





Research Article

Farmers' awareness and adoption of climate-smart farming in Nigeria: Determinants, barriers, and implications for food security

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Abstract

This study examined the awareness and adoption of climate-smart farming practices (CSF) and their impact on the food security of farming households in Nigeria. A multistage sampling procedure was adopted, and data were collected from 380 farmers using a questionnaire. Data were analyzed using descriptive (mean and percentages) and inferential (ordinary least square regression and chi-squares) statistics. Awareness of CSF practices was generally high, with crop rotation and intercropping ($\bar{X} = 3.94$), organic fertilizer and composting ($\bar{X} = 3.73$), and rainwater harvesting and irrigation ($\bar{X} = 3.67$) ranking highest. However, the chi-square test ($\chi^2 = 3.22$, $df = 1$, $p > 0.05$) indicated no statistically significant relationship between farmers' awareness of CSF and their perception of its contribution to food security. The results further reveal that access to technologies ($\beta = 0.42$, $p < 0.01$), agricultural equipment ($\beta = 0.31$, $p < 0.01$), and extension services ($\beta = 0.27$, $p < 0.05$) significantly enhance CSF adoption. Socio-demographic factors, including educational attainment ($\beta = 0.41$, $p < 0.01$), years of farming experience ($\beta = 0.33$, $p < 0.01$), and mixed farming ($\beta = 0.26$, $p < 0.01$) also positively influenced adoption. The study highlights low access to technology (89.8%) and insufficient farming facilities (88.4%) as the most prominent challenges to CSF adoption. The study concludes that CSF adoption is not driven by awareness alone but by an environment of enabling conditions, such as technology access, finance, infrastructure, and knowledge systems. Therefore, policies must pursue integrated approaches that combine technological provision, infrastructural investment, and input financing with capacity building, youth empowerment, and gender inclusivity.

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1. Introduction

Agriculture remains the backbone of Nigeria's economy and rural livelihoods, employing more than 70 percent of the population and making a significant contribution to food security and poverty alleviation [1]. Agriculture remained a major pillar of Nigeria's economy in 2023, contributing 22.9 percent to the country's Gross Domestic Product (GDP) and ranking as the second most important economic activity after the oil sector [2]. However, the agricultural sector is

increasingly exposed to the growing effects of climate change, as evidenced by erratic rainfall patterns, extended droughts, floods, rising temperatures and soil degradation, which are collectively undermining agricultural productivity and food security [3]. These climate shocks have increased the vulnerability of smallholder farmers, who are highly dependent on rain-fed systems and often lack the financial and institutional capacity to adapt to climate changes.

Addressing these challenges requires that transformation of Nigeria's agricultural systems to promote resilience, reduce greenhouse gas (GHG) emissions, and ensure sustainable productivity in a changing climate.

The climate-smart agriculture framework established by the Food and Agriculture Organisation [4, 5] provides an integrated outline for achieving this transition. Climate smart farming (CSF) aims to increase agricultural productivity sustainably, increase climate change resilience (adaptation), and reduce or eliminate GHG (mitigation), while contributing to national food security and sustainable development objectives [6]. Generally, it builds on existing agricultural knowledge, technologies and principles of sustainability [7]. Rather than being a one-size-fits-all approach, CSF is a holistic approach that integrates different practices, such as conservation tillage, agroforestry, improved plant varieties, efficient irrigation, integrated pest and nutrient management, and the use of renewable energy [8]. These practices improve soil health, conserve water, diversify production, and support ecosystem services, thereby stabilising yields and increasing adaptive capacity. The adoption of the CSF was widely supported as essential to achieve the agricultural policy ambitions and climate adaptation strategies of Nigeria [9]. Farmers' awareness and perception of climate variability and the adoption of CSF [10] are essential for developing adaptation methods to meet the challenges and risks of climate variability in agriculture. This knowledge is crucial in Nigeria, where climate is a key predictor of how well an economy can perform, and climate change (involving erratic rainfall, temperature, and other extreme events) has a major impact on agricultural productivity, food security and livelihood.

The existing literature has made valuable contributions to understanding agricultural modernisation, climate-smart farming (CSF), and their implications for food security. Several studies have examined CSF practices, the application of modern technologies in farming systems, and the challenges posed by climate variability. However, there are notable gaps in the literature. Most reviewed studies did not adequately address the persistent slow

adoption of CSF in Nigeria, particularly the absence of a comprehensive, context-specific, and operational framework integrating CSF into national agricultural and climate change policies.

Despite the acknowledged potential of CSF to enhance resilience and food security, its adoption in Nigeria remains low due to limited farmer awareness, inadequate access to appropriate technologies and extension services, high implementation costs, and weak institutional support mechanisms [11, 12]. Empirical evidence suggests that farmers' awareness, perceptions, and understanding of CSF significantly influence adoption decisions, as knowledge shapes attitudes toward innovation and willingness to invest in sustainable practices [13, 10]. Moreover, adoption outcomes are mediated by interacting financial, human, physical, social, and institutional factors that vary across ecological zones and socioeconomic contexts.

Consequently, there is a clear gap in empirical studies that holistically examine agricultural modernisation within the broader Nigerian context, explicitly linking CSF adoption challenges to food security outcomes. This study seeks to fill this gap by systematically assessing the constraints to agricultural modernisation in Nigeria, evaluating the awareness and adoption of CSF, and identifying structural and contextual bottlenecks to its implementation.

2. Materials and methods

This study adopted a descriptive survey research design, which enabled the systematic collection of quantitative and qualitative data to assess farmers' awareness, perceptions, and adoption of Climate-Smart Farming (CSF) in Nigeria. The design was appropriate for obtaining reliable information from a cross-section of farmers without manipulating the variables [14]. The research covered two geopolitical zones (Southeast and North central) to capture regional variations in agricultural practices, ecological conditions, and socioeconomic contexts. Two states were randomly selected from each zone (Southeast: Abia and Ebonyi states, North Central: Benue and Plateau states).

A multistage sampling procedure was used in this study. The first stage was the purposive selection of

two (2) geo-political zones of Nigeria (North central – high temperature and limited rainfall, and Southeast – moderate temperature and high rainfall). This was followed by the random selection of two (2) states from each of the zones (Southeast Abia and Ebonyi states; North central - Benue and Plateau states). Five (5) local government areas were randomly selected across the states, and 19 farmers were randomly selected from each local government. Thus, a total sample size of 380 farmers was used for the study. Primary data were collected using a structured questionnaire designed to capture the key variables relevant to the study objectives. The instrument comprised distinct sections addressing respondents' socio-demographic characteristics, level of awareness of climate-smart farming (CSF), perceived contributions of CSF to food security, and constraints to CSF adoption.

To ensure methodological rigor, the questionnaire was subjected to expert validation by agricultural extension specialists who assessed its content adequacy, relevance, and clarity. Subsequently, a pilot survey was conducted with 30 farmers from communities outside the study area to test the reliability of the instrument. The pilot data yielded a Cronbach's alpha coefficient of 0.81, indicating a high level of internal consistency and reliability.

Data collection was conducted through face-to-face interviews administered by trained enumerators to minimize response bias and enhance data accuracy. Prior to data collection, ethical approval was obtained, and informed consent was secured from all participants with assurances of confidentiality and voluntary participation.

Data were analyzed using descriptive and inferential statistical analyses. Frequencies, percentages, means, standard deviations and chi-square were used to summarize respondents' characteristics, levels of awareness, and adoption patterns. The degree of awareness was assessed using a five-point Likert scale with a benchmark mean of 3.0. This study applied multiple linear regression analysis to identify the factors influencing the intensity of climate-smart farming (CSF) adoption among farmers. This method was appropriate because the dependent variable (the CSF adoption index) was continuous and reflected

varying levels of adoption rather than a simple adopt/non-adopt outcome variable. The regression framework allowed for the simultaneous estimation of the magnitude and direction of the influence of selected socioeconomic, institutional, and production-related factors on CSF adoption.

The explanatory variables included farmers' age, gender, level of education, farming experience, access to credit, access to extension services, membership in cooperative societies, access to relevant technologies, and the cost of CSF practices. The statistical significance of the estimated coefficients was evaluated at the 5 percent level ($p < 0.05$), ensuring the reliability of the inferences drawn on the determinants, constraints, and food security implications of CSF adoption in Nigeria.

Prior to estimation, diagnostic tests were conducted to validate the assumptions underlying the multiple linear regression, including checks for linearity, multicollinearity among explanatory variables, and overall model adequacy. Standardized beta (β) coefficients were reported to facilitate the comparison of the relative importance of each predictor variable, while t-statistics and corresponding p-values were used to assess the significance of individual coefficients.

2.1. Model specification

The multiple linear regression model was specified as follows:

$$CSFi = \beta_0 + \beta_1 Age_i + \beta_2 Gend_i + \beta_3 Edu_i + \beta_4 Exp_i + \beta_5 Cost_i + \beta_6 Ext_i + \beta_7 Mixed_i + \beta_8 Tech_i + \beta_9 Avail_i + \epsilon_i$$

Where:

CSFi = CSF adoption index of the i^{th} farmer

β_0 = intercept term

$\beta_1 \dots \beta_9$ = regression coefficients to be estimated

Age = age of farmer (years)

Gend = gender (1 = male, 0 = female)

Edu = years of formal education

Exp = farming experience (years)

Ext = access to extension services (1 = yes, 0 = no)

Tech = access to CSF-related technology (1 = yes, 0 = no)

Cost = cost of CSF practices (naira)

Avail = Availability of farming facilities (1 = yes, 0 = no)

Mixed = Engagement in mixed farming (1 = yes, 0 = no)

ε_i = stochastic error term

2.2. Measurement of variables

The variables used in this study were operationalized and measured to reflect farmers' socioeconomic characteristics, institutional access, and production-related factors influencing the adoption of climate-smart farming (CSF). The dependent variable was the CSF adoption index, while the independent variables captured the demographic, economic, and institutional attributes of the respondents.

2.3. Dependent variable

Climate-Smart Farming (CSF) Adoption Index: This was measured as a continuous composite index reflecting the intensity of adoption of climate-smart farming practices by each farmer. The index captured the extent to which respondents implemented the identified CSF practices on their farms, with higher scores indicating greater levels of adoption.

2.4. Independent variables

Age: Measured in completed years at the time of survey.

Gender: Dummy variable, coded as 1 for males and 0 for females.

Education: Measured as the total number of years of formal schooling completed by respondents.

Farming experience: Measured in years of active engagement in farming.

Cost of CSF practices: Measured as the estimated financial cost incurred by farmers in implementing climate-smart farming practices, expressed in Nigerian Naira.

Access to extension services: Dummy variable indicating whether the farmer had access to agricultural extension support (1 = yes, 0 = no).

Access to CSF-related technology: Dummy variable indicating the availability and use of climate-smart farming technologies (1 = yes, 0 = no).

Availability of farming facilities: Dummy variable reflecting access to essential production facilities such as irrigation, storage, or mechanized tools (1 = yes, 0 = no).

Engagement in mixed farming: Dummy variable indicating whether the farmer practiced mixed farming (crop and livestock integration) (1 = yes,

0=no).

Awareness of CSF: Assessed using a five-point Likert scale ranging from 1 (very low awareness) to 5 (very high awareness), with a benchmark mean score of 3.0, indicating moderate awareness.

Perceived contributions to food security and constraints to adoption: Measured using structured Likert-type items capturing respondents' perceptions and experiences regarding CSF outcomes and adoption barriers.

3. Results and discussion

3.1. Background information of respondent

Background information on respondents as presented in Fig. 1, shows a predominately male sample (56%), reflecting the persistence of gender imbalances in the agricultural and professional environment in Nigeria, where men traditionally dominate access to production resources, land and formal agricultural education [1]. Although the 44 percent participation rate of women is higher than in many rural samples, it still reflects a gender gap. The age structure shows that the majority of respondents are matured and experienced, with less than half of the respondents (44.6) aged between 41 and 50 years, followed by those aged 31 to 40 years (25.1). Younger respondents (aged 21-30) represent only 11.8 percent of the sample, indicating that young people are under-represented in farming activities. The median age was 42.4 years, indicating a preference for older and more experienced workers. This implies a stable workforce with the requisite institutional knowledge.

The educational background of respondents varied considerably, with a high proportion having completed secondary education (28%), followed by respondents with BSc (19%), elementary (16%) and non-formal education (12%). This distribution shows a moderate literacy level, which may affect the capacity of farmers to understand and adopt climate-smart innovations. Empirical studies consistently point to education as a strong predictor of CSF uptake, as literacy improves farmers' ability to understand agricultural advice and evaluate new technologies [15, 16]. This educational advantage places them in a position to become potential knowledge multipliers, capable of understanding, adopting and disseminating complex CSF technologies such as

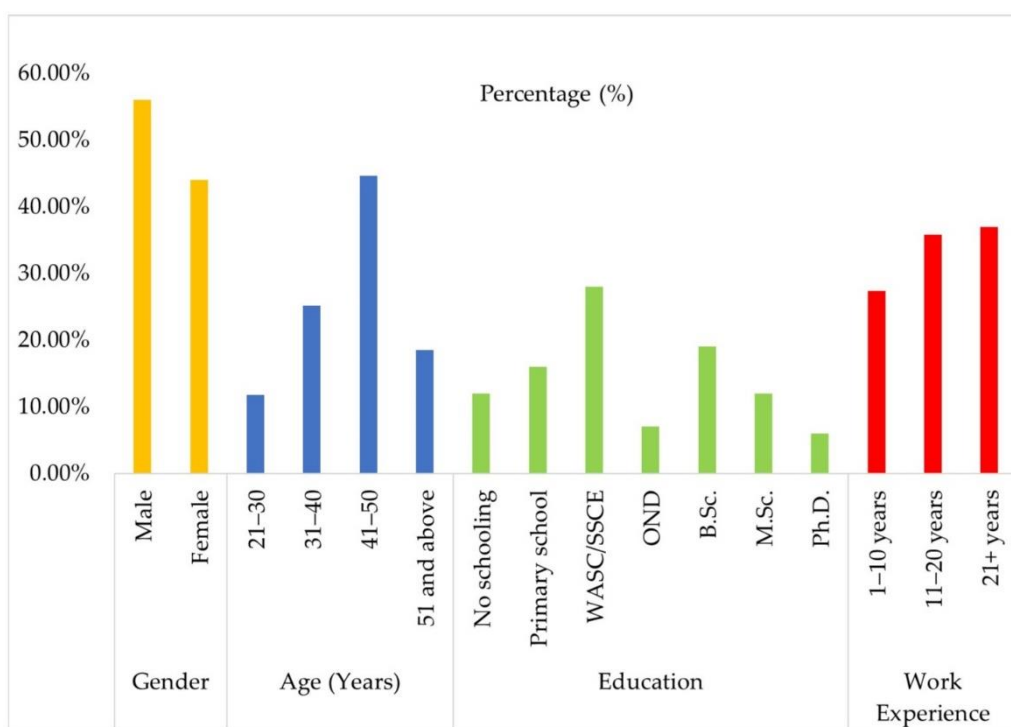


Figure. 1. The background information of respondents indicating their gender, age, educational qualification, and years of work experience.

precision agriculture, drought-resistant grasslands and climate-resilient seed systems. The profile is further enhanced by the number of years of professional experience, with more than 63% of respondents having at least 10 years of work experience, and 36.9% having 21 years or more of experience. This broad experience suggests a pool of decision makers and sectoral players that can drive the implementation and innovation of climate smart farming. However, it also shows that the continued involvement of early-stage workers (27.3) is crucial for ensuring continuity, innovation and generational renewal in the transition to climate smart farming in Nigeria.

The results concur with the findings of [17] and [18], which suggest that socio-economic and institutional factors such as education, gender, size of the farm, access to credit and contact with extension staff have a significant impact on the level of use. Educated farmers are more likely to understand the concept of climate change, interpret agricultural information and effectively apply new knowledge [19].

3.2. Farming systems practiced

Fig. 2 shows that the most common livelihood activities reported by respondents are arable farming

(84%) and mixed crops-and-livestock farming (76%), while livestock farming (41%) and agroforestry (39%) are less common.

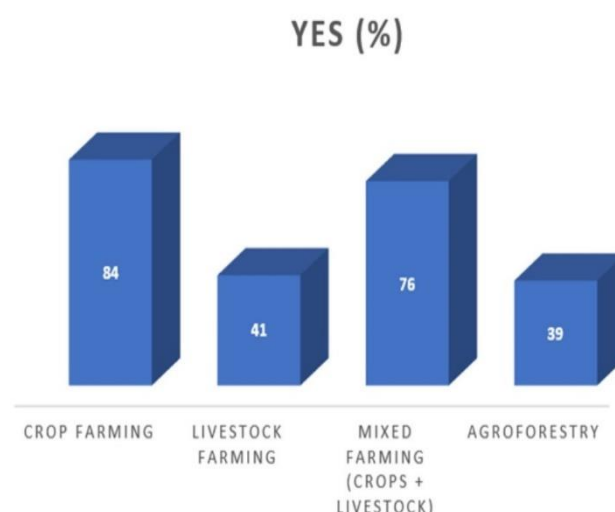


Figure. 2. Livelihood activities reported by farmers during the study.

This challenges in Fig. 3 indicates a production system that is highly dependent on the cultivation of crops with limited diversification into integrated or plantation systems. The predominance of Arable farming is in line with rural agricultural structures in

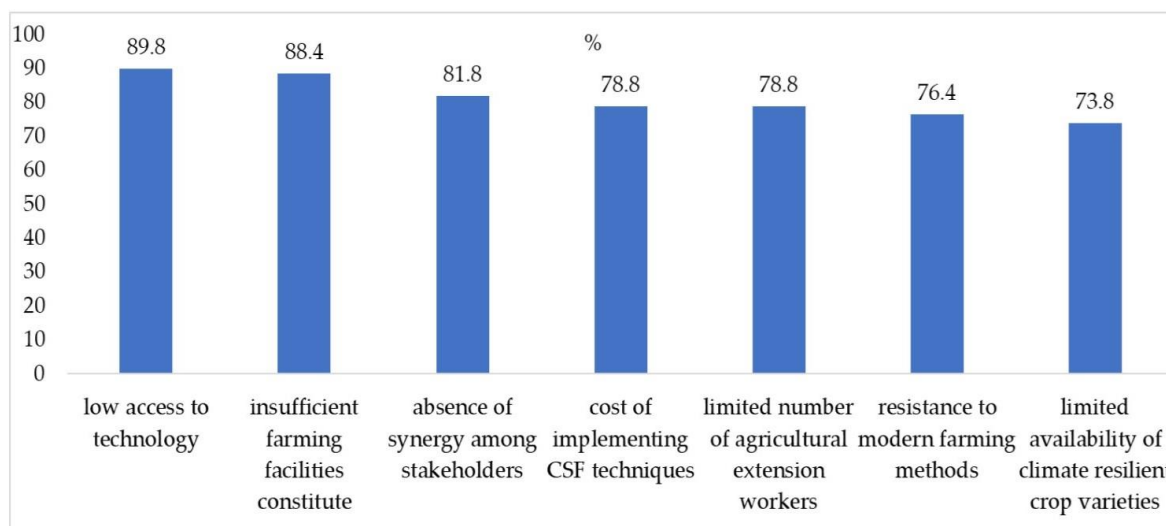


Figure 3. Challenges of CFS adoption.

Sub-Saharan Africa, where small-scale households rely mainly on seasonal crops for income and food [5]. However, this heavy dependence exposes farmers to climatic variability risks, such as drought, pests and soil degradation. The relatively high uptake of mixed farming is encouraging, as integrated cropping-livestock systems are well documented for increasing resource efficiency, nutrient recycling and climate change resilience [6].

Conversely, the low participation in agroforestry and livestock production systems highlights the remaining constraints, such as the lack of technical support, uncertainty of land tenure, limited access to inputs and delayed economic yield of tree crops [20, 21]. This has implications for climate-smart agriculture and food security, as the integration of agroforestry and livestock is key to achieving sustainable growth, restoring soil fertility and maintaining healthy ecosystems [5, 6]. Encouraging diversification beyond the cultivation system will strengthen local adaptation capacity, increase productivity and ensure long-term livelihood sustainability in changing climate conditions [5].

3.3. Awareness of climate-smart farming practices

Table 1 shows the awareness levels of CSF procedures. Practices such as crop rotation, drought-resistant crops and organic fertilizers showed a high level of awareness, whereas integrated pest management (IPM), renewable energy and agroforestry showed a low level of awareness.

Table 1. Level of awareness of CSF.

CSF practices	Mean
Use of drought-resistant crops	3.09 ^a
Conservation tillage	3.16 ^a
Crop rotation and intercropping	3.94 ^a
Rainwater harvesting and irrigation	3.67 ^a
Agroforestry	2.93 ^b
Organic fertilizers and composting	3.73 ^a
Integrated pest management	2.79 ^b
Renewable energy use	1.90 ^b

Source: Field survey 2025. a; high awareness level: b; low awareness level.

The results in Table 1 show the different levels of awareness of key climate-smart farming practices among respondents. The highest levels were recorded for crop rotation and intercropping ($\bar{X} = 3.94$), organic fertilizers and composting ($\bar{X} = 3.73$), and rainwater harvesting and irrigation ($\bar{X} = 3.67$). These findings indicate that respondents are generally aware of sustainable methods of managing land and water, which have immediate and visible benefits for crop productivity.

Similarly, moderate to high awareness of drought resistant crops ($\bar{X} = 3.09$) and conservation tillage ($\bar{X} = 3.16$) is increasingly recognized as a practical response to erratic rainfall and soil degradation. These results confirm previous studies, [22], which found that farmers in sub-Saharan Africa are more likely to adopt or understand CSF practices that directly increase yields or reduce production risk in a short period.

However, a lower level of awareness was observed in the areas of agroforestry ($\bar{X} = 2.93$), integrated pest management ($\bar{X} = 2.79$) and energy from renewable sources ($\bar{X} = 1.90$). Although, these areas essential for long-term climate resilience and ecosystem health, are often hampered by limited support for extension, technical complexity and delayed economic returns [23, 24]. For example, the low awareness of renewable energy consumption reflects wider findings in Africa, where knowledge and infrastructure of solar-powered irrigation systems, bio-gas and water-efficient drying systems remain low [25]. Similarly, the lack of awareness about IPM and agroforestry is consistent with the report [26], which found that insufficient training and institutional support prevent the adoption of bio-intensive or tree-based practices. The mixed level of awareness implies that while the basic CSF procedures are relatively well internalized, there is still a gap in the knowledge of advanced or technological adaptation.

3.4. Perception of the effect of adopted CSF practices on food security

The results (Table 2) indicate that farmers perceive adopted climate-smart farming (CSF) practices as contributing positively to overall food security (mean = 2.66) and the availability of safe food (mean = 2.39).

Table 2. Perceived effect of adopted CSF practices on food security.

Statement	Mean
Contributes to food security in Nigeria	2.66
Contributes to availability of safe food	2.39
Contributes to reducing hunger	2.20
Contributes to affordability of nutritious food	1.82
Contributes to access to sufficient food	1.46

Source: Field Survey 2025.

This suggests that CSF adoption is associated with improved productivity, better crop management, and enhanced food quality. In practical terms, the CSF appears to be effective in strengthening the supply side of the food system. However, the relatively low mean scores for reducing hunger (2.20), affordability of nutritious food (1.82), and access to sufficient food (1.46) reveal important limitations of this study. These findings imply that increased production and improved food quality do not automatically translate to improved household food access or purchasing

power. Many respondents remained uncertain or disagreed with the notion that CSF improves affordability or physical access to food.

The key implication is that productivity gains alone are insufficient to guarantee comprehensive food security in the future. Structural and systemic constraints, such as high food prices, weak market linkages, inefficient distribution systems, and income limitations, continue to mediate the benefits of CSF adoption. This suggests that while CSF strengthens food availability, it has a weaker influence on the access and affordability dimensions of food security.

3.5. Climate-smart farming and food security

The relationship between respondents' knowledge of climate smart farming practices and their perception of the contribution of CSF to food security was examined by Chi-Square independence. The results (Tables 3 and 4) show a Chi-square value (χ^2) of 3.22 with 1 degree of freedom, which is below the critical value of 3.84 at a significance level of 0.05.

Table 3. Cross-tabulation of awareness and perceived CSF contribution to food security.

Awareness Level	CSF Contributes (Yes)	No	Total
High awareness	228	5	233
Low awareness	123	7	130
Total	351	12	363

Source: Field Survey 2025.

This suggests that there is no statistically significant relationship between the level of awareness of CSF and the perception of its contribution to food security.

The analysis shows that awareness of CSF practices does not significantly affect the perception of their contribution to food security. Although 62.5 percent of respondents were highly aware of CSF practices (five practices with a mean score > 3.0) and 37.5 percent were low-informed (three practices with a mean score < 3.0), both groups had a generally positive perception with 96.7% acknowledging CSF as essential for improving food security. This convergence indicates that, despite the lack of a deep technical understanding, the respondents recognized the wider importance of CSF for agricultural resilience, productivity and sustainability.

This finding is consistent with the study [27], who

Table 4. Climate-smart farming and food security.

Awareness Level	Observed Yes (O)	Expected yes (E)	(O-E) ² /E	Observed no (O)	Expected no (E)	(O-E) ² /E
High	228	225.1	0.04	5	7.9	1.06
Low	123	125.9	0.07	7	4.1	2.05
Total	$\chi^2 = 3.22; df = 1; p > 0.05$					

Source: Field Survey 2025.

found that farmers' perceptions of the benefits of CSF are often derived from general awareness of climate problems rather than from specific technical knowledge. In many African contexts, food insecurity has become a daily experience, and farmers intuitively associate any climate-resilient innovation (whether fully understood or not) with improved food outcomes [27, 28]. Thus, while awareness is a major driver of adoption, the perception of benefits can be generated by wider social learning, shared experiences among the community and exposure to government or non-governmental sensitization programs [29].

However, the lack of a statistically significant relationship suggests that awareness alone may not be sufficient to induce changes in behaviour or CSF practice. As emphasized in Rogers' (2003) theory of diffusion of innovation knowledge must be complemented by trialability, audibility, and tangible benefits before acceptance can be widespread. In practice, this finding suggests that, while respondents recognize the potential of CSF, implementing it requires experiential and participative learning models such as farmer-based schools, demonstration plots and extension services to farmers [30]. These interactive approaches help to bridge the gap between awareness and adoption by linking knowledge to measurable improvements in yields, soil fertility and nutrition in households.

This study highlights that a positive perception of the role of CSF in food security creates a favourable environment for broad acceptance, even if there are differences in awareness. Policymakers should capitalize on this positive perception by including CSF in national agricultural extension curricula, ensuring that farmers not only know what CSF is, but also how and why it increases resilience to climate change. Furthermore, the relevance and uptake of the

CSF can be increased by aligning it with local priorities such as livelihoods, soil fertility and water management [25]. Future interventions should therefore focus on raising awareness through context-specific demonstrations, capacity building and community-led adaptation strategies to turn positive perceptions into action.

3.6. Determinant of climate-smart farming (CSF) adoption

The multi-regression analysis (Table 4) provides a detailed understanding of the factors influencing the adoption of climate smart farming by Nigerian farmers. The model was statistically significant (Adj R² = 0.64, p < 0.001) and explained approximately 64 percent (R² = 0.64) of the variation in the CSF response rates. The findings show that access to technologies ($\beta = 0.42, p < 0.01$), availability of agricultural equipment ($\beta = 0.31, p < 0.01$) and access to extension services ($\beta = 0.27, p < 0.05$) have a positive impact on the adoption of the CSF. Socio-demographic factors, particularly educational level ($\beta = 0.41, p < 0.01$), years of farming experience ($\beta = 0.33, p < 0.01$) and participation in mixed farming ($\beta = 0.26, p < 0.01$) also influenced the adoption of CSF practices. Conversely, age had a negative effect ($\beta = -0.18, p < 0.05$), indicating that older farmers may be less responsive to innovation and technology-intensive practices.

The results in Table 5 summarized that the factors influencing the adoption of CSF in Nigeria are multi-dimensional and shaped by both structural and human capital factors. The strong positive impact of access to technologies ($\beta = 0.42$) and agricultural equipment ($\beta = 0.31$) means that the enabling environment, such as access to inputs, irrigation systems, and mechanization, are key factors in facilitating the transition to climate smart systems. This finding is consistent with the findings of [31] who identified infrastructure capacity and access to

Table 5. Determinant of CSF adoption.

Predictor Variable	Standardized β	t-value	p-value
Access to technology	0.42	4.83	0.001***
Availability of farming facilities	0.31	3.72	0.004***
Extension services	0.27	2.98	0.010**
Cost of CSF	-0.21	-2.41	0.018**
Level of education	0.41	5.27	0.001**
Farming experience	0.33	4.01	0.002**
Engagement in mixed farming	0.26	3.45	0.004*
Age	-0.18	-2.09	0.038*
Model summary	Adj. R ² = 0.64; p < 0.001		

Source: Field data 2025.

adaptive technologies as key determinants of the uptake of CSF in sub-Saharan Africa. Farmers with access to affordable technologies, such as drought resistant seed varieties, water efficient irrigation systems and solutions for post-harvest storage are more likely to adopt and maintain CSF practices, ultimately improving food production and income stability.

Similarly, extension services ($\beta = 0.27$) emerged as a major positive driver of CSF adoption and food security. This supports the claim made by [30] and Cairns [32] that effective dissemination of knowledge, training for farmers and technical advice are essential to translate awareness into practical implementation. Extension systems not only serve as conduits for technical advice but also bridge the gap between research results and local realities, allowing farmers to adapt CSF practices to their specific agroecological environments. The empirical link between support for extension and adoption thus highlights the need to strengthen Nigerian networks for agricultural extension, which remain underfunded and fragmented [33]. Therefore, increasing the uptake of CSF will require institutional reforms to increase outreach, diversify channels of communication and integrate local knowledge systems.

Extension services are among the factors widely reported in many areas to promote of awareness of climate change issues and the extent of adaptation to the problem. Through the use of such services and capacity building, farmers can be made more aware of climate change challenges and how to respond to them. However, in this study, the two factors were found not to have significant influences on farmers'

awareness levels of CSF technologies. This was thought to be a reflection of the very low levels of presence of extension officers to deliver those services and provide the necessary training and capacity building that could promote high levels of awareness of CSF technologies and adoption by the farmers.

On the socio-demographic front, adoption and food security outcomes were strongly predicted by education ($\beta = 0.41$) and agricultural experience ($\beta = 0.33$). Highly educated farmers tend to have a higher ability to understand, assess and implement complex climate smart technologies, because they have a higher degree of cognitive flexibility and innovation-friendly attitudes [6, 14]. Similarly, experienced farmers use their accumulated practical knowledge to assess the risks and benefits of new practices, which facilitates selective adoption that maximises productivity and minimises losses.

The positive impact of participation in mixed farming ($\beta = 0.26$) is confirmed by previous studies [27, 34], which reported that diversification through mixed farming increases the resilience of ecosystems, nutrient cycling and economic stability, and makes households less vulnerable to climate change.

Conversely, the negative correlation between age ($\beta = -0.18$) and the cost of adopting CSF ($\beta = -0.21$) reflects generational differences in technological sensitivity and risk aversion. Younger farmers are more experimental and open to the use of digital and mechanized solutions, whereas older farmers are more likely to stick to traditional practices although youths are not attracted or motivated to embrace agriculture. They prefer white collar job, whereas older farmers are more likely to stick to traditional

practices [35]. This finding signals the political need to encourage the participation of young people in the CSF through targeted funding, mentoring and innovation programs. Moreover, the negative coefficient for the cost of CSF underlines the high cost of CSF technologies as the main obstacle to the spread of CSF. The high upfront investment costs of technologies such as renewable energy systems, irrigation pumps and soil protection infrastructure discourage adoption, particularly by smallholder farmers [36]. Financial inclusion mechanisms, such as climate-smart credit schemes, co-financing and input subsidies, are therefore essential to reduce costs and allow fair participation.

3.7. Challenges of climate smart farming

The findings reveal that farmers face multiple and interrelated barriers that significantly constrain the effective adoption of climate-smart farming (CSF). The most prominent challenges included low access to technology (89.8%) and insufficient farming facilities (88.4%), indicating that many farmers lack the essential tools, infrastructure, and technical resources needed to implement CSF practices. This highlights a major capacity gap that limits the practical application of climate-smart innovations at the farm level.

Institutional and coordination challenges are also evident. A high proportion of respondents reported the absence of synergy among stakeholders (81.8%) and a limited number of agricultural extension workers (78.8%), suggesting weak support systems for knowledge dissemination, technical guidance, and programme implementation. These gaps reduce farmers' exposure to innovations and hinder the sustained adoption of innovations.

Economic and behavioural constraints further compound this problem. The high cost of implementing CSF techniques (78.8%) makes their adoption financially burdensome, especially for smallholder farmers. Additionally, resistance to modern farming methods (76.4%) reflects attitudinal and knowledge barriers that slow the uptake of new practices. The limited availability of climate-resilient crop varieties (73.8%) also restricts farmers' ability to adapt effectively to climate risks.

The implications are clear, the successful scaling of

CSF requires more than just awareness creation. There is a need for affordable technologies, improved infrastructure, strengthened extension services, coordinated institutional support, and behavioural change interventions. Without addressing these systemic, economic, and capacity-related constraints, the widespread and sustained adoption of climate-smart farming practices remains limited.

4. Conclusions

The study concludes that the adoption of CSF is not driven by awareness alone, but by ecosystem enabling conditions, including access to technology, finance, infrastructure and knowledge systems. Therefore, policies must follow integrated approaches that combine supply-side strategies (technology provision, infrastructure investment and input finance) with demand-side strategies (capacity building, empowerment of young people and gender mainstreaming). Reinforcing extension schemes, improving access to affordable credit and encouraging diversification through mixed farming and agroforestry can significantly increase the uptake. Ultimately, strengthening these multidimensional drivers will allow Nigeria to move towards a climate-resilient and sustainable agricultural system that can ensure long-term food security.

This study highlights the need for policies and incentives to attract younger Nigerians who tend to be more innovative and technologically oriented to contribute to sustainable agriculture. The disparity between men and women must be addressed by deliberately incorporating women into climate-smart agriculture initiatives. Bridging this gap is crucial, as women continue to play a central role in ensuring household food security and smallholder production. Furthermore, future interventions should build on the existing strengths on mixed farming, while addressing barriers to adopting tree-based and livestock-friendly practices through targeted extension, policy incentives and access to climate-friendly financing. Farmer's capacity should be strengthened through experience-based learning and demonstration plots, while policymakers and development agencies should also prioritize the integration of low-information practices, such as agroforestry and renewable energy, into mainstream

CSF programs, capitalizing on existing farmers' interest in soil and water management. Increasing awareness of the full range of CSF technologies will ultimately improve adaptive capacity, resource efficiency and sustainable production in Nigeria and similar agro-ecological contexts.

Ethical statement

This study collected primary data from 380 respondents across two geopolitical zones in Nigeria. Although formal institutional ethical clearance was not obtained, all procedures adhered to the internationally accepted ethical standards for research involving human participants. The purpose of the study, expected benefits, and voluntary nature of participation were clearly explained to all the respondents. Informed consent was obtained prior to data collection, and all information was collected, handled, and reported in a manner that ensured anonymity, confidentiality, and protection of participants' rights and privacy.

Disclaimer (artificial intelligence)

Author(s) hereby state that no generative AI tools such as Large Language Models (ChatGPT, Capilot etc) and text-to-image generators were utilized in the preparation or editing of this manuscript.

Authors' contributions

Conceptualization, designed, review protocol, literature search, and supervised, N.C.U.; methodological refinement, validated the search strategy, and reviewed manuscript for intellectual content and provided critical revisions, J.G.A.; data extraction and analysis supported the synthesis of findings, drafted sections of the results, N.S.C.

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Availability of data and materials

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of interest

The authors declare no conflict interest.

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