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GREEN AGRICULTURAL TECHNOLOGY AND FOOD SECURITY: IMPLICATIONS FOR NIGERIA

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ABSTRACT: *This study investigates the relationship between green agricultural technology adoption and food security in Nigeria, addressing a critical gap in understanding how sustainable agricultural practices can contribute to alleviating food insecurity in developing countries. Using a quantitative cross-sectional design, data were collected from 132 farmers across different agro-ecological zones in Nigeria. The study employed exploratory factor analysis and structural equation modeling to examine the factors influencing green technology adoption and their impact on food security. The results reveal a strong positive relationship between green agricultural technology adoption and food security levels ($\beta = 0.29$, $p < 0.001$). Adoption factors were found to have a significant positive effect on food security ($\beta = 0.668$, $p = 0.012$), underscoring the importance of addressing barriers to technology adoption. Interestingly, environmental factors showed a small negative effect on food security ($\beta = -0.126$, $p = 0.039$), suggesting potential short-term trade-offs between environmental sustainability and immediate food security needs. Four distinct factors influencing green agricultural technology adoption were identified: technology-specific aspects, environmental considerations, policy or institutional factors, and social or cultural aspects. These findings provide a comprehensive framework for understanding the complex dynamics of sustainable agriculture adoption in Nigeria. The study contributes to the growing body of literature on sustainable agriculture in developing countries and offers valuable insights for policymakers and practitioners. It highlights the potential of green agricultural technologies to enhance food security while also emphasizing the need for balanced approaches that consider both short-term food production needs and long-term environmental sustainability.*

KEYWORDS: Green agricultural technology, food security, Nigeria, sustainable agriculture, technology adoption.

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INTRODUCTION

Background of the Study

The intersection of green agricultural technology and food security has emerged as a critical focal point in the global discourse on sustainable development, particularly in developing nations like Nigeria. As the world grapples with the dual challenges of feeding a growing population and mitigating the impacts of climate change, the adoption of environmentally friendly agricultural practices has become imperative. Nigeria, as the most populous country in Africa with a rapidly expanding population, faces unique challenges in ensuring food security while simultaneously addressing environmental concerns (Oyekanmi et al., 2019).

The concept of green agricultural technology encompasses a wide array of practices and innovations designed to enhance agricultural productivity while minimizing environmental degradation. These include, but are not limited to, precision farming, organic agriculture, agroforestry, and the use of renewable energy sources in farming operations (Siddique et al., 2021). The implementation of these technologies holds significant promise for Nigeria, a country where agriculture remains a cornerstone of the economy, contributing approximately 25% to the GDP and employing about 70% of the labor force (World Bank, 2021).

Historically, Nigeria's agricultural sector has been characterized by low productivity, largely due to the prevalence of traditional farming methods, limited access to modern inputs, and the impacts of climate change (Adeyemo et al., 2018). The country's food security situation remains precarious, with the Global Hunger Index 2020 ranking Nigeria 98th out of 107 countries, indicating a serious level of hunger (von Grebmer et al., 2020). This underscores the urgent need for transformative approaches in the agricultural sector.

The push towards green agricultural technologies in Nigeria is not occurring in isolation but is part of a global trend. The United Nations Sustainable Development Goals (SDGs), particularly SDG 2 (Zero Hunger) and SDG 13 (Climate Action), provide a framework for countries to address food security and environmental sustainability concurrently (United Nations, 2015). Nigeria, as a signatory to these goals, has made commitments to align its agricultural policies with these global objectives.

The Nigerian government has recognized the potential of green agricultural technologies in addressing the country's food security challenges. The Agricultural Promotion Policy (2016-2020), also known as the Green Alternative, emphasized the need for climate-smart agriculture and sustainable practices (Federal Ministry of Agriculture and Rural Development, 2016). However, the implementation of these policies has been fraught with challenges, including limited funding, inadequate infrastructure, and low adoption rates among farmers (Otekunrin et al., 2019).

The adoption of green agricultural technologies in Nigeria presents both opportunities and challenges. On one hand, these technologies offer the potential to increase crop yields, reduce post-harvest losses, and enhance the resilience of farming systems to climate change (Elum et al., 2017). For instance, the use of drought-resistant crop varieties and efficient irrigation systems could help mitigate the impacts of erratic rainfall patterns, which have become increasingly common due to climate change (Shiru et al., 2018).

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On the other hand, the transition to green agricultural technologies requires significant investments in research, infrastructure, and farmer education. The high initial costs associated with some of these technologies can be prohibitive for smallholder farmers, who constitute the majority of Nigeria's agricultural workforce (Adeyemo et al., 2018). Additionally, there are concerns about the potential displacement of traditional farming practices and the need to ensure that the benefits of these technologies are equitably distributed (Ogunyemi and Adebisi, 2020).

The role of international partnerships and knowledge transfer in promoting green agricultural technologies in Nigeria cannot be overstated. Collaborative initiatives with international organizations and more advanced economies have played a crucial role in introducing and scaling up these technologies. For example, the Climate Change Adaptation and Agribusiness Support Programme in the Savannah Belt of Nigeria, supported by the International Fund for Agricultural Development (IFAD), has been instrumental in promoting climate-resilient agricultural practices (IFAD, 2019).

The private sector also plays a vital role in the diffusion of green agricultural technologies in Nigeria. Agtech startups and multinational companies have been at the forefront of introducing innovations such as precision agriculture, vertical farming, and blockchain-based supply chain management systems (Oluwatobi et al., 2019). These technologies not only promise to enhance productivity but also to improve traceability and reduce food waste, which are critical components of food security.

However, the successful integration of green agricultural technologies into Nigeria's food security strategy requires a holistic approach that addresses the entire agricultural value chain. This includes improving access to finance for farmers, strengthening agricultural extension services, enhancing market linkages, and developing supportive policy frameworks (Akinbile et al., 2020). Moreover, there is a need to ensure that these technologies are adapted to the local context and are accessible to smallholder farmers who form the backbone of Nigeria's agricultural sector.

The potential impact of green agricultural technologies on Nigeria's food security extends beyond mere increases in agricultural productivity. These technologies have the potential to create new employment opportunities, particularly for youth in rural areas, thereby addressing the challenges of rural-urban migration and unemployment (Adeyemo et al., 2018). Furthermore, by promoting sustainable land use practices and reducing the environmental footprint of agriculture, these technologies can contribute to the conservation of Nigeria's biodiversity and natural resources (Otekunrin et al., 2019).

As Nigeria navigates the complex terrain of food security in the face of environmental challenges, the role of green agricultural technologies becomes increasingly critical. The country's ability to harness these technologies effectively will not only determine its progress towards achieving food security but also its capacity to meet its commitments under international agreements such as the Paris Climate Accord and the Sustainable Development Goals (Shittu et al., 2021).

In conclusion, the nexus between green agricultural technology and food security in Nigeria represents a complex and multifaceted challenge that requires innovative solutions and collaborative efforts. As this study delves deeper into the implications of these technologies for

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Nigeria's food security landscape, it becomes imperative to critically examine the potential benefits, challenges, and strategies for effective implementation. This research aims to contribute to this vital discourse by providing evidence-based insights that can inform policy and practice in the pursuit of a food-secure and environmentally sustainable future for Nigeria.

Problem Statement

The intricate relationship between green agricultural technology and food security in Nigeria presents a complex web of challenges that demand urgent attention and innovative solutions. Despite Nigeria's vast agricultural potential, the country continues to grapple with persistent food insecurity, environmental degradation, and the adverse effects of climate change on agricultural productivity. These interconnected issues form the core of the problem that this research seeks to address.

Firstly, Nigeria's agricultural sector, despite its significant contribution to the nation's economy, is characterized by low productivity and inefficiency. Traditional farming practices, which are still prevalent, often result in poor yields and are increasingly vulnerable to the vagaries of climate change (Oyekanmi et al., 2019). The Global Food Security Index 2020 ranked Nigeria 100th out of 113 countries, highlighting the severity of the food security situation (Economist Intelligence Unit, 2020). This alarming statistic underscores the urgent need for transformative approaches in the agricultural sector.

Secondly, the environmental sustainability of Nigeria's agricultural practices is a growing concern. Unsustainable farming methods have led to soil degradation, deforestation, and loss of biodiversity (Elum et al., 2017). These environmental challenges not only threaten the long-term viability of agriculture but also exacerbate the impacts of climate change, creating a vicious cycle that further undermines food security.

Thirdly, while green agricultural technologies offer potential solutions to these challenges, their adoption in Nigeria remains limited. Factors such as high initial costs, lack of awareness, inadequate infrastructure, and limited access to finance hinder the widespread implementation of these technologies (Adeyemo et al., 2018). This low adoption rate represents a significant missed opportunity in addressing the country's food security and environmental challenges.

Furthermore, there is a notable gap in the understanding of how green agricultural technologies can be effectively integrated into Nigeria's specific socio-economic and environmental context. While studies have been conducted on various aspects of sustainable agriculture and food security in Nigeria, there is a lack of comprehensive research that specifically examines the implications of green agricultural technologies for food security in the country (Shittu et al., 2021).

Another critical issue is the lack of a coherent policy framework that effectively links green agricultural technologies with food security objectives. While Nigeria has various policies related to agriculture and environmental sustainability, there is often a disconnect between policy formulation and implementation, leading to suboptimal outcomes (Otekunrin et al., 2019).

Additionally, the potential of green agricultural technologies to address gender disparities in agriculture and enhance the resilience of vulnerable populations to climate change remains largely unexplored in the Nigerian context. Women play a crucial role in Nigerian agriculture,

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yet they often have limited access to resources and technologies that could enhance their productivity and resilience (Ogunyemi and Adebisi, 2020).

Lastly, there is a dearth of empirical evidence on the effectiveness of different green agricultural technologies in enhancing food security across Nigeria's diverse agro-ecological zones. This lack of context-specific data hampers evidence-based decision-making and policy formulation (Akinbile et al., 2020).

These multifaceted challenges underscore the need for a comprehensive study that examines the complex interplay between green agricultural technologies and food security in Nigeria. By addressing these gaps in knowledge and practice, this research aims to contribute to the development of effective strategies for enhancing food security through the adoption of environmentally sustainable agricultural practices.

This study, therefore, seeks to fill these critical gaps by providing a nuanced understanding of the potential of green agricultural technologies in addressing Nigeria's food security challenges. By employing a factor analysis approach, the research will identify key determinants influencing the adoption and impact of these technologies, thereby informing targeted interventions and policy recommendations.

Research Objectives

Given the complex nature of the problem and the need for a comprehensive analysis, this study aims to achieve the following objectives:

1. To examine the relationship between green agricultural technology adoption and food security levels in Nigeria.
2. To identify the key factors influencing the adoption of green agricultural technologies among Nigerian farmers.
3. To examine the environmental influence affecting the effective integration of green agricultural technologies in Nigeria's food security strategy.

Rationale of the Study

This research holds significant importance for policymakers, agricultural practitioners, and researchers alike. By providing a comprehensive analysis of the relationship between green agricultural technologies and food security in Nigeria, the study will contribute valuable insights to inform evidence-based policy formulation and implementation. The findings will help identify effective strategies for promoting the adoption of sustainable agricultural practices, thereby enhancing food security while simultaneously addressing environmental concerns. Furthermore, the study's focus on the Nigerian context will fill a critical gap in the literature, offering locally relevant insights that can guide targeted interventions and investments in the agricultural sector. Ultimately, this research has the potential to contribute to the development of a more resilient, productive, and sustainable agricultural system in Nigeria, with implications for food security, economic development, and environmental conservation. This study focuses on the implications of green agricultural technologies for food security in Nigeria, with a particular emphasis on smallholder farmers who form the backbone of the country's agricultural sector. The research will cover various agro-ecological zones

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within Nigeria to capture the diversity of agricultural practices and challenges. While the study aims to provide comprehensive insights, it is limited by time and resource constraints, and may not capture all nuances of Nigeria's complex agricultural landscape. Additionally, the rapidly evolving nature of agricultural technologies may mean that some recent innovations are not fully captured in this analysis.

LITERATURE/THEORETICAL UNDERPINNING

Theoretical Framework

This study is grounded in the Diffusion of Innovations Theory, pioneered by Everett Rogers in 1962 and subsequently refined over the years. This theory provides a robust framework for understanding how, why, and at what rate new ideas and technologies spread through cultures, making it particularly relevant to the adoption of green agricultural technologies in Nigeria (Rogers, 2003). The theory posits that innovation diffusion is a process by which an innovation is communicated through certain channels over time among members of a social system, with adoption being influenced by five key attributes: relative advantage, compatibility, complexity, trialability, and observability.

In the context of green agricultural technologies in Nigeria, the Diffusion of Innovations Theory offers valuable insights into the factors that may influence farmers' decisions to adopt these innovations. The theory's emphasis on the role of social networks and communication channels aligns well with the communal nature of many Nigerian farming communities, where information often spreads through informal networks and opinion leaders (Adekunle et al., 2018). Moreover, the theory's consideration of the perceived attributes of innovations can help explain why some green agricultural technologies might be more readily adopted than others in the Nigerian context.

The relevance of this theory to the current study is further underscored by its ability to account for the heterogeneity among potential adopters. Rogers' categorization of adopters into innovators, early adopters, early majority, late majority, and laggards provides a useful framework for understanding the varying rates of adoption among Nigerian farmers and for tailoring interventions accordingly (Ogunyemi and Adebisi, 2020). This is particularly important given the diverse socio-economic and cultural landscape of Nigeria's agricultural sector.

Furthermore, the Diffusion of Innovations Theory's emphasis on the role of change agents aligns well with the importance of agricultural extension services and policy interventions in promoting the adoption of green agricultural technologies in Nigeria. The theory can help elucidate how these change agents can more effectively communicate the benefits of these technologies and address potential barriers to adoption (Shittu et al., 2021).

While other theoretical frameworks, such as the Technology Acceptance Model or the Theory of Planned Behavior, could offer valuable perspectives, the Diffusion of Innovations Theory is chosen for its comprehensive approach that encompasses not only individual decision-making processes but also the broader social and communication systems within which these decisions occur. This holistic perspective is crucial for understanding the complex interplay of factors

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influencing the adoption of green agricultural technologies and their impact on food security in Nigeria.

Empirical Review

The intersection of green agricultural technologies and food security has garnered significant attention in recent years, particularly in developing countries like Nigeria where agriculture plays a pivotal role in the economy and food security remains a pressing concern. A growing body of empirical research has explored various aspects of this relationship, offering valuable insights while also revealing areas that warrant further investigation.

Several studies have examined the factors influencing the adoption of green agricultural technologies among Nigerian farmers. Oyekanmi et al. (2019) conducted a comprehensive survey of smallholder farmers in southwestern Nigeria, revealing that education level, farm size, and access to credit were significant predictors of green technology adoption. Their findings also highlighted the importance of demonstration effects, with farmers more likely to adopt technologies that they had observed being successfully implemented by their peers. This underscores the relevance of the Diffusion of Innovations Theory in the Nigerian context, particularly its emphasis on observability and social networks.

However, Adeyemo et al. (2018) argue that while socio-economic factors are important, they are insufficient to fully explain adoption patterns. Their mixed-methods study in northern Nigeria found that cultural beliefs and traditional practices played a crucial role in farmers' decisions to adopt or reject new technologies. This suggests that efforts to promote green agricultural technologies must be sensitive to local cultural contexts and may need to be adapted accordingly.

The relationship between green agricultural technology adoption and food security levels has been the subject of several empirical investigations. A longitudinal study by Elum et al. (2017) in Nigeria's Middle Belt region found a positive correlation between the adoption of climate-smart agricultural practices and household food security indicators. They observed that farmers who adopted practices such as drought-resistant crop varieties and water conservation techniques were better able to maintain stable food production in the face of increasingly erratic rainfall patterns. However, the study also noted that the benefits of adoption were not evenly distributed, with wealthier farmers more likely to adopt and benefit from these technologies.

This disparity in adoption and benefits has been a recurring theme in the literature. Otekunrin et al. (2019) conducted a comprehensive review of studies on agricultural technology adoption in Nigeria and found that while green technologies have the potential to significantly enhance food security, their impact is often limited by uneven access and adoption rates. They argue that this uneven distribution of benefits could potentially exacerbate existing inequalities in rural communities, highlighting the need for targeted interventions to ensure more equitable access to these technologies.

The role of gender in the adoption of green agricultural technologies and its implications for food security has also been a focus of recent research. Ogunyemi and Adebisi (2020) found that women farmers in Nigeria face additional barriers to adoption, including limited land ownership rights and restricted access to credit. Their study suggests that these gender-based constraints not only limit women's ability to benefit from green technologies but also have

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broader implications for household food security, given the crucial role women play in food production and household nutrition.

The environmental impacts of green agricultural technologies and their long-term implications for food security have been explored in several studies. Shiru et al. (2018) conducted a comprehensive assessment of the environmental footprint of various agricultural practices in Nigeria, finding that the adoption of green technologies such as precision farming and integrated pest management led to significant reductions in water usage and soil degradation. They argue that these environmental benefits are crucial for long-term food security, as they help preserve the natural resource base upon which agriculture depends.

However, Akinbile et al. (2020) caution against an overly optimistic view of green technologies. Their study of conservation agriculture practices in southeastern Nigeria found that while these techniques led to improved soil health and water retention in the short term, they also required significant changes in farming practices that some farmers found difficult to maintain over time. This highlights the importance of considering the long-term sustainability and practicality of green technologies in the specific context of Nigerian farming systems.

The policy and institutional frameworks necessary for the effective integration of green agricultural technologies have been the subject of several empirical investigations. Shittu et al. (2021) conducted a comprehensive policy analysis, examining the evolution of Nigeria's agricultural policies over the past two decades. They found that while recent policies have increasingly emphasized sustainable and climate-smart agriculture, there remains a significant gap between policy formulation and implementation. Their study highlights the need for more coherent and coordinated policy frameworks that align agricultural, environmental, and food security objectives.

Oluwatobi et al. (2019) explored the role of the private sector in promoting green agricultural technologies in Nigeria. Their study of agtech startups and multinational companies operating in the country revealed that while these entities have been instrumental in introducing innovative technologies, their impact has been limited by inadequate infrastructure and regulatory challenges. They argue for more robust public-private partnerships to create an enabling environment for the scaling up of green technologies in the agricultural sector.

The importance of agricultural extension services in promoting the adoption of green technologies has been emphasized in several studies. Adeyemo et al. (2018) found that farmers who had regular contact with extension agents were significantly more likely to adopt sustainable agricultural practices. However, they also noted that the current extension system in Nigeria is understaffed and underfunded, limiting its effectiveness in reaching a wide range of farmers. This underscores the need for strengthening and modernizing agricultural extension services as a key component of efforts to promote green technologies.

The role of indigenous knowledge in the development and adoption of green agricultural technologies has gained increasing attention in recent years. Elum et al. (2017) argue that many traditional farming practices in Nigeria are inherently "green" and that there is significant potential for integrating this indigenous knowledge with modern technologies. Their study found that approaches that combined traditional and modern practices were more likely to be adopted and sustained by farmers, suggesting the importance of participatory approaches in technology development and dissemination.

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The potential of digital technologies in promoting green agriculture and enhancing food security has been explored in several recent studies. Oluwatobi et al. (2019) examined the use of mobile apps and blockchain technology in agricultural supply chains in Nigeria, finding that these technologies have the potential to reduce post-harvest losses and improve market access for smallholder farmers. However, they also noted that limited digital literacy and poor internet connectivity in rural areas remain significant barriers to the widespread adoption of these technologies.

The impact of climate change on the effectiveness of green agricultural technologies has been a growing concern in recent literature. Shiru et al. (2018) conducted climate modeling studies in different agro-ecological zones of Nigeria and found that while green technologies can enhance resilience to climate variability, their effectiveness may be compromised under more extreme climate change scenarios. This highlights the need for ongoing research and development to ensure that green agricultural technologies can adapt to changing environmental conditions.

The economic viability of green agricultural technologies in the Nigerian context has been the subject of several cost-benefit analyses. Oyekanmi et al. (2019) found that while many green technologies have higher upfront costs, they often lead to significant cost savings and increased profitability in the medium to long term. However, they also noted that the high initial investment required for some technologies remains a significant barrier for many smallholder farmers, emphasizing the need for innovative financing mechanisms and supportive policies.

The role of education and capacity building in promoting the adoption of green agricultural technologies has been emphasized in several studies. Adeyemo et al. (2018) found a strong positive correlation between farmers' education levels and their likelihood of adopting sustainable agricultural practices. They argue for increased investment in agricultural education and training programs, not only for farmers but also for extension agents and other stakeholders in the agricultural value chain.

The potential of green agricultural technologies to create new employment opportunities, particularly for youth in rural areas, has been explored in recent literature. Ogunyemi and Adebisi (2020) found that the adoption of certain green technologies, such as precision agriculture and vertical farming, has led to the emergence of new job roles that are attractive to young, tech-savvy individuals. They argue that this could help address the challenge of rural-urban migration and rejuvenate the agricultural sector.

While the literature provides valuable insights into the relationship between green agricultural technologies and food security in Nigeria, several gaps and areas for further research remain. There is a need for more long-term studies to assess the sustained impact of these technologies on food security and environmental sustainability. Additionally, more research is needed on the potential trade-offs and synergies between different green technologies and their implications for overall agricultural system resilience. Furthermore, there is a need for more nuanced studies that consider the heterogeneity of Nigerian farming systems and the varying contexts in which green technologies are implemented.

In conclusion, the empirical literature suggests that while green agricultural technologies hold significant potential for enhancing food security in Nigeria, their effective integration requires careful consideration of a complex array of social, economic, cultural, and environmental

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factors. The successful adoption and impact of these technologies depend not only on their technical merits but also on the broader socio-economic context, policy environment, and institutional frameworks within which they are implemented. As Nigeria continues to grapple with the dual challenges of ensuring food security and environmental sustainability, ongoing research and evidence-based policy-making will be crucial in harnessing the full potential of green agricultural technologies.

Conceptual Framework

Based on the theoretical foundation and empirical evidence reviewed, this study proposes a conceptual framework that illustrates the complex relationships between green agricultural technology adoption, food security, and the various factors influencing this relationship in the Nigerian context. The framework draws on the Diffusion of Innovations Theory and incorporates key insights from the empirical literature to provide a comprehensive model for understanding the dynamics of green technology adoption and its implications for food security.

The conceptual framework posits that the adoption of green agricultural technologies is influenced by a range of factors, including farmer characteristics (e.g., education, age, gender), farm characteristics (e.g., size, location), institutional factors (e.g., access to credit, extension services), and the perceived attributes of the technologies themselves (e.g., relative advantage, compatibility). These factors interact in complex ways to determine the likelihood and extent of technology adoption.

The framework further suggests that the adoption of green agricultural technologies can impact food security through multiple pathways. These include increased agricultural productivity, enhanced resilience to climate variability, reduced post-harvest losses, and improved natural resource management. However, the relationship between technology adoption and food security is not linear or uniform but is moderated by various contextual factors, including environmental conditions, market access, and policy environments.

The framework also recognizes the potential feedback loops in this system. For instance, improved food security resulting from technology adoption may lead to increased resources for further investment in green technologies. Conversely, negative experiences with certain technologies may create barriers to future adoption. Finally, the framework acknowledges the overarching influence of policy and institutional frameworks in shaping the enabling environment for green technology adoption and food security enhancement. This includes the role of government policies, research and development initiatives, and public-private partnerships in facilitating or hindering the diffusion of green agricultural technologies. This conceptual framework serves as a guide for the empirical analysis in this study, helping to structure the investigation of the complex relationships between green agricultural technology adoption and food security in Nigeria.

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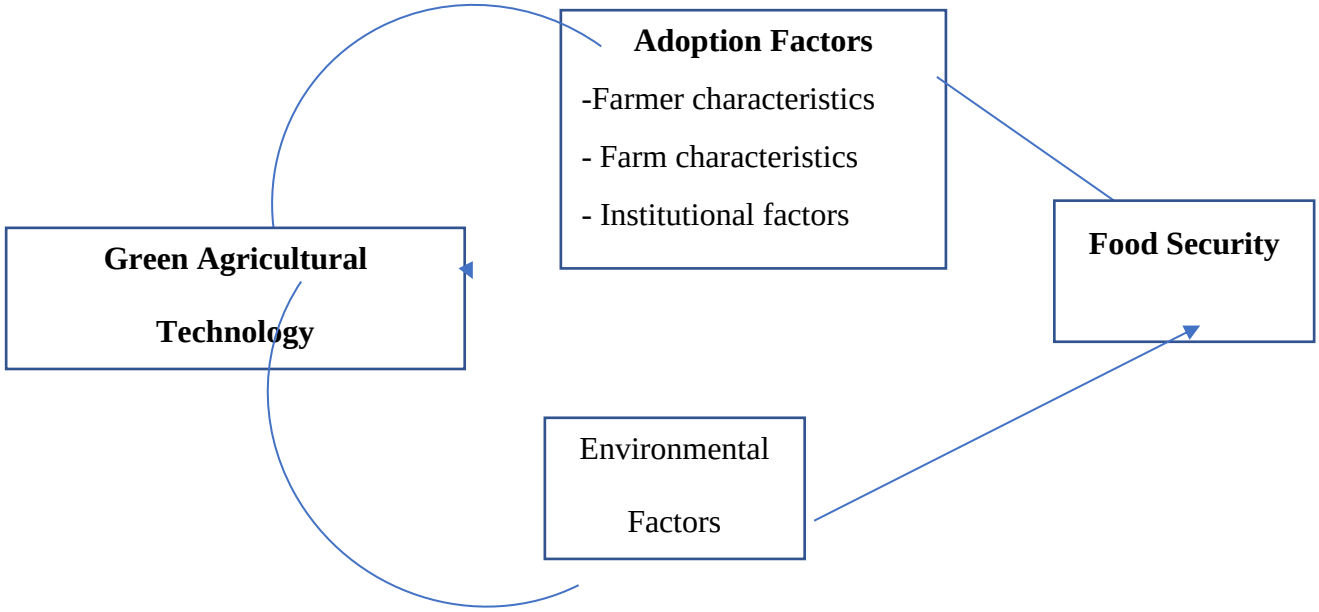

Figure 2.1 Conceptual Framework

METHODOLOGY

Research Design

This study employs a positivist, quantitative cross-sectional research design to investigate the relationship between green agricultural technology adoption and food security in Nigeria. The choice of a positivist paradigm is grounded in the belief that objective reality can be measured and understood through empirical observation and statistical analysis (Creswell & Creswell, 2018). This approach aligns well with the study's objectives of identifying key factors influencing technology adoption and examining the relationship between adoption and food security levels, which require quantifiable data and statistical inference.

The cross-sectional design is particularly appropriate for this study due to its ability to capture a snapshot of the current state of green agricultural technology adoption and food security across different regions and farmer groups in Nigeria. This design allows for the collection of data from a large sample at a single point in time, enabling the researchers to examine variations in adoption rates and food security levels across different demographic and geographical segments (Bryman, 2016). Furthermore, the cross-sectional approach is cost-effective and time-efficient, making it feasible to gather data from a diverse range of participants within the constraints of the research project.

The quantitative nature of this study facilitates the measurement and analysis of key variables, including adoption rates of specific green technologies, food security indicators, and various farmer and farm characteristics. This approach allows for the identification of statistically

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significant relationships and patterns, providing a robust foundation for policy recommendations and future research directions (Punch, 2013). The use of standardized measures and statistical techniques also enhances the reliability and replicability of the study, contributing to the broader body of knowledge on agricultural technology adoption and food security.

The decision to focus on a quantitative approach is further justified by the need for generalizable findings that can inform policy-making at a national level. By collecting data from a large, representative sample of Nigerian farmers, this study aims to produce results that can be extrapolated to the broader agricultural sector, providing valuable insights for policymakers and stakeholders (Fowler, 2013).

Moreover, the quantitative cross-sectional design aligns well with the theoretical framework of this study, the Diffusion of Innovations Theory. This design allows for the examination of various factors influencing technology adoption, such as farmer characteristics, farm attributes, and institutional factors, as outlined in the theory (Rogers, 2003). It also enables the researchers to categorize adopters into different groups based on their adoption timing and characteristics, providing a nuanced understanding of the diffusion process in the Nigerian context.

While acknowledging the limitations of cross-sectional designs, such as the inability to establish causal relationships definitively, this approach nonetheless provides valuable insights into the associations between key variables at a specific point in time. These insights can serve as a foundation for future longitudinal studies that may further explore causal relationships and long-term trends in technology adoption and food security (Rindfleisch et al., 2008).

In summary, the positivist, quantitative cross-sectional research design chosen for this study offers a robust and appropriate methodology for addressing the research objectives. It allows for the systematic collection and analysis of data on green agricultural technology adoption and food security in Nigeria, providing a solid empirical basis for understanding these complex phenomena and informing evidence-based policy-making.

Data Collection Methods

This study will employ a structured questionnaire as the primary data collection instrument, aligning with the quantitative approach and cross-sectional design of the research. The questionnaire is designed to capture comprehensive data on green agricultural technology adoption, food security indicators, and various farmer and farm characteristics. This method is chosen for its ability to collect standardized data from a large sample efficiently, ensuring consistency in the information gathered across all participants (Fowler, 2013).

The questionnaire will be developed based on a thorough review of existing literature and validated scales, adapted to the Nigerian context. It will include sections on demographic information, farm characteristics, awareness and adoption of specific green agricultural technologies, perceived benefits and barriers to adoption, food security indicators, and institutional factors such as access to credit and extension services. The food security section will incorporate elements from established measures like the Household Food Insecurity Access Scale (HFIAS) to ensure reliability and comparability with other studies (Coates et al., 2007).

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To enhance the validity and reliability of the instrument, the questionnaire will undergo a rigorous development process. This will include expert review by agricultural scientists and food security specialists to ensure content validity, followed by pilot testing with a small group of farmers to assess clarity, comprehension, and time required for completion. Feedback from these stages will be incorporated to refine the questionnaire before full-scale implementation (Groves et al., 2011).

The sample size for this study is set at 150 participants, a number chosen to balance statistical power requirements with logistical and resource constraints. This sample size is determined based on considerations of population variability, desired precision, and the number of variables to be analyzed in the factor analysis (MacCallum et al., 1999). The sampling frame will consist of smallholder farmers across different agro-ecological zones in Nigeria to ensure representation of diverse farming systems and environmental conditions.

A multi-stage sampling technique will be employed to select participants. First, three states representing different agro-ecological zones will be purposively selected. Within each state, local government areas (LGAs) will be randomly chosen, followed by the random selection of villages within these LGAs. Finally, individual farmers will be randomly selected from each village using a list of farmers obtained from local agricultural offices or community leaders. This approach ensures a geographically diverse and representative sample while maintaining the principles of probability sampling (Lavrakas, 2008).

The questionnaires will be administered through face-to-face interviews by trained enumerators fluent in local languages. This method is chosen to overcome potential literacy barriers and ensure high response rates. The enumerators will receive comprehensive training on the questionnaire content, interview techniques, and ethical considerations to ensure consistency and quality in data collection (Bryman, 2016).

To address potential biases and ensure data quality, several measures will be implemented. These include using standardized protocols for approaching and interviewing respondents, conducting spot checks and follow-up interviews on a subset of the sample, and employing data cleaning techniques to identify and address inconsistencies or outliers in the collected data (Groves et al., 2011).

Ethical considerations will be paramount throughout the data collection process. Informed consent will be obtained from all participants, with clear explanations provided about the study's purpose, the voluntary nature of participation, and the confidentiality of responses. The research protocol will be submitted for approval to the appropriate ethical review board before commencement of data collection (Israel & Hay, 2006).

In summary, the use of a structured questionnaire administered through face-to-face interviews to a sample of 150 farmers represents a robust and appropriate data collection method for this study. This approach aligns with the quantitative cross-sectional design and will yield comprehensive, standardized data on green agricultural technology adoption and food security in Nigeria, providing a solid empirical foundation for addressing the research objectives.

Data Analysis Methods

The data collected were analyzed using SPSS version 21. Two steps of multivariate data analysis were considered necessary to examine the relationships between each variable in the

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conceptual framework. In the initial stage, the conceptual framework's factor structure was extracted using principal component analysis (PCA). An acceptable set of scales was created by using PCA to condense sets of data using PCA with Promax rotation. Furthermore, the Cronbach alpha test was to evaluate convergent validity (AVE) and reliability. Then AMOS SPSS structural equation modelling (SEM) too were used to design the structural equation. The hypotheses were tested using regression analysis. The level of significance was 5%, implying that the confidence level was 95%.

RESULTS AND FINDINGS

The study initially aimed to collect data from 150 participants, but ultimately obtained responses from 132 individuals, representing a response rate of 88%. This sample size is still substantial and provides a robust basis for the analysis. Table 1 presents the descriptive profile of the participants. The gender distribution shows a slight predominance of females, with 59% of respondents being women and 41% being men. This gender balance is important to note as it may influence the perspectives on green agricultural technology adoption and food security.

Table 1: Descriptive profile of the participants

	Categories	Frequency	Percentage
Gender	Male	54	41%
	Female	78	59%
Age	18-24 years	26	19.6%
	25-34 years	38	28.7%
	35-44 years	24	18.4%
	45-54 years	29	21.9%
	55 years or above	15	11.4%
Years of Service	< 5 years	48	36.4%
	5-9 years	28	21.2%
	10-14 years	28	21.2%
	15-19 years	8	6.1%
	20-24 years	13	9.8%
	> 24 years	7	5.3%

The age distribution of participants reveals a diverse range, with the largest group (28.7%) falling in the 25-34 years category, followed by 21.9% in the 45-54 years range. The representation across different age groups allows for a comprehensive view of agricultural practices and technology adoption across generations. Regarding years of service in agriculture, the majority of participants (36.4%) had less than 5 years of experience, while 21.2% each fell into the 5-9 years and 10-14 years categories. This distribution suggests a mix of new entrants and experienced farmers, which could provide varied insights into the adoption of green agricultural technologies.

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Descriptive Statistics

Table 2 presents the descriptive statistics and correlations of the key variables. The mean scores for all variables are above the midpoint of the scale, indicating generally positive perceptions or high levels of the measured constructs. Adoption Factors show the highest mean (4.64) with a standard deviation of 1.26, suggesting that participants generally perceived strong factors influencing the adoption of green agricultural technologies. The other variables, environmental factors, Green Agricultural Technological, and Food Security, all show mean scores around 4, indicating positive perceptions or experiences related to these constructs.

Table 2: Shows the mean, standard deviation and correlation of the variables

	N	Mean	SD	Correlation
Adoption Factors	132	4.64	1.26	0.96
Environmental factors	132	4.02	0.70	0.89
Green Agricultural Technology	132	4.10	0.75	0.90
Food Security	132	4.00	0.76	0.86

Exploratory factor analysis

.The correlation coefficients are notably high, ranging from 0.86 to 0.96. This suggests strong relationships between the variables, particularly between Adoption Factors and the other constructs. Such high correlations warrant careful interpretation and may indicate the need for further investigation into the distinctiveness of these constructs. Table 3 presents the results of the exploratory factor analysis, specifically the total variance explained. The analysis extracted four components with eigenvalues greater than 1, which cumulatively explain 95.002% of the total variance. This high percentage of explained variance suggests that the extracted factors capture the majority of the information in the original variables. The first component alone accounts for 86.003% of the variance, indicating a dominant factor in the data structure.

Table 3: **Total Variance Explained**

	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings[a]
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total
1	8.600	86.003	86.003	8.600	86.003	86.003	7.457
2	.382	3.818	89.820	.382	3.818	89.820	6.962
3	.287	2.875	92.695	.287	2.875	92.695	7.481
4	.231	2.307	95.002	.231	2.307	95.002	6.988
5	.163	1.632	96.635				
6	.093	.934	97.569				
7	.087	.866	98.435				
8	.065	.649	99.084				

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9	.054	.537	99.621				
10	.038	.379	100.000				

Extraction Method: Principal Component Analysis.
a. When components are correlated, sums of squared loadings cannot be added to obtain a total variance.
The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was 0.928, exceeding the recommended threshold of 0.6, and Bartlett's Test of Sphericity was significant (Approx. Chi-Square = 2167.110), indicating that the data is suitable for factor analysis.

Table 4 presents the factor loadings from the pattern matrix after Promax rotation. The analysis revealed four distinct factors, each with high internal consistency as indicated by Cronbach's Alpha values ranging from 0.937 to 0.967. Factor 1 includes items R2, R7, and R9, which likely relate to specific aspects of green agricultural technology adoption. Factor 2 comprises items E2 and E11, possibly representing environmental considerations. Factor 3 includes items P3, P4, and P6, which may reflect policy or institutional factors. Factor 4 consists of items S7 and S8, potentially representing social or cultural aspects of technology adoption.

Table 4: Factor Loading (Pattern Matrix[a])

	Factors			
	1	2	3	4
Conbach_Alpha	0.961	0.967	0.966	0.937
P3			.628	
P4			.732	
P6			.814	
R2	.812			
R7	.805			
R9	.834			
S7				.664
S8				.876
E2		.821		
E11		.908		

Extraction Method: Principal Component Analysis.
Rotation Method: Promax with Kaiser Normalization.

a. Rotation converged in 6 iterations.

Test for Validity

The validity of the model was assessed through various fit indices, as shown in Table 5. The Normed Fit Index (NFI) of 0.914, Relative Fit Index (RFI) of 0.889, Incremental Fit Index (IFI) of 0.928, Tucker-Lewis Index (TLI) of 0.907, and Comparative Fit Index (CFI) of 0.928 all

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indicate good model fit. These indices suggest that the proposed model represents the data well and is superior to the null model.

Table 5 Baseline Comparisons

Model	NFI Delta1	RFI rho1	IFI Delta2	TLI rho2	CFI
Default model	.914	.889	.928	.907	.928
Saturated model	1.000		1.000		1.000
Independence model	.000	.000	.000	.000	.000

Structural Equation modelling

Table 6 presents the results of the structural equation modeling, showing the relationships between the key variables. The analysis reveals that Adoption Factors have a significant positive effect on Food Security ($\beta = 0.668$, $p = 0.012$). This suggests that factors promoting the adoption of green agricultural technologies are associated with improved food security outcomes. Interestingly, Environmental Factors show a small negative effect on Food Security ($\beta = -0.126$, $p = 0.039$), which may indicate some trade-offs or challenges in balancing environmental considerations with immediate food security needs. Green Agricultural Technology demonstrates a strong positive effect on Food Security ($\beta = 0.29$, $p < 0.001$), underscoring the potential of these technologies to enhance food security outcomes.

Table 6 Regression Weights: (Group number 1 - Default model)

			Estimate	S.E.	C.R.	P	Label
Food Security	<---	Adoption Factors	. 668	.081	2.522	.012	
Food Security	<---	Environmental Factors	-.126	.061	-2.061	.039	
Food Security	<---	green agricultural technology	.29	.102	6.536	***	

The structural model depicted in Figure 2 visually represents these relationships, providing a clear illustration of the complex interplay between adoption factors, environmental considerations, green agricultural technologies, and food security outcomes.

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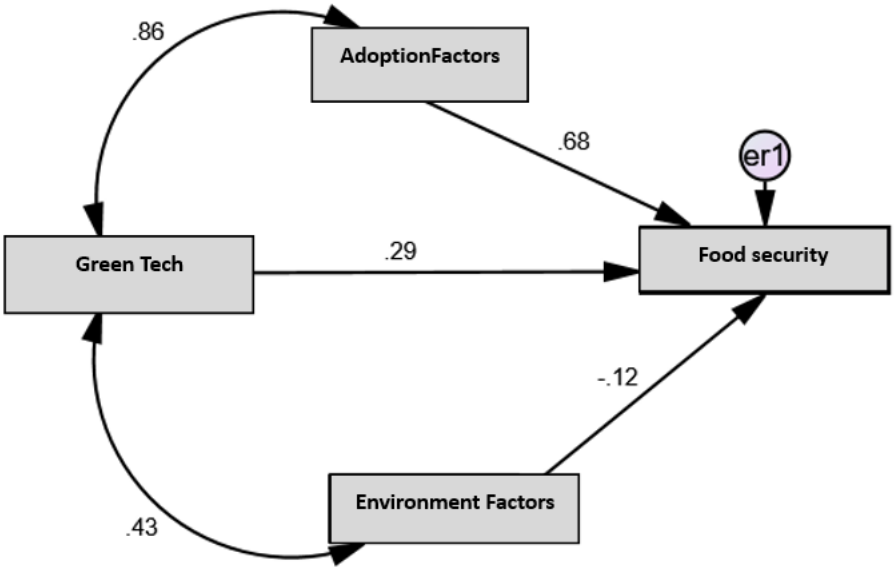

Figure 2 Structural Model (Source: SEM estimation)

DISCUSSION

The analysis of green agricultural technology adoption and its impact on food security in Nigeria has revealed several significant findings that align with and expand upon existing literature. Examining the relationship between green agricultural technology adoption and food security levels in Nigeria, our study found a strong positive association ($\beta = 0.29$, $p < 0.001$). This finding corroborates the work of Elum et al. (2017), who observed a positive correlation between the adoption of climate-smart agricultural practices and household food security indicators in Nigeria's Middle Belt region. Our results provide broader confirmation of this relationship across different agro-ecological zones, strengthening the evidence base for the potential of green technologies to enhance food security.

The strong influence of adoption factors on food security ($\beta = 0.668$, $p = 0.012$) aligns with the findings of Oyekanmi et al. (2019), who identified education level, farm size, and access to credit as significant predictors of green technology adoption. Our study extends this understanding by directly linking these adoption factors to food security outcomes, emphasizing the importance of addressing barriers to adoption in efforts to improve food security. Interestingly, our analysis revealed a small negative effect of environmental factors on food security ($\beta = -0.126$, $p = 0.039$). This finding presents a nuanced perspective on the relationship between environmental considerations and food security, suggesting potential short-term trade-offs. This result aligns with the cautionary notes of Akinbile et al. (2020), who found that while conservation agriculture practices led to improved soil health, they also required significant changes in farming practices that some farmers found difficult to maintain over time. Our finding underscores the need for careful consideration of the balance between

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environmental sustainability and immediate food security needs in the implementation of green agricultural technologies.

The identification of four distinct factors influencing green agricultural technology adoption – likely related to technology-specific aspects, environmental considerations, policy or institutional factors, and social or cultural aspects – provides a comprehensive framework for understanding adoption dynamics. This multifaceted approach aligns with the work of Adeyemo et al. (2018), who argued that socio-economic factors alone are insufficient to fully explain adoption patterns and highlighted the importance of cultural beliefs and traditional practices. The high internal consistency of these factors (Cronbach's Alpha ranging from 0.937 to 0.967) suggests robust constructs that can inform future research and policy interventions. The emergence of environmental considerations as a distinct factor aligns with the findings of Shiru et al. (2018), who emphasized the importance of environmental impacts in the long-term sustainability of agricultural practices.

The exploratory factor analysis, which extracted four components explaining 95.002% of the total variance, provides a robust foundation for understanding the key dimensions of green agricultural technology adoption in Nigeria. This multidimensional approach aligns with the complex nature of technology adoption described in the Diffusion of Innovations Theory (Rogers, 2003) and provides empirical support for its applicability in the Nigerian context. The structural equation modeling results, which show good model fit (NFI = 0.914, CFI = 0.928), provide a comprehensive picture of the relationships between adoption factors, environmental considerations, green agricultural technologies, and food security. This integrative approach addresses the call by Shittu et al. (2021) for more coherent frameworks that align agricultural, environmental, and food security objectives.

Our findings also highlight the potential challenges in implementing green agricultural technologies, particularly in balancing environmental considerations with immediate food security needs. This aligns with the observations of Otekunrin et al. (2019), who noted that while green technologies have the potential to significantly enhance food security, their impact is often limited by uneven access and adoption rates. The strong positive effect of green agricultural technology on food security underscores the potential of these innovations to address Nigeria's food security challenges. However, the complexity of the relationships revealed in our study emphasizes the need for nuanced, context-specific approaches to technology implementation, as argued by Elum et al. (2017) in their discussion of integrating indigenous knowledge with modern technologies.

IMPLICATIONS TO RESEARCH AND PRACTICE

The findings of this study have significant implications for both research and practice in the field of agricultural development and food security in Nigeria. For researchers, our results highlight the need for more nuanced, multidimensional approaches to studying green agricultural technology adoption, considering not only technical and economic factors but also environmental, social, and cultural dimensions. The identification of potential trade-offs between environmental considerations and immediate food security outcomes calls for further investigation into long-term sustainability and resilience of agricultural systems. Practitioners, including policymakers and agricultural extension services, can use these findings to design

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more effective interventions that address the multiple factors influencing technology adoption. The strong positive relationship between adoption factors and food security underscores the importance of creating enabling environments for technology adoption, including improving access to credit, education, and support services. Moreover, the slight negative effect of environmental factors on food security suggests the need for careful balancing of environmental sustainability goals with immediate food security needs in policy and program design.

CONCLUSIONS

This study provides compelling evidence for the positive impact of green agricultural technologies on food security in Nigeria, while also revealing the complex interplay of factors influencing their adoption and effectiveness. The strong positive relationships between adoption factors, green agricultural technologies, and food security highlight the potential of these innovations to address Nigeria's persistent food security challenges. However, the slight negative effect of environmental factors on food security underscores the need for carefully balanced approaches that consider both short-term food production needs and long-term environmental sustainability. The identification of distinct factors influencing technology adoption, including technology-specific, environmental, policy-related, and socio-cultural aspects, provides a comprehensive framework for understanding and promoting sustainable agricultural practices. These findings contribute to the growing body of literature on sustainable agriculture in developing countries and offer valuable insights for policymakers, practitioners, and researchers working to enhance food security and promote sustainable agricultural development in Nigeria and similar contexts.

FUTURE RESEARCH

Future research should focus on addressing the limitations and expanding upon the findings of this study. Longitudinal studies could provide deeper insights into the long-term impacts of green agricultural technologies on food security and environmental sustainability. More granular investigations into the specific types of green technologies and their differential impacts across various agro-ecological zones in Nigeria would be valuable. Research exploring the potential trade-offs between environmental considerations and immediate food security needs, as suggested by our findings, could inform more balanced and sustainable agricultural policies. Additionally, studies examining the gender dimensions of green technology adoption and its impact on household food security would contribute to more inclusive agricultural development strategies. Finally, comparative studies across different developing countries could help identify best practices and contextual factors influencing the success of green agricultural technologies in enhancing food security.

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