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The Contribution of Technology and Innovation to Achieving Food Security in Algeria

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Abstract. Food security is a critical issue for most governments, yet it remains difficult to achieve in many countries due to challenges such as resource scarcity, inefficient distribution systems, and climate-related risks. However, the effective integration of digital technology into agriculture may help mitigate these issues. Therefore, this study aimed to examine the contribution of technology and innovation to achieving food security in Algeria. A purposive sampling technique was used to collect data from 125 respondents, including farmers, agricultural extension workers, cooperatives, and policymakers. Using multiple regression analysis, the results indicated that supply chain and food distribution optimization, precision agriculture, reducing food waste, sustainable farming practices, and biotechnology significantly influence food security, with supply chain optimization and precision agriculture emerging as the strongest predictors. Ultimately, this study provides important insights for stakeholders, highlighting the need to align technological adoption with supportive policies and capacity-building initiatives to strengthen national food security.

Keywords: food security, digital technology, precision agriculture, supply chain optimization, sustainable farming, Algeria

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Вклад технологий и инноваций в обеспечение продовольственной безопасности в Алжире

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Аннотация. Продовольственная безопасность является одной из ключевых задач для большинства правительств, однако во многих странах ее достижение остается затруднительным из-за таких проблем, как ограниченность ресурсов, неэффективность систем распределения и климатические риски. Эффективная интеграция цифровых технологий в сельское хозяйство может способствовать смягчению этих проблем. Настоящее исследование направлено на анализ вклада технологий и инноваций в обеспечение продовольственной безопасности в Алжире. Для сбора данных использовалась целевая выборка, включающая 125 респондентов — фермеров, работников сельскохозяйственных служб, представителей кооперативов и органов власти.

На основе множественного регрессионного анализа было установлено, что такие факторы, как оптимизация цепочек поставок и распределения продовольствия, точное земледелие, сокращение продовольственных потерь, устойчивые фермерские практики и биотехнологии, оказывают значительное влияние на продовольственную безопасность. Наибольший вклад вносят оптимизация цепочек поставок и точное земледелие, выступая наиболее сильными предикторами модели. В конечном итоге исследование предлагает важные выводы для заинтересованных сторон, подчеркивая необходимость согласования внедрения технологий с поддерживающей политикой и инициативами по развитию потенциала для укрепления национальной продовольственной безопасности.

Ключевые слова: продовольственная безопасность, цифровые технологии, точное земледелие, оптимизация цепочек поставок, устойчивое сельское хозяйство, Алжир

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1. Introduction

Many developing countries continue to struggle with food insecurity, driven by factors such as population growth, climate change, low income levels, the spread of diseases and epidemics, and recurring droughts in certain regions (Galanakis et al., 2021; Hassoun et al., 2023; Oh & Lu, 2023). Addressing these challenges requires integrated agricultural policies and a strategic vision that considers economic, political, and social dimensions (Erokhin et al., 2021). The global population is projected to reach 9 billion by 2050, with food demand expected to increase by 70% (Yu et al., 2022). Food contamination and waste have significantly contributed to the rising incidence of foodborne diseases and the persistence of food insecurity in many countries worldwide (Meliana et al., 2024). According to the Food and Agriculture Organization of the United Nations, the four key principles of food security are «food availability, access, utilization, and stability» (Erickson et al., 2021). Food security challenges moved to the forefront of political and economic discussions during the COVID-19 pandemic, as many countries around the world faced severe food crises (e.g., supply chain disruptions) (Erokhin et al., 2021). Consequently, achieving food security is both an urgent necessity and a crucial step toward reducing poverty, eradicating hunger, and fostering sustainable development (Malec et al., 2024; Mihrete & Mihretu, 2025).

In this digital age, the successful adoption and implementation of technological solutions can play a vital role in enhancing the performance of the agricultural sector and mitigating the severity of food insecurity (Mouloudj et al., 2025; Smidt & Jokonya, 2022; Were et al., 2016). The adoption of digital technologies by farmers has improved efficiency, reduced negative environmental impacts, and enhanced the sustainability of production, supply, and marketing systems (Dibbern et al., 2024; Gupta et al., 2025; Wang et al., 2022). Pandey and Mishra (2024) argue that AI has the potential to address «food security challenges». The benefits of applying technology in agriculture extend to improved food security, nutrition, and public health (Richter et al., 2023; Zhao et al., 2025). Several recent studies have confirmed that the adoption of digital technologies — such as "artificial intelligence (AI), big data analytics, machine learning, cloud computing, the Internet of Things (IoT), and blockchain"— contributes positively to achieving food security in the agricultural sector (Galanakis et al., 2021; Gouvea et al., 2022; Hassoun et al., 2023; Malec et al., 2024). However, in many developing countries, including Algeria, agricultural practices remain largely traditional, and the integration of technology into farming activities is slow, requiring significant efforts from multiple stakeholders (Adegbaju et al., 2024; Erokhin et al., 2024). Indeed, numerous barriers hinder the adoption of agricultural technologies in these countries, including limited resources, inadequate infrastructure, low levels of awareness, lack of technological knowledge, and insufficient government support (Dibbern et al., 2024; Ma & Rahut, 2024).

Although numerous studies have examined the antecedents of digital technology adoption in the agricultural sector (e.g., Dibbern et al., 2024, 2025; Erokhin et al., 2024) and the barriers to implementing digital solutions on farms (e.g., Richter et al., 2023), relatively few have investigated the link between the adoption of modern technological tools and the achievement of food security, particularly in developing countries (e.g., Hasan et al., 2018; Oh & Lu, 2023), such as Algeria. Furthermore, Saha et al. (2025) recommended that geographical differences be carefully considered, since agricultural practices, climate conditions, and crop varieties vary significantly across countries. This implies that research findings from one context cannot be readily generalized to others. Therefore, further investigation is required to better understand the role of technology and innovation in supporting food security across diverse settings. So, this study seeks to address this gap by examining the impact of five dimensions of technology and innovation — namely precision agriculture, genetic engineering and biotechnology, sustainable farming practices, supply chain and food distribution optimization, and food waste reduction — on food security in Algeria. The analysis is conducted from the perspective of various stakeholders, including farmers, agricultural extension agents, agricultural experts, cooperatives, and policymakers.

2. Literature Review and Research Hypotheses

2.1. Using digital technology to achieve food security

Pandey and Mishra (2024) report that the causes of food insecurity are multifaceted and include insufficient agricultural investment and infrastructure, climate change, poverty and low income, market volatility, food waste, resource and technology scarcity, population growth, and conflicts. In this context, digital solutions can play an important role in reducing food insecurity, as smart and digital agriculture have emerged as contemporary models that complement or even challenge traditional agricultural practices (Gupta et al., 2025). Digital agriculture — also referred to as «digital farming», «Agriculture 4.0», «smart farming», or «smart agriculture» — encompasses a wide range of technology-driven approaches to modern farming (Dibbern et al., 2024). In recent years, technology has accelerated the digital transformation of many sectors, and agriculture is no exception (Richter et al., 2023). The sector has witnessed the emergence of numerous innovative technologies — such as AI, drones, IoT, sensors, and blockchain — that help farmers enhance the efficiency and effectiveness of their operations, thereby significantly improving overall performance (Erokhin et al., 2024). Digital agriculture is defined as "the use of information and communication technologies in collecting, generating, transmitting, storing, and analyzing data to enhance decision-making at all stages of the agricultural value chain" (Dibbern et al., 2024, p. 1).

In the same context, Smidt and Jokonya (2022) stated that digital technologies (e.g., mobile platforms) enable smallholder farmers to overcome key constraints that hinder their participation in agricultural value chains. Contemporary technologies (e.g., smart irrigation) have the potential to reduce energy consumption in agriculture. Pandey and Mishra (2024) emphasize that the use of AI enhances «predictive modeling» and precision agriculture, while also facilitating the detection of crop diseases, thereby contributing to food security. In addition to contributing to food sufficiency, Zhao et al. (2025) argue that agricultural technological innovation is an essential tool for promoting sustainable development and improving population health by reducing pollution. In addition, Wang et al. (2022) found that the implementation of blockchain technology increased the qualification rate of agricultural products by approximately 30% and significantly improved the efficiency of the agricultural product trading system, thereby enhancing «economic benefits».

In contrast, Dibbern et al. (2025) emphasized that the adoption of digital agriculture in Latin American countries is hindered by several barriers, including limited technological knowledge and digital awareness among producers, unfavorable economic and financial conditions, a shortage of qualified labor, the limited availability of companies providing agricultural technology services, and inadequate infrastructure. In Iran, Taheri et al. (2022) found that farmers' reluctance to adopt «wireless sensor networks» (WSNs) stemmed from concerns related to high costs, limited accessibility, complexity of use, and doubts about data reliability. Bačiulienė et al. (2023) note that the application of AI in the agricultural sector faces numerous social, technological, and economic barriers, particularly within the supply chain.

2.2. Hypotheses Development

2.2.1. Precision Agriculture

Precision agriculture is «a data-driven, technology-enabled farming management strategy that monitors, quantifies, and examines the requirements of specific crops and fields» (Saha et al., 2025, p.1). It use the advanced technologies — such as "global positioning systems" (GPS), "geographic information systems" (GIS), sensors, drones, and data analytics — to monitor, analyze, and manage variability in crops and soils, thereby optimizing resource use and improving productivity. Technologies such as AI, drones, and IoT sensors help farmers optimize the use of resources, including water, fertilizers, and pesticides (Meliana et al., 2024; Xu et al., 2024). Precision agriculture aims to increase food production and improve yields, efficiency, and environmental sustainability, thereby contributing to enhanced food security (Saha et al., 2025; Sanyaolu & Sadowski, 2024). In this context, Erokhin et al. (2024) emphasized that the adoption of digital technologies by farmers contributes to reducing water waste. Moreover, innovations in ICT, data analytics, and machine learning can predict weather patterns and improve yield forecasts (Gouvea et al., 2022) and improve food security (Hasan et al., 2018; Were et al., 2016). Malec et al. (2024) found that «investments in agricultural innovation» significantly enhance food security by improving food productivity. Richter et al. (2023) highlighted that achieving food security is one of the key drivers behind the adoption of modern agricultural technologies. Several studies have indicated that precision agriculture, which relies on information technology and innovation, has the potential to contribute to food security (e.g., Erickson et al., 2021; Kabato et al., 2025; Ncube et al., 2018; Raimi et al., 2021; Xu et al., 2024). Accordingly, we propose the following hypothesis:

H1: Precision agriculture has a positive influence on achieving food security.

2.2.2. Genetic Engineering and Biotechnology

Genetic engineering and biotechnology refer to the scientific techniques that manipulate an organism's DNA to modify, improve, or introduce traits for specific purposes. Biotechnology can contribute to food security by promoting sustainable agriculture in developing countries (Serageldin, 1999). In their review, Areche et al. (2023) emphasize that biotechnology and genetic engineering techniques can increase crop yields and improve food quality, thereby contributing to greater food abundance. Demirel et al. (2024) argue that sustainable biotechnology plays an important role in promoting both food safety and food security. Meliana et al. (2024) emphasized the urgent need for «smarter food tracking systems» and highlighted that agricultural biosensors can support early detection and routine monitoring of plant diseases and stress. Many studies have confirmed that the implementation of genetic engineering and biotechnology solutions plays an important role in improving crops and increasing food productivity, which contributes to food security (Adegbaju et al., 2024; Areche et al., 2023; De Souza & Bonciu, 2022; Kaya, 2025; Ouyang et al., 2017; Serageldin, 1999). Based on the above discussion, we propose the following hypothesis:

H2: Genetic engineering and biotechnology have a positive influence on achieving food security.

2.2.3. Sustainable Farming Practices

Sustainable farming practices refer to agricultural methods that aim to meet current food needs while preserving the environment, maintaining soil fertility, conserving water, and protecting biodiversity for future generations (Demirel et al., 2024). These practices often include crop rotation, organic farming, vertical farming, conservation tillage, integrated pest management, agroforestry, and the use of renewable resources (Erokhin et al., 2021). WSNs represent environmentally friendly technologies that support timely, efficient, and cost-effective farm production and management (Taheri et al., 2022). In their review, Capato et al. (2025) argue that climate-smart agricultural practices — such as «precision agriculture», «regenerative agriculture», and «agroforestry» — constitute sustainable approaches that enhance food security while mitigating pollution. Ecological agriculture plays a vital role in sustaining ecosystems and ensuring food security (Madsen et al., 2021; Mazumder et al., 2023). In addition, Oh and Lu (2023) highlighted that vertical farming, as «a sustainable farming practice», can play a significant role in addressing global food security challenges, particularly in African and Asian countries. Petrovics and Giezen (2022) argued that vertical farming holds great potential for ensuring long-term food security. Accordingly, the following hypothesis is proposed:

H3: Sustainable farming practices have a positive influence on achieving food security.

2.2.4. Supply Chain & Food Distribution Optimization

The loss of nearly one-third of food at various stages of the supply chain represents one of the most serious challenges facing the global food system (Areche et al., 2023). Food safety is a critical dimension of food security, as smart tracking across the supply chain is essential to ensuring it (Yu et al., 2022). Moreover, food safety is closely linked to consumer health and, by extension, to the overall well-being of society. Furthermore, emerging technological innovations, such as «Food Traceability 4.0», are enhancing digital food traceability, helping to prevent food fraud, minimize food waste, and provide reliable information to consumers (Hassoun et al., 2024). However, many existing food traceability systems face challenges, as food safety incidents and recalls have undermined consumer trust, caused economic losses, and increased pressure on food safety authorities (Bidyalakshmi et al., 2025; Dhal & Kar, 2025; Yu et al., 2022). In addition, agri-food delivery applications can help small farmers and producers reach customers more effectively, lower costs, and promote their agricultural products (Galanakis et al., 2021; Mouloudj et al., 2025). Galanakis et al. (2021) argued that digital technologies, particularly Industry 4.0, have the potential to transform food supply chains and significantly enhance agri-food productivity. Dhal and Kar (2024) emphasize that AI technologies improve supply chain performance, enhance food preservation, and reduce spoilage, thereby supporting food security. Hence, the following hypothesis is proposed:

H4: Supply chain and food distribution optimization have a positive influence on achieving food security.

2.2.5. Reducing Food Waste

Food waste refers to the disposal of excess food resulting from overpurchasing, uneaten meals, spoilage, or expiration due to prolonged storage. Consequently, food waste and loss are closely associated with food insecurity and heightened environmental pollution (Meliana et al., 2024; Pandey & Mishra, 2024). Innovations such as smart packaging and advanced traceability systems are expected to enhance food safety and availability, strengthen food supply chains, and reduce food waste (Galanakis et al., 2021; Hassoun et al., 2024; Pandey & Mishra, 2024). Lai et al. (2022) argued that wasted food could be redirected to significantly reduce food insecurity and address food sustainability challenges. Manzoor et al. (2024) pointed out that reducing food waste improves the efficiency of the food supply system and enhances food security. In the some context, several studies have linked food waste to food security, highlighting that reducing waste significantly enhances food security (Lai et al., 2022; Manzoor et al., 2024; Sarangi et al., 2024; Wani et al., 2024). Accordingly, we propose the following hypothesis:

H5: Reducing food waste has a positive influence on achieving food security.

3. Materials and Methods

3.1. Measurement Tool Development

A structured questionnaire was employed to collect the primary data for this study. The instrument consisted of two main sections. The first section gathered demographic information, including gender, age, educational level, and occupation. The second section comprised items designed to measure the study's constructs, which were adapted from established scales in the literature. Specifically, the measurement scales were developed as follows: Precision agriculture items were drawn from Erickson and Fausti (2021) and Ncube et al. (2018). Genetic engineering and biotechnology items were adapted from De Souza and Bonciu (2022) and Areche et al. (2023). Sustainable farming practices items were drawn from Erokhin et al. (2024). Supply chain and food distribution optimization items were drawn from Hassoun et al. (2024) and Smidt and Jokonya (2022). Reducing food waste was measured using items adapted from Lai et al. (2022). Achieving food security items were developed based on Demirel et al. (2024) and Erokhin et al. (2021).

To ensure content validity, two academic experts in agricultural technology reviewed the questionnaire, and their feedback was incorporated to refine some items. The instrument was initially prepared in English and subsequently translated into Arabic to enhance respondents' understanding. A pilot test with 15 respondents was conducted to verify clarity and reliability, leading to minor modifications. Table 1 presents the final measurement items used in the study.

Table 1

Measurement items

Таблица 1

Измеряемые параметры

Constructs	Statements
Precision Agriculture (PA)	PA1: The use of precision agriculture technologies can optimize resources such as water, fertilizers, and pesticides. PA2: Precision agriculture can improve crop yields and farm productivity.

End of Table 1

Constructs	Statements
Precision Agriculture (PA)	PA3: Precision agriculture can help farmers adapt to changing climate conditions
Genetic Engineering & Biotechnology (GEB)	GEB1: The use of improved crop varieties through biotechnology can increase agricultural productivity. GEB2: Genetic engineering can enhance the nutritional value of food products. GEB3: Biotechnology can help crops resist pests, diseases, and harsh climate conditions
Sustainable Farming Practices (SFP)	SFP1: Sustainable farming practices can improve soil fertility and protect natural resources. SFP2: Sustainable farming methods can reduce environmental damage. SFP3: Sustainable farming can contribute to long-term food production
Supply Chain & Food Distribution Optimization (SCFDO)	SCFDO1: Improved supply chain systems can reduce post-harvest food losses. SCFDO2: The use of digital platforms can make food distribution more efficient and transparent. SCFDO3: Optimizing food distribution can increase the availability of food in local markets
Reducing Food Waste (RFW)	RFW1: Better storage and packaging technologies can reduce food waste. RFW2: Food waste reduction initiatives can improve food availability for communities. RFW3: Reducing food waste can make food more affordable for households
Achieving Food Security (FS)	FS1: The use of agricultural technologies and innovations can increase the availability of food. FS2: The use of agricultural technologies can improve access to affordable food. FS3: The use of agricultural innovations can make food systems more resilient and stable

3.2. Participants and Procedure

The study population consisted of various stakeholders in northern Algeria, including farmers, agricultural extension agents, agricultural experts, cooperatives, and policymakers. Given the absence of a comprehensive sampling frame, a purposive sampling method was adopted. A total of 180 questionnaires were distributed in person at workplaces, including farms, between May and July 2025. Prior to participation, respondents were informed about the objectives of the study and were assured of confidentiality and voluntary participation. Out of the distributed questionnaires, 133 responses were received. After screening for completeness, 12 responses were excluded due to missing data, leaving 125 valid responses for analysis.

4. Results

4.1. Sample Characteristics

Table 2 presents the demographic characteristics of the respondents (N = 125). The sample is predominantly male (89.6%), with only a small proportion of female participants (10.4%), reflecting the male-dominated nature of agricultural activities in the study context. In terms of age, the majority of respondents fall within the 41–50 age group (36%), followed by those aged 31–40 (25.6%). Educational background shows a fairly balanced distribution, with 39.2% having a high school education or less, while 34.4% hold a bachelor's degree and 26.4% possess a master's degree or higher. Regarding occupation, farmers constitute the largest share (52%), followed by agricultural extension agents (16.8%) and other stakeholders such as cooperatives, agricultural engineers, policymakers, and experts. This distribution highlights that the sample captures a diverse range of perspectives from key actors directly and indirectly involved in food security.

Table 2

Demographic profile (N = 125)

Таблица 2

Демографический профиль (N = 125)

Demographic profile	Categories	n	%
Gender	Male	112	89.60
	Female	13	10.40
Age	18–30 years	21	16.80
	31–40 years	32	25.60
	41–50 years	45	36.00
	> 50 years	27	21.60
Educational level	High school or less	49	39.20
	Bachelor's degree	43	34.40
	Master's degree or above	33	26.40
Occupation	Farmers	65	52.00
	Agricultural extension agents	21	16.80
	Cooperatives	13	10.40
	Agricultural Engineer/Guide	14	11.20
	Policymakers	05	04.00
	Agricultural experts	07	05.60

4.2. Descriptive Statistics

Table 3 reports the descriptive statistics, reliability coefficients, and normality measures for the study constructs. The mean values range from 3.37 (supply chain & food distribution optimization) to 3.99 (food security), suggesting that respondents generally hold moderately positive perceptions toward the role of technology and innovation in advancing food security. Standard deviations remain below 1 for all constructs, indicating relatively consistent responses among participants. The Cronbach's alpha values range between 0.776 for reducing food waste and 0.945 for genetic engineering & biotechnology, all exceeding the recommended threshold of 0.70, which confirms strong internal consistency and reliability of the measurement scales (Henseler et al., 2015). Skewness and kurtosis values fall within acceptable ranges (±2 and ±7 respectively), supporting the assumption of normality in the data distribution (Erokhin et al., 2024).

Table 3

Descriptive statistics and Cronbach's alphas

Таблица 3

Описательная статистика и коэффициенты альфа Кронбаха

Constructs	Mean	Std. Dev.	CA	Skewness	Kurtosis
Precision Agriculture	3.842	0.753	0.867	–1.126	1.471
GEB	3.576	0.751	0.945	–1.391	2.212
Sustainable Farming Practices (SFP)	3.704	0.784	0.920	–1.480	2.391
SCFDO	3.373	0.671	0.941	–0.534	–0.281
Reducing Food Waste (RFW)	3.829	0.623	0.776	–0.881	0.950
Achieving Food Security (FS)	3.989	0.603	0.780	–0.898	0.858

Note: Genetic Engineering & Biotechnology (GEB); Supply Chain & Food Distribution Optimization (SCFDO); Cronbach's Alphas (CA)

Table 4 presents the correlation matrix among the study constructs. All predictors demonstrate strong and statistically significant positive correlations with food security, indicating that advancements in these technological and innovative practices are closely associated with improved food security outcomes. Precision agriculture (r = 0.762) shows the strongest correlation, underscoring its central role in enhancing efficiency and productivity. Sustainable farming practices (r = 0.723) and Reducing Food Waste (r = 0.718) also exhibit strong associations, highlighting their importance in building sustainable and resilient food systems. Supply chain and food distribution optimization (r = 0.707) and genetic engineering & biotechnology (r = 0.636) are likewise positively related, suggesting their contributions to strengthening availability and accessibility within the food system. Overall, the correlation results confirm that all five predictors are relevant drivers of food security, supporting their inclusion in the analytical model.

Table 4

Correlation matrix

Таблица 4

Корреляционная матрица

Constructs	PA	GEB	SFP	SCFDO	RFW
1. Precision Agriculture (PA)	1				
2. GEB	0.573**	1			
3. Sustainable Farming Practices (SFP)	0.806**	0.633**	1		

End of Table 4

Constructs	PA	GEB	SFP	SCFDO	RFW
4. SCFDO	0.650**	0.517**	0.555**	1	
5. Reducing Food Waste (RFW)	0.723**	0.594**	0.649**	0.648**	1
6. Achieving Food Security (FS)	0.762**	0.636**	0.723**	0.707**	0.718**

Note: Genetic Engineering & Biotechnology (GEB); Supply Chain & Food Distribution Optimization (SCFDO)

4.3. Testing Hypotheses

Table 5 presents the multiple regression analysis results, examining the influence of the five predictors on achieving food security. The model is statistically significant (F = 59.524, $p < 0.001$) and explains 70.2% of the variance in achieving food security, indicating strong explanatory power. Among the predictors, supply chain and food distribution optimization (β = 0.241, $p < 0.001$) emerges as the most influential factor, followed by precision agriculture (β = 0.187, $p = 0.016$), reducing food waste (β = 0.163, $p = 0.033$), sustainable farming practices (β = 0.140, $p = 0.043$), and genetic engineering & biotechnology (β = 0.119, $p = 0.029$). All predictors are statistically significant, confirming their meaningful contribution to food security. Furthermore, tolerance values and «variance inflation factor» (VIF) scores indicate no multicollinearity concerns, ensuring the robustness of the results (Erokhin et al., 2024).

Table 5

Multiple regression scores

Таблица 5

Результаты множественной регрессии

Constructs	β	t-value	Sig.	Tolerance	VIF
(Constant)	1.130	5.877	0.000		
Precision Agriculture	0.187	2.439	0.016	0.261	3.831
GEB	0.119	2.208	0.029	0.530	1.886
Sustainable Farming Practices (SFP)	0.140	2.048	0.043	0.305	3.282
SCFDO	0.241	3.867	0.000	0.500	1.999
Reducing Food Waste (RFW)	0.163	2.153	0.033	0.392	2.553
$F = 59.524$; Adjusted $R^2 = 0.702$					

Note: Genetic Engineering & Biotechnology (GEB); Supply Chain & Food Distribution Optimization (SCFDO)

These findings underscore the multidimensional role of technology and innovation in driving food security, with supply chain optimization and precision agriculture standing out as particularly critical drivers.

5. Discussions

Our results confirm that precision agriculture is one of the most significant contributors to achieving food security. This finding is consistent with previous studies, which have highlighted the potential of precision agriculture to safeguard food security (e.g., Erickson et al., 2021; Hasan et al., 2018; Ncube et al., 2018; Raimi et al., 2021; Richter et al., 2023; Saha et al., 2025; Xu et al., 2024; Were et al., 2016). These results suggest that precision agriculture can improve productivity, reduce costs, and enhance food availability through the use of digital technology and innovation (Sanyaolu & Sadowski, 2024). Smidt and Jokonya (2022) highlighted that the adoption of agricultural technologies not only supports food security but also enables farmers to increase their income and contributes to poverty reduction. Precision agriculture can play an important role in «increase productivity, improve resource allocation for inputs such as pesticides, fertilizers, water, feed, and labor, provide for more stable production, and reduce agricultural production's environmental effect» (Erickson et al., 2021, p. 4455). Furthermore, Xu et al. (2024) argue that precision agriculture contributes to food safety by "minimizing reliance on chemical fertilizers and pesticides, which are associated with various health and environmental concerns."

Moreover, our results demonstrate that genetic engineering and biotechnology can play a significant role in ensuring food security. Despite some criticism, genetic engineering and biotechnology are capable of improving both the quantity and quality of agricultural crops, thereby enhancing the performance of the agricultural sector and strengthening food security. These findings align with numerous previous studies that have highlighted the potential of genetic engineering and biotechnology in addressing food security (Areche et al., 2023; De Souza & Bonciu, 2022; Demirel et al., 2024; Kaya, 2025; Ouyang et al., 2017). In this context, Adegbaju et al. (2024) emphasize that «genome editing technology», as a component of biotechnology, can improve crops because of its cost-effectiveness and ease of use. Kaya (2025) argues that innovations in agricultural engineering are an important means of achieving food security and promoting health.

Moreover, our results confirm that optimizing supply chains and food distribution plays a critical role in achieving food security. This finding is consistent with prior studies, which demonstrate that efficient supply chain systems and improved distribution mechanisms are essential for ensuring stable food access (Bidyalakshmi et al., 2025; Dhal & Kar, 2024; Dhal & Kar, 2025; Pandey & Mishra, 2024). Pandey and Mishra (2024) emphasize that AI technologies can enhance supply chain efficiency, storage management, transportation systems, and food quality assurance — factors that directly influence the reliability of food availability. Likewise, Dhal and Kar (2024) indicate that AI-based predictive models improve agricultural productivity, supply chain management, and food storage, thereby strengthening resilience against disruptions and contributing to long-term food security. In addition, Dhal and Kar (2025) note that the implementation of AI technology contributes to food quality and safety by enabling contamination detection, enhancing traceability, and supporting predictive maintenance.

In addition, the empirical results indicate that sustainable agricultural practices make a significant contribution to achieving food security. These findings are consistent with previous studies showing that sustainable agricultural practices have the potential to mitigate food security challenges (e.g., Gupta et al., 2025; Madsen et al., 2021; Mazumder et al., 2023; Mihrete & Mihretu, 2025; Oh & Lu, 2023; Pandey & Mishra, 2024; Petrovics

& Giezen, 2022). Environmentally friendly farming behaviors — particularly those that employ technology to reduce the waste of water, seeds, fertilizers, and other resources — represent an important pathway toward this goal. For instance, hydroponics and vertical farming enable food production in urban areas, reducing dependence on arable land, while hydroponics and aeroponics provide resource-efficient agricultural solutions (Dibbern et al., 2024). Kabato et al. (2025) reveal that unsustainable agricultural practices decrease yields and exacerbate food insecurity. Similarly, Ma and Rahut (2024) argue that sustainable agriculture — particularly climate-smart agriculture — constitutes a pivotal approach to achieving food security, reducing poverty, and addressing the challenges of climate change, thereby contributing to the realization of the "United Nations Sustainable Development Goals". Moreover, education, awareness, and digital literacy are expected to play a crucial role in encouraging farmers to adopt sustainable practices and technologies (Bačiulienė et al., 2023).

Furthermore, our results confirm that reducing food waste contributes directly to achieving food security. In this regard, minimizing food waste is an effective way to address food security challenges and ensure greater food availability for others. Even small reductions in waste can help meet a portion of food needs, thereby strengthening food security. For this reason, initiatives to reduce food waste — no matter how minor — should not be underestimated. In Algeria, for example, households waste large amounts of bread, particularly during Ramadan. This finding aligns with numerous studies that emphasize the critical role of food waste reduction in overcoming food security challenges (e.g., Lai et al., 2022; Manzoor et al., 2024; Sarangi et al., 2024; Wani et al., 2024). Pandey and Mishra (2024) emphasize that AI technology helps reduce food loss and waste while supporting smart inventory management. The responsibility for reducing food waste rests with all stakeholders, including authorities, farmers, producers, retailers, and consumers (Meliana et al., 2024). Governments should enact stronger legislation and integrate technology to ensure food safety, while consumers must be made aware of the risks and consequences of food waste. Farmers and food producers can also contribute by designing packaging and containers that are more suitable for both quantity and quality preservation (Erokhin et al., 2021).

6. Conclusions

All countries, without exception, strive to achieve food security. Governments are under increasing pressure due to a number of factors, including water scarcity, economic and social crises, the spread of epidemics and diseases, and the demand to implement sustainable policies. Under these circumstances, technology and innovation in agriculture can help address some of the challenges threatening food security (Zhao et al., 2025). Accordingly, this study investigated the role of integrating digital technology into various agricultural activities to achieve food security. The findings revealed that digital technology tools and innovation play a pivotal role in enhancing food security through diverse and complementary pathways. Specifically, improvements in the food supply chain and distribution, precision agriculture, food waste reduction, sustainable agricultural practices, genetic engineering, and biotechnology all contribute meaningfully to food security. Among these, supply chain optimization and precision agriculture emerged as particularly influential, underscoring the importance of efficient agricultural production in the early stages and effective distribution and management in later stages.

The study further highlights the need to integrate technological innovation with supportive policies that promote food sufficiency and strengthen agricultural capacity among stakeholders. Farmers, agricultural extension workers, cooperatives, and policymakers must collaborate to overcome barriers such as limited knowledge, resource constraints, and infrastructure gaps. By fostering innovation systems and encouraging sustainable practices, stakeholders can collectively move closer to the overarching goal of food security. In conclusion, this research emphasizes that food security in the modern era cannot be achieved through traditional approaches alone; rather, it requires the strategic integration of agricultural technologies and innovation-driven solutions.

6.1. Managerial Implications

The results of this study provide several practical insights for managers, policymakers, and stakeholders in the agricultural sector. First, the strong impact of improving the food supply chain and distribution on food security highlights the need to invest in digital platforms, logistics infrastructure, and tracking systems that reduce bottlenecks and inefficiencies in food delivery. In this context, the smart management of storage centers and the digitalization of distribution networks can minimize losses and ensure that food reaches markets and consumers at the right time and place, thereby reducing both scarcity and waste.

Second, the findings show that precision agriculture and reducing food waste are also key factors in achieving food security. For farm and cooperative managers, this underscores the importance of adopting data-driven technologies — such as artificial intelligence, sensors, drones, and smart irrigation systems — to optimize resource use and increase yields. At the same time, food industry managers should implement strategies to minimize waste across production, storage, and retail stages. This dual approach not only enhances sustainability but also creates opportunities for cost savings and strengthens consumer confidence in food systems.

Finally, the positive influence of sustainable agricultural practices and biotechnology underscores the need for knowledge sharing and agricultural capacity building. Managers of agricultural organizations, extension services, and cooperatives should therefore prioritize training programs that improve farmers' awareness, knowledge, and skills in safely applying sustainable technologies and adopting biotechnology innovations (De Souza & Bonciu, 2022; Erokhin et al., 2021). By aligning management practices with technological advancements, organizations can play a proactive role in achieving food security while simultaneously contributing to broader goals of environmental sustainability and rural development.

6.2. Limitations and Future Research

While this study provides useful insights into how technology and innovation contribute to food security, it is not without limitations. First, the sample size was limited to 125 respondents. Although the sample included a diverse group of farmers, agricultural extension workers, cooperatives, and policymakers, it may not fully represent the diversity of all stakeholders in the food system. Future research could therefore broaden the scope to include more regions and a wider range of actors, such as private sector food distributors, agri-tech startups, and consumer associations, to develop a more comprehensive understanding of how technology and innovation can advance food security through multi-stakeholder engagement.

Second, the reliance on a questionnaire presents another limitation, as responses may have been influenced by participants' perceptions, knowledge, or biases rather than actual technology adoption practices. Future studies could complement survey data with field observations, case studies, or secondary data on agricultural production and distribution outcomes in Algeria. Moreover, while the study identifies the important role of various technologies, it does not examine in depth the contextual barriers — such as infrastructure challenges, financial constraints, or digital illiteracy — that may hinder technology adoption. Further research could investigate these structural and behavioral obstacles to provide more targeted recommendations for strengthening technology-based food security strategies.

Finally, the study was conducted within the Algerian context, which is characterized by distinct socioeconomic and agricultural conditions. While this offers valuable localized insights, it may also limit the generalizability of the findings to other countries in the region. Future research could therefore undertake comparative studies across North African countries or the broader Middle East and North Africa region to explore both the commonalities and differences in how innovation contributes to food security, thereby providing regional perspectives and strategies to support integration and collaboration in achieving food security.

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