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Leveraging disruptive technologies for food security: A systematic review on agricultural supply chain resilience to climate change

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A R T I C L E I N F O

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A B S T R A C T

Climate change and global warming are increasingly recognized as major threats to agriculture and food security worldwide. It is a major problem for supply chains and food safety. Digital agricultural transformation and primarily disruptive technologies are among the primary solutions to overcome these challenges to ensure food sustainability. This research fills the gap in studies that focuses exclusively on analyzing disruptive technologies in the agricultural sector. The primary purpose of this research is to offer findings from the literature on the application of disruptive technologies to support food security and the protection of agricultural supply chains. Therefore, a systematic literature review was conducted to review the use of disruptive technologies in agricultural supply chains to address the challenges presented by climate change. A total of 65 selected papers were coded and analyzed according to technology type, country, commodity, and challenges faced. This review primarily seeks to provide answers to the following research questions: what disruptive technologies are being used in the agricultural sector in response to climate change and disasters? And what is the role of disruptive technologies in maintaining resilience in the agricultural sector in the context of climate change and disasters? We provide a comprehensive analysis that offers a broad and comprehensive overview of many important issues regarding the use of disruptive technologies in agricultural supply chains. This technology helps farmers make better decisions, enables effective and efficient resource management, and increases productivity.

1. Introduction

Climate change and global warming pose increasing threats to the global agriculture and food security. Rising temperatures intensify disasters such as droughts, floods, and storms, which disrupt food supply chains and heighten food insecurity (Ballester et al., 2023; Favas et al., 2024; Nelson et al., 2016; Vermeulen et al., 2012). In 2023, the Emergency Events Database (EM-DAT) recorded 399 natural disasters, resulting in 86,473 deaths, impacting 93.1 million people and causing economic losses of US$202.7 billion, slightly above the 2003–2022 average of US$196.3 billion (Ballester et al., 2023; Gomez-Zavaglia et al., 2020). The effects of climate change on agriculture are myriad. Changing seasons complicate planting and harvesting calendars, encourage pest cycles, and interfere with crop yields (Ballester et al., 2023; Gomez-Zavaglia et al., 2020). Changing precipitation patterns lead to water scarcity, especially in developing areas that depend on rain-fed agriculture (Umetsu and Miura, 2023). These impacts greatly endanger food system resilience and require immediate adaptation measures (see Fig. 5).

Subsequently, disruptive technologies have become default devices

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for sustaining agriculture's productivity. Technologies such as artificial intelligence (AI), robots, the Internet of Things (IoT), drones, blockchain, and Agriculture 4.0 are reshaping agricultural processes (Ahmad and Afzal, 2020; Cao et al., 2020; Chandio et al., 2024; Kazancoglu et al., 2023). Such technologies enable precise monitoring of crop, soil, and weather conditions and facilitate effective decision-making for enhancing yields and optimising resources (Chandio et al., 2024; Ghasemian et al., 2022). Additionally, predictive analysis facilitates early risk detection, which leads to greater productivity and sustainability (Jararweh et al., 2023; Lioutas and Charatsari, 2021).

In spite of increasing interest, significant gaps in knowledge exist with regard to disruptive technologies' specific effects on agri-supply chains. Individual technologies, such as precision agriculture and blockchain, have been explored in studies, but comprehensive research synthesizing these technologies with end-to-end supply chain resilience in the context of climate stress is lacking. Furthermore, most of the earlier literature is descriptive, not critically evaluative, constraining more in-depth analysis of systemic effects and challenges of adoption. To address these gaps, this research question investigates two research questions: (1) What disruptive technologies are currently used in agriculture to mitigate climate change and disasters? (2) How do the technologies contribute to the agricultural supply chain resilience? By conducting a systematic literature review (SLR) of empirical studies, this article seeks to penetrate beyond surface descriptions, offering an organized and critical synthesis of technology application in agricultural supply chains. This research makes a contribution by collating and critically analyzing existing knowledge, giving researchers and practitioners a better integrated sense of how disruptive technologies create robust food systems. Through examination of publication trends, geographic distributions, technology typologies, and supply chain impacts, the research provides actionable insights and outlines areas that require additional research. Altogether, the findings in this research aim to inform policy-making and practical innovation that supports agricultural adaptation to increased climate risk.

The following section presents a comprehensive literature analysis based on the findings of the selected studies. Finally, the paper outlines the study's contributions, implications, and limitations.

2. Literature background

2.1. Resilience and disruptive technologies in agriculture

In the context of agriculture, resilience encompasses the ability of various elements, from individuals to societies, to prevent, anticipate, absorb, adapt, and positively transform in response to the risks they face. This requires efficient and effective implementation to ensure that essential functions are maintained without compromising long-term goals such as sustainable development, peace, security, the fulfilment of human rights, and overall well-being (United Nations, 2017). Furthermore, resilience is often defined through two main approaches, depending on the context: first, as the continuity of existing functions, and second, as the continued achievement of desired goals, either by resisting shocks or by adapting to overcome challenges (FAO, 2023).

Resilience in food systems, specifically, extends beyond mere resistance to shocks (The Global Panel, 2025). emphasizes that resilient food systems are those capable of adapting and continuing to function during periods of stress and disruption. This involves three key capacities: the ability to withstand shocks, to recover effectively after disturbances, and to proactively reorient in anticipation of changing conditions.

Importantly, resilience is not a static trait but a dynamic process. It reflects the inherent complexity of sustainable food systems and their exposure to a wide range of environmental, economic, and social challenges. Building resilience therefore requires not only technological innovation but also adaptive governance and institutional arrangements that are responsive to change and inclusive of diverse stakeholders (Newman et al., 2023).

Disruptive technologies have emerged as key enablers in this regard. These technologies—such as blockchain, artificial intelligence (AI), big data analytics, and the Internet of Things (IoT)—have the potential to fundamentally reshape agricultural practices. Beyond improving productivity, they enhance transparency, support data-driven decision-making, and enable real-time responses to emerging challenges.

Their relevance is particularly pronounced in the face of climate change. Technologies associated with climate-smart agriculture (CSA) help to sustainably increase productivity while simultaneously strengthening resilience to extreme weather events and other climate-related risks (Balcha et al., 2023; Kifle et al., 2022; Quarshie et al., 2023; Sardar et al., 2020). Likewise, precision agriculture—leveraging sensors, drones, and climate data—allows farmers to optimize resource use, protect crops, and make timely, informed decisions (Lubag et al., 2023; Walter et al., 2017; Yadav et al., 2022). These innovations not only improve efficiency but also help agricultural systems adapt to growing uncertainties, such as shifting weather patterns and evolving pest and disease pressures (Bukchin and Kerret, 2018).

Furthermore, disruptive technologies can support broader sustainability goals. For example, those enabling circular economy practices in agribusiness—through improved traceability, resource management, and waste reduction—contribute to more resilient and environmentally sound food systems (Manganda et al., 2024).

2.2. Agricultural supply chain and climate change

The agri-supply chain is the set of processes and activities associated with agriculture's production, processing, distribution, and use. As climate change puts tremendous strain on agriculture, knowing the agricultural supply chain is imperative to improve productivity, food security, and farm productivity.

Climate change influences many parts of the food supply chain. On the agroecological level, for instance, climate change through weather, temperature, and precipitation alters crop yields and agricultural techniques. Higher temperatures can strain crops. Rainfall variability can result in drought or flood, which degrades yields (Baig et al., 2021; Guo, 2023). Moreover, climate change can also influence pests and disease growth, affecting their levels to produce more infestations and poorer crops (Kaur, 2021; Reardon and Zilberman, 2018).

In the processing and storage process of food products, heat and moisture can change the microbial safety of the food products, leading to a higher possibility of contamination in the processing process (Feliciano et al., 2020). In the dairy industry, for instance, there might be more significant food safety risks because of climate-induced changes in microbial populations (van der Spiegel et al., 2012), and when it comes to storage, more humidity and fluctuation of temperature cause spoilage and waste (Matlala et al., 2024). For instance, fresh foods like fruits and vegetables must be stored at specialized locations so they will not rot, and climate change could make this more challenging to meet, making the supply chain lose more (Kaur, 2021; Morkūnas et al., 2022). Moreover, climate change further complicates agriculture transportation as floods, storms, and heatwaves can alter logistics and supply chains in ways that prolong the process and raise costs (Er Kara et al., 2021; Guo, 2023). Furthermore, climate change can also affect the transportation system and should be modified to deliver crops safely and efficiently (Guo, 2023).

Climate change affects agricultural production distribution as it affects market structure and consumption patterns. Supply chain interruptions from climate change could cause food shortages and make distribution operations more challenging (Guo, 2023; Oriekhoe et al., 2024). At the consumer level, climate change may influence the supply and quality of foodstuffs and produce more food insecurity, especially among the vulnerable (Baig et al., 2021; Oriekhoe et al., 2024).

3. Methodology

We conducted a systematic literature review (SLR) based on the rules proposed by Tranfield et al. (2003). SLR is used to review the existing literature on disruptive technologies in agricultural supply chains. It was split into three parts: (1) planning the review, (2) conducting the review, and (3) reporting the findings and disseminating knowledge.

SLR has a clear review process that follows a defined set of guidelines like research questions, databases, inclusion and exclusion criteria, and literature review. Such a systematic procedure makes the review transparent and repeatable (Pati and Lorusso, 2018; Saleh et al., 2023) and differs from older reviews, which are often personal and narrative in nature. The main advantage of SLR is that bias in choosing and interpreting studies is reduced. Underwritten criteria and protocols, the researcher can rest assured that the results are based on a rigorous and critical literature evaluation (Pati and Lorusso, 2018; Saleh et al., 2023). This method has been used extensively such as in business and management, and agriculture (Harsanto et al., 2023; Harsanto and Permana, 2019; Kaman et al., 2024; Rini et al., 2024).

3.1. Planning the review

In the first phase, we set the main study goal of exploring how disruptive technologies could be applied to agricultural supply chains in the face of climate change and disasters. Therefore, all journal articles about disruptive technologies within the agricultural supply chain were to be published as part of the SLR. Research that did not discuss disruptive technologies in the agricultural supply chain was excluded from the review and omitted. The following paragraph explains how this was done in the series of earlier studies.

3.2. Conducting the review

These data were pulled from the Web of Science (WoS) database. WoS enables cross-disciplinary research because the database encompasses so many areas. This is especially important for researchers who want to combine information from different fields since it allows them to make interdisciplinary comparisons (Birkle et al., 2020). Bringing in different voices makes the research more interesting and leads to new solutions to complicated problems. WoS has a strict selection of journals to ensure high-quality and relevant articles. WoS has the reputation of being selective in terms of which journals it accepts, and it is not just any publications. This attention to quality is key for SLRs because it increases the confidence of the conclusions derived from the review literature (Birkle et al., 2020). The database is vast and a helpful tool for any researcher. With the focus on credible sources in the database, flawed studies were excluded. For this paper, we wanted to know as much as possible about disruptive technologies in food supply chains under the influence of climate change and natural disasters.

Hence, we tried to list and include all publications that might be relevant. Two researchers worked together to establish a keyword pool and find search terms to ensure that data were pertinent and consistent between journal articles. Literature searches on several keywords in September 2024. The search phrases were more motivated by the primary goal of research and were two groups of strings. The first group “Agriculture” OR “Food” OR “Agri-food” OR “Farming” OR “Agribusiness” to broadly cover the agricultural sector; second category “Supply Chain” OR “Logistics” to accurately capture research on supply chain (Harsanto et al., 2024), from production through processing, distribution, and consumption phases in agriculture; Third group “Climate Change” OR “Disaster” OR “Global Warming” to ensure environmental context; and the fourth category was “Digital” OR “AI” OR “Machine Learning” OR “Smart Agriculture” to seize technology innovations. Boolean operators were applied to titles, abstracts, and keywords to achieve the highest number of retrievals of relevant literature. This approach was used to find sources that align with the research objectives of this study.

Adding words like “supply chain” and “logistics” in the search string was done on purpose and fit with our study goal, which was to investigate how disruptive technologies can help make the agricultural supply chain more resistant to climate change. This method might restrict more general studies of digital agriculture, but it makes sure that the chosen articles are directly related to agriculture’s logistics, processing, or distribution systems. The objective of this research is to gain insight about the utilization of technology in agriculture sector, then articles that we considered were only if they: (1) used a new or disruptive digital technology in farming, (2) were directly related to agricultural supply lines (like production, logistics, or distribution), and (3) talked about natural disasters or climate change. To keep things focused, studies that only looked at climate-smart farming or digital tools at the farm level without looking at how they connect to the supply chain were left out.

Data were identified based on several criteria, namely (All Fields) and Article (Document Types) and Science Citation Index Expanded (SCI-EXPANDED) or Social Sciences Citation Index (SSCI) (Web of Science Index) and English (Languages). Regarding the scope of the study, no specific fields were identified at the beginning, and only publications in English were included. This study only included full-text journal articles with SCI-EXPANDED or SSCI index. As illustrated in Table 1, the preliminary search yielded 236 journal articles in the Web of Science database. Two researchers undertook a detailed review of the remaining publications. To confirm the conceptual relevance of the collected articles, the publications were filtered based on their content, as indicated by their titles and abstracts. In addition, only empirical research articles were included in the study, so review articles were not included. The number of publications identified as eligible after the first screening round was 70.

After a thorough review, 65 journal articles were deemed relevant to the research objectives and were retained for final analysis. These articles were selected for further descriptive analysis. The papers selected for content analysis should provide information on disruptive technologies used to support agricultural supply chains facing challenges of climate change and natural disasters.

3.3. Reporting of findings and knowledge dissemination

Each paper was analysed according to the number of articles published annually, the journal in which the article was published, the type of technology used, the country where the study was conducted, the commodity in question, and the challenges faced. The following section presents a detailed discussion of the literature content in a narrative format, highlighting key areas of exploration in the topic.

4. Findings

This section presents an analysis of the distribution of publication years, leading journals where the publications were published, disruptive technologies used, countries where the research was conducted, agricultural commodities, and challenges faced due to the impacts of climate change.

4.1. Publication by year

The initial step involved analysing the number of journal articles published across various periods to identify trends in research interest. Fig. 1 presents the annual publication. The study of disruptive agricultural technologies related to climate change commenced in 2015 and gradually progressed until 2018. As depicted in Fig. 1, the number of published papers has generally increased since 2019, though a stagnation period is noted between 2020 and 2022. However, from 2023 onward, there has been a remarkable surge in research on disruptive technologies in agriculture, with 18 articles published by mid-2024. Among the 65 papers analysed, 61 were published between 2019 and

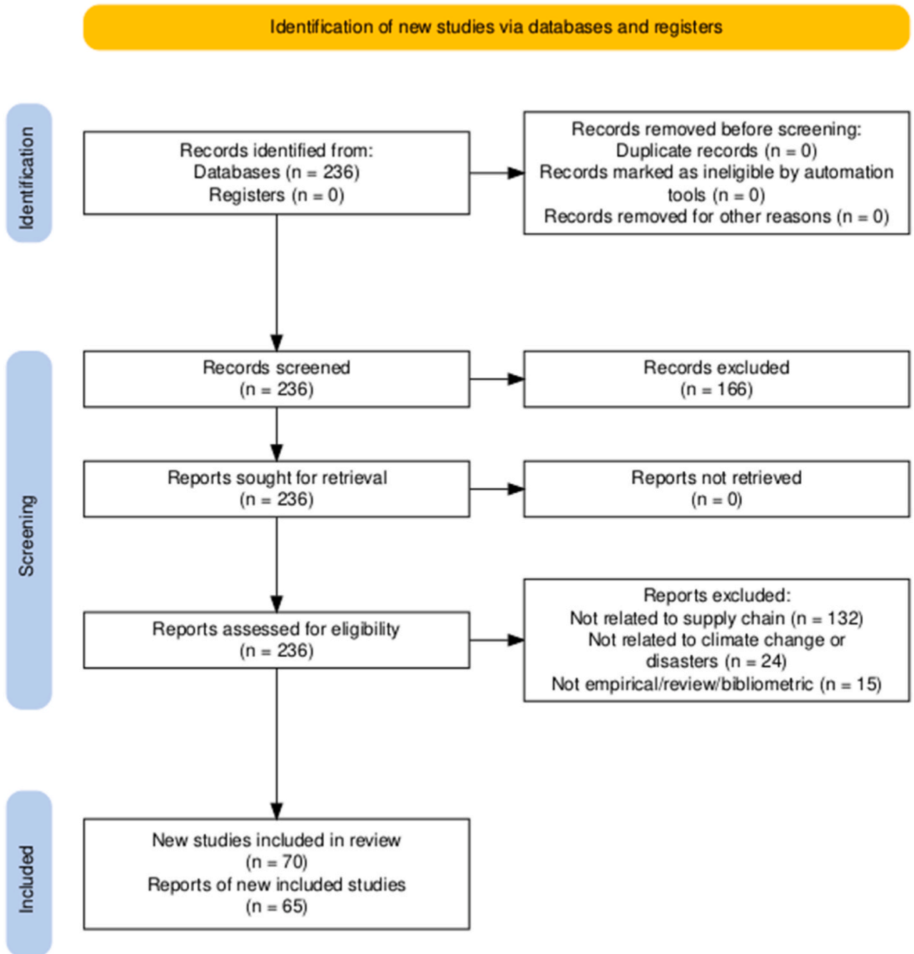
Table 1
Type of technologies.

Technology	Definition	Qty	Ref
Big Data	The massive volume of data generated from various agricultural operations (e.g., weather data, soil sensors, equipment usage) that can be analysed for insights to improve farming decisions.	12	(Effah et al., 2024; Fang and Zhang, 2021; Flores and Villalobos, 2020; Kazancoglu et al., 2023; Romeiko et al., 2020; Serazetdinova et al., 2019; Sharma et al., 2023; Singh et al., 2014; Sonar et al., 2024; Tabe-Ojong et al., 2024; S. Wang et al., 2024; Zhu et al., 2024)
AI and Machine Learning	The use of algorithms that allow machines to learn from agricultural data and make predictions or automate decisions without being explicitly programmed.	26	(Almoujahed et al., 2022; Bagnulo et al., 2024; Bouzembrak and Marvin, 2019; Cao et al., 2020; Effah et al., 2024; El Hathat et al., 2023; Etherton et al., 2024; Flores and Villalobos, 2020; Ghasemian et al., 2022; Jamil et al., 2023; Jiabul Hoque et al., 2024; Joshi et al., 2023; Joshi et al., 2023b; Lioutas and Charatsari, 2021; Mengi et al., 2024; Newman et al., 2023; Nikkhah et al., 2024; Qu et al., 2024; Serazetdinova et al., 2019; Sharma et al., 2023; Sharma and Khanal, 2024; Sonar et al., 2024; Sudha, 2023; Wang et al., 2022; S. Wang et al., 2024)
Robotics and automation	The application of automated machines (robots) to perform agricultural tasks traditionally done by humans.	6	(Almoujahed et al., 2022; Effah et al., 2024; Jararweh et al., 2023; S. Joshi et al., 2023b; Oruma et al., 2021; Thakur et al., 2023)
Genetics	The use of biotechnology and genomics to enhance desirable traits in crops and livestock, such as drought resistance or higher yield.	6	(Chandio et al., 2024; Jararweh et al., 2023; Makate et al., 2019; Njogu et al., 2024; Waaswa et al., 2024; Wilkus et al., 2022)
Sensors	Devices that detect and measure physical properties such as soil moisture, temperature, nutrient levels, and plant health indicators.	15	(Almoujahed et al., 2022; Bagnulo et al., 2024; Cao et al., 2020; Effah et al., 2024; Hajimirzajan et al., 2021; Jamil et al., 2023; S. Joshi et al., 2023b; Nasser et al., 2020; Oguz et al., 2024; Oruma et al., 2021; Serazetdinova et al., 2019; Sharma et al., 2022; Sonar et al., 2024; Sudha, 2023; Wang et al., 2024)
Controlled Environment Agriculture (CEA)	A technology-based approach to food production that controls environmental variables (temperature, humidity, light) to optimize plant growth.	2	(Mengi et al., 2024; Stanghellini and Katzin, 2024)
Unmanned Aerial Vehicle (UAV) and remote sensing (satellite imagery)	The use of drones (Unmanned Aerial Vehicles) and satellite imagery to capture detailed images and data from agricultural fields.	9	(Cao et al., 2020; Chuang and Shiu, 2016; Effah et al., 2024; Hajimirzajan et al., 2021; Joshi et al., 2023; Nasser et al., 2020; Obi and Maya, 2021; Oruma et al., 2021; Qu et al., 2024)
Precision agriculture	A farming management concept that uses information technology and various data sources to ensure crops and soil receive exactly what they need for optimal health and productivity.	26	(Almoujahed et al., 2022; Ardenti et al., 2024; Balcha et al., 2023; Cao et al., 2020; Chandio et al., 2024; Chuang and Shiu, 2016; Effah et al., 2024; Erol et al., 2021; Etherton et al., 2024; Fang and Zhang, 2021; Flores and Villalobos, 2020; Ghandar et al., 2021; Hajimirzajan et al., 2021; Jamil et al., 2021; Jamil et al., 2023; Javed et al., 2021; Joshi et al., 2023; Joshi et al., 2023b; Kifle et al., 2022; Lioutas and Charatsari, 2021; Mango et al., 2018; Mengi et al., 2024; Nasser et al., 2020; Njogu et al., 2024; Nyong et al., 2020; Obi and Maya, 2021; Oguz et al., 2024; Oruma et al., 2021; Sharma et al., 2022; Sonar et al., 2024; Sudha, 2023; Veerakachen and Raksapatcharawong, 2020; Waaswa et al., 2024; Wang et al., 2022; Wang et al., 2024; Wilkus et al., 2022)
Cellular agriculture	The production of agricultural products (especially proteins like meat, dairy) from cell cultures rather than from whole plants or animals.	1	Jararweh et al. (2023)
Blockchain	A decentralized digital ledger that records transactions securely and transparently, often used to track food supply chains.	8	(Ahmad and Afzal, 2020; Effah et al., 2024; S. Joshi et al., 2023b; Kazancoglu et al., 2023; Sardar et al., 2020; Sharma et al., 2023; Thakur et al., 2023; Wang et al., 2024)
Geographic Information System (GIS)	GIS is a technology that allows users to store, analyze, and display spatial data. It integrates remote sensing data with other information, such as population data, infrastructure details, and environmental factors, to create maps and insights.	3	(El Hathat et al., 2023; Ghasemian et al., 2022; Sharma and Khanal, 2024)

2024. This indicates a rapid acceleration in research focused on disruptive technologies in agriculture and underscores the growing urgency to address the sector's challenges, particularly in the last five years.

4.2. Publication by journal

To evaluate the extent of the journal's influence on research on disruptive technologies in agricultural supply chains, the journal classification was facilitated by the Bib Excel tool. As the criteria we have applied from the beginning, and the articles analysed are those with SSCI and SCI indices, all articles on disruptive technologies in agricultural supply chains have been published in various top-tier journals.The



Sources: Adapted from (Haddaway et al., 2022; Moher et al., 2009)

Fig. 1. The number of publications collected from the WoS database and selected for the review.
Sources: Adapted from (Haddaway et al., 2022; Moher et al., 2009).

journals that published the most on this topic were the Journal of Cleaner Production, Sustainability, and IEEE Access, which published nine papers (13.8 %). For example, the studies published in these journals (Obi and Maya, 2021; Oruma et al., 2021; Stanghellini and Katzin, 2024). This may indicate the general recognition of research on disruptive technologies in agriculture among leading academic journals and the increasing interest and attention the subject has attracted from researchers in recent years. The category designated "Others" in

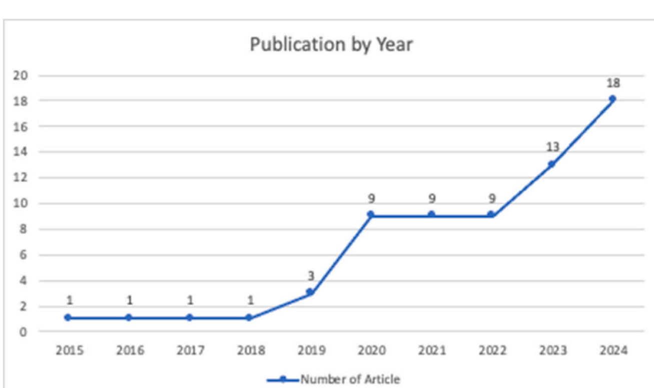


Fig. 2. Publication by year.

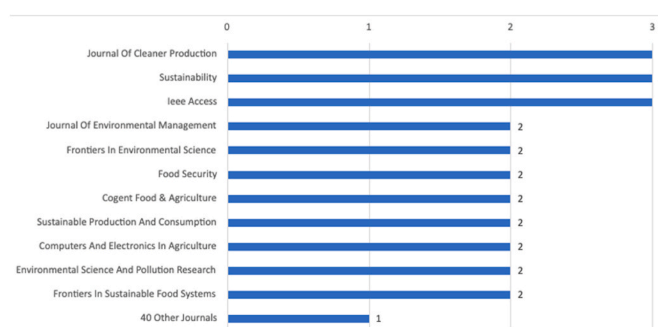


Fig. 3. Publications by journal.

Fig. 3consists of 40 journal titles, with one article published each. In total, papers on this topic were published in 51 journals, representing a variety of academic disciplines, including agriculture, business and management studies, social sciences, and engineering. Fig. 2 indicates that there is no dominant journal source covering the topic (see Fig. 4).

4.3. Type of technologies

A range of technologies have been identified to help address pressing challenges related to climate change, food security, and environmental

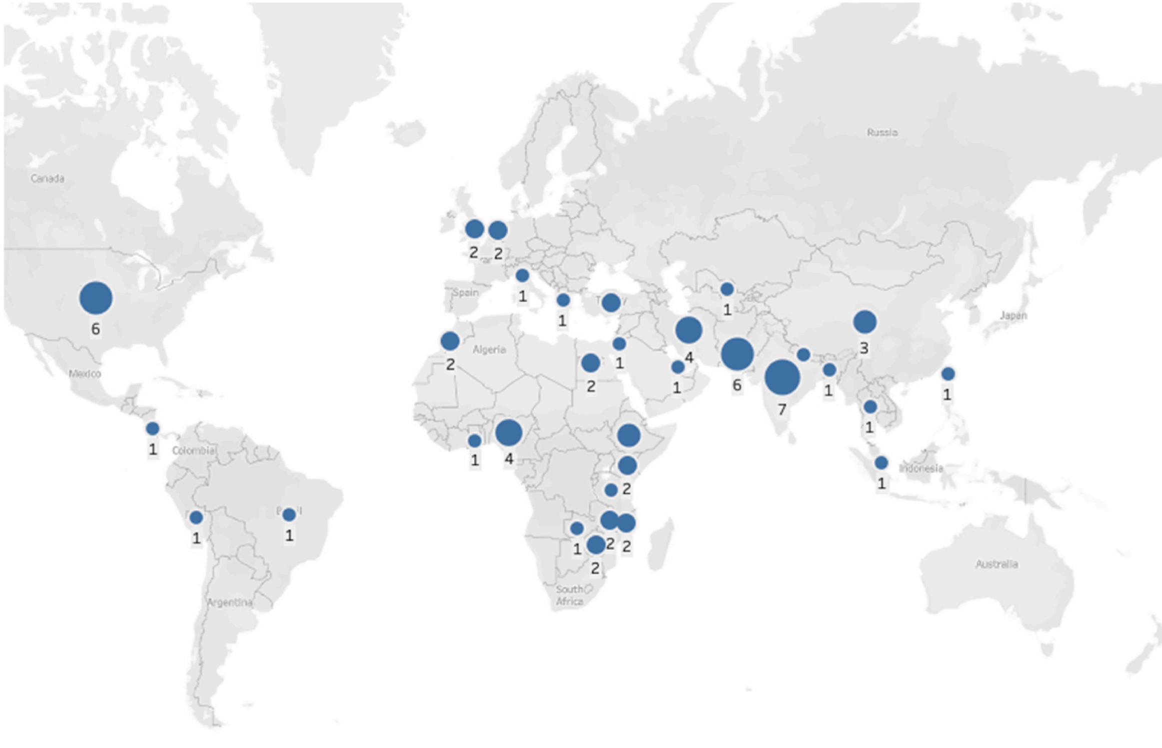


Fig. 4. Publications by country.

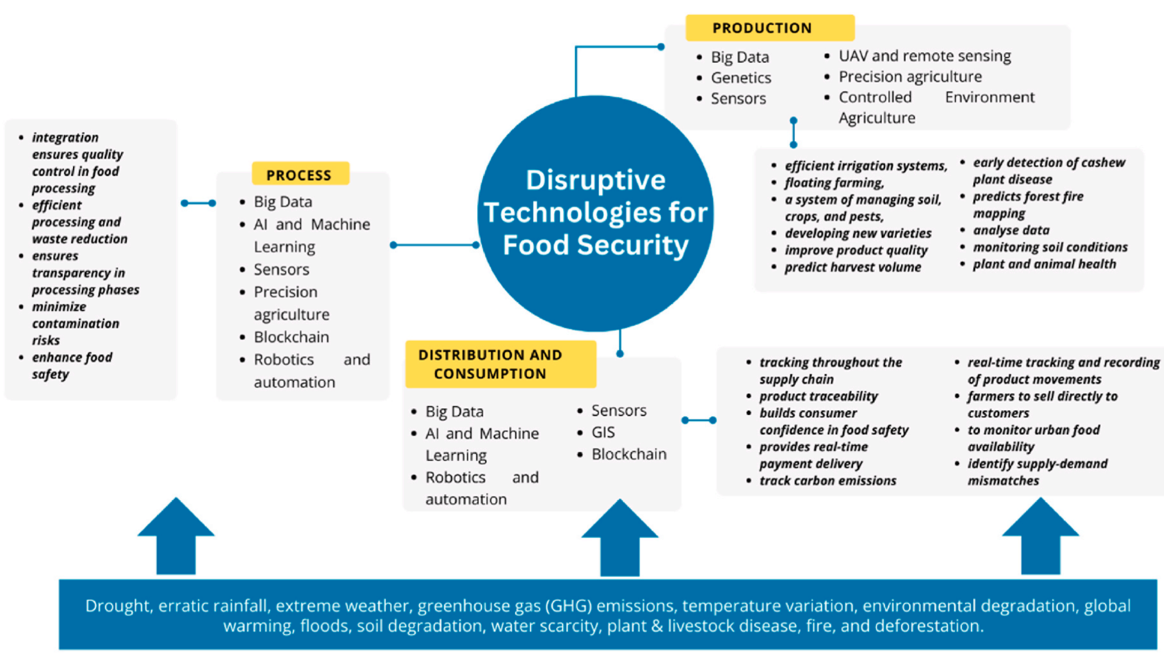


Fig. 5. Disruptive technologies used in agricultural supply chain.

degradation. The categories of these technologies were adapted from [48], and include big data, artificial intelligence (AI) and machine learning, robotics and automation, genetics, sensors, controlled environment agriculture (CEA), unmanned aerial vehicles (UAVs) and remote sensing, precision agriculture, cellular agriculture, blockchain, and Geographic Information Systems (GIS). Based on our analysis, the most commonly adopted technologies are presented in Table 1.

Table 1 outlines a wide range of technologies currently being used in agriculture to address interconnected global challenges, such as climate change, food security, and environmental degradation. These technologies, though diverse in function, complement one another in building more efficient, productive, and sustainable farming systems.

Among the most prominent are precision agriculture and artificial intelligence (AI) and machine learning. Precision agriculture, which leverages geospatial tools and data analytics to deliver tailored treatments—such as water, nutrients, or pesticides—according to the specific needs of crops and soil. This approach helps minimize input waste while maximizing crop performance. It appears in 36 studies.

AI and machine learning, which have become central to data-driven agriculture. These technologies are widely used to support predictive tasks such as crop yield estimation, pest and disease detection, and irrigation planning. By learning from complex datasets, AI systems can assist farmers in making more precise and timely decisions. They feature in 26 studies.

Equally important are sensor technologies, which serve as the foundation for real-time monitoring in agricultural environments. Sensors collect data on critical variables like soil moisture, temperature, and crop health, enabling responsive and adaptive management at the farm level. Sensor technologies are reported in 15 studies.

Blockchain technology supports this ecosystem of data and automation, which plays an increasingly important role in securing the agricultural supply chain. This technology ensures transparency and traceability, helping stakeholders verify the authenticity of products and track the production process from farm to consumer. Blockchain technology appears in 8 studies.

To gather detailed and spatially explicit insights into farmland, many agricultural operations now rely on UAVs and remote sensing. These tools provide high-resolution imagery that can be used for crop monitoring, disease identification, and field mapping—significantly improving the scope and accuracy of farm management. UAV and remote-sensing approaches are cited in 9 studies.

Underlying all of these systems is the role of big data, which encompasses the vast and diverse streams of information generated from agricultural activities. Whether it is weather data, machine performance logs, or sensor feedback, big data provides the analytical backbone for smart farming practices. This wealth of data supports the analytics that make smart farming possible, appearing in 12 studies.

To further enhance productivity in a controlled setting, CEA enables precise regulation of factors such as light, humidity, and temperature. CEA is particularly beneficial in urban or resource-limited environments, supporting year-round cultivation regardless of external conditions. CEA appears only in 2 studies.

Genetic technologies, including biotechnology and genomic tools, also play a strategic role in improving agricultural resilience. These innovations are used to develop crop varieties and livestock breeds with improved yield potential and tolerance to stress conditions such as drought or disease. Genetic approaches are found in 6 studies.

Geographic Information Systems (GIS) further support decision-making by visualizing and analyzing spatial data. They're often combined with remote-sensing tools to guide land-use planning, resource allocation, and risk assessment in agriculture, and appear in 3 studies. Meanwhile, robotics and automation offer labour-saving solutions by handling repetitive, physically demanding tasks—such as harvesting and spraying—with greater precision and consistency; these technologies are covered in 6 studies.

4.4. *Research by country*

The study analyzes the geographic distribution of research. Most studies highlight the global condition (9 research). Developing countries from Asia and Africa dominated the research conducted. From Asia, most of the countries discussed are India (7 research), Pakistan (6 research), and Iran (4 research). From Africa, there was research from Nigeria (4 research), Ethiopia (3 research), and Egypt (2 research). Some of the research also comes from developed countries such as the United States (6 research), China (3 research), the United Kingdom (2 research), and the Netherlands (2 research).

4.5. *The agricultural commodities being studied*

The research also examines the application of disruptive technologies across various agricultural commodities. Most of the research did not mention the specific agricultural commodities (16 articles). Rice and wheat are the most discussed commodities, with 12 articles each. It is followed by maize (9 articles), bean (7 articles), livestock (5 articles), vegetables (4 articles), potato (3 articles), sugar and sugarcane (3 articles), cocoa (2 articles), cotton (2 articles), fruits (2 articles), legume (2 articles), sorghum (2 articles), and tea (2 articles). Other commodities are only mentioned in one article, such as avocado, cassava, coffee, dairy, fishery, pomegranate, and sweet potato.

4.6. *Types of challenges faced*

The study identified several key challenges emerging in the context of disruptive technologies in agriculture, including the impact of climate change, food security, and environmental degradation. The effects of climate change represent a significant challenge for the agricultural sector. The main challenge is drought, which is discussed in 24 articles. Other climate changes discussed are erratic rainfall (11 articles), extreme weather (11 articles), greenhouse gas (GHG) emissions (4 articles), temperature variation (3 articles), environmental degradation (1 article), and global warming (1 article).

Another challenge mainly discussed is floods with 10 articles. Other issues related to environmental challenges are soil degradation (5 articles), water scarcity (4 articles), plant & livestock disease (3 articles), fire (2 articles), and deforestation (1 article). Other issues have also been identified, although they are unrelated to climate change. The issues are food security (7 articles), food supply chain disruptions (5 articles), financial risk (3 articles), resource inefficiency (2 articles), and robotic security (1 article).

5. Discussion

Our review of research on disruptive technology in the agricultural sector shows that this technology is increasingly being used in the agricultural sector. Especially in dealing with climate change, which harms the sustainability of the agricultural sector. This finding shows that disruptive technology is an essential solution in the agricultural sector amidst increasingly severe pressures. The discussion section will thoroughly discuss how technology is used based on the supply chain processes. Based on the analysis conducted, the use of disruptive technology in agriculture is divided into three elements in the agricultural supply chain, namely (1) production, (2) process, and (3) distribution and consumption.

5.1. *Use of disruptive technology in production*

The most used technology, climate-smart technology (CSA), is used in the production elements of the agriculture supply chain. CSA is an intervention and practice designed to address the challenges of climate change in agriculture. Some examples of CSA include efficient irrigation systems (Waaswa et al., 2024), floating farming (Kabir et al., 2022), a system of managing soil, crops (Waaswa et al., 2024), and pests (Jamil et al., 2021), and developing new varieties (Makate et al., 2019; Ndeko et al., 2025).

CSA consists of efficient irrigation systems in irrigation, which is an important solution for farmers facing erratic rainfall (Waaswa et al., 2024). This technology helps South African farmers overcome drought through water management, increasing their household incomes and promoting water conservation (Bojago and Abrham, 2023; Mango et al., 2018). It is also stated (Sardar et al., 2020) that water management techniques, such as bunds, terraces, and drip irrigation, can also improve water efficiency. Floating farming is also a type of CSA that can help overcome flooding. It is a technique of building floating beds on water bodies. In Bangladesh, floating farming has been implemented to cultivate vegetables and herbs such as pumpkin, chili, eggplant, turmeric, tomato, and spinach (Kabir et al., 2022).

In addition to water scarcity, other challenges solved with CSA are soil degradation (Waaswa et al., 2024) and pests (Jamil et al., 2021). Minimal tillage and mulching help to maintain soil fertility and reduce erosion for potato farming in Kenya (Waaswa et al., 2024). Using fertilizer could also help maintain soil quality (Bojago and Abrham, 2023; Mango et al., 2018). As for pest management, integrated pest management could be beneficial so farmers could reduce the use of chemicals (Jamil et al., 2021).

Another type of CSA is developing new varieties, such as drought-tolerant maize and improved legume varieties (Makate et al., 2019; Ndeko et al., 2025). Seed and feed banks can provide these new varieties for farmers to access (Oguz et al., 2024). In agriculture, CSA is used for livestock management and nutrient application (Oguz et al., 2024). Several benefits have been identified when using CSA. CSA can reduce environmental impacts such as greenhouse gas emissions, improve resource efficiency, and improve farmers' ability to adapt to climate change (Oguz et al., 2024).

In Turkey, CSA has been used for sheep farming (Oguz et al., 2024), increasing cattle and goat productivity in Kenya (Njogu et al., 2024), and raising productive cattle from dairy farmer cooperatives in Ethiopia (Balcha et al., 2023). This technology is also used for rice, wheat, potato, soybean, sweet potato, and sorghum plantations in India (Jiabul Hoque et al., 2024), increasing productivity and resilience of maize, sorghum, and pulses in South Africa (Obi and Maya, 2021), increasing cotton yields in Pakistan (Jamil et al., 2021), tomato farming in Italy (Ardenti et al., 2024), increasing wheat and rice yields in Pakistan (Sardar et al., 2020), coffee, cocoa, and tea (Bagnulo et al., 2024), increasing cereal productivity by 37.8 % and pulse productivity by 75.3 % in Malawi and Zimbabwe (Makate et al., 2019), and creating a sustainable cocoa system in Ghana (Nasser et al., 2020).

However, in its implementation, CSA is influenced by socio-economic factors (age, education, access to credit), availability of resources (access to equipment, reliable water sources, superior varieties), awareness and knowledge of CSA, and market access (Kifle et al., 2022). Therefore, stakeholders must facilitate through these factors so farmers can implement CSA for their benefit.

AI, especially machine learning, is another disruptive technology most widely used in production. This technology helps improve product quality (Bagnulo et al., 2024) and harvest volume (Wang et al., 2022b). Some widely implemented machine learning methods include Gradient boosting, intended to develop an early yield prediction system (Jiabul Hoque et al., 2024). Another type of gradient boosting is XGBoost, which offers a stable prediction range (Sudha, 2023). For example, early detection of cashew plant disease in India (Sudha, 2023), prediction of rice yields in Thailand (Veerakachen and Raksapatcharawong, 2020) and pomegranates in Iran (Nikkhah et al., 2024). In the United States, AI predicts forest fire mapping (S. Sharma and Khanal, 2024) and wild blueberry yield estimation (Qu et al., 2024), China also uses this technology to predict winter wheat yields (Cao et al., 2020).

In addition to developing predictions, machine learning methods are used for classification tasks. One of the methods is K-Nearest-Neighbors (KNN) and Random to classify data (Sudha, 2023; Zhang et al., 2020). Convolutional Neural Network (CNN) can detect patterns in image data (Kim et al., 2019). Another option is to use artificial neural networks (ANN) for nonlinear multivariate data relationships, which are useful in image and speech recognition (Kim et al., 2019; Salehi et al., 2023). Decision trees can be used if the data consists of numeric and categorical data (Burdett and Wellen, 2022; Patil and Kulkarni, 2019).

AI is mainly used to analyze data generated from various tools and technologies in its application. Technologies such as drones, sensors, and satellite imagery, such as WorldView-2, collect real-time data (Chuang and Shiu, 2016; Jararweh et al., 2023). One technology is digital twin technology, which visually represents the actual field (Ghandar et al., 2021). An example of digital twins is in hydroponic plants grown in vertical indoor farming to simulate lighting locations to optimize plant energy absorption (Mengi et al., 2024). This lighting placement increases photosynthesis, especially for plant growth in vertical farming, such as lettuce (Stanghellini and Katzin, 2024).

IoT is a technology often used in the agricultural sector. Its main benefits are increasing the efficiency of resource management, reducing waste (Sonar et al., 2024) and helping farmers make better decisions based on available real-time data (Kazancoglu et al., 2023). This technology is closely related to using sensors because it allows data transmission without human intervention, thus providing real-time observations. For example, IoT is used to monitor soil conditions and plant health (Sonar et al., 2024; S. Wang et al., 2024) as well as animal health by collecting data such as temperature, pressure, and humidity (Jararweh et al., 2023). In addition, IoT applications also include autonomous systems such as driverless tractors, drones, and fruit-picking robots designed to address labor shortages. These systems have been implemented for various crops and livest (Lioutas and Charatsari, 2021).

However, it is important to remember that IoT is vulnerable to cyber-attacks. Therefore, farmers should emphasize mutual authentication and ensure secure communication (Jararweh et al., 2023).Previous studies have also demonstrated the application of IoT in the agri-food sector in India (Sonar et al., 2024) and Turkey (Kazancoglu et al., 2023), illustrating the great potential of this technology to support sustainability across geographical contexts.

While the reviewed studies highlight various technical solutions such as CSA, AI, and IoT in enhancing productivity and managing climate risks, only a few explore how these technologies are adopted and sustained by farmers in low-resource settings. Most research emphasizes performance outcomes, but there is limited attention to behavioral, institutional, and cultural factors that influence actual usage on the ground.

5.2. *Use of disruptive technology in processing*

In the processing stage, blockchain and IoT are the major disruptive technologies utilized to increase transparency, traceability and food safety. Blockchain ensures safe information sharing and instant payments, and hence reduces the risk of contamination (Galvez et al., 2018; Sonar et al., 2024). However, most existing studies try to assume ideal infrastructure and neglect potential issues such as system interoperability and the high adoption costs for small-scale processors sector.

IoT with cloud computing supports real-time quality monitoring and control of food, especially perishable ones (S. Wang et al., 2024). Integrated with AI, efficient processing and waste reduction could be achieved in India's agri-food supply chain (A. Joshi et al., 2023). Even as blockchain and IoT offer clear process improvement and food safety, there is not sufficient literature on the inhibitors to mass deployment, suggesting future work with awareness of infrastructure, economic, and security constraints.

5.3. *Use of disruptive technology in distribution & consumption*

In the consumption and distribution stage, blockchain, AI, IoT and digital platforms are the most significant technologies improving transparency, efficiency and food safety in the supply chain (Kazancoglu et al., 2023; Oruma et al., 2021) ensures product traceability, and builds consumer confidence in food safety (Jararweh et al., 2023; Sonar et al., 2024). Blockchain has the potential to facilitate product traceability, real-time payment, and consumer trust, but practical issues such as technical complexity and regulation gaps are not addressed in existing research (Jararweh et al., 2023).

AI is used in the distribution process to track carbon emissions associated with packaging, fuel use, and port logistics, as found in a study in Morocco (El Hathat et al., 2023). In addition, the Internet of Things (IoT) also plays a role in product distribution and consumption. Integrated with cloud computing, IoT enables real-time tracking and recording of product movements, especially for perishable goods, such as food products (Wang et al., 2024). This technology is also applied in the beef supply chain to ensure efficiency and transparency in its distribution (Singh et al., 2014; Zekhnini et al., 2024).

Another disruptive technology that also plays a role in the distribution process is e-commerce. In Nigeria, e-commerce improves food commodity distribution by increasing efficiency, transparency, and farmer profits (Olaghere et al., 2023; Oruma et al., 2021).E-commerce allows farmers to sell directly to customers, avoiding wastage and enabling financial inclusion. However, this study conducted in the Nigerian context also shows many barriers to the entry of e-commerce in Nigeria due to logistical difficulties with perishable products, non-standard measurements, intermediary structures, consumers preferring direct purchases, and farmers having to sell at a large scale.

Another example is e-commerce in Egypt. It also allows farmers to ship directly to end users and minimize food wastage for efficient distribution (Tabe-Ojong et al., 2024). This is how digital platforms and e-commerce are changing distribution through better communication and coordination between parties in the supply chain, logistics, and lower costs. Furthermore, these platforms connect farmers and processors directly to retailers or consumers without intermediaries and cut the supply chain.

In addition to e-commerce, sellers also use social media to sell directly to consumers. In Peru, farmers use social media such as WhatsApp and Facebook to sell seafood directly to consumers (Gonzalez-Pestana et al., 2023). Social media is also used in China to monitor urban food availability and identify supply-demand mismatches (Zhu et al., 2024). Policymakers can intervene through data from social media. In the big picture, while disruptive technologies hold revolutionary potential for distribution and consumption, their real-world application is faced with fundamental issues that require additional context-specific and interdisciplinary investigations.

While the previous sections emphasize the practical benefits of digital technologies for distribution and market access, it is also important to critically examine the broader structural challenges these technologies may reinforce.

Although disruptive technologies such as the Internet of Things (IoT) offer exciting potential to make agriculture more resilient to climate change, their adoption comes with real challenges—especially when it comes to who gets access, and who benefits. Recent research has shown that we need to look beyond the technology itself and consider the broader political and economic systems it operates within (Abdulai et al., 2023; Duncan et al., 2021; Rotz et al., 2019).

Many of these tools—like smart sensors, GPS-guided tractors, and blockchain tracking—depend on things like high-speed internet, 5G networks, and reliable power, which are often only available in urban areas or on large, well-funded farms. This creates major barriers for smallholder farmers in rural regions, who often don't have access to the needed infrastructure or training. Without careful planning, digital agriculture could end up reinforcing the same inequalities it is meant to solve (Abdulai et al., 2023; Rotz et al., 2019b).

It is also important to remember that technology is never neutral. These systems often require a lot of money, technical support, and institutional backing—resources that favor large, commercial farms. Smaller farmers risk being left behind unless policies actively support their participation in this digital shift (Duncan et al., 2021; Rotz et al., 2019a,b).

So, while innovations like IoT can help us build more climate-smart farming systems, we have to be intentional about making them inclusive. That means investing in rural infrastructure, offering digital training, and creating policies that ensure all farmers—not just the well-connected ones—can benefit from these advances (Abdulai et al., 2023; Duncan et al., 2021). In addition, study also highlighted systemic risks and opportunities associated with new technology by mapping possible global food production models by 2050 via horizon scanning (Glaros et al., 2022). Their research emphasizes how crucial long-term planning and proactive governance are to creating just and resilient food systems.

Taken together, while disruptive technologies present promising tools for building climate resilience, their success depends on more than technological performance. Institutional alignment, inclusive access, and socio-cultural fit are essential to ensure that innovation translates into equitable and lasting change. Furthermore, several studies tend to overemphasize the technical efficiency of digital tools while under-exploring the socio-cultural and labor dynamics that shape farmers' capacity to engage with these innovations meaningfully. Future research should explore these dimensions more systematically and critically, particularly in diverse regional and socio-economic contexts.

6. Conclusion dan limitation

In conclusion, disruptive technologies like Climate-Smart Agriculture (CSA) and Artificial Intelligence (AI) are key to building resilience in the agricultural sector, especially as it faces the challenges of climate change. These technologies, when paired with sustainable practices, help farmers maintain productivity and adapt to unpredictable environmental shifts. Our study highlights some of the most commonly used technologies in agriculture, including machine learning, CSA, AI, the Internet of Things (IoT), blockchain, sensors, and drones. These tools are applied across different stages of the agricultural supply chain— from production to processing, distribution, and consumption. They enable farmers to make better decisions based on data, improve how resources are managed, and increase productivity, all of which strengthen the sector's resilience.

The findings from this study also point to several important considerations for future policy and research in the field of digital agriculture and climate resilience. A key focus of government policy is achieving food self-sufficiency, and one of the strategies to support this is by strengthening resilient supply chains. Integrating advanced technologies into these supply chains should be a top priority, as it is essential for ensuring that the agricultural sector can withstand climate change. Policymakers need to focus on expanding digital infrastructure, particularly in rural and underserved areas, so that all farmers can access these technologies. This includes supporting smallholder farmers with subsidies for smart agricultural technologies, improving rural connectivity, and leveraging agricultural extension services to close the digital divide.

Additionally, it is important for public policies to encourage collaboration between stakeholders in the public, private, and academic sectors to ensure the benefits of these technological advances are shared fairly across different farming communities to support transition to sustainable food systems. Offering training programs and financial support will help empower smallholder farmers, enabling them to adopt new technologies and avoid being left behind in the digital shift in agriculture.

Looking forward, future research should explore how these technologies are applied in different regions and countries, providing a broader view of adoption patterns and their socio-economic impact on farmers, particularly those who lack access to capital and technology. It is also crucial for research to focus on developing hybrid models that integrate traditional agricultural knowledge with modern technology, ensuring that innovations are inclusive and culturally sensitive while enhancing climate resilience.

Overall, integrating digital technologies into agriculture is not just about adopting new tools— it is about transforming the sector to be more resilient to climate change and ensuring food security for the future. It will take collaboration among policymakers, researchers, and farmers to make this transition successful and ensure its benefits are felt by all.

This review is not without limitations. Although we used a highly structured and rigorous approach to collect relevant literature, it is possible that this review does not fully cover all published materials related to disruptive technologies in agricultural supply chains. Furthermore, the literature search and collection process are guided by a specific combination of keywords, yet the theoretical conclusions drawn from this review are limited to the selected publications. Future studies also could consider expanding the keyword strategy to include general terms such as "resilience" or "digital agriculture" without supply chain filters. This would help capture more diverse work, particularly from regions like sub-Saharan Africa, which may not use supply chain terminology explicitly but still address digital transformation in agriculture. Among these significant contributions therefore, these conclusions should be validated by future research by surveying other research libraries such as Scopus and Google Scholar. Furthermore, these sources provide limited information on specific applications of disruptive technologies in different countries and for particular commodities. While these sources offer valuable insights into general trends and potential applications, further research is needed to understand how these technologies are applied in the field.

CRediT authorship contribution statement

Budi Harsanto: Conceptualization, Writing – original draft, Writing – review & editing, Supervision, Funding acquisition. **Yulistyne Kasumaningrum:** Conceptualization, Formal analysis, Writing – original draft, Writing – review & editing. **M. Rifqi Arviansyah:** Formal analysis, Writing – original draft, Visualization. **Adiatma YM. Siregar:** Writing – review & editing, Supervision. **Dwi Purnomo:** Validation, Data curation. **Freddy:** Validation, Data curation. **Yusuf Iskandar:** Methodology, Formal analysis, Writing – original draft, Writing – review & editing. **Iston Dwija Utama:** Methodology, Writing – review & editing. **Dian Inda Sari:** Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Attached in supplementary file

References

Abdulai, A.-R., Gibson, R., Fraser, E.D.G., 2023. Beyond transformations: zooming in on agricultural digitalization and the changing social practices of rural farming in Northern Ghana, West Africa. J. Rural Stud. 100, 103019. https://doi.org/10.1016/j.jrurstud.2023.103019.

Ahmad, D., Afzal, M., 2020. Climate change adaptation impact on cash crop productivity and income in Punjab province of Pakistan. Environ. Sci. Pollut. Control Ser. 27 (24), 30767–30777. https://doi.org/10.1007/s11356-020-09368-x.

Almoujahed, M.B., Rangarajan, A.K., Whetton, R.L., Vincke, D., Eylenbosch, D., Vermeulen, P., Mouazen, A.M., 2022. Detection of fusarium head blight in wheat under field conditions using a hyperspectral camera and machine learning. Comput. Electron. Agric. 203. https://doi.org/10.1016/j.compag.2022.107456.

Ardenti, F., Capra, F., Santelli, S., Lucini, L., Tabaglio, V., Fiorini, A., 2024. Potential of conservation tillage, cover crops, and digestate application as integrated C farming practices for processing tomato. Soil Tillage Res. 244. https://doi.org/10.1016/j.still.2024.106213.

Bagnulo, E., Strocchi, G., Bicchi, C., Liberto, E., 2024. Industrial food quality and consumer choice: artificial intelligence-based tools in the chemistry of sensory notes in comfort foods (coffee, cocoa and tea). In: Trends in Food Science and Technology, vol. 147. Elsevier Ltd. https://doi.org/10.1016/j.tifs.2024.104415.

Baig, I.A., Chandio, A.A., Ozturk, I., Kumar, P., Khan, Z.A., Salam, Md A., 2021. Assessing the long- and short-run asymmetrical effects of climate change on rice production: empirical evidence from India. https://doi.org/10.21203/rs.3.rs-893202/v1.

Balcha, E., Menghistu, H.T., Zenebe, A., Teferi, T., Hadush, B., 2023. Climate-smart agricultural practices: a case of dairy cooperative farmers in Agula and Maychew, Northern Ethiopia. Carbon Manag. 14 (1). https://doi.org/10.1080/17583004.2023.2271880.

Ballester, J., Quijal-Zamorano, M., Méndez Turrubiates, R.F., Pegenaute, F., Herrmann, F.R., Robine, J.M., Basagaña, X., Tonne, C., Antó, J.M., Achebak, H., 2023. 2023 disaster in numbers. In: Nature Medicine, vol. 29. Nature Research. https://doi.org/10.1038/s41591-023-02419-z, 7.

Birkle, C., Pendlebury, D.A., Schnell, J., Adams, J., 2020. Web of Science as a data source for research on scientific and scholarly activity. Quantitative Science Studies 1 (1), 363–376. https://doi.org/10.1162/qss_a_00018.

Bojago, E., Abrham, Y., 2023. Small-scale irrigation (SSI) farming as a climate-smart agriculture (CSA) practice and its influence on livelihood improvement in Offa District, Southern Ethiopia. J. Agric. Food Res. 12, 100534. https://doi.org/10.1016/j.jafr.2023.100534.

Bouzembrak, Y., Marvin, H.J.P., 2019. Impact of drivers of change, including climatic factors, on the occurrence of chemical food safety hazards in fruits and vegetables: a Bayesian Network approach. Food Control 97, 67–76. https://doi.org/10.1016/j.foodcont.2018.10.021.

Bukchin, S., Kerret, D., 2018. Food for hope: the role of personal resources in farmers' adoption of green technology. Sustainability 10 (5), 1615. https://doi.org/10.3390/su10051615.

Burdett, H., Wellen, C., 2022. Statistical and machine learning methods for crop yield prediction in the context of precision agriculture. Precis. Agric. 23 (5), 1553–1574. https://doi.org/10.1007/s11119-022-09897-0.

Cao, J., Zhang, Z., Tao, F., Zhang, L., Luo, Y., Han, J., Li, Z., 2020. Identifying the contributions of multi-source data for winter wheat yield prediction in China. Remote Sens. 12 (5). https://doi.org/10.3390/rs12050750.

Chandio, A.A., Ozdemir, D., Gokmenoglu, K.K., Usman, M., Jiang, Y., 2024. Digital agriculture for sustainable development in China: the promise of computerization. Technol. Soc. 76. https://doi.org/10.1016/j.techsoc.2024.102479.

Chuang, Y.C.M., Shiu, Y.S., 2016. A comparative analysis of machine learning with worldview-2 pan-sharpened imagery for tea crop mapping. Sensors (Switzerland) 16 (5). https://doi.org/10.3390/s16050594.

Duncan, E., Abdulai, A.-R., Fraser, E.D.G., 2021. Modernizing agriculture through digital technologies: prospects and challenges. In: Handbook on the Human Impact of Agriculture. Edward Elgar Publishing. https://doi.org/10.4337/9781839101748.00018.

Effah, D., Bai, C., Asante, W.A., Quayson, M., 2024. The role of artificial intelligence in coping with extreme weather-induced cocoa supply chain risks. IEEE Trans. Eng. Manag. 71, 9854–9875. https://doi.org/10.1109/TEM.2023.3289258.

El Hathat, Z., Sreedharan, V.R., Venkatesh, V.G., Zouadi, T., Arunmozhi, M., Shi, Y., 2023. Modelling and analyzing the GHG emissions in the VUCA world: evidence from tomato production in Morocco. J. Clean. Prod. 382. https://doi.org/10.1016/j.jclepro.2022.134862.

Er Kara, M., Ghadge, A., Bititci, U.S., 2021. Modelling the impact of climate change risk on supply chain performance. Int. J. Prod. Res. 59 (24), 7317–7335. https://doi.org/10.1080/00207543.2020.1849844.

Erol, I., Ar, I.M., Ozdemir, A.I., Peker, I., Asgary, A., Medeni, I.T., Medeni, T., 2021. Assessing the feasibility of blockchain technology in industries: evidence from Turkey. J. Enterprise Inf. Manag. 34 (3), 746–769. https://doi.org/10.1108/JEIM-09-2019-0309.

Etherton, B.A., Choudhury, R.A., Alcalá Briseño, R.I., Mouafo-Tchinda, R.A., Plex Sulá, A.I., Choudhury, M., Adhikari, A., Lei, S.L., Kraisitudomsook, N., Buritica, J.R., Cerbaro, V.A., Ogero, K., Cox, C.M., Walsh, S.P., Andrade-Piedra, J.L., Omondi, B.A., Navarrete, I., McEwan, M.A., Garrett, K.A., 2024. Disaster plant pathology: smart solutions for threats to global plant health from natural and human-driven disasters. In: Phytopathology, 114. American Phytopathological Society, pp. 855–868. https://doi.org/10.1094/PHYTO-03-24-0079-FI, 5.

Fang, D., Zhang, X., 2021. The protective effect of digital financial inclusion on agricultural supply chain during the covid-19 pandemic: evidence from China. Journal of Theoretical and Applied Electronic Commerce Research 16 (7), 3202–3217. https://doi.org/10.3390/JTAER16070174.

FAO, 2023. Guidelines to increase the resilience of agricultural supply chains. In: Guidelines to Increase the Resilience of Agricultural Supply Chains. FAO. https://doi.org/10.4060/cc5481en.

Favas, C., Cresta, C., Whelan, E., Smith, K., Manger, M.S., Chandrasenage, D., Singhkumarwong, A., Kawasaki, J., Moreno, S., Goudet, S., 2024. Exploring food system resilience to the global polycrisis in six Asian countries. Front. Nutr. 11. https://doi.org/10.3389/fnut.2024.1347186.

Feliciano, R.J., Boué, G., Membré, J.-M., 2020. Overview of the potential impacts of climate change on the microbial safety of the dairy industry. Foods 9 (12), 1794. https://doi.org/10.3390/foods9121794.

Flores, H., Villalobos, J.R., 2020. A stochastic planning framework for the discovery of complementary, agricultural systems. Eur. J. Oper. Res. 280 (2), 707–729. https://doi.org/10.1016/j.ejor.2019.07.053.

Galvez, J.F., Mejuto, J.C., Simal-Gandara, J., 2018. Future challenges on the use of blockchain for food traceability analysis. TrAC, Trends Anal. Chem. 107, 222–232. https://doi.org/10.1016/j.trac.2018.08.011.

Ghandar, A., Ahmed, A., Zulfiqar, S., Hua, Z., Hanai, M., Theodoropoulos, G., 2021. A decision support system for urban agriculture using digital twin: a case study with aquaponics. IEEE Access 9, 35691–35708. https://doi.org/10.1109/ACCESS.2021.3061722.

Ghasemian, B., Shahabi, H., Shirzadi, A., Al-Ansari, N., Jaafari, A., Geertsema, M., Melesse, A.M., Singh, S.K., Ahmad, A., 2022. Application of a novel hybrid machine learning algorithm in shallow landslide susceptibility mapping in a mountainous area. Front. Environ. Sci. 10. https://doi.org/10.3389/fenvs.2022.897254.

Glaros, A., Marquis, S., Major, C., Quarshie, P., Ashton, L., Green, A.G., Kc, K.B., Newman, L., Newell, R., Yada, R.Y., Fraser, E.D.G., 2022. Horizon scanning and review of the impact of five food and food production models for the global food system in 2050. Trends Food Sci. Technol. 119, 550–564. https://doi.org/10.1016/j.tifs.2021.11.013.

Gomez-Zavaglia, A., Mejuto, J.C., Simal-Gandara, J., 2020. Mitigation of emerging implications of climate change on food production systems. Food Res. Int. 134, 109256. https://doi.org/10.1016/j.foodres.2020.109256.
Gonzalez-Pestana, A., Thorne, D.C.S., Alfaro-Shigueto, J., Mangel, J.C., 2023. Vulnerabilities of northern Peruvian small-scale fishing communities revealed by the COVID-19 pandemic. Mar. Pol. 149. https://doi.org/10.1016/j.marpol.2023.105503.
Guo, X., 2023. A vicious cycle between agriculture supply chain and climate change. Highlights in Business, Economics and Management 5, 317–323. https://doi.org/10.54097/hbem.v5i.5098.
Haddaway, N.R., Page, M.J., Pritchard, C.C., McGuinness, L.A., 2022. *PRISMA2020* : an R package and Shiny app for producing PRISMA 2020-compliant flow diagrams, with interactivity for optimised digital transparency and Open Synthesis. Campbell Systematic Reviews 18 (2). https://doi.org/10.1002/cl2.1230.
Hajimirzajan, A., Vahdat, M., Sadegheih, A., Shadkam, E., Bilali, H. El, 2021. An integrated strategic framework for large-scale crop planning: sustainable climate-smart crop planning and agri-food supply chain management. Sustain. Prod. Consum. 26, 709–732. https://doi.org/10.1016/j.spc.2020.12.016.
Harsanto, B., Farras, J. I., Firmansyah, E. A., Pradana, M., & Apriliadi, A. (2024). Digital technology 4.0 on halal supply chain: a systematic review. Logistics, 8(1), 21. doi: https://doi.org/10.3390/logistics8010021.
Harsanto, B., Permana, C., 2019. Understanding sustainability-oriented innovation (SOI) using network perspective in Asia pacific and asean: a systematic review. In: Journal of ASEAN Studies, vol. 7. Bina Nusantara University, pp. 1–17. https://doi.org/10.21512/jas.v7i1.5756, 1.
Harsanto, B., Primiana, I., Sarasi, V., Satyakti, Y., 2023. Sustainability innovation in the textile industry: a systematic review. Sustainability 15 (2), 1549. https://doi.org/10.3390/su15021549.
Jamil, I., Jun, W., Mughal, B., Raza, M.H., Imran, M.A., Waheed, A., 2021. Does the adaptation of climate-smart agricultural practices increase farmers' resilience to climate change? Environ. Sci. Pollut. Control Ser. 28 (21), 27238–27249. https://doi.org/10.1007/s11356-021-12425-8.
Jamil, M., Rehman, H., Saqlain Zaheer, M., Tariq, A., Iqbal, R., Hasnain, M.U., Majeed, A., Munir, A., Sabagh, A. El, Habib ur Rahman, M., Raza, A., Ajmal Ali, M., Elshikh, M.S., 2023. The use of Multispectral Radio-Meter (MSR5) data for wheat crop genotypes identification using machine learning models. Sci. Rep. 13 (1). https://doi.org/10.1038/s41598-023-46957-5.
Jararweh, Y., Fatima, S., Jarrah, M., AlZu'bi, S., 2023. Smart and sustainable agriculture: fundamentals, enabling technologies, and future directions. Comput. Electr. Eng. 110. https://doi.org/10.1016/j.compeleceng.2023.108799.
Javed, T., Zhang, J., Bhattarai, N., Sha, Z., Rashid, S., Yun, B., Ahmad, S., Henchiri, M., Kamran, M., 2021. Drought characterization across agricultural regions of China using standardized precipitation and vegetation water supply indices. J. Clean. Prod. 313. https://doi.org/10.1016/j.jclepro.2021.127866.
Jiabul Hoque, M.D., Saiful Islam, M.D., Uddin, J., Abdus Samad, M.D., de Abajo, B.S., Vargas, D.L.R., Ashraf, I., 2024. Incorporating meteorological data and pesticide information to forecast crop yields using machine learning. IEEE Access 12, 47768–47786. https://doi.org/10.1109/ACCESS.2024.3383309.
Joshi, A., Pradhan, B., Chakraborty, S., Behera, M.D., 2023. Winter wheat yield prediction in the conterminous United States using solar-induced chlorophyll fluorescence data and XGBoost and random forest algorithm. Ecol. Inform. 77. https://doi.org/10.1016/j.ecoinf.2023.102194.
Joshi, S., Sharma, M., Ekren, B.Y., Kazancoglu, Y., Luthra, S., Prasad, M., 2023b. Assessing supply chain innovations for building resilient food supply chains: an emerging economy perspective. Sustainability 15 (6). https://doi.org/10.3390/su15064924.
Kabir, K.H., Sarker, S., Uddin, M.N., Leggette, H.R., Schneider, U.A., Darr, D., Knierim, A., 2022. Furthering climate-smart farming with the introduction of floating agriculture in Bangladeshi wetlands: successes and limitations of an innovation transfer. J. Environ. Manag. 323. https://doi.org/10.1016/j.jenvman.2022.116258.
Kaman, G.S., Bozkurt, İ., Bölükbaş, R., Özhasar, Y., Demirci, B., Yazicioğlu, İ., 2024. The strategy food waste in restaurants: a systematic literature review. Trends Food Sci. Technol. 151 (March). https://doi.org/10.1016/j.tifs.2024.104625.
Kaur, H., 2021. Modelling internet of things driven sustainable food security system. Benchmark Int. J. 28 (5), 1740–1760. https://doi.org/10.1108/BIJ-12-2018-0431.
Kazancoglu, Y., Lafci, C., Kumar, A., Luthra, S., Garza-Reyes, J.A., Berberoglu, Y., 2023. The role of agri-food 4.0 in climate-smart farming for controlling climate change-related risks: a business perspective analysis. Bus. Strat. Environ. 33 (4), 2788–2802. https://doi.org/10.1002/bse.3629.
Kifle, T., Ayal, D.Y., Mulugeta, M., 2022. Factors influencing farmers adoption of climate smart agriculture to respond climate variability in Siyadebrina Wayu District, Central highland of Ethiopia. Climate Services 26. https://doi.org/10.1016/j.cliser.2022.100290.
Kim, M., Yun, J., Cho, Y., Shin, K., Jang, R., Bae, H.J., Kim, N., 2019. Deep learning in medical imaging. In: Neurospine, vol. 16. Korean Spinal Neurosurgery Society, pp. 657–668. https://doi.org/10.14245/ns.1938396.198, 4.
Lioutas, E.D., Charatsari, C., 2021. Enhancing the ability of agriculture to cope with major crises or disasters: what the experience of COVID-19 teaches us. Agric. Syst. 187. https://doi.org/10.1016/j.agsy.2020.103023.
Lubag, M., Bonifacio, J., Tan, J.M., Concepcion, R., Mababangloob, G.R., Galang, J.G., Maniquiz-Redillas, M., 2023. Diversified impacts of enabling a technology-intensified agricultural supply chain on the quality of life in hinterland communities. Sustainability 15 (17), 12809. https://doi.org/10.3390/su151712809.
Makate, C., Makate, M., Mango, N., Siziba, S., 2019. Increasing resilience of smallholder farmers to climate change through multiple adoption of proven climate-smart agriculture innovations. Lessons from Southern Africa. J. Environ. Manag. 231, 858–868. https://doi.org/10.1016/j.jenvman.2018.10.069.
Manganda, A.S., Sehnem, S., Lara, A.C., 2024. Transition to the circular economy: innovative and disruptive production technologies adopted by agribusiness startups. Environ. Qual. Manag. 34 (1). https://doi.org/10.1002/tqem.22293.
Mango, N., Makate, C., Tamene, L., Mponela, P., Ndengu, G., 2018. Adoption of small-scale irrigation farming as a climate-smart agriculture practice and its influence on household income in the Chinyanja Triangle, Southern Africa. Land 7 (2). https://doi.org/10.3390/land7020049.
Matlala, N., Bavuma, A., Sipunzi, M., Ralenkoane, B., 2024. Supply chain innovation research trends: a bibliometric network analysis. International Journal of Applied Research in Business and Management 5 (1), 1–11. https://doi.org/10.51137/ijarbm.2024.5.1.1.
Mengi, E., Becker, C.J., Sedky, M., Yu, S.Y., Zohdi, T.I., 2024. A digital-twin and rapid optimization framework for optical design of indoor farming systems. Comput. Mech. 74 (1), 31–43. https://doi.org/10.1007/s00466-023-02421-9.
Moher, D., Liberati, A., Tetzlaff, J., Altman, D.G., Antes, G., Atkins, D., Barbour, V., Barrowman, N., Berlin, J.A., Clark, J., Clarke, M., Cook, D., D'Amico, R., Deeks, J.J., Devereaux, P.J., Dickersin, K., Egger, M., Ernst, E., Gøtzsche, P.C., et al., 2009. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. In: PLoS Medicine, vol. 6. Public Library of Science. https://doi.org/10.1371/journal.pmed.1000097, 7.
Morkūnas, M., Rudienė, E., Ostenda, A., 2022. Can climate-smart agriculture help to assure food security through short supply chains? A systematic bibliometric and bibliographic literature review. Business, Management and Economics Engineering 20 (2), 207–223. https://doi.org/10.3846/bmee.2022.17101.
Nasser, F., Maguire-Rajpaul, V.A., Dumenu, W.K., Wong, G.Y., 2020. Climate-smart cocoa in Ghana: how ecological modernisation discourse risks side-lining cocoa smallholders. Front. Sustain. Food Syst. 4. https://doi.org/10.3389/fsufs.2020.00073.
Ndeko, A.B., Chuma, G.B., Mondo, J.M., Kazamwali, L.M., Civava, R., Bisimwa, E.B., Mushagalusa, G.N., 2025. Farmers' preferred traits, production constraints, and adoption factors of improved maize varieties under South-Kivu rainfed agro-ecologies, eastern D.R. Congo: implications for maize breeding. Int. J. Agric. Sustain. 23 (1). https://doi.org/10.1080/14735903.2025.2464524.
Nelson, M., Zak, K., Davine, T., Pau, S., 2016. Climate change and food systems research: current trends and future directions. Geography Compass 10 (10), 414–428. https://doi.org/10.1111/gec3.12281.
Newman, L., Newell, R., Dring, C., Glaros, A., Fraser, E., Mendly-Zambo, Z., Green, A.G., Kc, K.B., 2023. Agriculture for the Anthropocene: novel applications of technology and the future of food. Food Secur. 15 (3), 613–627. https://doi.org/10.1007/s12571-023-01356-6.
Nikkhah, A., Esmaeilpour, M., Kosari-Moghaddam, A., Rohani, A., Nikkhah, F., Ghnimi, S., Blackstone, N.T., Van Haute, S., 2024. Machine learning-based life cycle assessment for environmental sustainability optimization of a food supply chain. Integrated Environ. Assess. Manag. https://doi.org/10.1002/ieam.4954.
Njogu, J.W., Karuku, G., Busienei, J., Gathiaka, J.K., 2024. Assessing determinants of scaling up pathways for adopted CSA climate smart agricultural practices: evidence from climate smart villages in nyando basin, Kenya. Cogent Food Agric. 10 (1). https://doi.org/10.1080/23311932.2024.2316362.
Nyong, A.P., Ngankam, T.M., Felicite, T.L., 2020. Enhancement of resilience to climate variability and change through agroforestry practices in smallholder farming systems in Cameroon. Agrofor. Syst. 94 (3), 687–705. https://doi.org/10.1007/s10457-019-00435-y.
Obi, A., Maya, O., 2021. Innovative climate-smart agriculture (Csa) practices in the smallholder farming system of South Africa. Sustainability 13 (12). https://doi.org/10.3390/su13126848.
Oguz, C., Örs, A., Öğür, A.Y., Çelik, Y., 2024. Determining the factors affecting the climate-friendly innovative technology usage levels of sheep farms. New Medit 2024 (1), 55–72. https://doi.org/10.30682/nm2401d.
Olaghere, J.A., Inegbedion, H.E., Osiobe, F.O., 2023. The implications of digitalization in retail service delivery on circular economy in Nigeria: an exploratory case study. Sustainability 15 (17). https://doi.org/10.3390/su151713192.
Oriekhoe, O.I., Adisa, O., Ilugbusi, B.S., 2024. Climate change and food supply chain economics: a comprehensive analysis of impacts, adaptations, and sustainability. International Journal of Applied Research in Social Sciences 6 (3), 267–278.
Oruma, S.O., Misra, S., Fernandez-Sanz, L., 2021. Agriculture 4.0: an implementation framework for food security attainment in Nigeria's post-covid-19 era. IEEE Access 9, 83592–83627. https://doi.org/10.1109/ACCESS.2021.3086453.
Pati, D., Lorusso, L.N., 2018. How to write a systematic review of the literature. HERD: Health Environments Research & Design Journal 11 (1), 15–30. https://doi.org/10.1177/1937586717747384.
Patil, S., Kulkarni, U., 2019. Accuracy prediction for distributed decision tree using machine learning approach. In IEEE. 3rd International Conference on Trends in Electronics and Informatics (ICOEI). IEEE, pp. 1365–1371.
Qu, H., Zheng, C., Ji, H., Barai, K., Zhang, Y.J., 2024. A fast and efficient approach to estimate wild blueberry yield using machine learning with drone photography: flight altitude, sampling method and model effects. Comput. Electron. Agric. 216. https://doi.org/10.1016/j.compag.2023.108543.
Quarshie, P.T., Abdulai, S., Fraser, E.D.G., 2023. (Re)assessing Climate-Smart Agriculture practices for sustainable food systems outcomes in sub-Saharan Africa: the case of Bono East Region, Ghana. Geogr. Sustain. 4 (2), 112–126. https://doi.org/10.1016/j.geosus.2023.02.002.
Reardon, T., Zilberman, D., 2018. Climate Smart Food Supply Chains in Developing Countries in an Era of Rapid Dual Change in Agrifood Systems and the Climate 335–351. https://doi.org/10.1007/978-3-319-61194-5_15.

Rini, L., Schouteten, J.J., Faber, I., Bom Frøst, M., J A Perez-Cueto, F., De Steur, H., 2024. Social media and food consumer behavior: a systematic review. Trends Food Sci. Technol. 143 (August 2023). https://doi.org/10.1016/j.tifs.2023.104290.

Romeiko, X.X., Lee, E.K., Sorunmu, Y., Zhang, X., 2020. Spatially and temporally explicit life cycle environmental impacts of soybean production in the U.S. Midwest. Environmental Science & Technology 54 (8), 4758–4768. https://doi.org/10.1021/acs.est.9b06874.

Rotz, S., Duncan, E., Small, M., Botschner, J., Dara, R., Mosby, I., Reed, M., Fraser, E.D. G., 2019a. The politics of digital agricultural technologies: a preliminary review. Sociol. Rural. 59 (2), 203–229. https://doi.org/10.1111/soru.12233.

Rotz, S., Gravely, E., Mosby, I., Duncan, E., Finnis, E., Horgan, M., LeBlanc, J., Martin, R., Neufeld, H.T., Nixon, A., Pant, L., Shalla, V., Fraser, E., 2019b. Automated pastures and the digital divide: how agricultural technologies are shaping labour and rural communities. J. Rural Stud. 68, 112–122. https://doi.org/10.1016/j.jrurstud.2019.01.023.

Saleh, C., Hidayati, F., Ar Rasyid, N.H., 2023. Public Human Resources Development Systematic Literature Review 249–262. https://doi.org/10.2991/978-2-38476-082-4_24.

Salehi, A.W., Khan, S., Gupta, G., Alabduallah, B.I., Almjally, A., Alsolai, H., Siddiqui, T., Mellit, A., 2023. A study of CNN and transfer learning in medical imaging: advantages, challenges, future scope. Sustainability 15 (7), 5930. https://doi.org/10.3390/su15075930.

Sardar, A., Kiani, A.K., Kuslu, Y., 2020. Does adoption of climate-smart agriculture (CSA) practices improve farmers' crop income? Assessing the determinants and its impacts in Punjab province, Pakistan. Environ. Dev. Sustain. 23 (7), 10119–10140. https://doi.org/10.1007/s10668-020-01049-6.

Serazetdinova, L., Garratt, J., Baylis, A., Stergiadis, S., Collison, M., Davis, S., 2019. How should we turn data into decisions in AgriFood? J. Sci. Food Agric. 99 (7), 3213–3219. https://doi.org/10.1002/jsfa.9545.

Sharma, S., Khanal, P., 2024. Forest fire prediction: a spatial machine learning and neural network approach. Fire 7 (6). https://doi.org/10.3390/fire7060205.

Sharma, P., Vimal, A., Vishvakarma, R., Kumar, P., de Souza Vandenberghe, L. porto, Kumar Gaur, V., Varjani, S., 2022. Deciphering the blackbox of omics approaches and artificial intelligence in food waste transformation and mitigation. Int. J. Food Microbiol. 372, 109691. https://doi.org/10.1016/j.ijfoodmicro.2022.109691.

Sharma, M., Joshi, S., Govindan, K., 2023. Overcoming barriers to implement digital technologies to achieve sustainable production and consumption in the food sector: a circular economy perspective. Sustain. Prod. Consum. 39, 203–215. https://doi.org/10.1016/j.spc.2023.04.002.

Singh, A., Mishra, N., Imran Ali, S., Shukla, N., Shankar, R., 2014. Cloud Computing Technology: reducing carbon footprint in beef supply chain. Int. J. Prod. Econ. https://ro.uow.edu.au/eispapers.

Sonar, H., Sharma, I., Ghag, N., Raje, B., 2024. Harvesting sustainability: assessing Industry 4.0 in agri-food supply chains. Int. J. Logist. Manag. https://doi.org/10.1108/IJLM-10-2023-0443.

Stanghellini, C., Katzin, D., 2024. The dark side of lighting: a critical analysis of vertical farms' environmental impact. In: Journal of Cleaner Production, vol. 458. Elsevier Ltd. https://doi.org/10.1016/j.jclepro.2024.142359.

Sudha, P., 2023. Early detection and control of anthracnose disease in cashew leaves to improve crop yield using image processing and machine learning techniques. Signal, Image and Video Processing. https://doi.org/10.21203/rs.3.rs-2490123/v1.

Tabe-Ojong, M.P., Salama, Y., Abay, K.A., Abdelaziz, F., Zaccari, C., Akramkhanov, A., Menza, G., Anarbekov, O., 2024. Harnessing digital innovations for climate action and market access: opportunities and constraints in the CWANA region. In: Global Food Security, vol. 41. Elsevier B.V. https://doi.org/10.1016/j.gfs.2024.100763.

Thakur, A., Sahoo, S., Mukherjee, A., Halder, R., 2023. Making robotic swarms trustful: a blockchain-based perspective. J. Comput. Inf. Sci. Eng. 23 (6). https://doi.org/10.1115/1.4062326.

The Global Panel, 2025. Building Resilience and Enhancing Nutrition in Africa's Food Systems.

Tranfield, D., Denyer, D., Smart, P., 2003. Towards a methodology for developing evidence-informed management knowledge by means of systematic review. Br. J. Manag. 14, 207–222.

Umetsu, C., Miura, K., 2023. Building resilience for food and nutrition security in africa: focusing on small-scale farmers. Journal of Rural Problems 59 (1), 53–59. https://doi.org/10.7310/arfe.59.53.

United Nations, 2017. Adopting an analytical framework on risk and resilience: a proposal for more proactive. Coordinated and Effective. United Nations action.

van der Spiegel, M., van der Fels-Klerx, H.J., Marvin, H.J.P., 2012. Effects of climate change on food safety hazards in the dairy production chain. Food Res. Int. 46 (1), 201–208. https://doi.org/10.1016/j.foodres.2011.12.011.

Veerakachen, W., Raksapatcharawong, M., 2020. RiceSAP: an efficient satellite-based AquaCrop platform for rice crop monitoring and yield prediction on a farm- to regional-scale. Agronomy 10 (6). https://doi.org/10.3390/agronomy10060858.

Vermeulen, S.J., Campbell, B.M., Ingram, J.S.I., 2012. Climate change and food systems. Annu. Rev. Environ. Resour. 37 (1), 195–222. https://doi.org/10.1146/annurev-environ-020411-130608.

Waaswa, A., Oywaya Nkurumwa, A., Mwangi Kibe, A., Ng'eno Kipkemoi, J., 2024. Adapting agriculture to climate change: institutional determinants of adoption of climate-smart agriculture among smallholder farmers in Kenya. Cogent Food Agric. 10 (1). https://doi.org/10.1080/23311932.2023.2294547.

Walter, A., Finger, R., Huber, R., Buchmann, N., 2017. Smart farming is key to developing sustainable agriculture. Proc. Natl. Acad. Sci. 114 (24), 6148–6150. https://doi.org/10.1073/pnas.1707462114.

Wang, P., You, K., Hun Ong, Y., Ning Yeoh, J., Pang Qi Ong, J., Thanh Lan Truong, A., Blasiak, A., Kai-Hua Chow, E., Ho, D., 2022. WisDM green: harnessing artificial intelligence to design and prioritize compound combinations in peat moss for sustainable farming applications. ADVANCED INTELLIGENT SYSTEMS. https://doi.org/10.22541/au.165244695.56681780.

Wang, X., Liu, C., van der Fels-Klerx, H.J., 2022b. Regional prediction of multi-mycotoxin contamination of wheat in Europe using machine learning. Food Res. Int. 159. https://doi.org/10.1016/j.foodres.2022.111588.

Wang, S., Ghadge, A., Aktas, E., 2024. Digital transformation in food supply chains: an implementation framework. Supply Chain Manag. 29 (2), 328–350. https://doi.org/10.1108/SCM-09-2023-0463.

Wilkus, E.L., deVoil, P., Marenya, P., Snapp, S., Dixon, J., Rodriguez, D., 2022. Sustainable intensification practices reduce food deficit for the best- and worst-off households in Ethiopia and Mozambique. Front. Sustain. Food Syst. 5. https://doi.org/10.3389/fsufs.2021.649218.

Yadav, S., Kaushik, A., Sharma, M., Sharma, S., 2022. Disruptive technologies in smart farming: an expanded view with sentiment analysis. AgriEngineering 4 (2), 424–460. https://doi.org/10.3390/agriengineering4020029.

Zekhnini, K., Cherrafi, A., Bouhaddou, I., Benabdellah, A.C., Raut, R., 2024. A holonic architecture for the supply chain performance in industry 4.0 context. Int. J. Logist. Res. Appl. 27 (6), 852–879. https://doi.org/10.1080/13675567.2021.1999912.

Zhang, H., Zimmerman, J., Nettleton, D., Nordman, D.J., 2020. Random forest prediction intervals. Am. Statistician 74 (4), 392–406. https://doi.org/10.1080/00031305.2019.1585288.

Zhu, B., Chen, J., Luo, S., 2024. The impact of citywide community quarantine policy on the urban fresh food availability: an insight from the topic clout on social media. Int. J. Disaster Risk Reduct. 108. https://doi.org/10.1016/j.ijdrr.2024.104550.