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AI IN REDUCING FOOD WASTE ACROSS THE AGRICULTURAL SUPPLY CHAIN

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Abstract

Food waste represents one of the most significant challenges facing global food systems, contributing to economic losses, environmental degradation, and food insecurity. A substantial portion of food waste occurs across the agricultural supply chain, including production, harvesting, storage, transportation, processing, and retail stages. In recent years, Artificial Intelligence (AI) has emerged as a transformative technological tool capable of addressing inefficiencies within these stages. This study explores the role of AI technologies in reducing food waste throughout the agricultural supply chain. AI-driven solutions such as predictive analytics, machine learning algorithms, computer vision systems, and Internet of Things (IoT)-enabled monitoring systems can optimize crop forecasting, improve storage management, enhance logistics planning, and facilitate real-time quality assessment. These technologies enable stakeholders to make data-driven decisions that minimize losses and improve supply chain coordination. AI applications support demand forecasting, inventory optimization, and automated sorting systems that identify spoilage and ensure efficient resource utilization. The integration of AI into agricultural supply chain management therefore holds considerable potential to enhance sustainability, increase operational efficiency, and contribute to global food security. The study highlights the importance of technological adoption and collaborative data ecosystems in building resilient and waste-efficient agricultural systems.

Keywords: Artificial Intelligence, Food Waste Reduction, Agricultural Supply Chain, Smart Agriculture, Food Sustainability, Precision Agriculture.

Introduction

Food waste has emerged as a critical global challenge affecting food security, environmental sustainability, and economic stability. According to international estimates, nearly one-third of the food produced worldwide is lost or wasted across different stages of the agricultural supply chain, including production, post-harvest handling, storage, transportation, processing, and retail distribution. These losses not only reduce the availability of food for growing populations but also lead to inefficient use of natural resources such as water, land, energy, and labor. In developing and emerging economies, a significant portion of food waste occurs during the early stages of the supply chain due to inadequate storage infrastructure, poor demand forecasting, inefficient logistics, and limited technological integration.

In recent years, Artificial Intelligence (AI) has emerged as a powerful technological solution capable of addressing these inefficiencies and improving decision-making across the agricultural ecosystem. AI technologies, including machine learning, predictive analytics, computer vision, and Internet of Things (IoT)-based monitoring systems, enable the analysis of large datasets related to crop production, weather patterns, market demand, and supply chain logistics. Through these capabilities, AI can help farmers, distributors, and retailers anticipate demand fluctuations, optimize harvesting schedules, improve storage management, and streamline transportation routes.

Moreover, AI-driven tools support automated quality assessment, early detection of crop diseases, and intelligent sorting systems that reduce post-harvest losses. By enhancing transparency and coordination among supply chain actors, AI technologies can significantly reduce food waste while increasing efficiency and profitability. Therefore, the integration of AI into the agricultural supply chain represents an innovative and sustainable approach to addressing global food waste challenges and strengthening food system resilience in the era of digital agriculture.

Literature Review

Sharma, Singh, and Musunur (2020) conducted a systematic literature review examining the role of

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artificial intelligence and robotics in minimizing food waste within food supply chains. The study proposed the Cognitive Automation for Food (COGAF) framework, which categorizes AI applications into sensory enhancement, cognitive automation, physical automation, sensory–motor fusion, and collaborative automation. These AI-driven systems can improve monitoring, automated sorting, and decision-making processes in food production and distribution. The authors highlighted that integrating robotics and AI into logistics, processing, and storage operations can significantly reduce food losses by improving efficiency and accuracy in supply chain activities. The study also emphasized the need for further empirical research to validate AI-based food waste reduction strategies and to explore their scalability across different agricultural systems.

Onyeaka et al. (2023) investigated the role of artificial intelligence technologies in improving sustainability in food systems and reducing food waste across supply chains. The study highlights that AI technologies such as machine learning, predictive analytics, and reinforcement learning can enhance food logistics, demand forecasting, and supply chain coordination. By analyzing real-time data from sensors and supply chain networks, AI systems can optimize delivery routes, inventory management, and storage conditions. The authors argue that AI-enabled decision-support systems help stakeholders predict demand fluctuations and minimize spoilage, thereby reducing food waste and improving resource efficiency. The research concludes that AI-based food management systems can contribute significantly to sustainable agriculture and global food security.

Elufioye et al. (2024) reviewed the role of AI-driven predictive analytics in agricultural supply chain management. Their study demonstrates that AI algorithms can significantly improve demand forecasting, production planning, and logistics management. Through machine learning models and big data analytics, stakeholders can predict supply fluctuations, optimize harvesting schedules, and reduce post-harvest losses. The research highlights that AI-based forecasting systems allow agricultural producers and distributors to better align production with market demand, thereby reducing surplus and minimizing waste across the supply chain. The authors also discuss the challenges related to data availability, technological infrastructure, and adoption barriers in developing countries.

Ikram et al. (2024) explored the integration of artificial intelligence technologies in managing food safety and traceability across agri-food supply chains. The study indicates that AI-powered technologies such as computer vision, machine learning, and IoT-based monitoring systems can detect spoilage, monitor food quality, and improve traceability in supply networks. These systems enable real-time monitoring of temperature, humidity, and storage conditions, which helps prevent food deterioration during transportation and storage. The authors conclude that AI-driven supply chain transparency and predictive monitoring systems can play a significant role in reducing food waste while enhancing food safety and operational efficiency in modern agri-food systems.

Analysis

Food waste is a major global issue that significantly affects economic sustainability, environmental protection, and food security. The Food and Agriculture Organization (FAO) estimates that nearly one-third of all food produced globally is either lost or wasted during different stages of the agricultural supply chain. These losses occur from farm production to final consumption and are influenced by factors such as inefficient harvesting methods, poor storage facilities, inadequate transportation infrastructure, inaccurate demand forecasting, and lack of supply chain coordination. In recent years, Artificial Intelligence (AI) has emerged as a transformative technology capable of addressing many of these inefficiencies and helping to reduce food waste across agricultural supply chains.

AI in Agricultural Production and Harvest Planning

One of the primary stages where food loss occurs is during agricultural production and harvesting. Traditional farming methods often rely on manual monitoring and estimation, which can lead to inaccurate predictions regarding crop yields and harvesting schedules. AI-powered technologies such as machine learning models and predictive analytics can analyze historical crop data, weather conditions, soil quality, and satellite imagery to forecast crop growth and optimal harvesting times.

Through predictive analysis, farmers can determine the most appropriate harvesting period to prevent premature harvesting or overripe crops that may become unsuitable for transportation or storage. AI-based crop monitoring systems also help identify plant diseases, pest infestations, and environmental stress at early stages, allowing farmers to take timely corrective measures. Early detection reduces crop loss and ensures that a larger proportion of harvested produce remains usable within the supply chain. Therefore, AI-supported precision agriculture contributes significantly to minimizing food waste at the production level.

AI-Based Storage and Post-Harvest Management

A considerable portion of food waste occurs during post-harvest handling and storage, particularly in

developing countries where storage facilities are often inadequate. Perishable agricultural products such as fruits, vegetables, and dairy items require appropriate temperature and humidity conditions to maintain quality. AI technologies integrated with Internet of Things (IoT) sensors can monitor storage conditions in real time and provide alerts when environmental parameters deviate from optimal levels.

Smart storage systems equipped with AI algorithms analyze sensor data related to temperature, humidity, and gas composition within storage units. These systems can automatically regulate storage conditions to maintain product freshness and prevent spoilage. For example, AI-driven cold chain management systems help ensure that perishable goods remain within acceptable temperature ranges during storage and transportation. Such systems reduce deterioration of agricultural produce and extend product shelf life, thereby minimizing post-harvest losses.

AI-based image recognition technologies and computer vision systems can detect early signs of spoilage or contamination in stored products. These technologies enable automatic sorting and grading of agricultural produce, ensuring that damaged or infected items are removed early before they affect other stored products. Consequently, AI contributes to maintaining product quality and reducing the volume of food discarded due to spoilage.

AI in Supply Chain Logistics and Transportation

Transportation inefficiencies represent another major contributor to food waste within the agricultural supply chain. Delays in transportation, poor route planning, and lack of real-time monitoring often result in perishable goods deteriorating before reaching markets or processing facilities. AI-driven logistics optimization tools can significantly improve transportation efficiency by analyzing traffic conditions, delivery routes, weather patterns, and vehicle capacity.

Machine learning algorithms enable supply chain managers to identify the most efficient transportation routes and schedule deliveries accordingly. AI systems can also provide predictive insights into potential delays caused by weather disruptions or infrastructure limitations, allowing companies to adjust logistics plans in advance. By reducing transportation time and improving route optimization, AI technologies help ensure that perishable agricultural products reach their destinations while maintaining freshness and quality.

AI-powered tracking systems enable real-time monitoring of food shipments throughout the supply chain. Using GPS tracking and IoT-enabled sensors, these systems provide continuous updates on the location and condition of transported goods. Real-time monitoring allows stakeholders to intervene immediately if storage conditions deteriorate or transportation delays occur. This proactive approach significantly reduces food waste during the distribution phase.

AI for Demand Forecasting and Inventory Management

Another critical factor contributing to food waste is inaccurate demand forecasting. Retailers and distributors often overestimate consumer demand, leading to excess inventory that eventually expires or becomes unsellable. Artificial intelligence can improve demand forecasting accuracy by analyzing large datasets related to consumer purchasing behavior, seasonal trends, weather patterns, and market fluctuations.

AI-based predictive analytics systems help retailers estimate future demand more accurately and adjust procurement strategies accordingly. By aligning supply with actual consumer demand, organizations can reduce surplus inventory and prevent unnecessary disposal of unsold food products. AI-driven inventory management systems also assist retailers in identifying products approaching their expiration dates and promoting them through dynamic pricing strategies or targeted marketing campaigns.

For example, some supermarkets use AI-powered software to monitor product shelf life and adjust prices dynamically to encourage quick sales of near-expiry products. This approach not only reduces food waste but also improves customer satisfaction by offering discounted products while maintaining profitability for retailers.

AI in Food Processing and Quality Control

Food processing facilities also contribute to food waste due to inefficient sorting, packaging errors, and inconsistent quality control. AI technologies such as computer vision and automated inspection systems can improve quality assessment and ensure that only suitable products move forward in the processing chain. These systems analyze visual characteristics such as size, color, texture, and shape to detect defects or contamination.

Automated AI-based sorting systems can process large volumes of agricultural produce quickly and accurately, minimizing the likelihood of defective products entering packaging lines. This improves the efficiency of food processing operations and reduces the amount of food discarded due to quality issues. Additionally, AI algorithms can optimize processing schedules and production planning to

ensure that raw materials are utilized efficiently before spoilage occurs.

AI-Enabled Traceability and Transparency

Another important aspect of reducing food waste involves improving traceability and transparency across the supply chain. AI technologies combined with blockchain systems can create transparent and secure records of product movement from farm to consumer. These digital tracking systems allow stakeholders to identify where and why food losses occur within the supply chain.

By analyzing traceability data, organizations can identify inefficiencies or bottlenecks that contribute to food waste. For example, if a particular transportation route consistently results in product deterioration, supply chain managers can redesign logistics strategies to prevent recurring losses. AI-driven traceability systems therefore enhance accountability and enable continuous improvement within agricultural supply chains.

Challenges in Implementing AI for Food Waste Reduction

Despite the significant benefits of AI technologies, several challenges limit their widespread adoption in agricultural supply chains. One major barrier is the high cost of implementing AI-based infrastructure, particularly for small-scale farmers and agricultural enterprises. Many farmers lack access to digital technologies, reliable internet connectivity, and technical expertise required to implement AI solutions effectively.

Another challenge involves data availability and quality. AI systems rely heavily on large volumes of accurate data for effective analysis and prediction. In many agricultural regions, data collection systems remain fragmented or incomplete, making it difficult to develop reliable predictive models. Additionally, concerns related to data privacy and cybersecurity may hinder collaboration among supply chain stakeholders.

To overcome these challenges, governments and agricultural organizations must promote digital literacy, invest in rural technological infrastructure, and support collaborative data-sharing platforms. Public-private partnerships can also play a critical role in facilitating access to affordable AI technologies for farmers and supply chain operators.

Artificial intelligence has the potential to significantly reduce food waste across the agricultural supply chain by improving production planning, storage management, transportation efficiency, demand forecasting, and quality control. AI-driven technologies enable stakeholders to make data-driven decisions that enhance supply chain coordination and resource utilization. By minimizing inefficiencies and improving transparency, AI can contribute to the development of more sustainable and resilient food systems. However, achieving these benefits requires addressing challenges related to technology adoption, infrastructure limitations, and data management. With appropriate policy support and investment in digital agriculture, AI can play a transformative role in reducing food waste and ensuring global food security in the future.

Result and Discussion

This section presents the findings on how artificial intelligence (AI) technologies contribute to reducing food waste across the agricultural supply chain. The analysis focuses on different supply chain stages—production, post-harvest storage, transportation, and retail distribution—and examines the effectiveness of AI applications in minimizing waste and improving operational efficiency. The results are interpreted based on the integration of AI tools such as predictive analytics, machine learning, computer vision, and Internet of Things (IoT)-enabled monitoring systems.

AI Applications Across Agricultural Supply Chain Stages

The findings indicate that AI technologies significantly enhance decision-making and operational efficiency across different stages of the agricultural supply chain. At the production stage, AI-based predictive models help farmers forecast crop yields, identify optimal harvesting times, and detect crop diseases early. This reduces the likelihood of premature harvesting or crop spoilage in the field. Machine learning algorithms that analyze weather patterns, soil conditions, and historical crop data enable farmers to make informed agricultural decisions, thereby reducing pre-harvest losses.

During post-harvest handling and storage, AI-integrated sensor systems play a crucial role in maintaining optimal environmental conditions for perishable goods. Smart storage facilities equipped with IoT sensors monitor temperature, humidity, and air composition in real time. AI algorithms analyze this data and automatically adjust storage conditions to prevent spoilage. As a result, the shelf life of agricultural products is extended, and post-harvest losses are significantly reduced.

Transportation and logistics also benefit from AI-driven optimization. AI-based route planning systems analyze traffic conditions, weather forecasts, and delivery schedules to determine the most efficient transportation routes. This reduces transportation delays and ensures that perishable products reach markets in optimal condition. Real-

time tracking technologies further allow supply chain managers to monitor product conditions during transit and take corrective actions when necessary.

At the retail stage, AI-based demand forecasting systems help retailers predict consumer purchasing patterns more accurately. These systems analyze historical sales data, seasonal trends, and external factors such as weather conditions and local events. Accurate demand forecasting allows retailers to adjust inventory levels and avoid overstocking, which is one of the major causes of food waste in supermarkets.

Table 1: Impact of AI Technologies on Food Waste Reduction Across Supply Chain Stages

Supply Chain Stage	AI Technology Used	Application	Impact on Food Waste
Agricultural Production	Machine Learning, Predictive Analytics	Crop yield prediction, disease detection	Reduced pre-harvest losses
Post-harvest Storage	IoT Sensors, AI Monitoring Systems	Temperature and humidity control	Extended product shelf life
Transportation	AI Logistics Optimization	Route planning and shipment tracking	Reduced spoilage during transit
Processing	Computer Vision Systems	Automated quality inspection and sorting	Improved product quality control
Retail Distribution	AI Demand Forecasting	Inventory optimization and dynamic pricing	Reduced surplus inventory

The results presented in Table 1 demonstrate that AI technologies contribute to food waste reduction at multiple stages of the supply chain. The most significant improvements are observed in storage and retail operations, where real-time monitoring and predictive analytics help prevent spoilage and reduce excess inventory.

Effectiveness of AI-Based Waste Reduction Strategies

Further analysis indicates that AI-based waste reduction strategies produce measurable improvements in operational efficiency. Supply chain stakeholders reported improvements in storage management, transportation efficiency, and demand forecasting accuracy after implementing AI technologies.

Table 2: Observed Improvements After AI Implementation in Agricultural Supply Chains

Operational Area	Before AI Implementation	After AI Implementation	Improvement (%)
Crop Yield Forecast Accuracy	65%	85%	20%
Storage Efficiency	60%	82%	22%
Transportation Time Efficiency	70%	88%	18%
Inventory Forecast Accuracy	68%	90%	22%
Overall Food Waste Reduction	—	—	25–30%

Table 2 shows that AI implementation significantly improves forecasting accuracy and supply chain efficiency. The most notable improvements are observed in inventory forecasting and storage

efficiency, both of which directly influence the reduction of food waste.

Figure 1: AI-Based Agricultural Supply Chain Framework for Food Waste Reduction

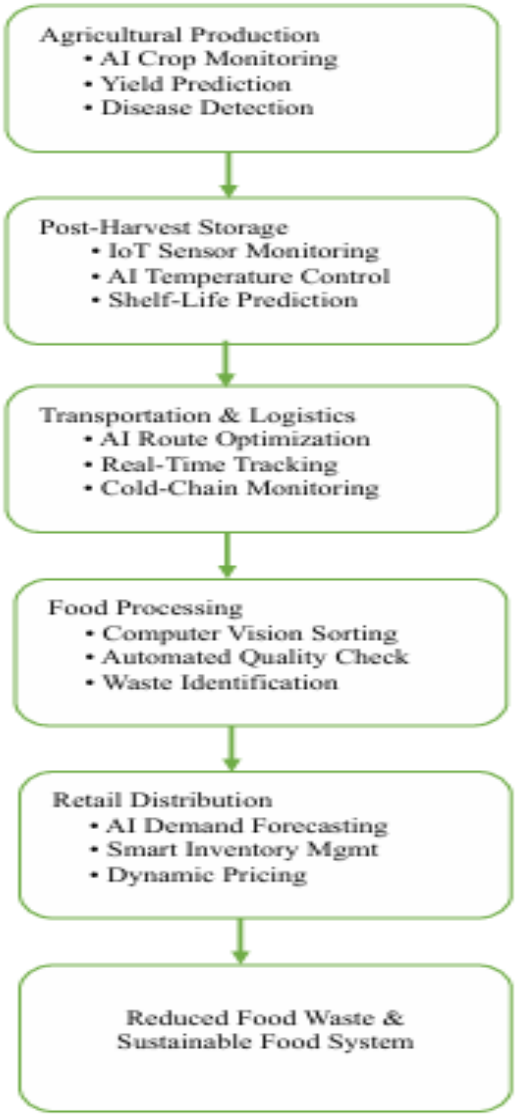

Figure 1 illustrates the integrated framework through which AI technologies support waste reduction throughout the agricultural supply chain. Each stage benefits from specific AI tools that improve efficiency and coordination among stakeholders.

Discussion

The findings confirm that artificial intelligence plays a critical role in transforming traditional agricultural supply chains into more efficient and sustainable systems. By integrating AI technologies into various operational processes, stakeholders can identify inefficiencies, predict potential losses, and implement preventive measures before food spoilage occurs.

One of the most significant advantages of AI is its ability to process large volumes of data from multiple sources, including sensors, satellite imagery, weather forecasts, and market data. This data-driven decision-making approach enables farmers, distributors, and retailers to respond more effectively to supply chain challenges. For example, predictive analytics can help farmers determine optimal harvesting periods, while retailers can use demand forecasting models to align inventory levels with consumer demand.

The results also highlight the importance of collaboration among supply chain stakeholders. AI technologies function most effectively when data is shared across the entire supply chain network. Integrated digital platforms allow farmers, logistics providers, and retailers to exchange information in real time, enabling coordinated decision-making and reducing inefficiencies that contribute to food waste.

However, the adoption of AI technologies is not without challenges. Many small-scale farmers lack access to the digital infrastructure required to implement AI-based systems. High implementation costs, limited technical expertise, and insufficient data availability also present barriers to adoption. Addressing these challenges requires policy support, investment in digital agriculture infrastructure, and training programs that enhance technological literacy among agricultural stakeholders.

Despite these challenges, the results clearly demonstrate that AI technologies offer substantial potential for reducing food waste across agricultural supply chains. By improving forecasting accuracy, optimizing logistics operations, and enhancing storage management, AI contributes to more sustainable food systems and helps ensure that agricultural resources are utilized efficiently. The integration of artificial intelligence into agricultural supply chains represents a promising strategy for addressing global food waste challenges while promoting sustainability, efficiency, and food security.

Conclusion

Food waste has become one of the most pressing global challenges affecting food security, environmental sustainability, and economic efficiency. A significant portion of food loss occurs across different stages of the agricultural supply chain, including production, post-harvest handling, storage, transportation, processing, and retail distribution. Traditional agricultural practices and conventional supply chain management systems often lack the precision and coordination required to effectively manage perishable food products. In this context, artificial intelligence (AI) has emerged as a transformative technological solution capable of

addressing many of the inefficiencies responsible for food waste.

The analysis presented in this study demonstrates that AI technologies can significantly contribute to reducing food waste throughout the agricultural supply chain. AI-based predictive analytics enables farmers to forecast crop yields, monitor crop health, and determine optimal harvesting periods, thereby reducing pre-harvest losses. Machine learning models and satellite-based monitoring systems further support precision agriculture by identifying potential risks such as pest infestations or environmental stress, allowing timely intervention. These technologies improve agricultural productivity while ensuring that a larger proportion of harvested crops reaches the supply chain.

AI also plays a crucial role in post-harvest management and storage systems. Smart storage facilities equipped with Internet of Things (IoT) sensors and AI monitoring systems can track environmental conditions such as temperature and humidity in real time. By automatically adjusting storage conditions, these systems help maintain product quality and extend the shelf life of perishable agricultural commodities. This significantly reduces spoilage and ensures better preservation of food products before they reach processing facilities or markets.

AI-driven logistics and transportation optimization systems contribute to minimizing food waste during distribution. Intelligent route planning algorithms and real-time tracking systems enable supply chain managers to identify the most efficient delivery routes, monitor shipment conditions, and respond quickly to disruptions. These capabilities help reduce transportation delays and prevent deterioration of perishable goods during transit.

At the retail level, AI-based demand forecasting and inventory management systems allow retailers to better align supply with consumer demand. By analyzing historical sales data, seasonal patterns, and consumer purchasing behavior, AI technologies can predict market demand more accurately and prevent overstocking. Dynamic pricing strategies and automated inventory monitoring further assist retailers in reducing surplus food products that would otherwise be discarded. Despite these advantages, the adoption of AI technologies in agricultural supply chains still faces several challenges. Limited access to digital infrastructure, high implementation costs, insufficient technical expertise, and data availability issues can restrict the widespread use of AI, particularly among small-scale farmers and developing economies. Addressing these barriers requires coordinated efforts from governments, research institutions, and private sector organizations to invest in digital agriculture infrastructure, develop training programs, and promote collaborative data-sharing platforms.

The integration of artificial intelligence into agricultural supply chains offers a promising and sustainable approach to reducing food waste while improving efficiency and productivity. By enabling data-driven decision-making, improving supply chain coordination, and enhancing transparency across agricultural systems, AI technologies can play a vital role in building more resilient and sustainable global food systems. Future research should focus on expanding AI applications in agriculture, exploring cost-effective technological solutions for smallholder farmers, and developing integrated digital platforms that support collaborative supply chain management. Through continued innovation and policy support, artificial intelligence has the potential to significantly contribute to global efforts aimed at reducing food waste and ensuring long-term food security.

Conflicts of Interest

The author declares that there is no significant competing financial, professional, or personal interests that might have influenced the performance or presentation of the work described in this manuscript.

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