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Evaluating the Effects of Climate-Smart Agricultural Techniques on Food Security in Rwanda, Case of Nyagatare District

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Abstract

Climate-smart agriculture (CSA) is widely regarded as an important technique for tackling climate change concerns while maintaining food security. This study assessed the effects of climate-smart agriculture on food security in Nyagatare District, Rwanda, a region vulnerable to climate variability and highly dependent on agriculture. The research focused on household farmers, chosen through stratified random sampling from 160,435 households, with additional interviews conducted with 5 local leaders and 15 agricultural officers. Data were collected using structured questionnaires, key informant interviews, focus group discussions and field observations. A mixed-methods approach incorporating both quantitative and qualitative data was used to assess the effectiveness of climate-smart agriculture practices on agricultural productivity, food status, relationship between climate-smart agriculture practices and food security. Quantitative data were analyzed with statistical methods such as SPSS software version 30.0 and Microsoft Excel, while qualitative data were examined through thematic analysis. The study evaluated the adoption and effectiveness of specific climate-smart agriculture techniques, including crop rotation, agroforestry, organic fertilization, water harvesting, drought-resistant seeds, and conservation tillage. Findings revealed high adoption and positive perception of crop rotation (mean = 4.34), agroforestry (mean = 4.04), and organic fertilizers and composting (mean = 4.58). Conversely, water harvesting (mean = 1.60) and drought-resistant seeds (mean = 1.76) were less adopted. A statistically significant positive correlation ($r = 0.152$, $p = 0.002$) was found between CSA adoption and food security, indicating that while the impact is modest, climate-smart agriculture practices contribute to improved food outcomes. The study concludes that climate-smart agriculture enhances food security in Nyagatare District.

Keywords: *Adaptation, Agro-ecology, Agroforestry, Climate change, Climate-smart agriculture, Drought, Food security, Livelihoods, Rwanda.*

1. Introduction

Climate change, combined with growing population growth, threatens global food security. As a result, an increase in sustainable food production is required to meet rising food demand while mitigating the effects of climate change (Mutengwa et al., 2023). Climate change poses a threat to food security systems and is one of the most significant concerns of the twenty-first century (Betts et al., 2018). It is widely agreed that the ability to restrict the rate of climate change by keeping change in temperature rise below the 2°C threshold in the long run is now limited and the world population will have to deal with its effects (Tekeste, 2021). East Africa, as part of Sub-Saharan Africa, experiences severe climate variability and food security issues (Lal et al., 2016). Efforts to deploy climate smart agriculture in this region have helped to improve agricultural productivity and reduce vulnerability to climate threats (Azadi et al., 2021). Countries like Kenya and Tanzania have implemented national climate smart agriculture frameworks that emphasize sustainable land management, effective water resource use and the adoption of climate-resilient agricultural varieties. However, the efficacy of these treatments varies with the local environment, policy backing and farmer participation (Muhan, 2023).

In Rwanda, climate change is already manifesting in shifting weather patterns, such as erratic rainfall, prolonged dry spells, and more frequent and intense storms (Muhire, 2015). Data from the Rwanda Meteorology Agency (RMA) indicates that average temperatures in the country have increased by 1.5°C over the past 40 years, with projections suggesting further increases in temperature and changes in rainfall patterns in the coming decades. These changes threaten agricultural productivity resulting in food insecurity, especially in rural areas like Nyagatare District, which depend heavily on crop farming and livestock rearing for livelihoods (Uwiragiye, 2016). Thus, increasing agricultural productivity is keys to success of Rwanda’s economy and the well-being of its population (MINAGRI, 2017). The increases in production need to come from the existing farmland, as the population density (591 persons’ per square kilometers) is very high and there is limited or no additional land that could be used for agriculture in Rwanda (NISR, 2024). Nyagatare, located in the Eastern Province of Rwanda, is particularly vulnerable to climate variability. The district has experienced severe droughts in recent years, impacting food production and increasing the risk of food insecurity (Green, 2019). In addition to the changing climate, rapid population growth which puts pressure on land resources further strain agricultural systems, making it even more difficult to ensure food security (Green, 2019). In response to these climate challenges, Climate smart agriculture (CSA) has emerged as a promising approach to enhance food security. CSA promotes agricultural practices that sustainably increase productivity, enhance resilience to climate change, and reduce greenhouse gas emissions (Andrew, 2024). Assessing the effects of CSA techniques adoption is essential as it show how climate-smart techniques might be tailored to local conditions in order to improve agricultural resilience, productivity, nutritional results, and economic stability, hence boosting food security in a sustainable manner.

1.1.Objectives of the study

1.1.1. General objective

The general objective of the study was to evaluating the effects of climate-smart agricultural techniques on food security in Rwanda, Nyagatare district.

1.1.2. Specific objectives

The specific objectives of this study include:

- To assess the climate smart agricultural techniques in Nyagatare district
- To assess the food security status in Nyagatare district
- To analyze the correlation between climate smart agriculture practices and food in Nyagatare district

2. Materials and methods

2.1. Profile of Nyagatare District

Nyagatare District, located in northeastern Rwanda, is the country's largest district, comprising around 1,741 square kilometers. Nyagatare District is administratively divided into 14 sectors, as shown in the figure 3.1, which are further divided into cells and villages (NISR, 2022). Nyagatare District is characterized by a semi-arid climate, with a mix of wet and dry periods, which significantly influences agricultural activities. The district has a relatively flat terrain**,** with elevations ranging from 1,200 to 2,200 meters above sea level. The climate and altitude conditions affect crop production, and the district is particularly prone to the challenges of droughts, which can impact agricultural productivity. However, Nyagatare benefits from the Muvumba River and other water sources, which are crucial for irrigation and livestock farming.

The main crops grown in Nyagatare include maize, beans, sorghum, cassava, sweet potatoes, and vegetables like tomatoes, onions, and cabbage. These crops are well-suited to the district's climate and soil types, contributing to food security for both the local population and the wider region. In addition, Nyagatare is a significant producer of rice, particularly in areas with adequate irrigation.

The results of 5th RPHC 2022 revealed that nationally, 2,280,854 of private households (68.9%) are engaged in agriculture, among them 62.6% are engaged in crop farming and 50.4% are engaged in Livestock husbandry, Overall, land utilization for agriculture in Nyagatare has surpassed 92,319 hectares, highlighting the district's robust agricultural sector (NISR, 2022).. In Nyagatare District, 106,284 Agricultural households occupy (66.3%) with 59.3% of households engaged in crop farming and 39.2% Households engaged in Livestock husbandry. Nyagatare District is mostly rural where the agriculture activities are practiced on high scale. Kiyombe sector has a high proportion of Households engaged in crop farming (84.7%) and Households engaged in Livestock husbandry (60.5%) (NISR, 2022). In Nyagatare District, agricultural households account for 66.3% of all households, with 59.3% engaged in crop farming and 39.2% engaged in livestock husbandry. Nyagatare District is largely rural, with large-scale agricultural activities(NISR, 2022).

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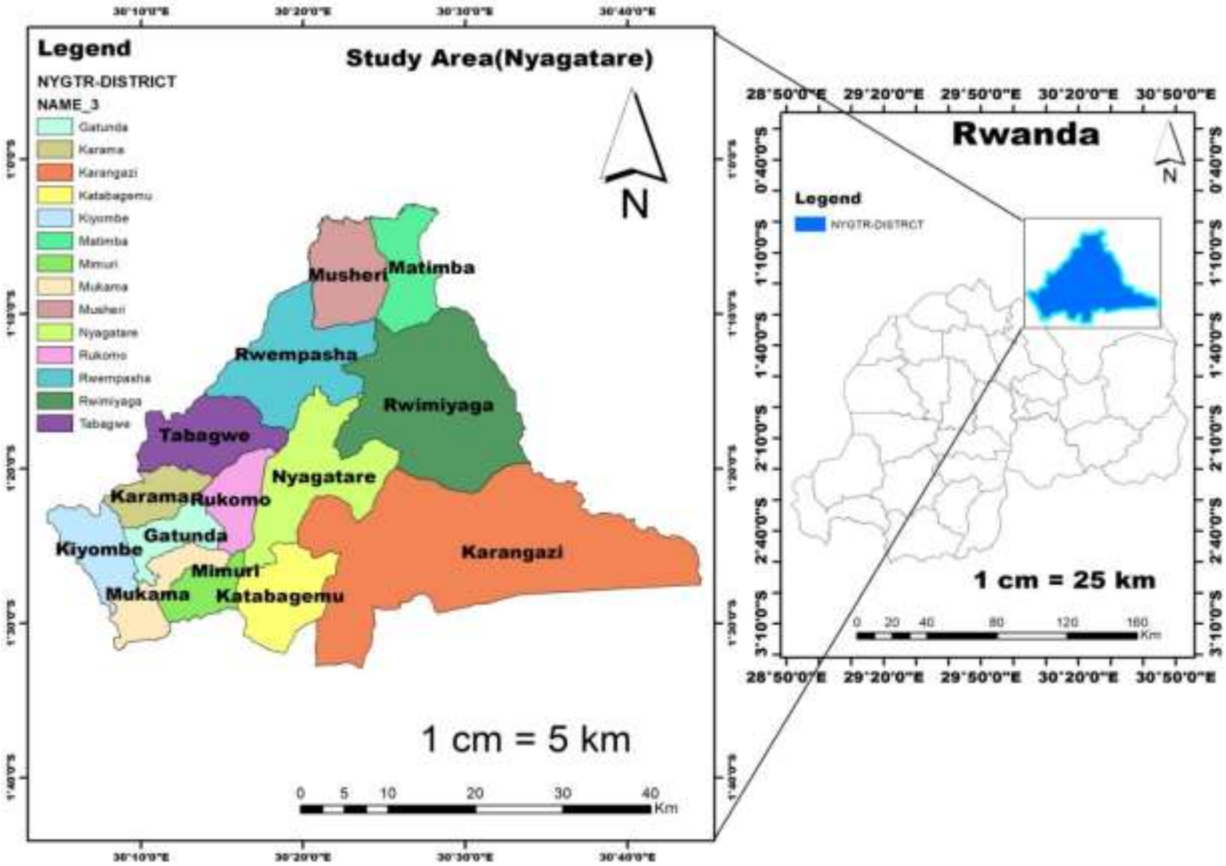

Figure 3.1. Geographical location map of the study

2.2. Research design and sampling techniques

This study adopts a descriptive research design utilizing a mixed-methods approach, which combines both quantitative and qualitative methodologies to thoroughly examine the effects of climate-smart agriculture (CSA) practices on food security in Nyagatare District, Rwanda. The mixed-methods approach enhances the depth and breadth of the study by integrating numerical data from surveys with rich, narrative data from interviews and focus group discussions. The quantitative component involves the use of structured household surveys to gather statistical information on the effectiveness of specific climate smart agriculture practices such as agroforestry, conservation tillage, and irrigation. These data help in identifying patterns and trends related to climate smart agriculture adoption and its correlation with food security. Meanwhile, the qualitative component explores farmers' experiences, perceptions, and challenges through key informant interviews and focus group discussions. This enables the study to capture the socio-cultural and contextual factors that influence the implementation and success of climate smart agriculture practices in the region. To ensure representative and reliable findings, the study employs both primary and secondary data sources. Primary data are collected directly from the field using surveys, interviews, and discussions, while secondary data, drawn from government

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documents, academic literature, and climate data archives, provide a contextual framework for interpreting primary findings.

In terms of sampling, the study uses stratified random sampling to select 399 households from a total population of 160,435 households in Nyagatare District. The stratification is based on key characteristics such as the household's use of climate smart agriculture methods, their food security status, and residency in the district for at least the past three years. This method ensures proportional representation of various subgroups within the population, enhancing the accuracy and generalizability of the results. For the qualitative aspect, purposive sampling is used to select key informants, including agriculture extension workers and local policymakers. This sampling method, also known as judgmental sampling, involves deliberately selecting individuals who have specific knowledge or experience relevant to the research objectives. By focusing on those directly involved in climate smart agriculture implementation and food security strategies, the study gathers in-depth insights that complement the quantitative data.

Table 3.1.Sample Size in each Sector of Nyagatare District

Sample size for each stratum= (Size of stratum×Total sample size)/ Total population

Sectors	**Target population/Households**	**Sample Size**	**Sampling technique**
Gatunda	9140	23	Stratified random sampling
Karama	8262	20	Stratified random sampling
Karangazi	23195	58	Stratified random sampling
Katabagemu	10819	27	Stratified random sampling
Kiyombe	4820	12	Stratified random sampling
Matimba	7113	18	Stratified random sampling
Mimuri	9196	23	Stratified random sampling
Mukama	6709	17	Stratified random sampling
Musheri	8532	21	Stratified random sampling
Nyagatare	20739	51	Stratified random sampling
Rukomo	10916	27	Stratified random sampling
Rwempasha	9139	23	Stratified random sampling

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Rwimiyaga	19261	48	Stratified random sampling
Tabagwe	12594	31	Stratified random sampling
Total(Nyagatare)	**160435**	**399**	

3. Results and discussion

3.1. Climate-Smart Agriculture Techniques in Nyagatare District

The socio-demographic profile of respondents in Nyagatare District highlights major trends that may influence farming practices. The majority of respondents (54.64%) were female, indicating that women are heavily involved in agriculture in the district. This emphasizes that any initiatives to promote climate smart agriculture practices should actively involve women and be customized to their unique needs and limitations. In terms of marital status, the majority of respondents (68.42%) were married, which suggests that farming decision-making is frequently a collaborative effort and may have an impact on the introduction of innovative practices such as climate-smart agriculture.

In terms of education levels, the majority of respondents had either primary (34.84%) or secondary (29.82%) education, with 11.53% having finished university studies and 23.61% having no formal education. These findings underline the importance of climate smart agriculture training programs that are inclusive and accessible to farmers of various literacy levels. The 46-60 age groups (40.35%) and the 31-45 age groups (35.84%) dominated the age distribution, indicating that Nyagatare's farming population is mature and experienced. Similarly, farming experience data revealed that the majority of respondents had more than ten years of experience, with 30.58% having 11-20 years and 27.32% having more than twenty years. This demonstrates a high level of local farming expertise, which can be useful for introducing new practices.

In terms of specific climate smart agriculture techniques, the study discovered that some are extensively implemented and highly valued, while others are underutilized. Organic fertilizers and composting had the highest mean score (4.58), indicating widespread agreement among farmers on their advantages to soil health and sustainability. Crop rotation (mean = 4.34) and agroforestry (mean = 4.04) both earned excellent ratings, indicating their perceived effectiveness in enhancing productivity and environmental resilience. Practices such as water harvesting (mean = 1.60), drought-resistant seeds (mean = 1.76), and livestock integration with crops (mean = 1.65) were less often utilized or valued, potentially due to a lack of resources, low understanding, or perceived impracticality in the local environment. Conservation tillage obtained a middling score (mean = 2.85), showing that farmers' opinions were mixed, most likely due to variances in farm conditions or understanding of the technique.

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CSA practices	Mean	Std. Deviation
Crop rotation	4.34	0.739
Agroforestry	4.04	0.715
Water harvesting	1.60	0.722
Conservation tillage	2.85	0.993
Use of organic fertilizers and composting	4.58	0.701
Use of drought-resistant seeds	1.76	0.809
Livestock integration with crops	1.65	0.818

Source: Field Data, 2025

3.2. Food Security Status in Nyagatare District

Food security remains a critical issue for many households in Nyagatare District. According to meal frequency data, 62.61% of households eat two meals every day, the most typical pattern. However, 26.06% reported eating only one meal each day, indicating widespread food insecurity. Only 11.05% of households eat three meals every day, with a very small proportion (0.28%) eating more than three. These results indicate the continuous problem of ensuring consistent food access for all households.

When it comes to food production, 54.15% of respondents said they generate adequate food all year, implying that more than half of households are self-sufficient. Nonetheless, 36.54% said they don't produce enough food, which could be due to poor soil conditions, inadequate inputs, or climate-related limits. Furthermore, 8.31% of respondents buy food from markets, which exposes them to risks including price swings and supply interruptions. A smaller proportion of the population reported borrowing food (0.66%) or receiving food help (0.33%), indicating that external support is low and not a key source of food for most households.

Affordability of food is also a significant concern. The majority of respondents (60.9%) consider food to be expensive, which underscores the economic challenges faced by many families despite the implementation of climate smart agriculture practices. Only 15.29% find food affordable, possibly due to higher productivity or greater access to markets. About 21.55% of respondents expressed indifference toward food prices, and 2.26% reported that food is very expensive. These insights suggest that economic barriers and market dynamics continue to affect food access, even in areas where food production is improving.

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3.3. Relationships between climate smart agriculture practices and food security in Nyagatare District

Impact of climate smart agriculture on food in Nyagatare District	Mean	Std. Deviation
Climate smart agriculture techniques have improved our farm productivity	4.24	0.760
Climate smart agriculture practices has reduced food shortages	3.97	0.753
Climate smart agriculture practices help us to adapt to climate change	3.75	0.741
climate smart agriculture practices reduced reliance on external food	3.71	0.734
Household practicing climate smart agriculture are more food secure	4.52	0.750
Government and NGOs support climate smart agriculture adoption	3.75	0.725

The study found a strong positive relationship between the adoption of climate-smart agriculture practices and food security in Nyagatare District. Respondents agreed that CSA practices have improved their farm productivity (mean = 4.24, SD = 0.76), and most strongly believed that households practicing climate smart agriculture are more food secure (mean = 4.52, SD = 0.75). These findings support the view that climate smart agriculture contributes significantly to stabilizing and improving food availability, especially in the context of climate variability. Furthermore, there was moderate agreement that climate smart agriculture practices reduce food shortages (mean = 3.97), help farmers adapt to climate change (mean = 3.75), and reduce reliance on external food sources (mean = 3.71). These responses reflect farmers' recognition of CSA's potential to enhance resilience and self-sufficiency, although some variability in responses suggests that not all farmers experience the same benefits possibly due to differences in implementation, resources, or farm size. Respondents also expressed moderate agreement that the government and non-governmental organizations support the adoption of climate smart agriculture practices (mean = 3.75). While this indicates some level of institutional involvement, it also suggests that more robust or widespread support may be necessary to ensure broader adoption and sustained success of these practices.

3.4. Correlation analysis

3.4.1. Correlations between climate smart agriculture practices and food security in Nyagatare District

Variables	CSA practices	Food Security
CSA practices	**1**	**0.**152**
Food security	0.152**	**1**

** Correlation is significant at the 0.01 level (2-tailed).

Source: Field Data, 2025

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The Pearson correlation coefficient of 0.152 indicates a positive correlation between climate-smart agriculture practices and food security, implying a slight but positive relationship between climate-smart agriculture practice adoption, the correlation between these practices and food security outcomes. As climate-smart agriculture methods are implemented, the associated food security outcomes improve modestly. The p-value of 0.002 falls below the usually accepted significance level of 0.01. This indicates that the observed association is statistically significant at the 0.01 level (high level of confidence). Because the correlation is substantial, I conclude that there is a genuine relationship between the two variables, implying that as climate-smart agriculture practices become more generally adopted; they have a moderate, statistically significant positive impact on food security outcomes. The study found a positive link between the adoption of climate-smart agriculture methods and improvements in food security outcomes in Nyagatare District. The connection is statistically significant, indicating that the link is not the result of random chance. However, the small link implies that, while climate-smart agriculture techniques are beneficial, they may not be sufficient to meaningfully affect food security outcomes.

3.5. Regression analysis

3.5.1. Analysis of variance (ANOVA) of climate smart agriculture on food accessibility in Nyagatare District

Model	Sum of squares	df	Mean square	F	Sig.
Regression	14.953	7	2.136	7.097	<0.001
Residual	117.985	392	0.301		
Total	132.938	399			

Source: Field data, 2025

The ANOVA findings demonstrate the regression model's overall importance in explaining the variation in food accessibility. The regression total of squares is 14.953, representing the variation explained by the predictors, whereas the residual sum of squares is 117.985, representing the unexplained variance. The mean square for the regression is 2.136, whereas the mean square for the residual is 0.301. The model's F-statistic is 7.097, with a p-value of less than 0.001, indicating that it is statistically significant. This suggests that the predictors (livestock-crop integration, agroforestry, crop rotation, conservation tillage, organic fertilizers and composting, water harvesting, and drought-resistant seeds) all have a major impact on food accessibility. The model is substantial, and the included factors help to explain the variation in food accessibility.

3.5.2. Analysis of variance (ANOVA) of climate smart agriculture and food availability

Model	Sum of squares	df	Mean square	F	Sig.
Regression	20.850	7	2.979	8.287	<0.001
Residual	140.898	392	0.359		
Total	161.748	399			

Source: Field data, 2025

The **ANOVA** table provides information on the overall significance of the regression model assessing the relationship between **CSA practices** and food availability. The regression model is statistically significant, with an F value of 8.287 and a p-value of <0.001. This suggests that CSA practices have a major role in explaining household food security. The model shows that adopting CSA practices is strongly associated with household food security. The model is statistically significant, with a high F value and a p-value < 0.001. While the model summary's R-squared value implies that the predictors account for only roughly 12.9% of the variation in food availability, the ANOVA confirms that these predictors have a significant effect on food availability. The relatively large residual sum of squares suggests that there is still significant unexplained variation, which could be related to factors not captured by the model, this implies that the combination of CSA practices adds considerably to understanding food security, albeit there is still some unexplained variation in food security, implying that other factors are also at play.

3.5.3. Analysis of variance (ANOVA) of CSA and market price

Model	Sum of squares	df	Mean square	F	Sig.
Regression	9.265	7	1.324	2.230	0.031
Residual	232.725	392	0.594		
Total	241.990	399			

Source: Field Data, 2025

The ANOVA table shows the statistical significance of the regression model that investigates the association between Climate Smart Agriculture (CSA) practices and the dependent variable, which in this case is the market price. The F value of 2.230 and the p-value of 0.031 shows that the model is statistically significant, implying that CSA practices have a statistically significant effect on market price. The Regression Sum of Squares of 9.265 implies that CSA practices account for a tiny percentage of the variation in market price, but there is still a significant amount of unexplained variation in the residuals (232.725), indicating that other factors influence market price.

While the regression model is statistically significant, its ability to explain market price is limited. A significant portion of the variation remains unexplained, implying the need for further research or the inclusion of other relevant predictors to better understand the factors influencing market price.

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3.5.4. Analysis of variance of CSA and food stability

Model	Sum of squares	df	Mean square	F	Sig.
Regression	59.432	7	8.490	20.244	<0.001
Residual	164.408	392	0.419		
Total	223.840	399			

Source: Field Data, 2025

The ANOVA results reveal that the regression model is highly significant, with an F-statistic of 20.244 and a p-value of less than 0.001. This suggests that a combination of predictors (such as livestock integration, agroforestry, crop rotation, and others) accounts for a large amount of the variation in food stability. Although the model effectively explains food stability, the residual sum of squares (164.408) indicates that a large amount of variability remains unexplained. This suggests that, while the predictors collectively contribute to understanding food stability, other factors not included in the model may have an even greater influence on this dependent variable.

3.6. The qualitative results

The qualitative findings from the study on the effects of Climate-Smart Agriculture (CSA) practices on food security in Nyagatare District provide important insights into the experiences, perspectives, and issues that farmers in the region confront. Many household farmers expressed interest in various climate smart agriculture techniques such as crop rotation, agroforestry, and organic fertilization, with many recognizing the potential benefits these practices could provide in terms of enhancing food security and farm productivity. However, the level of acceptance varied, with crop rotation and organic fertilizers being more widely used than other approaches such as agroforestry, which was viewed as expensive and required more land.

While some household farmers reported better crop yields and improved soil health as a result of using climate smart agriculture principles, there were significant barriers to widespread adoption. Financial restrictions were commonly noted as a major hurdle, with many farmers unable to make the first investment in new technologies or infrastructure. Despite the reported benefits of climate smart agriculture, numerous farmers reported that food prices in local markets remained high, with many still experiencing food insecurity, demonstrating a gap between greater farm output and cheap food access. This is most likely attributable to external reasons including inflation, market inefficiencies, and food distribution issues.

3.7. Discussion

The study reveals a varied level of adoption of climate-smart agriculture (CSA) techniques in Nyagatare District, shaped by socio-demographic characteristics and practical constraints. Widely adopted practices such as organic fertilizer use (mean = 4.58), crop rotation (4.34), and agroforestry (4.04) are favored due to their affordability, accessibility, and visible short-term

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benefits, such as improved soil fertility and crop yields. In contrast, low adoption of water harvesting (1.60), drought-resistant seeds (1.76), and livestock integration (1.65) suggests significant barriers, including lack of technical knowledge, financial resources, and infrastructure. Conservation tillage received mixed views (2.85), likely due to limited awareness or resource challenges. These findings highlight the importance of tailoring climate-smart agriculture interventions to local capacities and needs, especially for less adopted yet climate-resilient techniques.

Despite partial climate-smart agriculture adoption, food insecurity persists across many households. Most respondents (62.61%) consume only two meals a day, while 26.06% eat just one, indicating ongoing challenges in food access. Although 54.15% report producing enough food year-round, a significant proportion (36.54%) do not, and 60.9% of households perceive food as expensive. These results point to a disconnect between production and affordability, suggesting that increased yields alone are insufficient without supportive market structures and economic access. Food security in Nyagatare remains vulnerable, especially among households with limited resources or market access, the study finds a strong perceived link between climate-smart agriculture adoption and improved food security. Respondents agree that climate-smart agriculture techniques enhance productivity (mean = 4.24) and that climate-smart agriculture practicing households are more food secure (4.52). However, moderate agreement on CSA's role in reducing food shortages (3.97), aiding climate change adaptation (3.75) and lowering external food reliance (3.71) indicates uneven benefits, likely due to differences in farm size, access to resources, and support services. The moderate perception of government and NGO support (3.75) suggests that while institutional efforts exist, they may be insufficient or unevenly distributed. Overall, climate-smart agriculture holds strong potential to improve food security, but its effectiveness depends on broader systemic support, including education, infrastructure, and inclusive policy implementation.

4. Conclusion and recommendation

According to the study's findings, climate-smart agriculture (CSA) practices improve food security in Rwanda's Nyagatare District. The application of climate-smart agriculture practices such as agroforestry, conservation tillage, and irrigation has resulted in enhanced agricultural output, higher household incomes and greater food availability. Households that applied these practices reported more consistent food security outcomes. Qualitative findings also demonstrated that farmers, extension workers, and policymakers appreciate the importance of climate-smart agriculture in increasing climate resilience and improving food systems. However, barriers such as restricted availability to agricultural inputs, insufficient technical knowledge, and weak institutional backing impede widespread implementation.

To overcome these issues and optimize the benefits of climate-smart agriculture, the study suggests improving farmer training through capacity-building initiatives and raising awareness of climate-smart agriculture practices. Improving access to crucial agricultural inputs and technologies, such as drought-resistant seeds and irrigation infrastructure, is also critical. Enhancing the efficacy of agricultural extension services by providing them with the appropriate tools and knowledge can help farmers adopt more readily. Collaboration among stakeholders including government agencies, non-governmental organizations (NGOs), academic institutions, and the corporate sector is critical for sharing resources and expertise. Finally, regular monitoring and evaluation should be carried out to assess the performance of climate-smart agriculture programs and ensure that interventions are data-driven and tailored to local requirements. These strategies can help to increase climate-smart agriculture adoption in Nyagatare District, contributing to long-term food security and climate resilience.

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