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Technological innovation in agribusiness: A systematic review of emerging technologies, sustainability impacts and adoption challenges

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Abstract

Technological innovation is rapidly transforming the agribusiness sector by providing solutions to food security, climate change, and resource management challenges. This systematic review synthesizes recent literature on major technological innovations in agribusiness, including precision agriculture, Internet of Things (IoT), artificial intelligence (AI), agricultural robotics, and blockchain technology. Using a structured review approach, peer-reviewed studies published between 2002 and 2025 were analyzed to evaluate the impacts of these technologies on productivity, efficiency, sustainability, and supply chain management.

The review reveals that precision agriculture and AI-based systems demonstrate the strongest positive impacts on productivity and resource optimization, while blockchain technology shows promise primarily in traceability and food safety management. However, the effectiveness of these technologies varies depending on infrastructure availability, technical expertise, and economic capacity. Studies also indicate that smallholder farmers in developing countries face significant barriers related to cost, digital literacy, and limited internet connectivity, contributing to a widening digital divide in agriculture.

Although technological innovation offers substantial benefits, some studies highlight concerns regarding data privacy, high implementation costs, technological dependency, and unequal access to digital resources. Existing literature remains heavily focused on developed economies, with limited long-term studies assessing socio-economic impacts in developing regions. The review emphasizes the need for inclusive innovation strategies, stronger policy support, affordable digital solutions, and future research focused on accessibility and sustainability.

Keywords: Agribusiness; Technological Innovation; Digital Agriculture; Artificial Intelligence; Iot; Sustainability

1. Introduction

Agribusiness plays a critical role in global food systems, rural development, employment generation, and economic growth. As the world population is projected to reach nearly 10 billion by 2050, agricultural production must significantly increase while maintaining environmental sustainability and efficient resource utilization (FAO, 2017). However, the agricultural sector continues to face major challenges, including climate change, land degradation, water scarcity, increasing production costs, and labor shortages.

In response to these challenges, technological innovation has emerged as a major driver of transformation within agribusiness systems. Advances in digital technologies have enabled the modernization of agricultural practices, improving productivity, operational efficiency, and sustainability (Wolfert et al., 2017). Technological innovations now

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influence nearly all stages of the agricultural value chain, including production, processing, storage, distribution, marketing, and supply chain management.

The emergence of precision agriculture, Internet of Things (IoT), artificial intelligence (AI), agricultural robotics, and blockchain technology has significantly reshaped agricultural decision-making processes. These technologies enable farmers and agribusiness firms to collect real-time data, automate operations, optimize resource allocation, and improve traceability within food systems. Precision agriculture technologies, for example, allow site-specific management of crops through GPS systems, remote sensing, and geographic information systems. Similarly, AI and machine learning applications support predictive analysis, crop disease detection, and farm optimization.

Despite the increasing adoption of digital technologies, the benefits of technological innovation remain unevenly distributed across regions and farming systems. Developed countries generally demonstrate higher levels of technological adoption due to stronger infrastructure, financial support, and technical expertise. In contrast, developing countries and smallholder farmers often face barriers related to affordability, digital literacy, limited internet access, and insufficient institutional support.

Furthermore, although many studies highlight the benefits of technological innovation, concerns remain regarding implementation costs, technological dependency, data privacy, and socio-economic inequality. Existing literature also lacks sufficient long-term assessments of the economic, environmental, and social impacts of digital agriculture, particularly in developing economies.

Given these issues, there is a need for a comprehensive synthesis of current literature on technological innovation in agribusiness. This study aims to systematically review major technological innovations, evaluate their impacts on productivity and sustainability, identify barriers to adoption, and examine existing research gaps. The findings of this review may provide valuable insights for researchers, policymakers, agribusiness practitioners, and stakeholders involved in sustainable agricultural development.

2. Methodology

2.1. Research Design

This study employed a systematic literature review approach to comprehensively analyze existing research on technological innovation in agribusiness. A systematic review was selected because it allows for the organized identification, evaluation, and synthesis of relevant scholarly studies while minimizing bias and improving research transparency. Compared to traditional narrative reviews, this approach ensures a more structured and replicable analysis of technological trends, impacts, and adoption challenges.

The review followed four major stages: literature identification, screening, eligibility assessment, and thematic synthesis. This process enabled the study to compare findings across different technological innovations and identify recurring patterns, limitations, and research gaps.

2.2. Data Sources and Search Strategy

Relevant studies were collected from major academic databases, including Google Scholar, Scopus, and Web of Science. The search process focused on peer-reviewed journal articles published between 2002 and 2025. Keywords used in the search included "precision agriculture," "IoT in agriculture," "artificial intelligence in farming," "digital agriculture," "blockchain in agriculture," "smart farming," and "agribusiness innovation."

A total of 145 articles were initially identified during the database search. After removing duplicate and unrelated studies, 87 articles remained for screening. Following eligibility assessment based on the inclusion criteria, 52 studies were selected for final analysis.

The screening process excluded studies that:

- were not peer-reviewed,
- lacked relevance to agribusiness applications,
- focused solely on engineering without agricultural implications,
- or provided insufficient empirical or theoretical evidence.

The publication trend showed increasing scholarly interest after 2015, reflecting the rapid expansion of digital agriculture and Industry 4.0 technologies.

2.3. Selection Criteria

Studies were selected based on the following criteria:

- Peer-reviewed journal articles
- Direct relevance to agribusiness and technological innovation
- Publication within the last 20 years
- Empirical or theoretical contribution
- Availability of clear methodology and findings

To ensure research quality, selected studies were evaluated according to methodological rigor, clarity of data analysis, relevance to agribusiness applications, and contribution to technological innovation literature.

2.4. Data Analysis

The selected studies were analyzed using thematic coding and comparative analysis techniques. Key themes were identified based on recurring topics across the literature, including technological innovations, productivity impacts, sustainability outcomes, adoption barriers, and policy implications.

A comparative matrix was also used to examine similarities and differences among technologies in terms of cost, accessibility, efficiency, sustainability contribution, and implementation challenges. This analytical approach enabled the identification of major trends, limitations, and research gaps across various technological applications in agribusiness.

3. Theoretical Foundations

The adoption of technological innovation in agribusiness can be explained through several theoretical frameworks.

The Diffusion of Innovation Theory proposed by Rogers (2003) explains how new technologies spread among individuals and organizations over time. According to this theory, adoption is influenced by perceived advantages, compatibility, complexity, trialability, and observability. In agribusiness, technologies perceived as expensive, difficult to operate, or inaccessible are adopted more slowly, particularly among smallholder farmers in developing regions.

The Resource-Based View (RBV) introduced by Barney (1991) suggests that technological capabilities can serve as strategic resources that improve competitive advantage. Agribusiness firms with stronger financial capacity, technological infrastructure, and skilled human resources are better positioned to adopt and benefit from digital innovation.

Additionally, the Triple Bottom Line (TBL) framework developed by Elkington (1997) highlights the importance of balancing economic, environmental, and social performance. Technological innovation contributes to this integration by improving operational efficiency, reducing environmental impact, and enhancing sustainability outcomes.

The Diffusion of Innovation Theory also helps explain disparities in technological adoption between developed and developing countries. Developed economies generally possess stronger digital infrastructure, higher literacy levels, and better institutional support systems, enabling faster diffusion of innovation. Conversely, many rural agricultural communities continue to experience technological exclusion due to limited internet access and insufficient technical support.

Similarly, the Triple Bottom Line framework is directly related to sustainability outcomes discussed in this review. Technologies such as precision agriculture and IoT contribute to economic efficiency, environmental conservation, and improved resource management. However, unequal access to technology may limit the social sustainability benefits of innovation, particularly in low-income farming communities.

4. Key Technological Innovations in Agribusiness

4.1. Precision Agriculture

Precision agriculture involves the use of GPS systems, remote sensing technologies, drones, and geographic information systems to optimize agricultural management practices (Zhang et al., 2002). These technologies enable site-specific input application, allowing farmers to manage crops based on variations in soil, moisture, nutrient levels, and environmental conditions.

Precision agriculture improves productivity while reducing environmental impact through efficient resource utilization. Farmers can optimize fertilizer application, irrigation schedules, and pesticide use, thereby reduce operational costs and minimize waste.

However, despite its advantages, precision agriculture requires substantial investment in equipment, software, and technical training. Smallholder farmers often face affordability challenges and may lack sufficient knowledge to maximize the technology's effectiveness.

4.2. Internet of Things (IoT)

The Internet of Things (IoT) refers to interconnected devices and sensors that collect and exchange real-time agricultural data. IoT technologies enable continuous monitoring of soil conditions, weather patterns, crop growth, livestock health, and irrigation systems (Verdouw et al., 2016).

These systems improve farm management by providing accurate and timely information that supports data-driven decision-making. IoT technologies contribute to water conservation, efficient fertilizer use, and early detection of agricultural problems.

Despite these benefits, IoT implementation depends heavily on stable internet connectivity and reliable infrastructure. In many rural areas, weak network coverage and limited digital infrastructure reduce the effectiveness of IoT-based systems. Data security and privacy concerns also remain major challenges in large-scale agricultural data collection.

4.3. Artificial Intelligence and Big Data

Artificial intelligence and big data analytics have become increasingly important in modern agriculture. AI technologies support predictive decision-making, crop disease detection, yield forecasting, weather prediction, and farm optimization (Liakos et al., 2018).

Machine learning algorithms analyze large volumes of agricultural data to identify patterns and improve operational efficiency. AI systems can also support automated decision-making processes that reduce labor requirements and improve productivity.

However, the effectiveness of AI applications depends heavily on data quality and accessibility. Poor-quality datasets may reduce prediction accuracy and algorithm reliability. Additionally, advanced AI technologies often require expensive infrastructure, technical expertise, and continuous data management.

4.4. Agricultural Robotics

Agricultural robotics involves the use of automated machines and robotic systems to perform agricultural tasks such as planting, harvesting, spraying, and monitoring crops (Duckett et al., 2018).

Robotic systems improve operational efficiency by reducing labor dependency and increasing precision in farming activities. Automation also helps address labor shortages and reduces human exposure to hazardous agricultural chemicals.

Nevertheless, agricultural robotics remains expensive for many farmers, particularly small-scale producers. High acquisition costs, maintenance expenses, and training requirements continue to limit widespread adoption.

4.5. Blockchain Technology

Blockchain technology improves transparency and traceability within agricultural supply chains. Through decentralized digital records, blockchain systems help improve food safety, product authentication, and transaction security (Tian, 2017).

Blockchain enhances consumer trust by enabling transparent tracking of agricultural products from production to distribution. The technology also reduces fraud and improves accountability among supply chain participants.

However, blockchain implementation faces challenges related to interoperability, scalability, implementation costs, and technical complexity. Some researchers argue that blockchain systems may be difficult to implement effectively in developing agricultural markets with limited digital infrastructure.

5. Results and Discussion

5.1. Productivity and Efficiency Gains

The literature consistently demonstrates that technological innovation significantly improves agricultural productivity and operational efficiency. Precision agriculture technologies reduce input waste through site-specific management practices, while IoT systems improve real-time monitoring and resource optimization.

Comparative findings indicate that precision agriculture and AI-based systems provide the strongest positive impacts on productivity enhancement and resource management. AI applications improve predictive analysis and operational decision-making, while IoT technologies contribute to monitoring efficiency and automated farm management.

Blockchain technologies contribute more significantly to supply chain transparency and traceability than direct productivity improvement. Agricultural robotics, meanwhile, primarily improves labor efficiency and operational precision.

5.2. Sustainability Impacts

Technological innovation contributes significantly to environmental sustainability through efficient use of water, fertilizers, pesticides, and energy resources. Precision agriculture and IoT systems help reduce excessive chemical use and improve conservation practices.

AI technologies support climate-smart agriculture by improving weather forecasting, crop monitoring, and predictive analysis. These technologies help farmers respond more effectively to environmental risks and climate variability.

However, some researchers argue that digital agriculture may also create unintended environmental consequences. Energy consumption associated with data centers, blockchain systems, and continuous digital operations may increase carbon emissions if not properly managed.

5.3. Adoption Disparities

The review highlights significant disparities in technological adoption across regions and farming systems. Developed countries demonstrate higher adoption rates due to stronger internet infrastructure, government support programs, and greater financial capacity.

In contrast, smallholder farmers in developing countries face substantial barriers related to affordability, limited digital literacy, weak infrastructure, and inadequate technical support. These conditions contribute to a widening digital divide within the agricultural sector.

The unequal distribution of technological resources may increase socio-economic inequalities between large-scale agribusiness firms and resource-constrained farmers. Consequently, inclusive innovation strategies are necessary to ensure equitable access to digital technologies.

5.4. Critical Analysis

Although technological innovation offers significant benefits, its effectiveness remains highly context-dependent. Advanced technologies often provide greater advantages to agribusiness firms with strong financial and technical capabilities.

Critics argue that rapid digitalization may increase dependency on external technology providers and widen inequalities if smallholder farmers remain excluded from innovation systems. Additionally, concerns regarding data privacy, cybersecurity, and ownership of agricultural data continue to emerge as important ethical issues.

Therefore, technological innovation should not be viewed solely as a technical solution but also as a socio-economic issue requiring supportive policies, institutional collaboration, and inclusive development strategies.

6. Challenges in Adoption

Several barriers continue to limit the widespread adoption of technological innovation in agribusiness.

One major challenge is the high initial investment cost associated with digital technologies, including sensors, drones, automated machinery, and data management systems. Many smallholder farmers cannot afford these technologies without financial assistance or government support.

Limited digital literacy also affects adoption rates. Farmers with insufficient technical knowledge may struggle to operate advanced technologies effectively. In addition, inadequate internet connectivity and weak infrastructure reduce access to digital agricultural systems in rural areas.

Data privacy and cybersecurity concerns also present important challenges. Large-scale collection and storage of agricultural data raise questions regarding data ownership, security, and ethical management.

Furthermore, lack of standardization among digital platforms and technologies may create compatibility issues that hinder integration across agricultural systems.

7. Research Gaps and Future Directions

Despite growing literature on digital agriculture, important research gaps remain.

Existing studies focus primarily on large-scale farming systems and developed economies, while limited attention has been given to smallholder farmers and low-income agricultural communities. There is also insufficient long-term empirical research evaluating the economic, environmental, and social impacts of technological innovation over time.

Moreover, limited studies examine the relationship between policy interventions, digital infrastructure development, and technology accessibility. Future research should investigate how government policies, educational programs, and institutional partnerships influence adoption outcomes.

Future studies should prioritize:

- affordable and scalable technologies for smallholder farmers,
- long-term sustainability assessments,
- policy-driven digital inclusion strategies,
- ethical management of agricultural data,
- and integrated technological systems combining AI, IoT, and blockchain applications.

Researchers should also explore how technological innovation can reduce, rather than intensify, socio-economic inequalities in global agricultural systems.

8. Conclusion

Technological innovation is reshaping agribusiness by improving productivity, efficiency, sustainability, and supply chain transparency. Technologies such as precision agriculture, IoT, AI, agricultural robotics, and blockchain systems offer substantial opportunities to modernize agricultural operations and support sustainable development.

Among the technologies reviewed, precision agriculture and AI-based systems demonstrate the strongest contributions to productivity improvement and resource optimization. However, the benefits of technological innovation remain unevenly distributed due to barriers related to affordability, infrastructure limitations, digital literacy, and technical capacity.

The findings also reveal that technological innovation should be implemented through inclusive and sustainable approaches that consider social, economic, and environmental dimensions. Policymakers, researchers, and agribusiness stakeholders must collaborate to improve digital infrastructure, strengthen technical education, and support affordable technology access for smallholder farmers.

Future research should focus on long-term impact assessment, digital inclusion strategies, and sustainable innovation systems that promote equitable agricultural development. Through inclusive and responsible technological advancement, agribusiness can contribute significantly to global food security, environmental sustainability, and rural economic growth.

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