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The Exploring how Industry 4.0 and AI Technologies Can be Applied in the Agricultural Food Supply Chain: A Systematic Literature Review

Exploración de Cómo se Pueden Aplicar las Tecnologías de la Industria 4.0 y la IA en la Cadena de Suministro Agroalimentaria: Una Revisión Sistemática de la Literatura

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Abstract: In today's day and age, it is undoubtedly the case that the process by which food is manufactured, processed, and delivered is due to the transformation of Industry 4.0. The study aims to explore how Industry 4.0 and AI technologies can be integrated into and foster the agricultural food supply chain. For the methodology, a qualitative approach was conducted through a systematic literature review, using reliable scientific databases such as ScienceDirect, Scopus, and ResearchGate. The finding reveals that technologies such as the Internet of Things (IoT), Artificial Intelligence, and Blockchain play a pivotal role in enhancing the agri-food supply chain. Those innovations promote traceability, food safety, and demand forecasting while also maintaining sustainability through waste reduction and resource optimization. However, factors such as high costs, limited digital infrastructure, and skill gaps remain challenges to the adoption of Industry 4.0 technologies in some regions.
Keywords: *Industry 4.0; Artificial Intelligence; Agriculture; Food supply chain; Internet of Things.*

Resumen: En la actualidad, es indudable que el proceso mediante el cual se fabrican, procesan y distribuyen los alimentos se debe a la transformación de la Industria 4.0. El estudio tiene como objetivo explorar cómo la Industria 4.0 y las tecnologías de inteligencia artificial pueden integrarse y fomentar la cadena de suministro agroalimentaria. En cuanto a la metodología, se llevó a cabo un enfoque cualitativo mediante una revisión sistemática de la literatura, utilizando bases de datos científicas fiables como ScienceDirect, Scopus y ResearchGate. Los resultados revelan que tecnologías como el Internet de las cosas (IoT), la inteligencia artificial y el blockchain desempeñan un papel fundamental en la mejora de la cadena de suministro agroalimentaria. Estas innovaciones promueven la trazabilidad, la seguridad alimentaria y la previsión de la demanda, al tiempo que mantienen la sostenibilidad mediante la reducción de residuos y la optimización de los recursos. Sin embargo, factores como los altos costes, la infraestructura digital limitada y la falta de cualificación siguen siendo retos para la adopción de las tecnologías de la Industria 4.0 en algunas regiones.
Palabras clave: *Industria 4.0; Inteligencia artificial; Agricultura; Cadena de suministro alimentario; Internet de las cosas.*

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INTRODUCTION

The agricultural food supply chain plays a vital role in maintaining food security by establishing a web of connections between manufacturers, processors, and consumers. As the global population rises, there's a need for the agri-food industry to produce more effectively and sustainably. Responding to these challenges, Industry 4.0 emerges as a catalyst for transforming the sector and enhancing supply chain sustainability.

In recent years, the agricultural sector has been turning towards digital transformation to address the mentioned obstacles. Technologies under the Industry 4.0 framework - such as the IoT, AI, Big Data analytics, and Blockchain - are redefining the way in which food is produced, processed, and distributed. By incorporating automation and real-time analysis, these innovations have the potential to promote a smarter and sustainable agri-food system (Moudoud, Cherkaoui & Khoukhi, 2019).

Among these technologies, machine learning (ML) enables predictive analysis for demand forecasting, decision-making in logistics, and inventory management; thereby assisting producers and distributors in reducing delays and minimizing waste. Moreover, IoT, such as sensors and trackers, also ensures visibility across every stage of the supply chain. Specifically, the visibility spans from monitoring crop storage conditions to tracking temperature and humidity during transport, thus preserving product quality and safety.

Despite the given benefits, widespread implementation still remains limited. Factors, including high infrastructure costs, skill gaps, and data privacy concerns, pose major obstacles to the adoption of the Industry 4.0 framework, especially in developing countries.

Given the context, our study aims to explore how Industry 4.0 and AI technologies can be integrated into the agricultural food supply chain. By conducting a systematic literature review, the study is able to identify three main keys: main benefits, barriers, and future opportunities of Industry 4.0 technologies; thus emphasizing how those technological innovations can foster efficiency, sustainability, and traceability across the agri-food sector (Islam, Mehta & Akter, 2022).

THEORETICAL BACKGROUND

Industry 4.0 and Agriculture

Industry 4.0 represents the fourth industrial revolution, characterized by the fusion of physical, digital, and biological systems. It relies on automation, cyber-physical systems, and real-time data analytics to create smart, interconnected production environments (Andronie et al, 2021). In agriculture,

this paradigm shift leads to Agriculture 4.0, where digital tools and data-driven technologies enhance every phase of food production—from cultivation and processing to logistics and retail.

The integration of Industry 4.0 technologies brings a holistic change to agricultural practices. Precision farming, smart irrigation, autonomous machinery, and digital marketplaces are redefining efficiency and sustainability. By collecting granular data on soil moisture, crop health, and weather patterns, farmers can make data-informed decisions that reduce waste and increase yields (Chen, Z. & Zou, T., 2024). Furthermore, through predictive maintenance powered by AI, machinery downtime is reduced, operational costs decline, and productivity rises.

The Role of Artificial Intelligence and IoT

Artificial Intelligence enables the transformation of raw data into actionable insights. In agriculture, AI systems can identify disease symptoms in crops using computer vision, predict pest infestations, and optimize harvest timing through machine learning algorithms (Javaid et al., 2023). The combination of AI and IoT creates a "smart network" of devices—drones, sensors, and cameras—that communicate with centralized systems for real-time decision-making.

IoT technologies are instrumental in achieving visibility throughout the supply chain. From smart greenhouses to automated cold storage facilities, IoT devices collect continuous data on temperature, humidity, and location. This information ensures that perishable products are maintained under optimal conditions during transportation and storage, significantly reducing food loss (Ahmed. & Shakoor, 2025). AI further enhances this by predicting demand, enabling producers to plan distribution routes efficiently, reducing both waste and costs.

Blockchain and Traceability in the Food Supply Chain

Blockchain's immutable and decentralized nature offers unique advantages in addressing one of agriculture's most pressing issues: traceability. Traditional supply chains often involve multiple intermediaries, making it difficult to trace the origin of food products or detect points of contamination. Blockchain technology eliminates this opacity by recording every transaction cultivation, processing, shipment, and saleon a transparent ledger accessible to all stakeholders (Sivakumar, Nagarajan, & Maruthi, 2023).

By linking Blockchain with IoT, every batch of produce can carry a digital identity, accessible through QR codes. Consumers can instantly verify where their food came from, under what conditions it was produced, and whether it meets safety standards. For instance, IBM's Food Trust platform has demonstrated the capacity to trace the source of contaminated lettuce within 2.2 seconds, compared to

nearly seven days using traditional methods (Civitillo, 2024). This capability not only safeguards consumer health but also prevents financial losses caused by large-scale recalls.

Sustainability and Smart Logistics

Sustainability is at the heart of Industry 4.0 applications in agriculture. AI-powered analytics optimize fertilizer and water usage, reducing pollution and conserving natural resources. IoT-driven logistics platforms monitor fuel consumption and temperature control, minimizing spoilage and carbon emissions. By integrating these technologies, agricultural supply chains can transition toward circular economy models—where waste is minimized, and by-products are reintegrated into the production cycle (Khan et al., 2025).

Moreover, data-driven logistics powered by AI contribute to demand forecasting and inventory management, preventing overproduction and ensuring better resource allocation. As global trade and climate variability increase complexity in food systems, such adaptive and intelligent mechanisms are critical for long-term resilience.

METHODOLOGY

This research follows a qualitative approach through a systematic literature review, aiming to synthesize recent academic findings regarding the integration of Industry 4.0 and AI technologies into agricultural supply chains. The methodological process was carried out between August and November 2024.

Data Collection

Data were gathered from recognized scientific databases including ScienceDirect, Scopus, IEEE Xplore, and ResearchGate. The keywords applied were: “Industry 4.0”, “Artificial Intelligence”, “Internet of Things”, “Blockchain”, “Agriculture”, and “Food Supply Chain”, using Boolean operators such as “AND” and “OR” to refine searches.

Inclusion and Exclusion Criteria

Inclusion criteria consisted of:

- Articles published between 2015 and 2024.
- Peer-reviewed journal papers or conference proceedings.
- Studies in English addressing digital transformation in agriculture.

Exclusion criteria were:

- Non-peer-reviewed sources, monographs, or incomplete studies.
- Articles not focusing on agri-food supply chain applications.

Screening and Analysis

An initial search yielded 67 publications. After abstract screening and applying inclusion criteria, 22 articles were selected for full-text analysis. Among these, 15 papers were deemed most relevant and used in this review. Each study was analyzed based on its focus area (IoT, AI, Blockchain, or integration models), benefits, challenges, and regional context.

The selected literature was organized into a thematic synthesis, categorizing findings into four dimensions: (1) operational efficiency, (2) traceability and safety, (3) sustainability, and (4) barriers to implementation. This approach aligns with the methodology applied in similar integrative reviews such as RIMA.

RESULTS AND DISCUSSION

Digital Transformation and Operational Efficiency

Findings demonstrate that Industry 4.0 technologies significantly improve efficiency in agricultural supply chains. IoT sensors provide real-time monitoring of crop growth and storage environments, allowing early detection of irregularities. AI-based systems analyze these datasets to forecast yield and market demand, reducing inventory waste (Kollia, Stevenson & Kollias, 2021). Automation, supported by robotics and drones, accelerates harvesting and quality inspection, shortening time-to-market.

Furthermore, digital platforms enhance coordination among suppliers, processors, and distributors. Smart contracts powered by Blockchain ensure that payments and deliveries are executed automatically once conditions are met, minimizing human error and delays (Khan, 2021). This level of transparency and automation represents a paradigm shift from traditional, linear supply chains to interconnected, data-driven networks.

Traceability and Food Safety

One of the most impactful applications of Blockchain and IoT integration lies in food traceability. Data collected through IoT sensors—temperature, humidity, or GPS coordinates—are continuously updated on Blockchain systems, creating a tamper-proof digital footprint for each product batch (Vitaskos

et al., 2024). In case of contamination or recall, authorities can immediately identify the source, preventing further spread and ensuring accountability across the chain.

Consumer confidence has also increased through such systems. QR code-enabled packaging allows individuals to trace a product's origin, processing methods, and transportation details. Companies like Ripe.io and Provenance have successfully implemented Blockchain-based traceability platforms to enhance consumer transparency and trust (TRACEX, 2024).

Sustainability and Environmental Impact

Industry 4.0 technologies contribute extensively to environmental sustainability. AI algorithms optimize resource allocation, leading to substantial reductions in water and fertilizer consumption. Smart irrigation systems using predictive models can lower water use by up to 35%, while precision agriculture reduces the overuse of agrochemicals by 20% (Kharat et al., 2025).

In logistics, AI-driven route optimization reduces fuel consumption and emissions, while IoT devices in storage units maintain optimal temperature and humidity, decreasing spoilage rates. These improvements collectively advance the United Nations' Sustainable Development Goals (SDGs), particularly SDG 2 (Zero Hunger) and SDG 12 (Responsible Consumption and Production).

Barriers to Implementation

Despite these advantages, several obstacles persist. The high cost of digital infrastructure and IoT devices limits accessibility for small-scale farmers. Limited digital literacy and lack of training hinder technology adoption, particularly in rural communities (Arangurí et al., 2025). Data privacy and interoperability remain unresolved, as various systems use incompatible standards and protocols.

Moreover, in many developing regions, unreliable electricity and internet connectivity restrict the effectiveness of real-time monitoring systems. Public–private collaboration and government policies are essential to build the technological and educational foundation required for a successful digital transition.

CONCLUSIONS

The convergence of Industry 4.0 technologies - Artificial Intelligence, IoT, and Blockchain - has redefined the future of the agricultural food supply chain. These technologies bring forth unprecedented opportunities for efficiency, traceability, and sustainability. Through the digitalization of processes, farmers gain actionable insights that optimize resource use, enhance productivity, and minimize waste. At the same time, Blockchain provides transparency and trust, ensuring that consumers receive safe, verifiable products.

However, the digital transformation of agriculture also presents complex challenges. The gap between technologically advanced and resource-limited regions continues to grow, threatening inclusivity. Financial constraints, lack of standardization, and insufficient human capital slow down the pace of adoption. To address these challenges, governments, research institutions, and the private sector must collaborate to provide financial incentives, training programs, and infrastructure development.

Future research should focus on developing integrated frameworks that combine AI, IoT, and Blockchain in a cost-effective and scalable manner. Furthermore, policy frameworks ensuring data protection and interoperability are crucial for establishing trust among stakeholders. If these barriers are overcome, Industry 4.0 technologies will not only revolutionize food supply chains but also contribute to achieving global food security, environmental sustainability, and economic resilience in the decades to come.

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