Advancing Global Smart Agriculture with AI and IoT: A Systematic Review of Technologies, Applications, and Challenges

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ABSTRACT

The integration of Artificial Intelligence (AI) and the Internet of Things (IoT) is transforming agriculture by enhancing precision farming, improving resource efficiency, and promoting sustainability. This study systematically reviews emerging AI and IoT applications in smart agriculture, examining their role in agricultural productivity, identifying barriers to adoption, and assessing their impact on climate-smart practices. A structured data extraction process was employed, sourcing peer-reviewed studies from databases such as PubMed, Scopus, IEEE Xplore, and Google Scholar. Eligibility criteria ensured a focus on AI and IoT applications in crop management, pest control, food safety, and supply chain optimization, with studies published between 2019 and 2024 included. Thematic and statistical synthesis categorized findings based on technological innovations and agricultural applications. The results highlight the transformative potential of AI and IoT in optimizing agricultural processes, though challenges such as high implementation costs, technical limitations, and socio-cultural barriers persist. To maximize the benefits of these technologies, policymakers and stakeholders must invest in infrastructure, enhance digital literacy among farmers, and promote inclusive policies that facilitate the adoption of AI and IoT, particularly in resource-limited settings. This review provides valuable insights for advancing smart and sustainable agricultural practices globally.

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INTRODUCTION

The integration of Artificial Intelligence (AI) and the Internet of Things (IoT) in agriculture has gained significant traction as a sustainable solution to modern farming challenges. These technological advancements have the potential to enhance precision agriculture, optimize resource use, and improve food security globally (Abdul Hussein, Jabbar, Mohammed, and Al-Jawahry, 2024). The fusion of AI and IoT, often referred to as AIoT, enables real-time monitoring and predictive analytics that support data-driven decision-making in farming operations (Adli *et al*., 2023). The increasing demand for sustainable agricultural practices necessitates the adoption of smart farming solutions, where AI and IoT collectively contribute to enhanced efficiency, productivity, and environmental sustainability (Alazzai, *et al*., 2024).

Smart agriculture leverages AI-powered algorithms and IoT-enabled sensors to automate various aspects of farming, including irrigation management, pest control, and soil health assessment (Alreshidi, 2019). These innovations facilitate precision agriculture, where farmers can make informed decisions based on real-time data, thereby reducing waste and improving crop yields (AlZubi and Kalda, 2023). Recent advancements in AI and IoT have also enabled the development of predictive models that enhance agricultural supply chain efficiency, ensuring timely interventions and reducing post-harvest losses (Elufioye, *et al*., 2024).

Despite these advancements, several challenges hinder the widespread adoption of AI and IoT in agriculture. High initial costs, technological infrastructure limitations, and data privacy concerns remain significant barriers to implementation, particularly in developing regions (Morchid *et al*., 2024). Additionally, the effectiveness of AI-driven farming solutions depends on the availability of high-quality data and the ability of farmers to interpret and act upon AI-generated insights (Karunathilake, *et al*., 2023). Addressing these challenges requires collaborative efforts from policymakers, researchers, and industry stakeholders to develop scalable and inclusive AIoT-based agricultural solutions (Gikunda, 2024; Das, Majumder, and Panwar, 2024). The integration of AI and IoT in agriculture presents transformative opportunities for enhancing food production and sustainability. By harnessing these technologies, farmers can achieve greater efficiency, resilience, and adaptability in the face of climate change and resource constraints. The study systematically examines the role of AI and IoT in advancing global smart agriculture by enhancing productivity and precision farming. It identifies key challenges and barriers to adoption, including technical, economic, and socio-cultural factors. Additionally, it assesses the impact of AI and IoT applications on sustainability, resource efficiency, and climate-smart agricultural practices.

METHODOLOGY

The systematic review systematically extracted data from peer-reviewed studies on AI, IoT, and ML in agriculture from PubMed, Scopus, IEEE Xplore, and Google Scholar. Two independent extractors used a structured Excel template to record study details, including title, authors, publication year, study design, key findings, and agricultural applications like crop management, pest control, food safety, and supply chain optimization. Eligibility criteria included empirical and theoretical studies (2019–2024) focused on smart agricultural technologies, while non-peer-reviewed articles, duplicates, and irrelevant studies were excluded using Rayyan. Boolean search strategies optimized the retrieval of studies, ensuring a broad and relevant dataset. Screening involved title, abstract, and full-text reviews, with disagreements resolved by a third reviewer. Data synthesis categorized studies by technology (AI, IoT, ML) and application, with further sub-themes on precision farming and automation. Qualitative and statistical analyses assessed the impact of these technologies on crop yield, resource efficiency, and sustainability, grouping studies by citation source for consistency. This structured approach ensured a thorough evaluation of the role of smart technologies in agriculture (AI, IoT, ML, Cloud Computing, Robotics, Renewable Energy, Smart Sensors, Big Data Analytics, Data Mining, Data Analytics, High-Performance Computing (HPC), Predictive Analytics, Foundation Models, Deep Learning, Remote Sensing, Sensors Technology, Drones, Digital Platforms, Neural Networks).

AI and IoT in Agriculture: Transforming Productivity and Sustainability

AI and IoT are revolutionizing agriculture by enabling precision farming, real-time monitoring, and optimized resource management (Hussein *et al*., 2024). These technologies enhance crop yield predictions, pest control, and irrigation efficiency (Issa *et al*., 2024; Qazi *et al*., 2022). However, adoption remains slow due to high costs, interoperability challenges, and digital illiteracy, especially in developing regions (Alazzai *et al*., 2024; Alreshidi, 2019). Despite these barriers, AIoT—the fusion of AI and IoT—shows promise for tackling post-harvest losses and improving supply chain transparency (Adli *et al*., 2023). Yet, issues such as market readiness and infrastructure gaps persist (Subeesh and Mehta, 2021; Sharma *et al*., 2023). Dhanaraju *et al*. (2022) highlight that aligning smart technologies with traditional farming systems remains a challenge, particularly in Africa and Asia.

Key Barriers to Adoption

The major obstacles to AI and IoT adoption in agriculture are technological, economic, and socio-cultural. High implementation costs and inadequate rural infrastructure hinder accessibility (Hussein *et al*., 2024; Alreshidi, 2019). Limited digital literacy among farmers slows adoption (Qazi *et al*., 2022), while financial constraints disproportionately affect smallholder farmers (Subeesh and Mehta, 2021; Sharma *et al*., 2023). Additionally, traditional farming communities often resist new technologies due to skepticism and lack of awareness (Hussein *et al*., 2024; Qazi *et al*., 2022). Insufficient data availability and unreliable network connectivity further limit AI and IoT adoption, particularly in rural areas, where access to real-time agricultural insights and digital tools remains constrained. Institutional support and large-scale validation of AI's effectiveness are crucial to overcoming these barriers (Thilakarathne *et al*., 2023).

Adli et al.	2023	Not specified	AIoT (AI + IoT)	Pest & Post-Harvest Management	Systematic Literature Review	AIoT significantly enhances agriculture but faces challenges in adoption.	AIoT transforms traditional farming but requires further research to overcome barriers.	Adoption barriers, data integration issues, and lack of standardization.
AlZubi & Kalda	2023	Not specified	AI, IoT	Smart Sustainable Agriculture (SSA)	Review & Framework Proposal	AI and IoT technologies enhance SSA, but data sharing and interoperability remain issues.	Proposes an IoT/AI framework to support SSA development.	Limited real-world validation of the proposed framework.
Subeesh & Mehta	2021	Not specified	AI, IoT	Agriculture Automation	Review & Analysis	AI/IoT help automate farming processes like irrigation, pest control, and greenhouse management.	Digital technologies have matured and are now in the execution phase.	Adoption barriers, technical challenges, and need for infrastructure support.
Sharma et al.	2023	Not specified	AI, IoT	Precision Agriculture	Review	AI and IoT facilitate precision farming by optimizing input use and increasing crop yields.	Precision farming improves productivity and sustainability through AI and IoT.	Challenges in large-scale implementation and farmer adoption.
Soussi, et al.	2024	Not specified (Review Paper)	Smart Sensors, IoT, AI, Big Data Analytics	Precision Agriculture	Literature Review	Integration of smart sensors, IoT, AI, and big data enhances crop management, optimizes resource use, and promotes sustainable agriculture.	Adoption of these technologies is crucial for transitioning to sustainable and efficient farming.	Does not provide empirical data or case studies.
Durai, et al.	2022	Not specified	IoT, Data Mining, Machine Learning, Data Analytics	Precision Farming	Conceptual Analysis	Smart farming using AI can improve productivity, reduce manual labor, and optimize farming decisions.	AI-driven precision farming enhances efficiency and cost-effectiveness.	No empirical validation of proposed methods.
Alazzai et al.	2024	Not specified	IoT, AI, Cloud Computing	Crop Management	Literature Review	AI and IoT facilitate real-time monitoring, predictive analytics, and automation in agriculture, improving yield and sustainability.	Digital transformation in agriculture is essential for addressing food security and climate adaptation.	Lacks empirical case studies or field validation.
Thilakarathne , et al.	2023	Not specified	IoT, Cloud Computing	Crop Management (Tomato Plantation)	Experimental Study	Cloud-enabled IoT sensors improve real-time crop monitoring and automate decision-making, increasing yield and sustainability.	IoT-based automation can enhance efficiency and sustainability in agriculture.	Focused on an indoor environment; applicability to open-field farming needs further exploration.
Di Bitonto et al.	2024	Not specified	AI, High-Performance Computing (HPC), Machine Learning	Food Safety and Nutrition	Case Study (METROFOOD-IT)	AI models enhance food safety, diet personalization, and disease risk prediction; data infrastructure is crucial for implementation.	AI-driven models can transform food safety and nutrition through predictive analytics and personalized recommendations.	Challenges in data privacy, model interoperability, and ethical considerations remain.
Ba˛ciulien˙e et al.	2023	Global (Food Value & Supply Chain)	Artificial Intelligence (AI) integration in food supply and value chain, robotics, drones, sensors, digital platforms	Food value and supply chain, technology in agriculture	Systematic literature review, 55 articles analyzed	AI is integrated into the entire food supply chain through various technologies such as robotics, drones, sensors, and big data. However, social, technological, and economic barriers hinder AI's application. The barriers can be overcome by improving digital literacy and disseminating best practices.	AI has a rapidly evolving role in food supply chains and can be applied to different phases such as production, processing, and logistics. Successful AI application faces barriers that need addressing. Overcoming these barriers will enable further integration of AI for better efficiency in food systems.	Limited by the small number of reviewed articles (55), and AI integration in the food supply chain is still evolving. Some studies lacked full applicability to real-world scenarios.
Monteiro, et al.	2021	Global (Agri-food Supply Chain)	Artificial Intelligence (AI) in extended agri-food supply chains,	Agri-food supply chain	Literature review of 18 papers, focused on AI in the agri-food supply chain	AI has started impacting the extended agri-food supply chain, focusing on production and stakeholders. More research is needed in storage and distribution stages. The use of	AI integration in agri-food supply chains is still in its early stages, and significant opportunities exist for applying AI to various stages, especially storage and distribution.	Limited by the small number of studies analyzed (18). Focus on production stages, requiring more

			data-driven decision-making			AI should also focus on food waste reduction and sustainable agriculture.	A broader integration across stakeholders will enhance sustainability.	research in other areas like storage and distribution.
Sharma, et al.	2021	Global (Food Industry)	Artificial Intelligence (AI) and Big Data Analytics (BDA) in the food industry, machine learning, neural networks	Food industry, food production, logistics	Systematic literature review using multiple databases (Scopus, Science Direct, Wiley)	AI and BDA have substantial applications in food production, logistics, supply chain, and marketing. Technologies like machine learning and AI enable optimization and efficiency in food industry processes.	AI and BDA are transforming the food industry by improving efficiency, reducing labor costs, and optimizing decision-making. The transition to automated systems is crucial for addressing challenges in food production and supply.	Limitations include a focus on specific databases and keywords, which might overlook other relevant studies. Future research should involve more field interventions to validate the recommendations.
Quy, et al.	2022	Global	IoT, Big Data	Smart Agriculture	Survey and literature review	IoT applications enhance productivity, reduce labor, improve efficiency	IoT and big data can improve agriculture productivity, reduce human labor, but face challenges in affordability and security	High costs and security concerns, especially for small- and medium-scale farms
Dhanaraju, et al.	2022	Global	IoT, Cloud Computing	Smart Farming	Review of IoT tools and challenges	IoT enhances farming productivity but faces integration challenges	IoT in agriculture will revolutionize the industry, with challenges in merging technology with traditional methods	Challenges in integrating IoT with conventional farming methods
Dipti et al.	2021	Global	IoT	Smart Agriculture	Review	IoT improves agricultural processes, optimizes crop cycles	IoT has a promising future in agriculture, promoting green revolution	Overcoming IoT challenges in agriculture
Deribe & Girma Ashe	2024	Global	AI, Food Processing	Food Safety and Sustainability	Literature review	AI enhances food safety, quality assurance, and waste reduction	AI is crucial for advancing sustainability, food safety, and addressing food industry challenges	Job displacement, technical limitations, and ethical considerations
Ziemba, et al.	2024	Global	AI	Sustainable Development Goals	Review	AI plays a critical role in meeting SDGs by improving various sectors	AI offers solutions for sustainability, economic growth, and innovation	Ethical concerns and challenges in AI integration
Sosa-Holwerda, et al.	2024	Multiple (Global)	Artificial Intelligence (AI)	Nutrition Research	Systematic review with systematic database search (PubMed, Scopus, etc.), article screening, quality assessment	AI in nutrition is developmental, focusing on dietary assessment, malnutrition prediction, and disease understanding. Ethics and efficacy are key concerns. Studies were mostly from high-income countries.	AI in nutrition is still in its early stages, clinical research and specialized reviews are necessary to explore AI's potential and address ethical concerns. The studies' diversity limits a focused exploration on specific nutritional areas.	Heterogeneity of included studies limits focus on specific areas within nutrition. Need for specialized future research.
Shashanka et al.	2024	International (Global)	Internet of Things (IoT), AI, Data Analytics	Sustainable Crop Management	Literature review of technologies in smart agriculture, case studies, and implementation issues	Smart agriculture improves productivity and sustainability through real-time monitoring, precision farming, and data-driven decisions in crop management. Challenges include costs, technological integration, and connectivity.	Smart agriculture offers sustainable solutions to food security by optimizing resource efficiency and improving productivity. Collaboration among stakeholders is needed to overcome technological and infrastructure barriers.	High upfront costs, technological integration challenges, and connectivity issues limit the widespread adoption of smart agriculture.
Elufioye, et al.	2024	International (Global)	AI, Predictive Analytics	Agricultural Supply Chains	Systematic literature review and content analysis using databases like IEEE Xplore, Google Scholar, and ScienceDirect	AI improves demand forecasting, supply chain operations, and real-time data analysis. Challenges include data quality, infrastructure gaps, and skill deficits. AI's	AI has the potential to transform agricultural supply chains, improving efficiency and sustainability. However, challenges such as equitable access and ethical	Data quality, infrastructure development, and skill gaps among agricultural professionals remain significant challenges.

						integration with emerging tech like IoT shows promise.	issues must be addressed for widespread adoption.	
Mohamed et al.	2023	Global	AI Foundation Models, Deep Learning, Machine Learning, Remote Sensing	Food Security, Crop Type Classification, Crop Yield Prediction	Integration of AI foundation models with multispectral imagery, meteorological data, soil properties, historical records, and high-resolution satellite imagery.	AI foundation models provide accurate predictions, improve resource allocation, and support decision-making for food security. Enhanced accuracy, optimized resource use, and efficient data processing are achieved.	AI foundation models are transformative in global food security, addressing challenges through improved predictions, optimized resource use, and efficient decision-making. They empower policymakers, researchers, and farmers.	No specific limitations noted
Kinyua et al.	2024	Africa	Artificial Intelligence (AI)	Sustainable Agricultural Development, Smallholder Farmers	Exploration of AI applications in precision farming, crop monitoring, and climate-resilient practices. Challenges related to infrastructure, data accessibility, and skills gap were analyzed.	AI can revolutionize agriculture in Africa, improving productivity, resilience, and inclusivity. However, challenges like data accessibility and technical skill gaps must be addressed for successful integration.	AI promises transformative outcomes in African agriculture, but requires ethical frameworks and inclusive policies for equitable benefits. Focus on collaboration, responsible AI, and sustainable practices is essential for resilience.	Lack of technical infrastructure and data accessibility in developing regions. Challenges in training and adoption, particularly for smallholder farmers.
Hussein, et al.	2024	Global	AI, Internet of Things (IoT)	Sustainable Farming, Precision Agriculture, Crop Yield Forecasting	Review of the role of AI and IoT in farming. Exploration of IoT-based monitoring, real-time data analysis, and automation in agriculture. Discussion on challenges like high costs, technical expertise, and data security.	AI and IoT enhance agricultural efficiency, precision, and sustainability. They offer economic benefits by improving resource management and crop monitoring. Challenges remain in adoption due to high costs and technical barriers.	AI and IoT are reshaping agriculture toward sustainability and resilience, but successful implementation requires affordable solutions, education, and infrastructure development. Tailored solutions for specific regions are essential.	Challenges in adoption, high costs, need for technical expertise, and concerns over data security and privacy.
Abdennabi et al.	2024	Global	Internet of Things (IoT), Sensors Technology	Food Security, Agricultural Sustainability	Examination of IoT and sensor technologies in agriculture, including their applications in irrigation, crop disease detection, climate monitoring, and fire detection. Review of IoT architecture.	IoT and sensor technologies significantly enhance agricultural sustainability by improving monitoring, resource management, and product quality. Issues like infrastructure, training, and data privacy still need addressing.	IoT and sensors hold transformative potential for agriculture, promoting sustainability and increasing productivity. Future success depends on policy development, infrastructure investment, and education to enable broad adoption.	High costs, infrastructure limitations, and the need for research, training, and effective policies for successful implementation of IoT and sensor technologies in agriculture.
Shashanka et al.	2024	International	IoT, AI, and Data Analytics for crop management	Sustainable crop management	Literature review and case studies on smart agriculture implementation	IoT sensors, AI, and data analytics help optimize crop farming, improve sustainability, and manage resources effectively.	Smart agriculture, driven by AI, IoT, and data analytics, improves crop yields, resource efficiency, and sustainability. However, it faces challenges like high initial costs and technological limitations.	Obstacles include high upfront costs, technological difficulties, and issues with interoperability and connectivity.
Rania et al.	2024	Global	AI applications in food science	Food safety and quality, supply chain optimization	Literature review on AI applications in food science and technology	AI technologies such as machine learning and predictive analytics enhance food safety, supply chain management, and product development.	AI is transforming food science and technology, improving food safety, quality, and efficiency. However, challenges like data privacy and the skills gap need to be addressed.	Concerns about data privacy, regulatory challenges, environmental impacts, and accessibility of AI tools for smaller enterprises.

Sustainability and Climate Smart Agriculture

AI and IoT play a crucial role in sustainability by optimizing input use, reducing waste, and enhancing climate resilience. Real-time monitoring improves water and fertilizer efficiency, reducing environmental degradation (Hussein *et al*., 2024). Predictive models help farmers adapt to climate change by forecasting weather patterns and soil conditions (Qazi *et al*., 2022). However, the increasing unpredictability of weather due to climate change poses challenges to forecast accuracy, potentially limiting the effectiveness of AI-driven decision-making in agriculture (Subeesh and Mehta, 2021). Economic and technical barriers still limit large-scale adoption (Sharma *et al*., 2023; Subeesh and Mehta, 2021). Policy interventions, training programs, and investment in rural infrastructure are necessary to bridge these gaps and maximize AI's potential in sustainable agriculture.

CONCLUSION AND RECOMMENDATIONS

The integration of AI and IoT in agriculture holds immense potential to enhance productivity, optimize resource use, and improve decision-making. These technologies enable real-time monitoring, predictive analytics, and supply chain transparency, making farming more efficient and sustainable. However, widespread adoption is hindered by high costs, digital infrastructure gaps, and socio-cultural resistance, particularly in resource-constrained regions. Addressing these barriers requires collaborative efforts among governments, technology providers, and agricultural stakeholders to improve accessibility and affordability.

RECOMMENDATIONS

i. The Federal Government, in collaboration with private telecom companies and development agencies, should establish a nationwide Smart Agriculture Infrastructure Initiative. This initiative should expand AI-driven broadband access, IoT networks, and cloud-based data systems to enhance digital connectivity in rural farming communities.

ii. The Ministry of Agriculture, in partnership with financial institutions and fintech companies, should develop an AI-powered agricultural financing platform. This platform should use machine learning to assess creditworthiness and provide smallholder farmers with dynamic, need-based access to subsidies, low-interest loans, and microfinance schemes.

iii. The National Agricultural Extension Services, in collaboration with universities, agricultural research institutions, and technology firms, should create AI-driven agricultural extension hubs. These hubs should leverage virtual reality (VR) simulations and interactive digital platforms to deliver region-specific training programs, improving digital literacy and facilitating AI adoption in farming.

iv. The Federal Government, in partnership with research institutions and agritech startups, should develop a national AI-driven open-data ecosystem for agriculture. This system should use blockchain-secured platforms to collect, analyze, and share real-time farm-level data, improving AI model accuracy and decision-making for smallholder farmers.

v. Research institutions, climate agencies, and technology companies, with support from the government, should design and implement an adaptive AI climate forecasting system. This system should integrate real-time localized data with machine learning models to improve the accuracy of weather predictions and support climate-resilient farming strategies.

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