental, social, and economic issues with advanced system digitalization, sustainable practices adoption, and modern machinery and tools introduction in the 'Agri-Food 4.0' era (Miranda et al., 2019). New opportunities are provided with digital technologies in agri-food right from 'farm to fork' as it offers new solutions to meet old and new challenges. These opportunities are considered essential, particularly on climate change challenges and in an integrated global food system (OECD, 2019).

Technological advancement also drives horizontal integration and vertical integration in the agri-food chain, favoring major food suppliers (Kirova et al., 2019). Specifically, digital technologies also enable novel business model development by offering probabilities for new practices that provide entrepreneurship (Gregori and Holzmann, 2020). Smart technologies are also viewed as adjuncts that can cause a short food supply chain conventionalization, thereby altering the optimally distinct (Lioutas and Charatsari, 2020). Today, the global challenges of managing the efficacy of resources in agri-food is a key concern. Some issues like energy-related concerns are the same at the global level, while others, like water scarcity, vary based on their economic condition (Anastasiadis et al., 2018). The impacts of digital transformations on commercial and ecological performance are mediated by digital platforms (Li et al., 2020). The digital transformations can reduce waste, strengthen logistical processes & information, and support flexible production and resource-sparing by encouraging lean production (Hoellthaler et al., 2020). However, digitalization is not new because it is a crucial component of modern supply chains. Material requirement planning, i.e., MRP-I and MRP-II, implementation can be considered as a starting point for supply chain operations digitization (Kittipanya-ngam and Tan, 2020). ERP systems and continual digital transformations in food production technologies facilitated the food supply chain streamlining towards downstream, boosting efficiency (Gharehgozli et al., 2017). Also, the developments in farming-related processes, including machinery, robots, and drones, have replaced the existing traditional means of transportation and aid in last-mile deliveries (Robinson 2017). Agri-Food 4.0, a digitization approach for sustainable agriculture acceleration and support, land management, and competitiveness, the agri-food sector presents an excellent potential for improved efficiency, intelligence, performance, and sustainability accompanied by internet-based networks and services (Hernández Jorge et al., 2018). Integrating demographic changes, unequal resource distribution, poverty, climate change, and digital technology would also emerge as a challenge in agri-food 4.0. Between concerns and capabilities of digital transformation, exploitation, and management of agricultural data act as the central node (Lezoche et al., 2020). Technological interventions, real-time monitoring, and cost containment are the advantages of agriculture digitalization towards sustainability improvement and territory management (Kamble et al., 2020; Panetto et al., 2020). There would be more cost-effective and less labor-intensive supply chains with high responsiveness to market demands using highly integrated digital platforms. Ivanov et al. (2019) studied the impact of supply chain digitization, where increased demand responsiveness and capacity flexibility encouraged the adoption of digital technologies. This paper addresses the emerging technologies for transforming the traditional supply chain into a digitized one via innovations such as AI, IoT, robotics, blockchain, big data, RFID, etc. This paper presents a systematic literature review aimed at answering the following research questions:

RQ.1. What are the issues resolved by the implementation of digitized agri-food chains?

RQ.2. What are the trends or innovations in different digital technologies to address new challenges in the agri-food supply chain?

RQ.3. What should future research emphasize on the successful execution of a digitized agri-food supply chain?

Further, this paper highlights the findings and research governing digital transformations in agri-food. There is a focus on an urgent need to optimize the existing processing methods and management techniques in the agri-food sector for sustainable development. The rest of the paper is structured as follows. Section 2 covers the methodology part, and section 3 includes the analysis of articles. The sustainable agri-food and digital technologies are discussed in section 4, while section 5 is the conclusion, limitation, and future scope of the research area.

## 2. Methodology

The methodology included three stages, i.e., planning the review, extraction of articles, and analysis of extracted articles (Fig. 1).

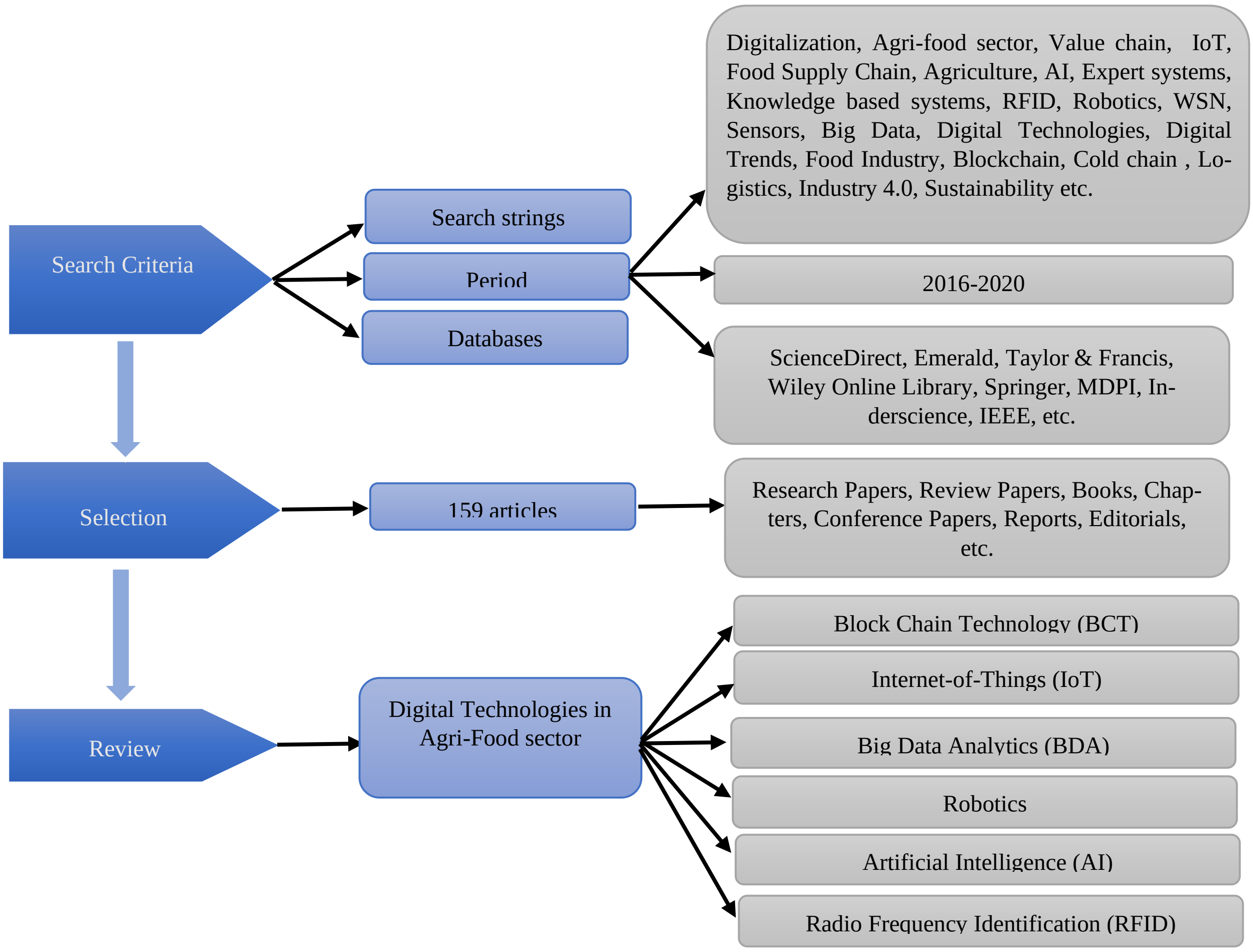


**Fig. 1.** Review Methodology

## 2.1. Planning the Review

After identifying the study area, an analysis was carried out for the existing literature reviews (Table 1). After placing limitations from these articles, three research questions were framed, which formed the review base.

**Table 1.** Reviews on digitization

| Reference | Focus |
|---|---|
| Camaréna (2020) | AI usage for sustainable food systems (44 papers are reviewed) |
| Kamble and Gunasekaran (2020) | Supply chain performance measurement based on BDA (66 papers). |
| Misra et al. (2020) | Role of IoT, BDA, and AI in Agri-food systems (126 papers) |
| Ping et al. (2018) | IoT in monitoring the product's quality and safety (116 papers) |
| Kosior (2018) | Opportunities & challenges in the agri-food sector for digitization (19 papers) |
| Antonucci et al. (2019) | Blockchain usage in the agri-food sector (39 papers) |
| Feng et al. (2020) | BCT solutions for food traceability, its benefits, and challenges (82 papers) |
| Lezoche et al. (2020) | New technologies and supply chains for future paths (206 papers) |
| Zhao et al. (2019) | BCT in agri-food for food safety, quality, traceability (90 papers) |
| Hernándezet al. (2018) | Operational research for decision-making in the agri-food |
| Gharehgozli et al. (2017) | Supply chain and implications of digitization on transport (153 papers) |
| Arunachalam et al. (2018) | Capabilities of BDA in the supply chain (95 papers) |
| Iqbal et al. (2017) | Robotics, efficiency, hygiene, human-robot interaction, maintenance, and safety for the food industry (41 papers) |

| | |
|---|---|
| Ghalehkhondabi et al. (2020) | BDA application in of supply chain: 2010-2019 (173 papers) |
| Biradar and Shabadi (2017) | Usage of IoT-based CPS and WSNs in farming (7 papers) |
| Himesh et al. (2018) | Digital technologies applications in agriculture (15 papers) |
| Duan et al. (2020) | Blockchain for improving traceability, transparency, recall efficiency (80 papers) |
| Fielke et al. (2020) | Trends in the agricultural (28 papers) |
| Liakos et al. (2018) | Machine learning usage in Agricultural production systems (113 papers) |
| Pathan et al. (2020) | AI tools for precision farming, disease detection (153 papers) |
| Kumar and Srivastava (2018) | RFID development in the agri-food sector (47 papers) |
| Athauda and Karmakar (2019) | Applications and limitations of RFID based sensors in smart packaging (81 papers) |
| Khan and Ismail (2017) | Opportunities and challenges of IoT in the agriculture sector (103 papers) |
| Gill et al. (2019) | Influence of IoT, Blockchain, and AI on cloud computing systems (181 papers) |
| Casino et al. (2019) | Blockchain-enabled applications (260 papers) |
| Bibi et al. (2017) | RFID usage in the agri-food sector for food quality monitoring (81 papers) |
| Villalobos et al. (2019) | Sensing data and information integration in the food supply chain (111 papers) |
| Elbasani et al. (2020) | Industry 4.0 technologies and RFID (54 papers) |
| Kumperščak et al. (2019) | Traceability systems for foods supply chain (34 papers) |
| Ni et al. (2019) | Trends in machine learning for supply chain: 1998-2018 (123 papers) |
| Galvez et al. (2018) | BCT in traceability and authenticity of the food supply chain (85 papers) |
| Khan et al. (2018) | Robotics and usage in food manufacturing (105 papers) |
| Pierson and Gashler (2017) | Deep learning: application, limitations, and benefits (30 papers) |
| Fernando et al. (2016) | Robotic transformation and its uses in the food industry |
| Wang et al. (2016); Wamba et al. (2018) | BDA usage in logistics and supply chain (122 papers; 31 papers) |

## 2.2. Extraction of Articles

The internet and other databases were used for article extraction. This screening process resulted in 250 papers that were further screened by selecting articles published from 2016 to 2020, which resulted in 159 articles. The articles were collected from databases and AI-based research tools like google scholar, semantic scholar, research gate, etc. Different keywords were used in combination with our research aim. Some specifically used search strings were: "digitalization", "agri-food sector", "Value chain", "IoT", "food supply chain", "agriculture", "AI", "Expert systems", "Knowledge-based systems", "RFID", "robotics", "WSN", "Sensors", "big data", "digital technologies", "food industry", "blockchain", "Cold chain", "Logistics", "Industry 4.0", "Sustainability" etc. (Fig. 1). The articles were selected by looking into the title, keywords and abstract, and the full text was studied.

## 2.3. Analysis of Extracted Articles

The articles selected were sub-categorized based on the technology emphasized like: Big data, IoT, Robotics, AI, Blockchain technology (BCT), and RFID, as these are the leading technologies highlighted in this paper. Based on the existing literature reviews, it was observed that the articles covering all technologies are in minimal number, and the sustainability concept was also not emphasized on all papers, which becomes the base of this paper.

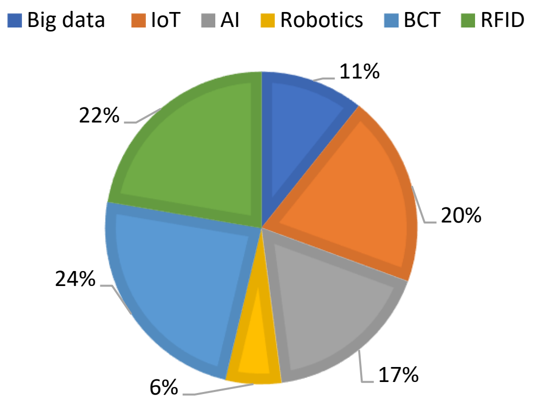


**Fig. 2.** Classification for digital technologies

The classification of articles for different digital technologies depicts that maximum studies were on blockchain technology, which accounted for ~24%, and only 6% of total papers were on robotics (Fig. 2). More research on robotic technology and its usage in agri-food is needed to uncover the challenges and opportunities. All other technologies had enough approach, and their uses are exploited in all sectors, including agri-food.

It is evident that most of the articles in the review were published in 2020 and 2019, and the least, i.e., 5% in 2016, showing increased research studies on digitalization from 2016 to 2020 (Fig. 3).

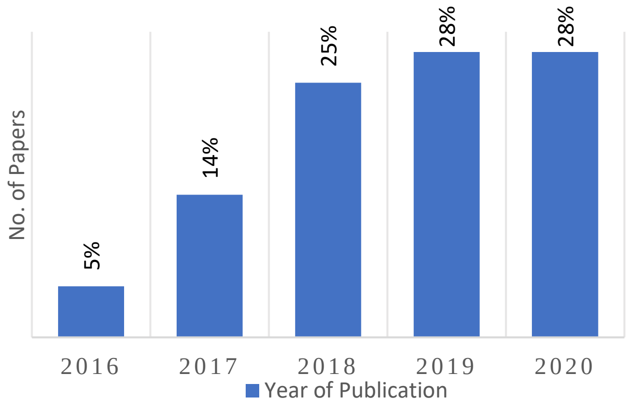


**Fig. 3.** Articles per publication year

A maximum of 7 articles were taken from 'Journal Computers in Industry', 6 articles from 'Journal of Food Engineering', 5 articles from 'Artificial Intelligence in Agriculture', and 4 articles from 'Trans. Res. Part E: Logi. and Trans. Rev.'. 'Food Control', 'Journal of Cleaner Production', 'International Journal of Production Economics', 'Sustainability' contributed 3 articles each.

### 2.4. Validity and Reliability

Validity indicates the extent to which a measuring process implies the quality of attained outcome leading to as representative. External validity demonstrates whether the study sample approves to the population or not (Neuendorf, 2002; Krippendorff, 2004). In this paper, the articles concerning digital technologies and their roles in operations and supply chain management for agri-food sector are selected. Hence, the external validity is assured. Further, this review has been confirmed with the academicians and agri-food industry professionals for content validity. The reliability is assessed through the percent agreement procedure (Mor et al., 2018a), 82%, and thus deemed reliable.

## 3. Analysis

### 3.1. Big Data Analytics

Data-driven supply chain decisions have become trouble-free, using tools and techniques developed by big data analytics (BDA). Better and faster decisions can assist enterprises by analyzing and comprehending real-time results that deal with large datasets that portray integrity, volume, variety, and velocity. Organizations can also improve the supply chain by cost reduction and risk mitigation (Govindan et al., 2018). A combination of data technologies and agri-food projects too crucial for creating new knowledge by extension of farmers' data, advanced services, processes, and software. It also plays a role in the adaptation of factories-of-future (FoF) and information & communication technologies (ICT) and related to agricultural patterns and big data models (Lezoche et al., 2020). Yu et al. (2018) explored financial performance affected by a Chinese firm's data-driven supply chain. This study proposed a data analysis method based on structural equation modelling. This study depicted a positive association with increased financial performance when there was harmony among supply chain partners. A change in supply chain responsiveness was also seen in fast response to market demand shifts in an organization. Singh et al. (2018) proposed a methodology using BDA by identifying constraints in prevailing food supply chains and logistics from social media data (Twitter). The text analytics approach analyzed the captured Twitter data, which uses hierarchical clustering and a support vector machine (SVM) with multiscale bootstrap sampling. The cluster of words about improvement in various segments of the supply chain was the outcome of this analysis.

Belaud et al. (2019) proposed a five-step approach in which big data is integrated to improve sustainability in the supply chain and increase agricultural waste value. Oncioiu et al. (2019) concentrated on supply chain management and BDA usage in supply chains of Romanian companies to evaluate the experience, professional capabilities, and strategies in successfully implementing BDA as determining the tools required to achieve the goal. Results showed that 90% of respondents endorsed an enterprise-wide approach, encouraging big data to add business value. Roßmann et al. (2017) studied BDA applications by a multi-method approach, which is part of the organizational information processing theory (OIPT). By conducting a Delphi survey, projections up to the year 2035 were integrated, and fuzzy c- clustering was employed to identify future scenarios that depict the future of BDA in SCM. It was suggested that BDA would help improve demand forecasts, safety stock reduction, and supplier performance management. Jha et al. (2020) studied the criteria for capability-building and profit maximization through BDA technologies.

### 3.2. Internet of Things (IoT)

IoT layer produces an anomalous amount of data, using sensor technology, nanotechnology, higher connectivity through satellite or 5G, and devices such as robots or drones, which can remotely generate live data (Valentini et al., 2019). A connected world is visualized by IoT where things can communicate measured data and interact, making the digital representation of the real-world for the development (Reyna et al., 2018). Recently, smart farming systems that enhance food production and are based on embedded systems and IoT are getting attention and popularity among people (Mahbub, 2020). Integration of IoT with agriculture offers data related to agri-features like water, humans, soil, animals, etc. (Lezoche et al., 2020). The Agri-food sector is deficient in ICT uptake. The high cost is incurred in data capture and analytics, delivering different decision support tools (Brewster et al., 2017). IoT employs several technologies like wireless sensor networks (WSN), radio frequency identification (RFID), sensors, and global positioning systems (GPS) that are useful for environmental monitoring, greenhouse management, traceability, cold chain monitoring, etc. (Ping et al., 2018). Precision Agriculture (PA) is one such promising example of the IoT application in agriculture. The use of guidance systems can achieve cost savings in terms of seed, fertilizer, and tractor fuel, and reduction in the field working hours during planting and fertilizer application (Trendov et al., 2019; Kamble et al., 2019). By IoT usage, self-adaptive food supply chains can be formed, in which objects decide, operate, and learn continuously and autonomously (Verdouw et al., 2016).

Brewster et al. (2017) emphasized setting up Large scale pilot plants (LSPs) based on IoT by identifying technological and Agri-food requirements and describing sectoral and technical challenges. Design and description of four agri-food domains LSP (dairy, meat, arable, fruit, and vegetable supply chain) based on IoT are provided. This provided a detailed account of the most appropriate IoT technologies in the agri-food sector and their applications and the key performance indicators to assess the proposed LSP's performance in a quantifiable manner. Kittipanya-ngam & Tan (2020) studied IoT usage to export Thai Jasmine rice and organic rice to global markets and reach consumers, both B2B and B2C, a major downstream challenge. There were safety and quality issues in the upstream case, where real-time data availability and transparency through IoT resolved it. Verdouw et al. (2016) proposed architecture for enabling information systems implementation by analyzing virtual supply chains from a perspective of IoT and usage of architecture in the fish supply chain for 'Proof of concept'. Based on online operational data, a basis for optimization, simulation, and decision support of the virtual supply chain is expected to be established. Accorsi et al. (2017) discussed goals and strategies for IoT design and formation, which aid in Food Supply Chain planning, management, and control. An IoT paradigm embedded simulation gaming tool was also proposed and elucidated, reflecting the pros and cons of the 'physical food ecosystems' direct integration into a computerized environment virtually. Cui (2018) proposed cold chain traceability system architecture by conducting systematic research in supply chain characteristics for IoT and its role in innovation. Competences needed to improve supply chain resilience are reinforced with the decision-making model. In this system, the knowledge database in the IoT environment is the key to the firm's contingency management to make necessary improvements. Related staff and links of the supply chain also need to be activated to enhance the supply chain resilience capabilities.

Amandeep et al. (2017) developed a novel design approach for smart farming using IoT and automation to increase productivity. A remote-controlled GPS-based vehicle helps monitor fields to prevent thefts, sensing soil moisture content, sensing soil moisture, spraying composts & insecticides, weeding, etc. Smart warehouse management is also enforced with the sensing of the stored products' temperature and humidity and the detection of missing products in the warehouse. A smart device with interfacing sensors and internet connectivity will monitor operations and control, and Zigbee modules with a micro-controller will execute operations. Zhang et al. (2017) addressed the challenges in the perishable supply chain based on IoT captured real-time data using a conceptual model using two-echelon supply hubs. These hubs, which act as supply chain dominators, react to the real-time data acquired from an IoT-enabled supply chain operational process providing information on public warehousing and logistic services. Lu et al. (2019) studied the multi-tag spot collision evasion in IoT technology for the "connected objects" feature to offer data from processing to sales, tracking each link in a process flow, finding the food source and product flow effectively. Alonso et al. (2019) presented a platform for IoT application, Artificial Intelligence, Edge Computing (EC), and BCT in smart farming environments, using the new global edge computing architecture. It was also developed for real-time monitoring of the cattle and feed grain and to ensure the sustainability and traceability of various production processes (Mor et al., 2019).

Kamble et al. (2019) worked on the food retailing scenario, increasing complexity in pressurizing the retailing firms to incorporate the changing consumer behavior and re-design their marketing strategies. IoT is predicted to control the food product quality, plan waste management of shelf life exceeded items, manage the store, freezer, and other equipment temperatures contributing to reduced energy consumption. Despite IoT's potential in food retails, its adoption is still in its emergent stage. Therefore, various barriers were identified that affect IoT adoption at the retail level in the Indian context. Elavarasi et al. (2019) reduced the fresh fruits spoilage and wastage using IoT, which continuously monitors the produce. Tracking fruit quality throughout the process was done by using contact and non-contact sensors and smart logistics usage. MQ3 sensors were used to detect fruit spoilage and send messages to operators' mobile, and he removes the spoiled produce by using a pick and place robot. Pal and Kant (2018) aimed to improve the distribution efficiency, transportation, and removal of sour products from the supply chain using centralized data collection and analysis techniques in IoT-based mechanisms. This reduced food wastage by analyzing produce characteristics like flavor emissions, color, etc.

Nirenjena et al. (2018) utilized advanced IoT to observe nutritive qualities and nourishment levels in food substances to indicate contamination and degradation in foods throughout the supply chain. A WASPTOME sensor gathers food degradation information, and an alert is sent to manufacturers and consumers by the raspberry pi unit. GPS and temperature sensors are also used in combination with WASPTOME and raspberry pi unit. Wadhwa et al. (2018) proposed architecture to implement enabling information systems from an IoT perspective in virtual supply chains. Matsumoto et al. (2017) developed a simulation-based on the information of IoT on cultivated fields to perform an advanced evaluation of business by considering insufficient stock and crop loss has given an unreliable amount of harvest. Prosanjeet et al. (2016) worked on increasing agricultural production by optimally using resources and continuous monitoring using remote monitoring systems based on IoT protocol. For re-programmability and reduction of expenses, the use of a microcontroller and ESP8266 was proposed. Khattab et al. (2016) presented an IoT-based three-layer architecture for precision agriculture, which collects data needed and relays it to a cloud-based backend for processing and analysis. Front end nodes receive feedback actions based on the analyzed data.

### 3.3. Artificial Intelligence (AI)

AI is a technique that aids in tasks and processes' automation by recreating human-like cognitive abilities (Barnewold and Lottermoser, 2020). For agri-food applications, AI techniques can provide essential contributions to identifying service creation, knowledge models, and decision-making processes. In agriculture, AI has three broad categories: agricultural robotics, crop and soil monitoring & predictive analytics (Gurumurthy and Bharthur, 2019; Lezoche et al., 2020). Moreover, AI-augmented farms can robotically alter crop amounts for supply & demand data, making earth cycles more resilient (Valentini et al., 2019). In the case of fresh produce, AI helps estimate shelf life, reducing guesswork, reducing wastage of food as there are improved planning and inventory management (Payne, 2019). AI has applications in the food industry, like food item segmentation, ensuring stability in FSC, improving food delivery (Abhijit, 2019). Machine learning (ML), deep learning, and neural networks help solve complex problems, and the human level concerning reasoning, speech, and vision is the benchmark for AI (Singh et al., 2020). ML is an AI-based application around the concept that machines should be given data access and allowed to learn by themselves using structured historical information (Barnewold and Lottermoser, 2020; Donatelli and Pisante, 2019; Sharma et al., 2019). Machine learning models can be used for business decision-making by predicting the backorder of products with more flexibility, process clarity, higher accuracy (Islam and Amin 2020), and demand forecasting due to their learning ability and finding data patterns (Tavana, 2016). Automated reasoning, multi-agent systems, semantic web, autonomous systems, natural language understanding, and decision-making are other AI applications.

**Table 2.** Studies on AI

| Reference | Methodology/ Framework | Objective | Outcome |
|---|---|---|---|
| Pathan et al. (2020) | Artificial neural networks (ANN) and fuzzy logic controller | Determines the crop water requirement, grading crop produced, plant disease detection, phenotyping of crops, etc. | Reduction in expenditure, chemical usage, improved soil fertility and increased productivity |
| Anami et al. (2020) | Deep convolutional neural network framework (DCNN) | Automatic cataloging of biotic and abiotic stresses in paddy through field images | The technical viability of the deep learning method was achieved up to 92.89% |
| Mondino and Gonzalez (2019) | Web Decision Support System | Control and diagnosis of pests in apple orchards using three modules | 92 % of problems were identified correctly |
| Boshkoska et al. (2019) | Decision support system (DSS) | Usage of machine learning and ontology technologies and providing directions for knowledge sharing in the agri-food value chain | DSS was executed successfully to evaluate knowledge boundaries |
| Bonaccorsi et al. (2017) | Human Machine Interface (HMI) design associated with Industrial design thinking | Food waste reduction at retail and consumer levels | 100 % accuracy was seen in products with 0.5 kg and more weight |
| Gardas et al. (2019) | Interpretive structural modeling | Identifying the challenges in the Indian food chain to improve supply chain performance | Low national agricultural markets integration and lack of agricultural market infrastructure were identified as the major factors |
| Grainger et al. (2018) | Alternative analytical methods | Drivers of food wastages | The family wastes significantly influences the self-assessed food waste. |
| Griffin et al. (2018) | Machine learning (ML) | Agri. production estimation, resource requirements, and impacts of climate change | Peri-urban zones contain significantly to agriculture production and business concentration, and climate change. |
| Gurumurthy and Bharthur (2019) | - | Summary of AI-based technologies in agriculture | Policies for the usage of these AI tools in Indian agriculture were provided |
| Chyuan, A (2020) | Machine learning, Deep learning, and Neural networks | Usage of AI in smart farming, supplier management, smart retail, and autonomous transportation | Cost and continuous-data management maintenance cost is long-term to the farmers and need a solution. |
| Otogawa et al. (2017) | Decision-making support system | AI usage for optimizing supply chains | Prior running of simulations and real-world execution plans can aid in faster decision making. |
| Abraham et al. (2020) | Machine learning | Monitoring the optimum agricultural production remotely | Proposed the Rivest-Shamir-Adleman digital signature, fake nodes existence and active participation were prevented |
| Mercier et al. (2018) | Neural networks | Predict temperatures in real-time along FSCs | A neural network helps to measure the temperature distribution having an average error under 0.5 K |

| | | | |
|---|---|---|---|
| Tavana et al. (2016) | Artificial Neural Network (ANN) and Adaptive Neuro-Fuzzy Inference System (ANFIS) | Assessing the supplier's performance by ANFIS. | Offered a hybrid ANFIS-ANN model for supplier evaluation that allowed more accessible and faster AI-based supplier evaluation and selection |
| Estelles-Lopez, L et al. (2017) | Machine learning | Automated identification of the best ML for linking data from analytical techniques | Proposed "Meat Reg" application for optimization and validation of the selected analytical platform and ML method |
| Liu et al. (2016) | Grey neural networks (GNN) | Demand prediction after disruption of transportation | Usage of GNN model for feasible, proving demand prediction, inventory management |

Different research focused on AI and frameworks like ANN, DSS, machine learning, etc. are given in Table 2, demonstrating that AI techniques are not in use significantly as there is a lack of awareness and huge costs associated with this technology's help. Many other advantages of AI in the food sector need to be researched, like usage in assessing fruit maturity, involvement in manufacturing, etc.

## 3.4. Robotics

Robotics and autonomous systems (RAS) are presented in the economy depicting low productivity like agri-food (Duckett et al., 2018). The technology aims to reduce and replace intense human efforts and produce significant mini and macro-scale productions. Productivity has seen massive amplification with the usage of robotic technologies. According to Markets and Markets, the agricultural robots' market is estimated to grow from USD 4.6 billion in 2020 to USD 20.3 billion by 2025. The compound annual growth rate (CAGR) rises at 34.5% from 2020 to 2025 (Markets and Markets, 2017). The robots perform various agriculture operations autonomously, ensuring that the adverse climatic and soil conditions have less or no effect on production and better precision (Talaviya et al., 2020). Drones are used in agriculture to monitor crop health, equipment, weed recognition, and disaster control. Also, pesticides and herbicides can be sprayed effectively with drones' aid, and plants can be monitored (Talaviya et al., 2020). These also benefit the supply chain by creating soil maps that aid in damage control (Kirova et al., 2019). Trendov et al. (2019) reported the usage of small robots for replacing high mass tractors. Todorova and Tcacenco (2019) stated unmanned aerial vehicles (UAV) as the agricultural sector's most progressive and prospective trend and elaborated on drone usage's pros and cons. Robinson (2017) reported using autonomous delivery robots, which move at a speed of four miles per hour and have nine cameras and ultrasonic sensors embedded inside them, enabling faster delivery and reducing human interference. Rigorous research is needed in the agri-food as there is much variability, need for sensitive handling.

## 3.5. Blockchain Technology

It is a technological concept evolved from Bitcoin (Dujak and Sajter, 2019). It also finds food security applications, safety, integrity, and waste reduction in the present complex food supply chains, including numerous actors like farmers, shipping companies, wholesalers, retailers, and consumers. Traditional supply chains are highly inefficient and unreliable, where there is a high risk, trust issues, and complexity between buyers and sellers during the value exchange involving massive paper settlement. There is an increment in overall transfer cost, and transactions are fraud vulnerable involving intermediaries, making the cost of operating the supply chain increase, amounting to 2/3rd of the final cost of goods (Kamilaris et al., 2019). Food provenance can be traced with blockchain technology (BCT), which helps create food supply chains with trust (Xiong et al., 2020; Dujak and Sajter, 2019). Blockchain facilitates the digital traceability and authentication of food products throughout the entire supply chain, from suppliers to store shelves and finally to end consumers (Tijan et al., 2019). Blockchain is proving its prominence for hitching transparency and solving the problems in scenarios where some resource distribution involves numerous untrusted actors. It also aids in automatically matching real-time data, avoiding manual checks and duplication, reducing documentation work to a fifth of the time. The origin of goods and the environmental footprint of production can also be harnessed. Traceability tags in BCT can efficiently attain tag source verification, information, and ownership (Liu and Li, 2020).

Kamilaris et al. (2019) represented an example of a digitized supply chain using QR codes, RFID, digital signatures, sensors, etc., supported by blockchain. Every action along the supply chain is recorded in blockchain blocks where the internet/web serves as a connecting bridge. Businesses validate the information in blocks as it passes through the chains forming immutable means to store information, becoming a permanent record (Kamilaris et al., 2019).

**Table 3.** Studies on Blockchain Technology (BCT)

| Reference | Objective | Outcome |
|---|---|---|
| Stranieri et al. (2020) | Assessing efficiency, responsiveness, flexibility, transparency, and food quality | There is a positive impact on profit, extrinsic food quality attributes, and improved availability, and info sharing |
| Kumar and Iyengar (2017) | BCT in India rice industry for traceable supply chain, and to combat food fraud. | BCT based on a decentralized system assures product safety and increased efficiency |
| Lucena et al. (2018) | Trace-and-track the quality of grain for the Brazilian exporter's business network. | Blockchain was established using Hyper ledger that leads to 15% added value for GM-free soy |
| Motta et al. (2020) | Blockchain frameworks usage, tokens utilization, and realization implementation | Immutability, trust, and redundancy were three significant characteristics of BCT identified by concluding six companies |
| Xiong et al. (2020) | BCT applications for smart farming, agricultural insurance, agricultural product transaction | Improper info sharing, cost-effectiveness, and lack of BCT integration with existing legacy systems are the main limitations |
| Kamath (2018) | Demonstration of 'complete end-to-end traceability'. | Recognized systemic vulnerabilities in the food supply chain and to retrieve people's trust and confidence |
| Shahid et al. (2020) | Maintaining credibility, product quality rating, integrity, and immutability of transactions in the blockchain | Interplanetary File Storage System (IPFS) addressed by smart contracts along with their algorithms |
| Tripoli and Schmidhuber (2018) | Distributed ledger technologies (DLT) applications in agri-food for food security, transparency, and traceability. | DLT embedded cryptography, digital records, transaction disintermediation processing, and data storage makes work easier |
| Caro et al. (2018) | Agri-block (IoT-BCT)-based tool in AFSC for traceability by integrating IoT devices. | Hyperledger Sawtooth was considered better for CPU, latency, and network than Ethereum. |
| Fu et al. (2020) | Agri supply chain and blockchain for assurance and trust mechanism | Two cases from China were analyzed, emphasizing on uncertainty, trading frequency, and asset specificity |
| Mao et al. (2018) | Eliminating asymmetry in information and guarantee fairness in the market | Usage of online double auction mechanism and improved Practical Byzantine Fault Tolerance (iPBFT) algorithm is promoted |
| Dujak and Sajter (2019) | The current and future applications of the BCT are studied | Embedding Zero-knowledge protocols used in BCT within supply chain networks can evolve them to a higher level. |
| Holmberg and Åquist (2019) | Challenges and possibilities of traceability system implementation through BCT for milk packaging | Increased traceability demands of stakeholder and product specific information are easy to achieve by BCT |
| Rogerson and Parry (2020) | BCT as a visibility enabler of reliable data through in food companies | Technology trust, human-error, a scam at the boundaries, and consumer data access were assumed as main challenges |
| Kumar et al. (2020) | BCT concept for information security for better food supply chain | Decentralized and permission-less blockchain system delivers real-time information and food safety |
| Tipmontian et al. (2020) | System dynamics modeling and on BCT implementation | Critical dimensions and their implications for performance improvements were assessed |
| Behnke et al. (2020) | Categorizing the boundary conditions in quality, business, and traceability | For successful BCT usage, organizational measures need to be taken |
| Tse et al. (2017) | BCT application and information security in comparison with the traditional supply systems | The food supply chain's processing and circulation efficiency was improved |
| Tian (2017) | Hazard analysis and critical control points (HACCP), BCT, and IoT in FSC traceability | Supply chain efficiency and transparency was found to be enhanced that ensured food safety and consumer trust |

The usage of blockchain technology and frameworks derived from it in escalating the supply chain's key concerns is signified in Table 3, where authors considered BCT usage for streamlining different issues such as traceability, quality, operations, supply systems, transparency, cost-effectiveness, etc.

### 3.6. Radio Frequency Identification

Radiofrequency detection (RFID) is a pervasive technology with complete food logistics applications and cold chain monitoring, which is vital to producing storage retails and supply chain management. It does not need visual contact and is more accurate, providing real-time data consisting of a tag, reader, and software. (Kumar and Srivastava, 2018). It is also used in resolving food safety and security issues, giving an account of food freshness and the origin of food (Athauda and Karmakar, 2019). Bottani et al. (2017) dealt with the RFID logistics pilot III (RLP3) project that focused on RFID deployment and IT infrastructure development for real-time data management in fresh produce supply. Benefits of the supply chain were assessed with a focus on retail store inventory management and backroom and store area shelf replenishment considering 145 fresh food items categorized under cold dairy cuts. The study provided some insights into the backroom feasibility and shopfloor management systems in fresh food retailing. RFID has potential applications in shrinkage reduction and optimization of shelf inventory levels of products. Mondal et al. (2019) developed an architecture utilizing sensor-based-RFID at the physical film and BCT at the cyber film. RFID delivers unique identification, sensor aids in monitoring real-time quality, and BCT creates digital databases tamper-proof. Detailed security analysis for cyber-attacks investigated the vulnerability of the architecture proposed.

Biswal et al. (2018) studied the effect of the available shrinkage recovery rate and ordering rate on the warehouse costs and investigating the RFID adoption. It is mainly dependent on the cost of deprivation, error severity, and shrinkage recovery rate. Arnaud and Costa (2020) developed Ultra-low-cost RFID-based sensors that sense nodes and loggers to collect data on food production and logistics using IoT. An application-specific integrated circuit (ASIC) was used to enhance semi-active low-frequency sensor transponder reading up to a distance of a few meters. It was fabricated in 0.6μm high voltage- complementary metal oxide semiconductor (HV-CMOS), which reported a portable reader presence up to 5m. Karuppuswami et al. (2019) presented a 'near-field wireless thin-film coated RFID compatible sensor tag' for evaluating the volatility of packed food at room temperature, and the sensor tags having polyaniline, coated as thin-film on the interdigitated capacitor. In the direct-wired structure, conductivity is measured across the film by introducing ammonia gas at different concentrations in an enclosed chamber. An inductor-capacitor resonant tank is formed by soldering an inductor across the interdigitated capacitor in the wireless configuration. The proposed sensor is a highly sensitive sensor detecting ammonia as low as 3 PPM, and it can be easily adapted across the supply chain to monitor packaged food quality. Parada et al. (2019) designed the RFID food management (RFM) system in the IoT network paradigm to bring in healthy eating habits and help in the fight against food wastage. RFM is composed of a multi-platform application to process real-time RFID information.

A web-based application is also developed to allow users about food expiry and other details. Recipes that can be prepared with foods available are also shown along with nutritional information, preventing wastage. This embedded system may economically benefit the manufacturer as it permits superstores to pay for advertising the items. Barge et al. (2019) evaluated composition, food product temperature, and the mutual label-reader orientation role in RFID tag identification performances. Findings show that reading ranges critical food product identification by UHF RFID (Ultra-high frequency RFID) systems can be assessed and improvised for the food composition directly from the design phase. Fan et al. (2019) improved the traceability in the bidirectional transformation of barcode-RFID, an effective traceable resource unit (TRUs). Yiying et al. (2019) developed a food traceability system for a complete life cycle, using RFID, which ensures full supervision from source to consumer. The RFID fault tolerance mechanism confirmed system practicability. This design ensured food safety, especially in perishable foods like meat. A sensor was developed to evaluate the food expiry date, which contains an RFID tag and a conductive polymer. It operates on the principle that the conductivity of polymer changes on exposure to spoiled foods and is detected as an RFID signal by the reader (Honari et al., (2018). Saggin et al. (2019) introduced a flexible UHF-RFID sensor to detect the food quality with an interdigitated capacity in a vegetal biopolymer layer deposited RFID antenna. Experimental measurements validated this study by exposing it to the environment of real food gas in degradation. Yuan et al. (2018) focused on designing and simulating wearable RFID patches to sense food spoilage and read temperature information using near field communication technology supporting devices.

Karuppuswami et al. (2018) developed an antibody-free biosensor to rapidly detect pathogenic bacteria in milk using dextrin capped gold nanoparticles (d-AuNP). These sensors can perceive microbes count as low as 5 log CFU/ml in an hour and is compatible with RFID tag making them useful in the food chain. Chetanraj et al. (2017) described the block diagram and the RFID communication protocol and advantages over WSN. This technology helps detect spoiled food during long-distance transportation leading to losses and rejections by the consumer. Dabbene et al. (2016) studied the challenges and opportunities of adopting RFID for food traceability in food supply chains and its applications in warehouses, retail management, intelligent packaging, cold chain monitoring, logistics, etc. Alfian et al. (2020) proposed machine learning models to detect passive RFID tags' direction to improve the traceability system's efficiency, which is more needed in perishable products. Received signal strength (RSS) and tags timestamp depict input features. Xiao et al. (2017) explored RFID applications in food warehouse management and storage. RFID process simulation model reported increased store management efficiency with RFID application when compared with previous technology. Fathi et al. (2020) emphasized introducing chipless RFID sensors for temperature, humidity, gas, pH, and bio-sensors. Such sensors are used in smart and active packaging for food quality evaluation in the food industry.

Existing economic, electrical, and material challenges of chipless RFID sensor technology were also highlighted, providing future research direction. Li et al. (2017) proposed an effective and efficient platform for tracing pre-packed food supply based on IoT, a service-oriented structure. QR code and RFID tags integrated solution was proposed to reduce implementation cost. Karuppuswami et al. (2020) proposed a battery-less RFID coupled with a digital sensor tag for sensing ammonia in the packaged food. Polyaniline coated capacitive sensor works as a sensing element with a higher affinity for ammonia.

Among the two methods, direct probing was found as more stable as it can detect a minimum of ammonia of 3 ppm with 30 min response time and 60 min recovery time. Zhang et al. (2020) focused on the whole dairy tracking system, as there are increased safety and quality concerns in the dairy industry like leather milk and melamine incidents. RFID is the most effective and viable method, and its application needs to be put forth across supply chains shortly. Alfian et al. (2017) recommended an e-pedigree food traceability method to use RFID technology, WSN, for temperature and humidity data collection. This approach was tested on Korea's Kimchi supply chain, and increased customer satisfaction and optimized food distribution were observed. Miao et al. (2018) proposed a rice traceability system for agricultural products and real-time using RFID and WSN. Collected rice growth environment data was transmitted through the CC2530 wireless module. RFID was used to trace rice harvest information, transportation, storage, and engineering aspects of supporting a traceability database for agri-food products. The usage of technologies, in combination with each other, might ameliorate them with increased advantages.

Sobral et al. (2018) enhanced the IoT application performance by integrating RFID with WSNs through Fuzzy Q-Algorithm to improve an anti-collision protocol for RFID and the Fuzzy System-Based Route Classifier. RFID tag's identification performance improvement, lowered packet loss rates, decreased energy consumption by nodes, and improved network load balancing was significantly observed, thus providing better energy efficacy and service quality for IoT applications. Desai et al. (2019) developed an architecture where blockchain technology as value-added services was integrated into an IoT-based product tracing & tracking solution by testing and implementing it on the NIMBLE-B2B platform. With this approach, small & medium enterprises control the data and can be benefitted from flexible scalability and cost. Alfian et al. (2019) proposed using machine learning algorithms to filter false positives generated by RFID. These models also helped in successfully classifying RFID outcomes with high precision and assimilating for detecting the outlier.

## 4. Sustainable Agri-Food Industry and Digital Technologies

Agricultural sustainability can be supported by the digital marketplace, which can act as a platform for financial technology (FinTech), which aid in innovating crowdfunding and payment systems in a broader agriculture ecosystem that promotes empowerment, transparency, and resourcefulness (Anshari et al., 2019). Precision agriculture, which uses digital technologies, has environmental benefits of addressing climate change, improving resource efficiency, and toxin reduction (Claap et al., 2020). Blockchain forms sustainable supply chain networks that are economical as these reduce transaction costs, business waste, and time utilized by decreasing the number of tiers in the chain and reducing human errors (Ward 2017). Environmental supply chain sustainability is ensured by reducing resource consumption and greenhouse emissions by reducing rework and recall practices by identifying substandard products (Saberi et al., 2019). It makes information stable and immutable, ensures food safety, and provides adequate information infrastructure to manage all humanitarian eventualities at the field level, which aids in building a socially sustainable supply chain (Rejeb et al., 2020). Concerning the three sustainability dimensions, blockchain and mobile technology seem to have the highest economic impact. The sensors and actuators, followed by AI, big data analytics, and cloud technology, have the highest impact on the environmental sustainability dimension. In contrast, cloud technology and big data analytics seem to impact the social sustainability dimension (Bai et al., 2020).

## 5. Conclusions

Food safety, security, traceability concerns in the agri-food need to be predicted and prevented rather than reacting and responding as people are more concerned about health nowadays. Digitization remains a perfect way out for all these issues with reducing human interference and provides food monitoring along the supply chain, which is highly impossible for humans. Thus, there is a need for science-based decision-making and advanced technology usage, which helps supply chains, especially food, safer and more secure, with better traceability and accountability. Digital technologies help to develop efficient agri-food supply chains in varied ways, i.e., RFID can sense the food environment; big data can help analyze vast info in a fraction of seconds; IoT is a combination of different technologies; robots can automate work. Robots can reduce human interference; AI can think independently and act accordingly. The usage and generalization of such high-end technologies are needed in the agri-food sector. Thus, there seems to be a vast scope of research in the area, such as:

a) The cost associated with data acquisition remains significantly high in data-driven agriculture, acting as a barrier for IoT and AI usage in agriculture. This indicates there is a need for innovation in inexpensive sensing technologies.
b) Cybersecurity is the main concerning IoT issue, and data security breaches in big data could be incurable to businesses.
c) BCT application to the full extent of food supply chain management needs to be done to remove significant barriers.
d) A combination of one or more technologies would be more promising, providing a featured supply chain that complies with all food needs.
e) Integrating technologies like blockchain with IoT can complement the usage by providing a reliable and traceable service.
f) There are also difficulties associated with bringing all stakeholders on board and a lack of regulations in implementation.

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# 农业食品4.0与创新：改进供应链运作

**關鍵詞**
数字技术 农业食品行业
革新性 人工智能（AI）
物联网（IoT）

**摘要**
尽管面临诸多挑战，例如食品安全与保障，需求与供应缺口，产品质量，可追溯性等，但农业食品部门仍为全球经济和社会进步做出了巨大贡献。改善了数据准确性。农业食品供应链（AFSC）的数字化转型引领的创新是“农业食品4.0”的主要目标。通过减少食品浪费，实时产品监控，减少可扩展性问题等，这在农业食品领域带来了重大变革。本文对数字技术（如互联网，物，人工智能，大数据，RFID，机器人技术，区块链技术等。AFSC从“农场到餐桌”的这些技术的使用强调了对来自不同来源的159篇文章的评论。本文还着重介绍了数字化在发展智能，明智和可持续的农业食品供应链系统中的作用。