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SMART FARMING FOR IMPROVED FOOD AND NUTRITION SECURITY IN RURAL COMMUNITIES IN DANKO-WASAGU LOCAL GOVERNMENT AREA OF KEBBI STATE, NIGERIA

STEPHEN, BALKISU MANGA[1], MUSA, FATIMA AHMED[2], AND PAUL T.[3]

[1 & 2]*Department of Home Economics, Federal College of Education,Gidan Madi, Sokoto.*

[3]*Department of Home Economics, Bauchi State University, Nigeria.*

**Corresponding author: stephenbikisu@gmail.com*

ABSTRACT

The study assessed the awareness, adoption, and effects of smart farming technologies on food and nutrition security among rural households in Danko Wasagu Local Government Area of Kebbi State, Nigeria. A mixed-methods research design was adopted involving 150 smallholder farmers selected through purposive, simple random, and convenience sampling techniques. Data were collected using structured questionnaires, key informant interviews, and field observations and analysed using descriptive statistics and regression analysis. The findings revealed moderate awareness but generally low adoption of smart farming technologies. Farmers who adopted these technologies recorded higher crop yields, lower post-harvest losses, and better household dietary diversity than non-adopters. Regression analysis further showed that smart farming adoption had a significant positive effect on crop yield and household dietary diversity while significantly reducing post-harvest losses. The study concludes that promoting smart farming technologies through improved extension services, affordable technologies, digital infrastructure, and access to agricultural finance will enhance agricultural productivity and strengthen food and nutrition security among rural households.

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INTRODUCTION

Food and nutrition security remain fundamental to sustainable development, poverty reduction, and improved public health. Food security exists when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life (Food and Agriculture Organization [FAO], 2023). Despite Nigeria's enormous agricultural potential, food and nutrition insecurity continues to affect millions of households, particularly in rural communities where poverty, low agricultural productivity, inadequate

infrastructure, climate variability, insecurity, and limited access to improved agricultural technologies constrain food production and access to nutritious diets.

Agriculture remains the principal source of livelihood for a large proportion of Nigeria's rural population and contributes substantially to employment, household income, and national food supply. However, agricultural production is dominated by smallholder farmers who depend largely on traditional farming practices characterized by low mechanization, poor access to quality farm inputs, inadequate extension services, and limited financial resources. These challenges significantly reduce farm productivity and increase vulnerability to food shortages and malnutrition. Smallholder farms produce a substantial proportion of the world's food supply, yet they continue to experience constraints that limit productivity and resilience. Investment in agricultural innovation, rural infrastructure, and improved technologies has been identified as a critical strategy for strengthening food security and rural livelihoods (Lowder et al., 2021; World Bank, 2023). The increasing impacts of climate change, rapid population growth, land degradation, declining soil fertility, and water scarcity have intensified the need for more efficient and sustainable agricultural systems. Conventional farming methods that rely on generalized management practices and manual operations are becoming increasingly inadequate to meet rising food demand while conserving natural resources. Consequently, smart farming has emerged as an innovative agricultural approach that integrates digital technologies with improved agronomic practices to optimize production efficiency, enhance resource-use efficiency, reduce production risks, and strengthen resilience against climate variability (Klerkx et al., 2019; Wolfert et al., 2017).

Smart farming refers to the application of modern information and communication technologies (ICTs) to improve agricultural productivity through precision management and informed decision-making. It encompasses technologies such as improved seed varieties, soil testing, remote sensing, mobile advisory services, the Internet of Things (IoT), drones, sensors, robotics, cloud computing, geographic information systems, and data analytics for monitoring and managing agricultural production. These technologies enable farmers to optimize the use of water, fertilizers, pesticides, labour, and other production inputs while minimizing production costs and environmental degradation (Ayaz et al., 2019; Tripicchio et al., 2015). In developing countries such as Nigeria, smart farming does not necessarily imply expensive automation or highly sophisticated technologies. Rather, it includes practical and affordable innovations such as improved crop varieties, climate-smart agricultural practices, mobile phone-based extension services, soil fertility testing, weather information systems, efficient irrigation techniques, and improved post-harvest management practices. These technologies have demonstrated significant potential for increasing crop yields, reducing post-harvest losses, improving farmers' incomes, enhancing resource-use efficiency, and strengthening household food and nutrition security.

Nevertheless, successful adoption depends on farmers' knowledge, institutional support, access to finance, extension services, and enabling policies (Rose & Chilvers, 2018; Wolfert et al., 2017).

Danko Wasagu Local Government Area of Kebbi State is predominantly agrarian, with most households relying on rain-fed subsistence agriculture for their livelihoods. The area possesses considerable agricultural potential due to its fertile land and favourable climatic conditions. However, farmers continue to face numerous production challenges, including declining soil fertility, erratic rainfall patterns, pest infestations, inadequate access to agricultural extension services, limited mechanization, poor market access, and low adoption of modern agricultural technologies. These constraints negatively affect agricultural productivity, household food availability, income generation, and nutritional outcomes, particularly among vulnerable groups such as women and children.

Given the increasing importance of digital agriculture and climate-smart farming in promoting sustainable food systems, there is a growing need to assess farmers' awareness, adoption, and utilization of smart farming technologies in rural communities. Understanding the extent to which these technologies contribute to improved food and nutrition security will provide valuable evidence for policymakers, extension agencies, development partners, and agricultural institutions in designing interventions that enhance technology adoption, improve agricultural productivity, and strengthen rural livelihoods (Klerkx et al., 2019). It is against this background that this study investigates smart farming for improved food and nutrition security among rural communities in Danko Wasagu Area of Kebbi State, Nigeria. Several empirical studies have examined the role of agricultural technologies in improving food production and nutrition outcomes among rural households. However, findings vary across geographical and socio-economic contexts. Gyamfi *et al.* (2024) investigated the application of Agricultural 4.0 technologies and reported that the adoption of smart farming practices significantly improved farm productivity, resource-use efficiency, and climate resilience among smallholder farmers. The study emphasized that digital agriculture technologies can contribute substantially to sustainable food production systems. Guzev *et al.* (2020) examined the use of smart technologies in agriculture and found that technologies such as sensors, precision farming tools, and automated advisory systems improved decision-making, reduced input wastage, and enhanced crop yields. Their findings demonstrated that technology-driven agriculture increases both productivity and profitability.

Ukwuaba *et al.* (2023) assessed the role of information and communication technologies in agricultural production systems in Nigeria and observed that farmers who had access to digital advisory platforms recorded better market access and improved farm management practices compared with non-users. Ikelegbe and Edokpa (2013) reported that low agricultural productivity remains a major contributor to

food insecurity in rural Nigeria and recommended increased adoption of improved agricultural technologies as a strategy for improving household food security and reducing poverty. Fasoyiro and Taiwo (2012) found that improving access to agricultural innovations among rural farmers significantly increased food availability and income generation while reducing vulnerability to food shortages. International evidence from studies conducted in Asia and Europe similarly indicates that smart farming technologies contribute to increased productivity, reduced post-harvest losses, and improved resource management, thereby strengthening food security and agricultural sustainability (Guzev *et al.,* 2020; Gyamfi *et al.,* 2024). Despite these findings, most existing studies have concentrated primarily on agricultural productivity and economic returns, with relatively limited attention given to nutrition outcomes such as dietary diversity and household food utilization. Furthermore, few studies have examined the relationship between smart farming technologies and food and nutrition security in rural communities of Kebbi State, particularly in Danko Wasagu Local Government Area.

Although previous studies have established the positive contribution of agricultural technologies to productivity and food security, empirical evidence linking smart farming technologies directly to both food and nutrition security outcomes in rural communities of Kebbi State remains scarce. Existing studies have focused predominantly on crop productivity, farm income, and technology adoption, while giving limited consideration to nutrition indicators such as dietary diversity and food utilization. Furthermore, studies specifically examining awareness, adoption, and impacts of smart farming technologies among smallholder farmers in Danko Wasagu Local Government Area are virtually non-existent. This study therefore fills this knowledge gap by simultaneously examining awareness levels, adoption patterns, productivity outcomes, and nutrition security indicators associated with smart farming technologies among rural households in the study area. The study is anchored on two complementary theories: the Diffusion of Innovations (DOI) Theory developed by Rogers (2003) and the Sustainable Livelihoods Framework (SLF) developed by the Department for International Development (DFID, 1999). The Diffusion of Innovations Theory explains how farmers become aware of, evaluate, and adopt smart farming technologies based on their perceived advantages, compatibility, complexity, trialability, and observability. It provides a suitable framework for understanding the awareness and adoption of improved seed varieties, soil testing technologies, mobile advisory services, and climate-smart agricultural practices among rural farmers. The Sustainable Livelihoods Framework complements this perspective by explaining how the adoption of productive agricultural technologies enhances livelihood assets, increases agricultural productivity, reduces post-harvest losses, and ultimately improves household food availability and dietary diversity. Together, these theories provide a comprehensive explanation of the pathways through which smart farming technologies contribute to improved food and nutrition security among rural households in Danko Wasagu Local Government Area of Kebbi State, Nigeria.

The study is based on the assumption that adoption of smart farming technologies improves agricultural productivity and efficiency, which subsequently enhances household food availability and dietary quality. Improved seed varieties, soil testing technologies, mobile advisory services, and climate-smart agricultural practices are expected to increase crop yields, reduce production inefficiencies, and minimize post-harvest losses. These improvements ultimately contribute to better food access and nutrition security among rural households.

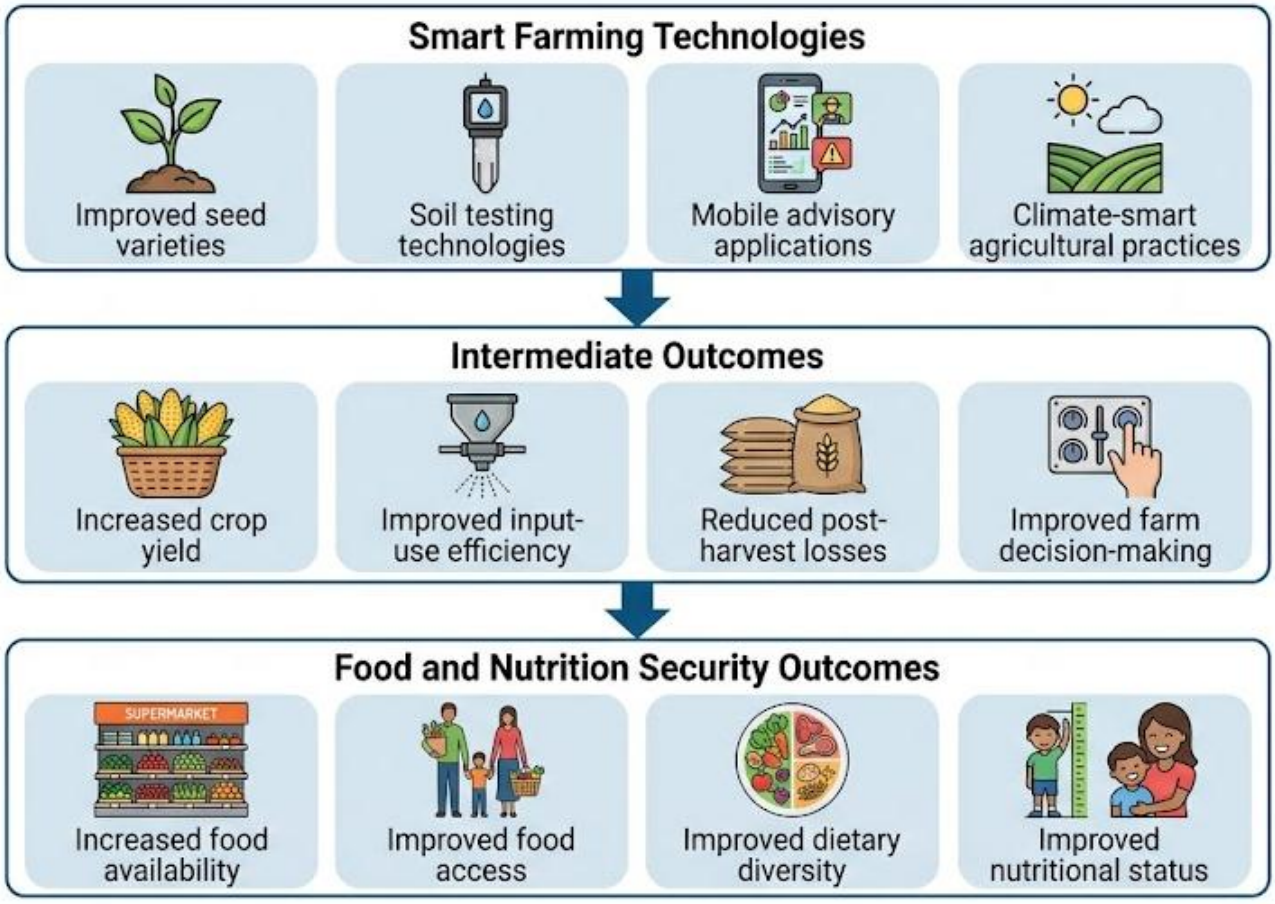

Figure 1: *Conceptual Framework Showing the Relationship Between Smart Farming Technologies and Food and Nutrition Security.*

STATEMENT OF THE PROBLEM

Despite the strategic importance of agriculture to food production and rural livelihoods in Nigeria, food and nutrition insecurity remain persistent challenges, particularly among smallholder farming

households. In Danko Wasagu Local Government Area of Kebbi State, agriculture is predominantly subsistence-based and characterized by low productivity, declining soil fertility, dependence on rainfall, inadequate access to improved technologies, poor extension services, and limited access to agricultural finance. These challenges have contributed to low crop yields, high post-harvest losses, poor household income, inadequate dietary diversity, and increasing vulnerability to food insecurity. Recent advances in smart farming have demonstrated considerable potential to transform agricultural production through the application of digital technologies, climate-smart practices, precision agriculture, mobile advisory services, and improved resource management. Evidence from previous studies indicates that these technologies can increase productivity, improve resource-use efficiency, reduce production risks, and enhance household food security (Ayaz et al., 2019; Tripicchio et al., 2015). However, the adoption of smart farming technologies among rural farmers in many parts of Nigeria remains generally low due to inadequate awareness, poor digital infrastructure, limited technical knowledge, insufficient institutional support, and financial constraints (Rose & Chilvers, 2018). Although several studies have examined agricultural productivity and food security in Nigeria, relatively few have specifically investigated the extent to which smart farming technologies influence both food and nutrition security among rural households in Danko Wasagu Local Government Area of Kebbi State. Consequently, there is limited empirical evidence regarding farmers' awareness, level of adoption, and the contribution of these technologies to improving household food availability and nutritional outcomes in the study area.

Therefore, this study seeks to assess the awareness, adoption, and impact of smart farming technologies on food and nutrition security among rural households in Danko Wasagu Area of Kebbi State. The findings are expected to provide empirical evidence that will assist policymakers, agricultural extension agencies, development partners, and other stakeholders in formulating effective strategies and interventions for promoting smart farming technologies and improving sustainable food and nutrition security in rural communities.

OBJECTIVES OF THE STUDY

The following objectives guided the study:

1. To determine the level of awareness of smart farming technologies among rural farmers in Danko Wasagu Local Government Area.

2. To determine the extent of adoption of smart farming technologies among rural households in Danko Wasagu Local Government Area.

3. To examine the effect of smart farming technology adoption on crop yield among rural households in

Danko Wasagu Local Government Area.

4. To determine the effect of smart farming technology adoption on post-harvest losses among rural households in Danko Wasagu Local Government Area.

RESEARCH QUESTIONS

1. The following questions were analysed in the study::
2. What is the level of awareness of smart farming technologies among rural farmers in Danko Wasagu Local Government Area?
3. To what extent are smart farming technologies adopted by rural households?
4. What effect does smart farming technology adoption have on crop yield among rural households?
5. What effect does smart farming technology adoption have on post-harvest losses among rural households?

RESEARCH HYPOTHESES

The following hypotheses were formulated and tested at 0.05 level of significance:

1. Smart farming technology adoption has no significant effect on crop yield among rural households in Danko Wasagu Local Government Area.
2. Smart farming technology adoption has no significant effect on post-harvest losses among rural households in Danko Wasagu Local Government Area.
3. Smart farming technology adoption has no significant effect on household dietary diversity among rural households in Danko Wasagu Local Government Area.

METHODOLOGY

Research Design and Study Area

The study employed a mixed-methods design to assess awareness, adoption, and impacts of smart farming technologies on food and nutrition security in Danko Wasagu Local Government Area, Kebbi State, Nigeria (Mansur et al., 2024). The area is predominantly rural, with subsistence agriculture characterized by low input use and high climate vulnerability (Wakkala *et al.*, 2022).

Population and Sample

The target population for this study comprised approximately 2,450 smallholder farming households distributed across selected rural communities in Danko Wasagu Local Government Area of Kebbi State, Nigeria. Three sampling techniques were employed to select the study participants. First, wards were purposively selected based on the intensity of agricultural activities. Second, rural communities within the selected wards were selected using simple random sampling. Finally, available and willing smallholder farming households within the selected communities were recruited through convenience sampling to participate in the study.

A total of 150 farmers participated in the quantitative survey. In addition, key informants, comprising agricultural extension officers and community leaders, were purposively selected for the qualitative interviews because of their knowledge and experience regarding agricultural practices and the adoption of smart farming technologies in the study area. The sample size of 150 respondents was determined from the target population of 2,450 smallholder farming households using the Yamane (1967) sample size determination formula.

Instrumentation

Primary data were collected using a Smart Farming and Food and Nutrition Security Questionnaire (SFFNSQ) and a semi-structured interview guide. The SFFNSQ was developed by the researchers and consisted of 35 items organized into five sections. Section A elicited information on the socio-demographic characteristics of the respondents. Section B contained items on awareness of smart farming technologies, including improved seed varietieas, soil testing technologies, mobile advisory services, and climate-smart agricultural practices. Section C assessed the level of adoption of smart farming technologies. Section D contained items on agricultural productivity, including crop yield and post-harvest losses, while Section E measured household food and nutrition security, particularly food availability and household dietary diversity. The semi-structured interview guide was administered to agricultural extension officers and community leaders to obtain in-depth information on smart farming practices, challenges to technology adoption, and strategies for improving food and nutrition security in the study area.

The questionnaire and interview guide were subjected to face and content validity by three experts in Agricultural Extension, Home Economics, and Research Measurement and Evaluation, whose observations and recommendations were incorporated before the final administration of the instruments. The reliability of the questionnaire was established through a pilot study involving 20 smallholder

farmers from a neighbouring community outside the study area. The responses were analysed using Cronbach's alpha, which yielded an overall reliability coefficient of 0.84, indicating that the instrument possessed good internal consistency and was suitable for data collection.

RESULTS

Demographics

Table 1: Socio-demographic Characteristics (N = 150)

Variable	Category	F	Percent
Gender	Male	118	78.7
	Female	32	21.3
Age	<30	28	18.7
	30–49	79	52.7
	≥50	43	28.6
Education	No formal	54	36.0
	Primary	47	31.3
	Secondary	38	25.3
	Tertiary	11	7.4
Farm size	≤2 ha	96	64.0
	>2 ha	54	36.0
Experience	≤10 years	45	30.0
	>10 years	105	70.0

Table 1 shows that the majority of the respondents were male (78.7%), aged 30–49 years (52.7%), and had more than 10 years of farming experience (70.0%). Most respondents had no formal education (36.0%), while others had primary (31.3%), secondary (25.3%), and tertiary (7.4%) education. In

addition, 64.0% cultivated 2 hectares or less, indicating that most were smallholder farmers. Overall, the respondents were predominantly experienced male smallholder farmers in their economically active years, although many had low levels of formal education, a factor that may influence the adoption of smart farming technologies.

Research Question 1

What is the level of awareness of smart farming technologies among rural farmers in Danko Wasagu Local Government Area?

Table 2: Awareness of Smart Farming Technologies

Technology	Aware %	Not aware %
Improved seed varieties	78	22
Soil testing technologies	51	49
Mobile advisory applications	33	67
Climate-smart practices	41	59

Table 2 shows that awareness of smart farming technologies varied among the respondents. Awareness was highest for improved seed varieties (78%), followed by soil testing technologies (51%), while awareness of climate-smart practices (41%) and mobile advisory applications (33%) was relatively low. Overall, the findings indicate that although most farmers were aware of improved seed varieties, awareness of other smart farming technologies, particularly digital agricultural tools, remained limited in the study area.

Research Question 2

To what extent are smart farming technologies adopted by rural households in Danko Wasagu Local Government?

Table 3: Adoption of Smart Farming Technologies

Technology	Adopted %	Not adopted %
Improved seed varieties	42	58
Soil testing kits	18	82
Mobile advisory platforms	11	89
Climate-smart practices	24	76

Table 3 indicates that the adoption of smart farming technologies among the respondents was generally low. Improved seed varieties recorded the highest adoption rate (42%), followed by climate-smart practices (24%), soil testing kits (18%), and mobile advisory platforms (11%). Conversely, the majority of respondents had not adopted these technologies, with non-adoption rates ranging from 58% to 89%. Overall, the findings suggest that despite some level of awareness, the adoption of smart farming technologies remains limited among rural farmers in the study area.

Research Question 3

What effect does smart farming technology adoption have on crop yield among rural households?

Table 4: Agricultural Outcomes by Adoption Status

Indicator	Adopters	Non-adopters
Mean crop yield increase (%)	32.4	3.1
Mean post-harvest loss (%)	17.6	35.0

Table 4 shows that respondents who adopted smart farming technologies achieved better agricultural outcomes than non-adopters. Adopters recorded a substantially higher mean crop yield increase (32.4%) compared to non-adopters (3.1%). Similarly, adopters experienced a lower mean post-harvest loss (17.6%) than non-adopters (35.0%). Overall, the findings indicate that the adoption of smart farming technologies contributed to increased crop productivity and reduced post-harvest losses among rural farmers in the study area.

Research Question 4

What effect does smart farming technology adoption have on post-harvest losses among rural households?

Table 5: Household Food and Nutrition Outcomes

Indicator	Adopters	Non-adopters
Food availability	High	Moderate
Household dietary diversity (Mean)	6.2	4.3
Diet quality	Diverse	Limited

Table 5 indicates that households adopting smart farming technologies had better food and nutrition outcomes than non-adopters. Adopters reported higher food availability, a higher mean household dietary diversity score (6.2) than non-adopters (4.3), and more diverse diets. Overall, the findings suggest that smart farming technology adoption positively enhanced household food availability, dietary diversity, and nutrition security in the study area.

Hypothesis Testing

Table 6: Regression Analysis

Dependent variable	Predictor	β	SE	t	p
Crop yield	Smart farming adoption	0.38	0.08	4.75	0.000
Post-harvest losses	Smart farming adoption	-0.31	0.07	-4.21	0.000
Dietary diversity	Smart farming adoption	0.42	0.09	4.89	0.000

Table 6 presents the regression analysis examining the effect of smart farming technology adoption on

selected agricultural and nutrition outcomes. The results show that smart farming adoption had a significant positive effect on crop yield ($\beta = 0.38$, $t = 4.75$, $p < .000$) and household dietary diversity ($\beta = 0.42$, $t = 4.89$, $p < .000$). Conversely, smart farming adoption had a significant negative effect on post-harvest losses ($\beta = -0.31$, $t = -4.21$, $p < .000$), indicating that adoption reduced post-harvest losses among rural households. Overall, the findings demonstrate that smart farming technology adoption significantly improved agricultural productivity and household food and nutrition security in the study area.

DISCUSSION

The findings of this study demonstrate that smart farming technologies have substantial potential to enhance food and nutrition security in rural communities of Danko Wasagu Local Government Area. Although awareness of improved seed varieties was relatively high, the adoption of other smart farming tools particularly soil testing technologies and mobile advisory platforms remained low (Ukwuaba *et al.*, 2023). This gap between awareness and adoption highlights persistent barriers such as cost, limited technical support, and inadequate digital infrastructure, which are consistent with previous studies on technology adoption among smallholder farmers in sub-Saharan Africa (Sanchi *et al.*, 2022). This finding agrees with Gyamfi *et al*. (2024), who reported that financial constraints and poor digital infrastructure remain major barriers to smart farming adoption in developing countries.

The significant yield improvements observed among adopters underscore the productivity-enhancing role of smart farming technologies. Yield increases of 25–40% among adopters compared with marginal gains among non-adopters indicate that even partial adoption of improved practices can substantially improve agricultural output. Reduced post-harvest losses among adopters further suggest that smart farming contributes not only to increased production but also to improved efficiency along the value chain (Ogunjobi, 2024). The findings are consistent with Guzev *et al.* (2020), who reported significant productivity gains among farmers adopting precision agriculture technologies. Improvements in household dietary diversity among adopters demonstrate a strong link between smart farming and nutrition security. Higher dietary diversity scores suggest that increased productivity and reduced losses translate into improved food utilization and access to diverse food groups. This finding supports the argument that agricultural innovation is a critical pathway for addressing malnutrition in rural communities. The result also supports Akinyele (2009), who emphasized that increased agricultural productivity contributes positively to household nutrition outcomes and dietary quality.

Regression analysis confirmed that smart farming adoption is a significant determinant of food and nutrition security outcomes. Improved seeds and climate-smart practices emerged as key drivers,

highlighting the importance of promoting technologies that are both accessible and adaptable to local farming conditions. These findings emphasize the need for integrated interventions that combine technology dissemination with extension services, digital infrastructure development, and nutrition education. The significant predictive effect observed in this study aligns with findings from international studies that identified smart farming technologies as important determinants of food security and agricultural resilience. The study provides empirical evidence that scaling up smart farming technologies can strengthen food availability, productivity, and dietary quality in rural northern Nigeria. Policy efforts should therefore focus on reducing adoption barriers through subsidies, improved extension support, enhanced digital access, and inclusive financing mechanisms to ensure sustainable food and nutrition security.

CONCLUSION

The study concludes that smart farming technologies have significant potential to improve food and nutrition security among rural households in Danko Wasagu Local Government Area of Kebbi State. Although awareness of some smart farming technologies is relatively high, their adoption remains generally low due to various barriers. Nevertheless, farmers who adopted these technologies recorded higher crop yields, lower post-harvest losses, and better household dietary diversity than non-adopters. Therefore, promoting the adoption of smart farming through improved extension services, affordable technologies, enhanced digital infrastructure, access to credit, and nutrition education will strengthen agricultural productivity and contribute to sustainable food and nutrition security in the study area..

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