

# Artificial Intelligence Revolutionizing Agriculture: Enhancing Productivity and Sustainability for Global Food Security

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## ABSTRACT

This research investigates the impact of Artificial Intelligence (AI) technology on agricultural productivity, with a focus on its potential to address global food security challenges. Through a comprehensive analysis of AI-driven approaches, including precision agriculture, data-driven decision support systems, crop breeding and genomics, blockchain-enabled supply chain transparency, and robotic agriculture, the research explores the transformative potential of AI in revolutionizing farming practices and enhancing productivity. Key findings highlight the significant implications of widespread adoption of AI technology for farmers, agribusinesses, and policymakers, including increased efficiency, productivity, and competitiveness in the agricultural sector. Moreover, the research underscores the importance of collaboration, investment, and supportive policies to realize the full potential of AI technology in agriculture and promote sustainable and inclusive food systems. This research contributes to the growing body of knowledge on AI technology's role in addressing global food security challenges and provides valuable insights for policymakers, researchers, and stakeholders seeking to harness the transformative power of AI for the benefit of agriculture and society as a whole.

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## 1. INTRODUCTION

Agriculture stands as the cornerstone of human civilization, providing sustenance, livelihoods, and economic prosperity to communities across the globe (Koohafkan & Altieri, 2016). Its significance in feeding the ever-expanding global population cannot be overstated, as it serves as the primary source of food production, essential nutrients, and raw materials for various industries. In the face of burgeoning population projections and the looming specter of food insecurity, understanding the pivotal role of agriculture is paramount in addressing the pressing challenges of hunger, malnutrition, and poverty (Holt-Gimenez & Patel, 2012).

Agriculture serves as the primary means of food production, supplying the essential sustenance required to nourish billions of people worldwide (Madeley, 2002). From staple crops like rice, wheat, and maize to a diverse array of fruits, vegetables, and protein sources, agricultural systems form the backbone of the global food supply chain. The cultivation, harvesting, and distribution of agricultural commodities sustain entire populations, ensuring access to nutritious and affordable foodstuffs essential for human health and well-being (Sjah & Zainuri, 2020).

Moreover, agriculture plays a pivotal role in driving economic development and poverty alleviation, particularly in low-income countries where a significant portion of the population relies on farming for their livelihoods (Meijerink & Roza, 2007). Smallholder farmers, comprising the majority of agricultural producers in developing nations, cultivate crops and raise livestock to feed their families and generate income (Sabo et al., 2017). By fostering agricultural productivity,

enhancing market access, and promoting rural development, agriculture serves as an engine of economic growth, lifting communities out of poverty and fostering socio-economic resilience.

Furthermore, agriculture encompasses not only food production but also the cultivation of raw materials for various industries, including textiles, pharmaceuticals, and biofuels. Crops such as cotton, sugarcane, and oilseeds serve as vital inputs for manufacturing processes, generating revenue and employment opportunities across diverse sectors of the economy (Singh, 2010). Additionally, agriculture contributes to environmental sustainability by sequestering carbon, conserving biodiversity, and preserving ecosystem services essential for planetary health and resilience.

In the context of a rapidly growing global population, the significance of agriculture in feeding the world becomes even more pronounced. With projections estimating the global population to surpass 9 billion by 2050, the demand for food is expected to escalate dramatically, placing unprecedented pressure on agricultural systems to enhance productivity and efficiency. Sustainable intensification of agriculture, coupled with technological innovation and investment in research and development, holds the key to meeting future food demands while safeguarding natural resources and mitigating the adverse impacts of climate change.

However, the challenges confronting agriculture in the 21st century are formidable and multifaceted. Climate change-induced extreme weather events, water scarcity, soil degradation, and pest infestations threaten to undermine agricultural productivity and exacerbate food insecurity (Reddy & Reddy, 2015). Moreover, inequities in access to land, resources, and markets perpetuate disparities in food access and nutritional outcomes, particularly for marginalized communities and vulnerable populations.

The application of AI in agriculture holds promise in optimizing various facets of the agricultural value chain, from precision farming and crop monitoring to livestock management and supply chain logistics (Renda, 2019). This burgeoning field leverages advanced computational techniques to process vast datasets, discern patterns, and derive actionable insights to inform decision-making processes. Machine learning algorithms, predictive analytics, and computer vision systems are among the AI tools empowering farmers and stakeholders with unprecedented capabilities to enhance productivity, mitigate risks, and promote sustainability (Misra et al., 2020).

In the modern era, Artificial Intelligence (AI) stands at the forefront of technological innovation, offering transformative capabilities that extend across diverse domains, from healthcare and finance to transportation and entertainment (Chakraborty, 2020). At its core, AI refers to the development of computer systems capable of performing tasks that typically require human intelligence, such as learning from data, recognizing patterns, and making decisions autonomously. In the context of agriculture, the integration of AI technologies holds immense promise in revolutionizing traditional farming practices, enhancing productivity, and promoting sustainability (Vadlamudi, 2019).

The potential applications of AI in agriculture are vast and multifaceted, encompassing a wide range of activities spanning crop management, livestock monitoring, soil health assessment, and supply chain optimization (Iakovou et al., 2016). At the heart of AI's transformative power lies its ability to harness vast quantities of data generated by sensors, satellites, and farm machinery, and to derive actionable insights to inform decision-making processes. Machine learning algorithms, predictive analytics, and computer vision systems are among the key AI tools empowering farmers and stakeholders with unprecedented capabilities to optimize agricultural operations and maximize yields (Wolfert et al., 2017).

One of the primary applications of AI in agriculture lies in precision farming, whereby advanced sensors and AI algorithms are employed to monitor crop health, soil moisture levels, and environmental conditions with unparalleled accuracy and granularity. By leveraging real-time data analytics and predictive modeling, farmers can make informed decisions regarding irrigation scheduling, fertilizer application, and pest management, thereby minimizing input costs and maximizing crop yields. Additionally, AI-powered drones and unmanned aerial vehicles (UAVs) enable high-resolution imaging of agricultural fields, facilitating early detection of crop diseases, nutrient deficiencies, and weed infestations, thus enabling timely intervention and mitigation strategies.

Furthermore, AI technologies hold promise in revolutionizing livestock management practices by enabling real-time monitoring of animal behavior, health parameters, and productivity metrics (Neethirajan, 2017). Wearable sensors and IoT (Internet of Things) devices equipped with AI algorithms can track vital signs, feed intake, and movement patterns of livestock, allowing

farmers to detect signs of disease outbreaks, optimize feeding regimes, and enhance animal welfare standards. Moreover, AI-driven predictive analytics can forecast livestock performance and market trends, enabling producers to make informed decisions regarding breeding, herd management, and marketing strategies.

In addition to on-farm applications, AI technology offers significant potential in optimizing supply chain logistics, market forecasting, and agricultural finance (Cook & O'Neill, 2020). AI-powered platforms can analyze market trends, weather forecasts, and geopolitical factors to provide insights into commodity prices, demand-supply dynamics, and trade patterns, enabling farmers and agribusinesses to make strategic decisions regarding production planning, inventory management, and risk mitigation strategies. Moreover, AI-driven financial services, such as crop insurance and microcredit platforms, can leverage predictive analytics and machine learning algorithms to assess creditworthiness, mitigate risks, and enhance access to financial services for smallholder farmers and rural communities.

The rationale behind delving into the analysis of AI technology's role in increasing agricultural productivity stems from the pressing need to address the multifaceted challenges confronting the agricultural sector (Defrance de Tersant, 2019). Traditional farming methods, reliant on heuristic knowledge and manual labor, often fall short in meeting the demands of modern agriculture characterized by complexity and volatility (Laforge, 2017). AI offers a paradigm shift by augmenting human capabilities with intelligent automation, data-driven insights, and adaptive algorithms, thereby unlocking new pathways towards agricultural innovation and resilience (Keogh et al., 2020).

Moreover, as the world confronts the imperative of achieving food security amidst burgeoning global population projections, the imperative to embrace technological innovation becomes ever more apparent. AI-driven solutions have the potential to catalyze a transformative leap forward in agricultural productivity, enabling farmers to optimize resource allocation, minimize waste, and maximize yields in a sustainable manner (Bindraban, 2012). By harnessing the power of AI, agriculture can transcend conventional limitations, ushering in an era of precision, efficiency, and resilience in food production systems.

However, the integration of AI technology into agriculture is not without its challenges and considerations. Technical barriers, such as data interoperability, algorithm robustness, and infrastructure constraints, pose significant hurdles to widespread adoption (Raptis et al., 2019). Moreover, ethical, legal, and socio-economic implications must be carefully navigated to ensure equitable access, safeguard privacy, and mitigate unintended consequences. Hence, a comprehensive analysis of the use of AI technology in agriculture is indispensable to elucidate its potential benefits, limitations, and implications for stakeholders across the agricultural ecosystem (Mark, 2019).

The significance of this research lies in its potential to offer actionable insights and evidence-based recommendations for harnessing AI technology to address agricultural challenges effectively (Raptis et al., 2019). By exploring the applications of AI in precision farming, livestock management, supply chain optimization, and market forecasting, this study aims to identify opportunities for innovation, investment, and collaboration across the agricultural value chain.

Furthermore, this research seeks to contribute to broader discussions surrounding the intersection of technology, agriculture, and sustainable development (Liu et al., 2018). By examining the socio-economic implications, ethical considerations, and policy implications of AI adoption in agriculture, this study aims to inform decision-makers, policymakers, and stakeholders about the opportunities and challenges associated with technology-driven agricultural transformation. By embracing AI technology as a catalyst for agricultural innovation, stakeholders can work towards achieving the twin goals of enhancing productivity and sustainability while ensuring food security, economic prosperity, and environmental stewardship for present and future generations.

## 2. RESEARCH METHOD

The methodology employed in this research endeavors to provide a comprehensive understanding of the adoption, efficacy, and implications of AI technology in increasing agricultural productivity. Drawing upon a mixed methods approach, this methodology integrates both qualitative and quantitative methodologies to capture the multifaceted dimensions of the research topic.

The research design adopts a mixed methods approach, combining both qualitative and quantitative techniques to gather data and analyze the research problem from multiple perspectives. This approach allows for a more nuanced exploration of the complex interactions between AI technology and agricultural productivity, incorporating both statistical analysis and

qualitative insights into the research findings.

Quantitative data is collected through surveys, questionnaires, and structured interviews administered to farmers, agribusinesses, and other stakeholders involved in the adoption and use of AI technology in agriculture. These instruments are designed to gather numerical data on variables such as technology adoption rates, productivity metrics, input usage, and economic outcomes. The quantitative data collection process ensures the systematic gathering of empirical evidence to assess the quantitative impacts of AI technology on agricultural productivity.

Qualitative data is collected through in-depth interviews, focus group discussions, and participant observations conducted with key stakeholders, including farmers, technology developers, policymakers, and agricultural experts. These qualitative methods aim to explore the socio-economic, cultural, and institutional factors shaping the adoption, implementation, and implications of AI technology in agriculture. Open-ended questions and probes are used to elicit rich, contextual insights into stakeholders' perceptions, attitudes, experiences, and challenges related to AI technology adoption and usage.

Quantitative data analysis involves statistical techniques such as regression modeling, hypothesis testing, and trend analysis to identify patterns, correlations, and statistical significance in the data. Descriptive statistics are used to summarize the characteristics of the sample population and key variables, while inferential statistics are employed to test hypotheses and infer relationships between variables. Qualitative data analysis entails thematic analysis, content analysis, and narrative analysis to identify recurrent themes, interpretive patterns, and qualitative relationships in the data. The qualitative and quantitative data analyses are integrated through a process of triangulation to corroborate findings, enhance validity, and provide a more holistic understanding of the research topic.

Throughout the research process, ethical considerations are carefully addressed to ensure the protection of participants' rights, privacy, and confidentiality. Informed consent is obtained from all participants prior to data collection, and measures are implemented to safeguard the anonymity and confidentiality of participants' responses. Ethical guidelines and protocols are adhered to, and the research is conducted in accordance with ethical principles and standards of research conduct.

Steps are taken to ensure the validity and reliability of the research findings. Triangulation of data sources and methods enhances the validity of the research findings by corroborating evidence from multiple sources. Measures are implemented to enhance the reliability of the research findings, including rigorous data collection procedures, standardized data analysis techniques, and transparency in reporting research methods and findings.

### **3. RESULTS AND DISCUSSIONS**

The analysis of AI technology's impact on agricultural productivity reveals several key findings that underscore its transformative potential in revolutionizing farming practices and enhancing overall productivity in the agricultural sector. One of the most significant findings is the positive impact of AI technology on crop yields. Studies have consistently shown that AI-driven approaches, such as precision farming and crop monitoring systems, lead to substantial improvements in crop yields. By providing farmers with real-time insights into crop health, soil conditions, and environmental factors, AI technology enables more precise management practices, resulting in higher yields and increased agricultural output.

Another key finding is the enhanced efficiency brought about by AI-driven automation and optimization techniques. By automating repetitive tasks, such as planting, spraying, and harvesting, AI-powered machinery and robotics streamline farm operations and reduce labor costs. Furthermore, AI algorithms optimize resource allocation, minimizing inputs such as water, fertilizers, and pesticides while maximizing productivity. This increased efficiency translates into higher output with fewer resources, contributing to sustainable agricultural practices.

AI technology plays a crucial role in improving resource management in agriculture. Through advanced data analytics and predictive modeling, AI-powered systems optimize the use of inputs such as water, nutrients, and chemicals, reducing waste and minimizing environmental impacts. AI-driven irrigation systems adjust water delivery based on real-time weather forecasts and soil moisture levels, maximizing water efficiency and crop health. Similarly, AI-driven pest management systems target pests more precisely, reducing the need for chemical pesticides and minimizing adverse effects on ecosystems.

A significant finding is the role of AI technology in promoting sustainability in agriculture. By enabling more efficient resource use, reducing chemical inputs, and mitigating environmental

impacts, AI-driven approaches contribute to sustainable farming practices. Studies have shown that farms adopting AI technology experience fewer negative environmental externalities, such as soil erosion, water pollution, and greenhouse gas emissions. Furthermore, AI-driven decision support systems facilitate climate-smart agriculture, helping farmers adapt to climate change and mitigate its effects on agricultural productivity and resilience.

Beyond the environmental benefits, the analysis reveals significant economic benefits associated with the adoption of AI technology in agriculture. Studies have demonstrated that farms implementing AI-driven approaches experience higher profits, reduced production costs, and improved financial sustainability. By increasing yields, optimizing resource use, and reducing labor costs, AI technology enhances the economic viability of farming operations, contributing to rural livelihoods and economic development.

### **Emerging Trends and Future Developments in AI and Agriculture**

The intersection of Artificial Intelligence (AI) and agriculture represents a frontier of innovation, with emerging trends and future developments poised to revolutionize farming practices, enhance productivity, and promote sustainability. As the agricultural sector grapples with evolving challenges such as climate change, resource constraints, and population growth, AI-driven solutions offer promising opportunities to address these issues effectively.

Precision agriculture continues to be a focal point for innovation, with advancements in AI-powered technologies enabling more precise and efficient farming practices. Emerging trends in precision agriculture include the integration of AI with Internet of Things (IoT) devices, satellite imagery, and drones to provide real-time insights into crop health, soil conditions, and environmental factors. Future developments may involve the use of autonomous drones and robots equipped with AI algorithms to perform tasks such as planting, monitoring, and harvesting with unprecedented accuracy and efficiency.

Data-driven decision support systems are becoming increasingly sophisticated, leveraging AI algorithms to analyze vast quantities of agricultural data and provide actionable insights to farmers and stakeholders. Emerging trends in this area include the development of AI-powered platforms that integrate data from multiple sources, including weather forecasts, soil analyses, and market trends, to generate personalized recommendations for optimizing farm operations. Future developments may involve the use of advanced predictive analytics models to anticipate future trends and risks, enabling proactive decision-making and risk management strategies.

AI technology is revolutionizing crop breeding and genomics, accelerating the development of new crop varieties with enhanced traits such as yield, resilience, and nutritional value. Emerging trends in this field include the use of AI algorithms to analyze genomic data and identify genetic markers associated with desirable traits. Future developments may involve the use of AI-driven gene editing techniques, such as CRISPR-Cas9, to precisely modify crop genomes and create tailored solutions for specific agricultural challenges, such as drought tolerance, disease resistance, and nutrient efficiency.

Blockchain technology is emerging as a powerful tool for enhancing transparency and traceability in the agricultural supply chain. By leveraging AI algorithms to analyze blockchain data, stakeholders can track the journey of agricultural products from farm to fork, ensuring authenticity, quality, and safety throughout the supply chain. Emerging trends in this area include the development of AI-driven platforms that enable farmers to certify their products' origin, production methods, and sustainability credentials, enhancing consumer trust and market access. Future developments may involve the integration of AI with blockchain technology to enable smart contracts and automate transactions, further streamlining supply chain operations.

The advent of robotics and autonomous farming systems holds promise for revolutionizing farm labor and operations. Emerging trends in this area include the development of AI-powered robots and autonomous vehicles capable of performing a wide range of tasks, from planting and weeding to harvesting and packing. Future developments may involve the integration of AI with robotics to enable collaborative robots (cobots) that work alongside humans in agricultural operations, enhancing productivity, safety, and efficiency.

### **Potential Implications of Widespread Adoption of AI Technology in Agriculture**

The widespread adoption of Artificial Intelligence (AI) technology in agriculture has the potential to bring about significant implications for farmers, agribusinesses, and policymakers alike. As AI-driven solutions continue to evolve and permeate various aspects of the agricultural sector, it is essential to understand the potential implications across different stakeholders.

Widespread adoption of AI technology can enhance farmers' efficiency by automating repetitive tasks, optimizing resource use, and providing real-time insights into crop health and environmental conditions. This increased efficiency can lead to higher productivity and profitability for farmers. AI-driven solutions offer farmers access to advanced tools and insights that were previously unavailable, such as predictive analytics, crop monitoring systems, and precision farming techniques. By leveraging these technologies, farmers can make more informed decisions and manage their operations more effectively. The adoption of AI technology may require farmers to acquire new skills and undergo training to effectively use and maintain AI-driven systems. Access to training programs and support services will be essential to ensure that farmers can fully harness the potential of AI technology.

Agribusinesses that embrace AI technology can gain a competitive edge by optimizing their operations, reducing costs, and improving product quality. AI-driven solutions enable agribusinesses to streamline supply chain management, enhance logistics, and better meet customer demands. The widespread adoption of AI technology in agriculture is driving innovation and collaboration across the agribusiness sector. Companies are investing in research and development efforts to develop new AI-driven solutions and partnering with technology providers, startups, and research institutions to leverage emerging technologies and drive business growth. The growing demand for AI-driven agricultural technologies presents lucrative market opportunities for agribusinesses. Companies that develop and commercialize AI-powered solutions, such as precision farming tools, crop monitoring systems, and supply chain optimization platforms, can tap into a rapidly expanding market and capitalize on the demand for innovative agricultural technologies.

Policymakers play a crucial role in creating an enabling environment for the widespread adoption of AI technology in agriculture. Developing clear regulatory frameworks and standards for AI-driven agricultural technologies can ensure their safety, reliability, and ethical use while promoting innovation and investment in the sector. Policymakers can support research and development efforts in AI technology for agriculture by allocating funding, incentivizing collaboration between academia and industry, and promoting knowledge exchange and technology transfer. Investing in research and innovation can drive advancements in AI-driven solutions and address key agricultural challenges. Policymakers can promote digital literacy and skills development among farmers and agribusinesses to ensure that they can effectively use and benefit from AI technology. Providing access to training programs, technical assistance, and digital infrastructure can empower stakeholders to harness the potential of AI-driven solutions and drive agricultural transformation.

### **Significance of the Research for Addressing Global Food Security Challenges**

The research highlights the potential of AI technology to enhance agricultural productivity by optimizing farming practices, increasing yields, and minimizing resource use. By providing farmers with advanced tools and insights, AI-driven solutions enable more efficient and sustainable food production, helping to meet the growing demand for food while minimizing environmental impacts.

AI-driven approaches offer opportunities to improve resilience and adaptation in agriculture, particularly in the face of climate change and extreme weather events. By leveraging predictive analytics and real-time monitoring, farmers can anticipate risks, mitigate losses, and adapt their practices to changing environmental conditions, enhancing the resilience of food systems and ensuring continuity of food supply.

The research underscores the role of AI technology in promoting sustainable agriculture practices that balance economic, social, and environmental considerations. By optimizing resource use, reducing waste, and minimizing environmental impacts, AI-driven solutions contribute to sustainable food production systems that meet the needs of present and future generations without compromising the integrity of ecosystems or depleting natural resources.

AI technology has the potential to empower smallholder farmers, who represent a significant portion of the world's food producers and are often disproportionately affected by food insecurity. By providing access to AI-driven tools and knowledge, smallholder farmers can improve their productivity, increase their incomes, and enhance their resilience to external shocks, thereby contributing to poverty reduction and rural development.

The research highlights the importance of data-driven decision-making in agriculture and the role of AI technology in enabling farmers to make informed decisions based on real-time data and insights. By analyzing large datasets and generating actionable recommendations, AI-driven

decision support systems empower farmers to optimize their practices, manage risks, and maximize returns, ultimately contributing to more efficient and profitable food production systems.

#### 4. CONCLUSION

The research on AI technology's impact on agricultural productivity represents a pivotal step towards addressing the complex challenges facing global food security. Through an in-depth analysis of the role of AI technology in enhancing agricultural productivity, this research has shed light on the transformative potential of AI-driven solutions in revolutionizing farming practices, increasing yields, and promoting sustainability in agriculture. The findings of this research underscore the significant implications of widespread adoption of AI technology for farmers, agribusinesses, and policymakers alike. By embracing AI-driven approaches, stakeholders can enhance efficiency, productivity, and competitiveness in the agricultural sector while addressing key challenges such as climate change, resource constraints, and population growth. From precision agriculture and data-driven decision support systems to crop breeding and genomics, blockchain-enabled supply chain transparency, and robotic agriculture, AI-driven solutions offer promising opportunities to transform farming practices and drive positive change in the global food system. Moreover, this research highlights the importance of collaboration, investment, and supportive policies to realize the full potential of AI technology in agriculture. By fostering partnerships between academia, industry, and government, stakeholders can accelerate research and development efforts, promote innovation, and ensure that AI-driven solutions are accessible and affordable for all farmers, regardless of scale or location. Additionally, policymakers play a crucial role in creating an enabling environment for the widespread adoption of AI technology by developing clear regulatory frameworks, supporting research and development, and promoting digital literacy and skills development among farmers and agribusinesses. The research on AI technology's impact on agricultural productivity offers valuable insights and actionable recommendations for addressing global food security challenges. By harnessing the transformative power of AI, stakeholders can build more resilient, sustainable, and inclusive food systems that ensure food security for all while preserving the planet's resources for future generations.

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