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A Review on Artificial Intelligence Integration in Food Processing Supply Chains: Framework for Sustainable Development

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Abstract

Background: Food processing supply chains face increasing challenges related to food safety, product perishability, demand uncertainty, and sustainability requirements. Recent advancements in artificial intelligence (AI) have created opportunities to improve decision-making, automation, and operational efficiency across supply chain activities. Consequently, AI is emerging as a key technology for developing smarter and more resilient food systems.

Objective: This review aims to examine the current applications of AI in food processing supply chains and evaluate their impact on efficiency, food safety, traceability, and sustainability. It also identifies key challenges and future research directions for AI adoption in the sector.

Methods: A systematic review of 25 peer-reviewed studies published between 2015 and 2025 was conducted. Relevant literature was collected from scientific databases focusing on AI applications in food processing and supply chain management. The selected studies were screened based on relevance, quality, and contribution to the field. AI technologies were classified according to their application areas, including procurement, processing, quality control, packaging, logistics, and traceability. The studies were further analyzed to assess technological maturity, operational benefits, sustainability impacts, and implementation challenges.

Results: The review revealed that machine learning, deep learning, computer vision, predictive analytics, federated learning, and blockchain-integrated AI systems are increasingly used throughout food processing supply chains. AI applications significantly improve demand forecasting accuracy, product quality assessment, inventory management, predictive maintenance, and supply chain visibility. Computer vision technologies enhance automated inspection and quality assurance processes, while intelligent traceability systems strengthen food safety and transparency. Several studies reported reductions in food waste, operational costs, and resource consumption through AI-driven optimization. AI-based decision-support systems also contribute to faster and more accurate responses to supply chain disruptions. However, widespread implementation remains constrained by data quality issues, high investment requirements, limited technical expertise, infrastructure limitations, and regulatory compliance challenges. The level of adoption varies across supply chain stages, with quality control and traceability demonstrating the highest technological maturity.

Conclusion: Artificial intelligence offers substantial potential to enhance the efficiency, sustainability, resilience, and safety of food processing supply chains. Addressing technological and organizational barriers will be critical for achieving wider adoption and maximizing the benefits of AI-driven food supply chain management.

Keywords: *Artificial intelligence; Food processing supply chain; Machine learning; Computer vision; Food safety; Traceability; Sustainability; Predictive analytics; Block chain.*

Introduction

Artificial intelligence (AI) aims to develop computer systems that perform tasks typically requiring intelligence associated with an average human being's intellect. Tasks normally associated with having intelligence include learning, reasoning, perceiving, deciding, and processing language. [1] [2] [3] Recent growth in AI adoption across many industries, including food, has occurred primarily due to the enhanced speed of computers, improvements in sensor technologies, and large amounts of digitized data available to support computations. [3] [4] Common AI methods used to accomplish this functionality include deep learning (DL) and machine learning (ML), which allow computer systems to learn from data over time, identify complex patterns, and generate automated (machine-generated) accurate predictions. [4] [5]

Food processing supply chains are highly complicated and include a connection between the farm and the end-user (consumer) through a series of processes, including processing, packaging, storage, distribution and retail. A large reason for the complexity of food processing supply chains is that food can spoil very quickly; as a result, food processing supply chains can have very high chances of losing quality through spoilage, deterioration, contamination and lower demand. According to FAO [6], there continue to be global issues regarding how to ensure food safety, reduce food waste, and create environmentally sustainable food supply chains.

Traditional food supply chain management relies heavily on analyzing historical data, adhering to established protocols, and conducting manual inspections. For decades, these kinds of systems have worked for industrial food systems, but they have difficulties with changes that happen in real time, big, diverse data sets, and regulations that are growing tougher to follow. [5] Because of this, demand forecasting, inventory management, quality control, and traceability are still not operating well. Artificial intelligence is a big part of digital transformation in agri-food systems since it offers solutions that are predictive, adaptable, and automated. AI is being used more and more in food processing supply chains for things like automated quality checks, predictive maintenance, cold-chain monitoring, developing eco-friendly packaging, and identifying contamination. [7] [9]

Even if there is a lot of new research on AI, most of the studies that are already out there are either not finished or just look at one application at a time instead of the whole supply chain. This review critically assembles knowledge regarding AI technology, applications, benefits, limitations, and prospective research avenues throughout the entire food processing supply chain.

In contrast to previous reviews, which have either examined a limited number of applications or focused on one part of the food processing supply chain, this review provides an overview of the use of artificial intelligence in food processing throughout the entire supply chain. This review classifies various AI applications according to their supply chain stage, technological readiness level, and their effects on sustainability, thereby providing useful information to both researchers and industry players.

Methodology of the Review

We use a structured narrative literature review approach to synthesize recent literature associated with the application of AI in food processing supply chains. We sourced scientific literature from several well-known electronic databases: Google Scholar, Scopus, Web of Science, Science Direct and Springer Link. Included in this search were peer-reviewed journal articles, key review papers, proceedings from academic conferences, and authoritative reports published by industry scholars, with the majority of these documents published between 2015 and 2025.

Some of the key search terms used to define the literature included 'artificial intelligence', 'food processing', 'supply chain', 'machine learning', 'deep learning', 'computer vision', 'food safety', 'traceability' and 'sustainable packaging'. We selected relevant studies based on their practical benefit in the real world, the quality of the study, and the relevance of the paper(s) to the overall theme and purpose of our literature review concerning food processing supply chains. We did not include any agricultural primary industry papers where the literature was specific only to this area and which were not related to food processing supply chains.

The selected studies were classified according to (i) the employed AI technique, (ii) the phase of the food processing supply chain, (iii) the application domain, and (iv) the technology readiness level (TRL). This classification enabled a comparative and critical synthesis of trends, maturity levels, industry preparedness, and research shortages. This study follows a structured narrative review approach with systematic screening and thematic classification of the literature.

Artificial Intelligence Techniques Used in Food Processing Supply Chains

AI employs various algorithms and techniques to perform arithmetic calculations across food processing

supply chains. Several different machine learning techniques are often employed to assist in predicting consumer demand for food, finding high-quality food products, determining which suppliers should be used, and assessing how much risk exists. Common techniques include linear regression, decision trees, support vector machines, and ensemble models. [5] [10] These techniques provide information on how data has behaved historically, but they also assist with predicting how data will behave going forward based on previously identified trends.

The application of deep learning techniques, particularly Convolution Neural Networks (CNNs), in food processing has increased substantially with the advancement of computer vision technologies. CNNs are widely employed for the analysis of images captured during automated food inspection processes due to their ability to extract complex visual features with high accuracy. [7] CNN-based computer vision systems can effectively identify surface defects, foreign contaminants, variations in product shape, and colour inconsistencies that may not be easily detected through conventional inspection methods. Similarly, Zhu [8] reported that deep learning models outperform traditional machine learning approaches in food image analysis by providing higher classification accuracy and greater robustness under varying environmental conditions. The ability of CNNs to learn hierarchical feature representations makes them particularly suitable for quality control applications involving complex and heterogeneous food products.

Hybrid or computer-assisted artificial intelligence approaches combine traditional expert knowledge with data-driven analytical techniques to improve the reliability, interpretability, and accuracy of decision-making processes. These systems integrate rule-based reasoning with machine learning algorithms, thereby leveraging both human expertise and computational intelligence. [9] emphasized that hybrid AI systems are especially valuable in food processing environments where regulatory compliance, food safety, and product quality assurance are critical requirements. Furthermore, the transparent nature of hybrid decision-support systems enhances explainability and facilitates stakeholder trust, making them particularly suitable for applications that require clear and auditable decision-making processes.

Recent advances in federated learning and privacy-preserving artificial intelligence technologies have further expanded the scope of AI applications in food supply chains. Unlike conventional centralized machine learning approaches, federated learning enables multiple organizations to collaboratively develop predictive models without directly sharing sensitive data. [11] demonstrated that federated learning frameworks can effectively support food fraud detection and supply chain analytics while maintaining data privacy and confidentiality. Likewise, [12] highlighted that privacy-preserving AI technologies address major concerns related to data security, regulatory compliance, and intellectual property protection, thereby encouraging greater collaboration among stakeholders across food supply chains. These developments are expected to play a significant role in promoting secure, scalable, and trustworthy AI adoption within the food industry.

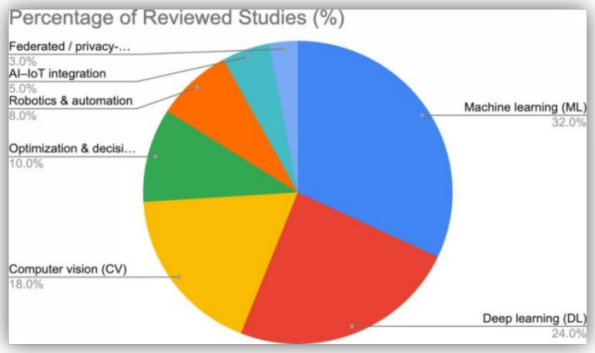

Figure 1. Major artificial intelligence techniques applied in food processing supply chains based on synthesis of peer-reviewed literature published between 2015 and 2025.

AI Applications Across the Food Processing Supply Chain

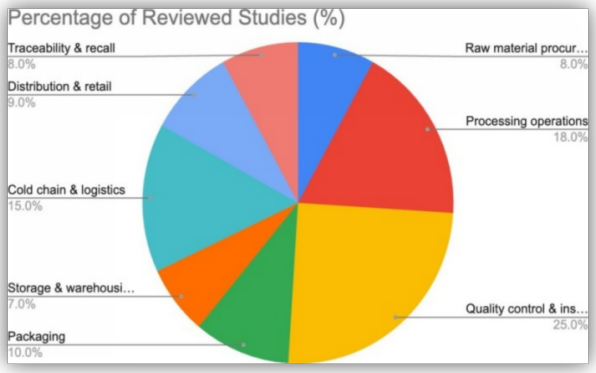

Figure 2. Distribution of AI Applications across Food Processing Supply Chain Stages.

Raw Material Procurement and Supply Risk Management

Food processors can use AI-based decision-making systems to determine their suppliers' efficiency, quantify potential raw materials available, and anticipate problems with supplies due to seasonal changes, weather

changes, or market conditions. Predictive sourcing analytics tools allow food processors to make better decisions on material sourcing based on both their previous purchases and conditions external to the stage operations and help increase the level of operational efficiency while simultaneously lowering the risk of being reliant upon any one source for supplies, which helps improve overall supply chain resiliency. [6] [24]

Processing Operations and Quality Control

AI is being applied in various innovative ways within the food industry, and AI's role in improving processes within the food production sector is by providing assistance with quality control. Computer vision systems are frequently used to rapidly and automatically assess dimensions, morphology, colour, surface defects and package integrity on production lines. [7] [13] This type of technology ensures that the end results are more consistent and less subjective while also enhancing speed.

Additionally, more complex deep-learning models allow for higher inspection accuracy with varying types of lighting conditions or original product conditions. [8] [14] As an example, multimodal sensory fusion provides an integrated form of the data from an image sensor, aspects and a chemical sensor, providing an accurate determination of freshness/quality, composition and spoilage without damaging the item being tested. [15] [16]

Predictive Maintenance of Processing Equipment

Any machine that fails unexpectedly can have an enormous impact on production schedules and the usability of a product and increase waste. Predictive maintenance systems powered by artificial intelligence (AI) utilize data related to energy consumption, noise, vibration and temperature to determine when a particular piece of equipment is at risk for failure and schedule maintenance prior to the failure. Industry examples demonstrate that using AI will significantly reduce costs associated with maintenance and downtime.

Inventory Management and Demand Forecasting

Food items with a high likelihood of spoiling require precise estimates of how much demand will exist. AI forecasting models produce accurate predictions by analyzing historical sales trends, weather data and previous marketing strategies, along with understanding how consumers behave. [5] Retailers and manufacturers using AI-enabled inventory systems experience stock-outs, reduce excess waste from overproduction, and provide flexible supply chain logistics. [17] [18]

Cold Chain and Logistics Optimization

Eliminating the risk of a cold-chain failure is critical to providing safe food products, so maintaining accurate and consistent temperatures from point-of-manufacture to point-of-sale is essential – for example, via cloud-based sensors that monitor temperature and humidity level changes in real-time in addition to estimating remaining shelf life. [19] AI-based delivery scheduling will increase the speed at which product arrives at its destination while simultaneously reducing negative environmental impact and damaging product during transportation. [20]

AI in Sustainable and Smart Food Packaging

Recent research indicates that the role artificial intelligence (AI) can play in producing intelligent, biodegradable and dynamic food packaging systems is becoming more prominent. AI modeling aids in selecting the correct materials for making packaging, improving the barrier properties of packaging, correctly predicting the shelf life of products and determining how sustainable packaging. [9] The combination of AI and lifecycle assessment (LCA) tools can also help understand the environmental impact of products and support the goals of creating a circular economy. [21]

Traceability, Food Safety, and Fraud Detection

Using AI, blockchain, and AI technologies together allows for better transparency in the tracing of food products, thus allowing for easier detection of food products which could be contaminated or to manage the product recall process. [20] Federated learning frameworks enhance the ability to expose fraudulent food products within worldwide distributed supply chains where data are kept private. [11] With the growing interest of regulatory agencies to better understand and utilize AI systems for food safety purposes, many researchers are applying explainable AI methods (such as LIME and SHAP) to help these agencies. [22]

Benefits of AI Adoption in Food Processing Supply Chains

The utilization of Artificial Intelligence (AI) methods has the potential to provide significant value to companies within the food production supply chain. Advantages include less food waste, increased operational efficiencies, higher product consistency, improved food safety systems, and improved sustainability results. [23] Using automation powered by AI allows people to make decisions before things happen, as well as to create strong supply chains when things are not clear. [16]

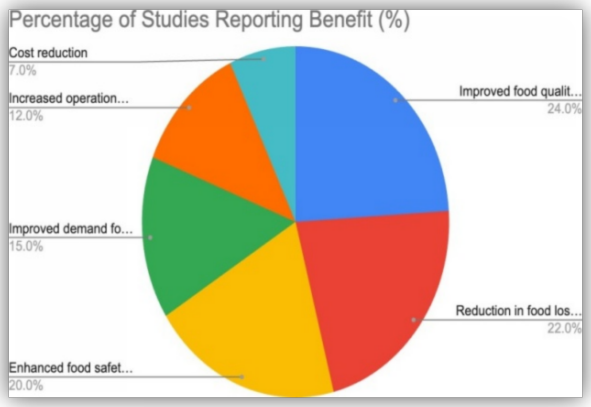

Figure 3. Key benefits achieved through artificial intelligence adoption in food processing supply chains based on synthesis of peer-reviewed literature.

Challenges and Limitations

There are many benefits that could come from using AI in food processing supply chains, but there are several obstacles that need to be overcome first. Obstacles include high costs to implement, difficulty in connecting to legacy systems, a shortage of available experienced personnel, and concerns about transparency and compliance with regulations. [5] [6] Small- and medium-sized food businesses face a larger amount of difficulty in overcoming these obstacles than large businesses. [19]

Technology Readiness and Industrial Adoption

Research indicated that the majority of artificial intelligence (AI) applications (quality inspection, predictive maintenance, and demand forecasting) have reached medium-to-high levels of technical readiness (TRL 6–8), while most applications relative to AI-driven sustainable package development, federated learning, and digital-twin-based supply chain optimization have lower TRLs (generally 3–5), demonstrating significant opportunity for both translational research and industry-based research. [9] [23]

Future Research Directions

Future investigations should focus on creating models of artificial intelligence that can provide explanation and applicability for food safety evaluations, low-data learning methods for small processors, federated analytics for cooperative supply chains and optimized models that reflect environmental considerations. There is still a major problem in linking the accomplishment achieved in the laboratory to large-scale commercial accomplishments.

Conclusion

The use of artificial intelligence is changing the way that supply chains in food processing operate by allowing processes to be automated, data-driven, and predictive for future occurrences. Although much advancement has been made, there remain many technical, organizational and regulatory obstacles that must be resolved prior to widespread deployment. Adopting and implementing AI technology thoughtfully and responsibly will enable more efficient, safe, sustainable and resilient supply chains for food processing around the world. Food processors, supply chain managers, policymakers, and developers of technology that are developing AI-based systems in the food sector find the results of this study useful. From a food science perspective, AI offers unprecedented opportunities to enhance safety assurance, quality consistency, and sustainability across food processing supply chains.

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