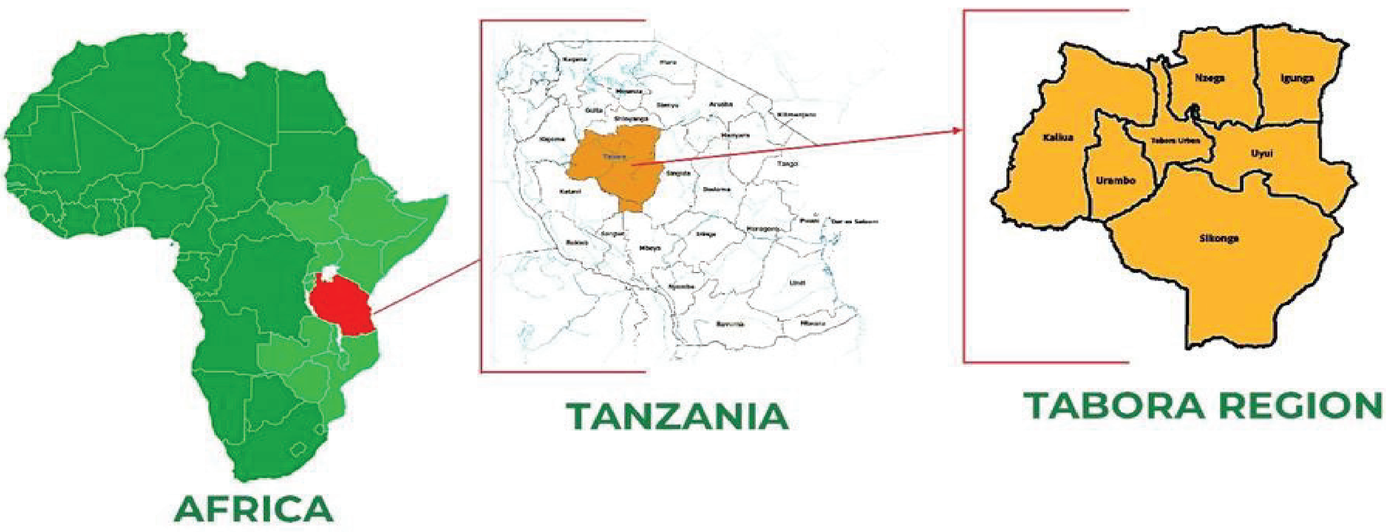
Effects of Climate Smart Agriculture (CSA) on food security and incomes of smallholder farmers in Tabora region

▶ Felician A. Kitole & Jennifer K. Sesabo



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ABSTRACT

Climate Smart Agriculture (CSA) is recognized as a vital strategy for enhancing food security and increasing the incomes of smallholder farmers, particularly in regions vulnerable to climate variability. However, a limited number of smallholder farmers in developing, climate-endangered regions have adopted CSA, resulting in a double burden of food insecurity, and low incomes that undermine their livelihoods. This study employed a cross-sectional research design, collecting data from 490 smallholder farmers in Tabora region in Western Tanzania, to examine the factors influencing CSA adoption and its effects on household income. The analysis employed Multivariate Probit and Instrumental Variable (IV Probit and Two-Stage Least Squares) models. The results indicate that CSA adoption significantly improves both food security and household income. Key determinants include socio-demographic factors, such as gender and age, economic factors like credit financing availability and market access, infrastructural elements including irrigation facilities, and attitudinal aspects such as farmers' perceptions on climate risks and their attitudes towards sustainable practices. Specifically, credit financing and reliable crop markets are crucial for facilitating CSA adoption, thereby enhancing economic resilience and food production capacity. In addition, extension services and community-based organisations (CBOs) play significant roles in promoting CSA practices, while secure land tenure policies encourage long-term investments in sustainable agriculture. To promote CSA adoption among smallholder farmers, policymakers should enhance availability of credit financing, improve market access, invest in irrigation infrastructure, strengthen extension services, support CBOs, secure land tenure, foster positive attitudes through awareness campaigns, and reduce CSA costs via subsidies. These measures can lead to improved food security and increased incomes for smallholder farmers.

1. INTRODUCTION

Climate change is recognized as one of the most pressing global challenges, significantly undermining sustainable development by adversely affecting various sectors, particularly agriculture (Zeeshan, 2022; Agbenyo *et al.*, 2022). Extreme weather events such as prolonged droughts, heatwaves, and irregular rainfall patterns severely reduce agricultural productivity and threaten food security (Ali *et al.*, 2022; Liu *et al.*, 2021). These environmental changes disrupt food supply chains, jeopardizing the livelihoods of millions who depend on farming for their survival (Pani and Mishra, 2023; Tesfaye *et al.*, 2016). The increasing frequency and intensity of climate-related disruptions necessitate urgent and effective strategies to safeguard global food systems and ensure the resilience of agricultural communities (Kitole *et al.*, 2024; Heather and James, 2020).

In Sub-Saharan Africa, the impacts of climate change are particularly acute due to the region's inherent vulnerabilities (Kurgat *et al.*, 2020). The combination of high dependency on rain-fed agriculture, limited access to technology, and socio-economic challenges exacerbates the region's susceptibility to climate variability (Martey *et al.*, 2020). Prolonged droughts, unpredictable rainfall, and extreme temperatures have led to significant declines in crop yields and livestock productivity, intensifying food insecurity and economic instability (Khoza *et al.*, 2022). These climatic stresses disproportionately affect smallholder farmers, who form the backbone of Sub-Saharan Africa's agricultural sector, thereby threatening regional food security and poverty reduction efforts (Kitole *et al.*, 2024; Dube *et al.*, 2016; Hulme *et al.*, 2018).

Tanzania exemplifies the severe challenges posed by climate change within Sub-Saharan Africa, given its heavy reliance on agriculture, which employs over two-thirds of the population and contributes approximately 30% to the national GDP (Kitole and Komba, 2025; Dube *et al.*, 2016; Hulme *et al.*, 2018). The country's predominantly rain-fed agricultural system makes it highly vulnerable to climate variability, with significant repercussions for both the economy and food security (Nkumulwa and Pauline, 2021). Smallholder farmers, who are the primary stakeholders in Tanzania's agricultural landscape, face increasing difficulties in maintaining crop yields and securing stable incomes amid fluctuating climatic conditions (Kurgat *et al.*, 2020). This reliance on agriculture underlines the urgent need for effective climate adaptation strategies to sustain livelihoods and ensure food availability (Ministry of Agriculture, 2021)[1].

In response to these challenges, the Tanzanian government and various international organisations have implemented several strategies aimed at mitigating the impacts of climate change on agriculture (Karwani *et al.*, 2016). These efforts include the adoption of modern agricultural techniques, such as improved seed varieties and intercropping, as well as enhancements in water management and soil conservation practices

[1] National Horticulture Development Strategy and Action Plan 2021-2031

(Kahimba *et al.,* 2015). Additionally, initiatives to expand irrigation infrastructure and provide agricultural extension services have been undertaken to support farmers in adopting more resilient farming practices (Mafie, 2022). These strategies are designed to increase agricultural productivity, enhance resilience to climate shocks, and promote sustainable land management, thereby addressing the multifaceted impacts of climate change on the agricultural sector (Gwambene and Saria, 2024).

Despite these comprehensive strategies, the agricultural sector in Tanzania continues to grapple with persistent challenges, including recurring food shortages and unstable livelihoods for many smallholder farmers (Mwungu *et al.,* 2018; Mwakaje *et al.,* 2017). The effectiveness of implemented measures has been limited by factors such as inadequate infrastructure, limited access to financial resources, and insufficient extension services tailored to farmers' specific needs. Consequently, the anticipated improvements in agricultural resilience and productivity have not been uniformly realized, leaving many farmers vulnerable to ongoing climate variability and its detrimental effects on food security and income stability (Kitole *et al.,* 2024).

Climate change has had profound effects on the food security and incomes of smallholder farmers in Tanzania. The increasing frequency of extreme weather events has led to significant reductions in crop yields and livestock productivity, directly undermining food availability and increasing the prevalence of hunger and malnutrition (Kitole *et al.,* 2024; Nkumulwa and Pauline, 2021). Additionally, the instability in agricultural production translates into fluctuating incomes, exacerbating poverty and limiting farmers' ability to invest in sustainable practices. These impacts not only threaten individual livelihoods but also have broader implications for national food security and economic stability, highlighting the urgent need for more effective and widespread climate adaptation measures (Gwambene and Saria, 2024).

Considering these ongoing challenges, Climate-Smart Agriculture (CSA) has been promoted as a transformative approach to enhance agricultural resilience, increase productivity, and reduce the carbon footprint by integrating climate adaptation and mitigation strategies into farming practices (Mwakaje, 2017; Hulme *et al.,* 2018). CSA encompasses a range of practices, including intercropping, crop rotation, mulching, improved seed varieties, and enhanced water management, which are designed to make agriculture more sustainable and resilient to climate impacts. However, despite the recognized benefits of CSA, its adoption among Tanzanian smallholder farmers remains limited (Kurgat *et al.,* 2020). This gap between the potential effectiveness of CSA practices and their actual implementation underscores the need for targeted interventions to facilitate the widespread adoption of CSA, thereby improving food security and enhancing the economic stability of farmers in the Tabora region.

1.1 Problem Statement

Globally, climate change poses one of the most formidable challenges to sustainable development, with agriculture being one of the most severely affected sectors (Zeeshan, 2022). Extreme weather events such as prolonged droughts, intense heatwaves, and unpredictable rainfall patterns significantly diminish agricultural productivity and threaten food security worldwide (Pani and Mishra, 2023). These climatic disruptions not only reduce crop yields but also destabilize food supply chains, thereby endangering the livelihoods of millions who depend on agriculture for their sustenance (Tesfaye *et al.,* 2016; Mwungu *et al.,* 2018). The escalating impacts of climate change necessitate urgent and effective strategies to enhance the resilience and sustainability of agricultural systems globally.

In Sub-Saharan Africa, the adverse effects of climate change are intensified due to the region's inherent vulnerabilities, including heavy reliance on rain-fed agriculture, limited access to advanced technologies, and socio-economic constraints (Kurgat *et al.,* 2020). Tanzania exemplifies these challenges, as agriculture employs over two-thirds of its population and contributes approximately 30% to the national GDP (Dube *et al.,* 2016; Hulme *et al.,* 2018). The country's dependence on predominantly rain-fed farming makes it highly susceptible to climate variability, resulting in frequent food shortages and unstable incomes for smallholder farmers (Mwungu *et al.,* 2018; Mwakaje *et al.,* 2017). Despite various initiatives aimed at mitigating these impacts through modern agricultural techniques and improved water management, the effectiveness of these strategies remains limited, leaving many farmers vulnerable to ongoing climatic stresses (Kahimba *et al.,* 2015; Karwani *et al.,* 2016).

Efforts to promote Climate Smart Agriculture (CSA) as a solution have been undertaken to enhance agricultural resilience, increase productivity, and reduce the carbon footprint by integrating climate adaptation and mitigation strategies into farming practices (Mwakaje, 2017; Hulme *et al.,* 2018). However, the adoption rate of CSA technologies among Tanzanian smallholder farmers remains critically low, particularly in Tabora region, despite their potential to alleviate the double burden of food insecurity and low incomes (Kurgat *et al.,* 2020). The existing literature highlights significant barriers to CSA adoption, including low educational levels, economic constraints, inadequate extension services, and structural obstacles such as poor market access and unsupportive policy frameworks (Mwungu *et al.,* 2018; Ali *et al.,* 2022; Khoza *et al.,* 2022). Nevertheless, there is a notable gap in comprehensive studies that specifically examine the socio-economic, educational, and structural factors influencing CSA adoption among smallholder maize producers in Tabora. This study aimed to address this gap by investigating the behaviours and barriers faced by these farmers, thereby providing critical insights to inform targeted interventions that can enhance food security and improve incomes amidst the persistent challenges of climate change.

1.2. Research Objectives and Guiding Questions

This section outlines the specific objectives and guiding questions that direct the focus of this study.

1.2.1 Specific Objectives

i) To identify benefits of the CSA technologies among smallholder farmers in Tabora region.
ii) Investigate the extent of adoption of CSA technologies among smallholder farmers in Tabora region.
iii) To estimate the effects of CSA technologies on the livelihood of smallholder farmers in Tabora region.

1.2.2 Research Questions

i) What are the benefits of the CSA technologies among smallholder farmers in Tabora region?
ii) What is the extent of the CSA technologies adoption among smallholder farmers in Tabora region?
iii) What are the effects of CSA technologies on the livelihood of the smallholder farmers in Tabora region?

1.3 Significance of the Study

The significance of this study lies in its unique focus on the determinants of Climate Smart Agriculture (CSA) adoption and its effects on food security and household income among smallholder farmers in Tabora region, Tanzania. By analysing both conventional and novel factors influencing CSA uptake, this study provides a comprehensive understanding of how CSA adoption enhances food security and boosts incomes in climate-vulnerable farming communities. A distinctive aspect of this study is the inclusion of farmers' climate risk perception as a determinant—an area previously unexplored in the Tanzanian context. The findings demonstrate that farmers who perceive a higher risk from climate variability are more likely to adopt CSA practices, indicating that risk awareness plays a crucial role in farmers' willingness to invest in adaptive strategies. This insight is particularly valuable for policymakers, as it highlights the need for awareness-raising initiatives that build farmers' understanding of climate risks alongside providing CSA resources, thereby fostering a more resilient agricultural sector.

Theoretically, the findings of this study enrich the body of knowledge on CSA adoption by extending the determinants framework to include risk perception and empirically validating its effects on adoption, food security, and income outcomes. Unlike prior studies that focused predominantly on socio-economic or infrastructural factors, this research integrates an attitudinal dimension, capturing how climate risk perception shapes CSA adoption decisions. The study's use of advanced econometric models to quantify these effects also provides a methodological advancement, setting a benchmark for future CSA studies in Tanzania and other developing regions. The results not only establish the importance of incorporating climate risk awareness into

CSA promotion but also contribute to the development of targeted, evidence-based strategies that support sustainable agriculture. These strategies can significantly improve food security and economic resilience among smallholder farmers, ultimately advancing climate adaptation efforts within the Tanzanian agricultural sector.

2. LITERATURE REVIEW

2.1 Theoretical Foundation

The primary objective of this research study was to establish a robust theoretical framework that will facilitate a thorough comprehension of the adoption of CSA technologies among maize smallholder farmers in Tanzania, as well as the subsequent effects on their overall well-being. To accomplish this objective, the present study employed the Technology Acceptance Model (TAM) as its principal theoretical framework. Nevertheless, the inherent constraints of the Technology Acceptance Model (TAM) in comprehensively encompassing the intricacies of technology adoption within the agricultural domain require the incorporation of the Diffusion of Innovation Theory (DIT) to augment the theoretical foundation of the study.

2.1.1 The Technology Acceptance Model (TAM)

The Technology Acceptance Model (TAM) is a prevalent theoretical framework employed in the realm of information systems and research on the adoption of technology. The TAM proposes that the adoption and utilisation of a technology by individuals are shaped by two primary factors: the perceived usefulness (PU) and the perceived ease of use (PEOU). Based on the TAM, the likelihood of individuals adopting a technology is higher when they perceive it to be both useful and easy to use. In this study, the Technology Acceptance Model (TAM) offers a valuable theoretical framework for analysing the adoption of CSA technologies among small-scale maize farmers in Tanzania.

Additionally, the applicability of the TAM in the agricultural context is constrained by the distinctive characteristics that are inherent to the agricultural sector. Although TAM has been widely employed to comprehend technology adoption, its effectiveness is restricted in the agricultural domain. The agricultural sector is subject to the influence of sociocultural factors, complexity, and risk perception, which are not sufficiently accounted for in the TAM. Hence, it is imperative to incorporate an additional theoretical framework to attain a more comprehensive comprehension of technology adoption within the agricultural domain.

2.1.2 Diffusion of Innovation Theory

To address the constraints of the TAM and strengthen the theoretical underpinnings of the reported research, the Diffusion of Innovation Theory (DIT) was employed as an adjunct framework. The DIT, formulated by Everett Rogers in 1962 (Khoza *et al.* 2022), centres on the intricate dynamics involved in the adoption and dissemination of novel innovations within a given social system. This theoretical framework encompasses various factors that extend beyond the realm of individual perceptions. These factors encompass the attributes of the innovation itself, the communication channels employed, the social networks involved, and the characteristics of the population that adopts the innovation.

The incorporation of the DIT in conjunction with the TAM facilitates a more comprehensive analysis of the adoption patterns of CSA technologies within the context of Tanzanian maize smallholder farmers. The research framework provides a comprehensive understanding of technology adoption in the agricultural community by considering various factors such as individual perceptions of usefulness and ease of use, broader sociocultural factors, complexity, risk perception, and the diffusion process.

Therefore, the reported research study utilized the TAM as the principal theoretical framework, acknowledging its limitations in comprehensively capturing the intricacies associated with technology adoption within the agricultural domain. To overcome these constraints, the present study incorporates the DIT into the TAM, thus bolstering the theoretical foundation of the research. The utilisation of this integrated framework facilitated a thorough analysis of the implementation of CSA technologies among smallholder maize farmers in Tabora region, Tanzania.

2.2 Empirical Review

Numerous prior research endeavours have thoroughly investigated the implementation of CSA technologies across diverse settings, yielding significant knowledge regarding the determinants that shape farmers' choices to adopt CSA. An example of this can be seen in studies conducted by Wekesa *et al.* (2018), Ogada *et al.* (2020) and Ochieng *et al.* (2016) in Kenya, where it was observed that the perceptions of farmers regarding the utility and ease of use of a particular technology had a significant impact on their decisions to adopt irrigation technologies. This implies that farmers are more inclined to adopt a technology when they perceive it as advantageous and user-friendly. These results are consistent with the fundamental principles of the TAM, which asserts that individual perceptions are pivotal in the process of adopting technology (Zakaria *et al.,* 2020). The comprehension of farmers' perceptions is crucial for policymakers and practitioners to develop efficacious strategies aimed at facilitating the adoption of technology.

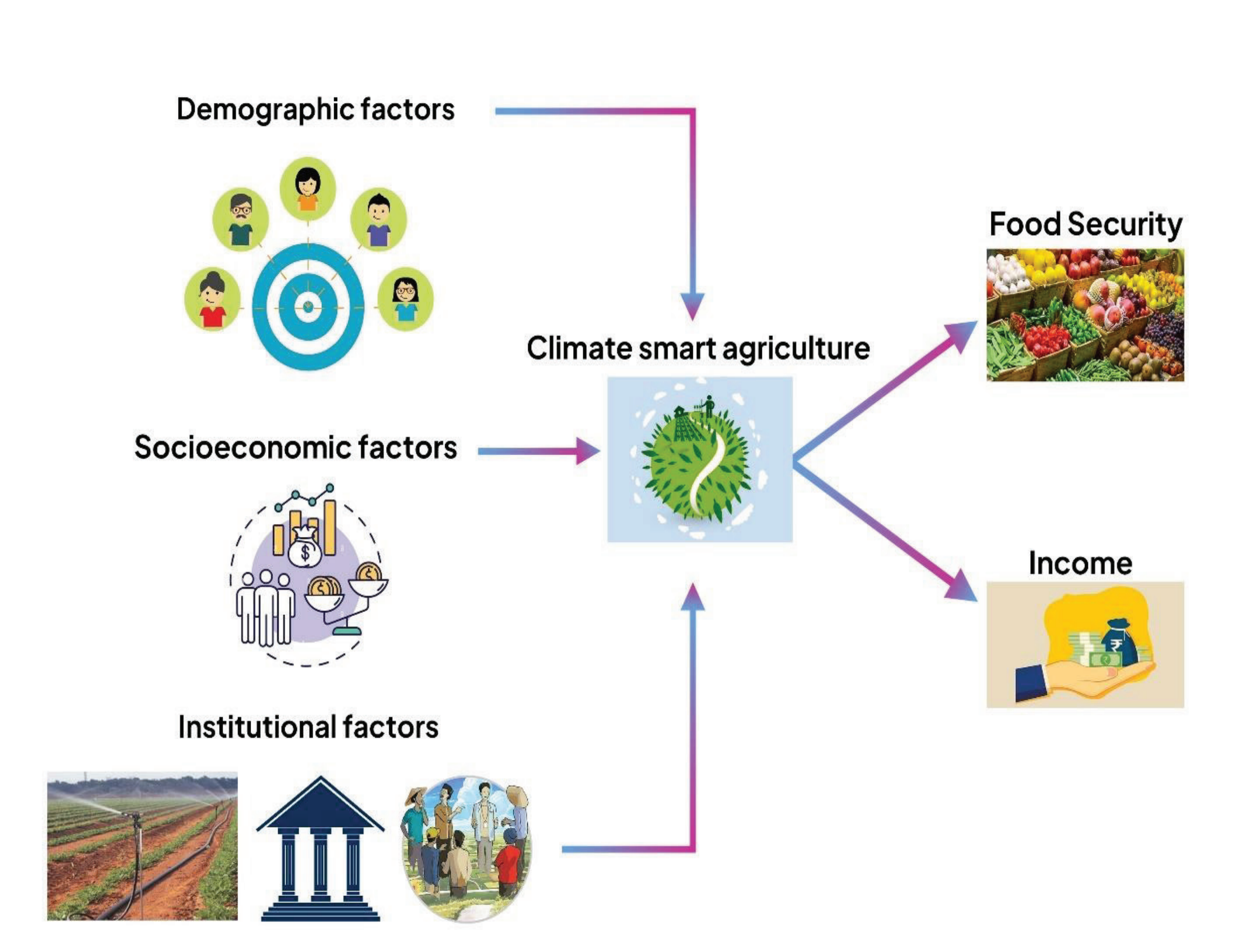
Drawing upon the theoretical framework of TAM, Agbenyo *et al.* (2022) and Zakaria *et al.* (2020) conducted a research study in Ghana to extend the existing knowledge beyond individual perceptions. The study aimed to explore the wider contextual factors that play a role in influencing the adoption of climate-smart technologies. The adoption of these technologies was significantly influenced by factors such as access to credit, extension services, and market access, as discovered by the researchers. This emphasises the significance of considering not only the subjective viewpoints of individuals but also the facilitating context within which farmers carry out their activities. By integrating these contextual factors, policymakers and stakeholders can develop interventions that effectively target the obstacles and facilitate the uptake of CSA technologies.

Studies conducted across diverse regions reveal a complex interplay of factors influencing the adoption of CSA. Researchers like Ding *et al.* (2022) and He *et al.* (2020) highlight that the comparative advantage and compatibility of CSA practices with existing systems significantly dictate adoption rates. This notion is supported by Karwani *et al.* (2016) and Kahimba *et al.* (2015), who found that education, credit access, and extension services are pivotal in Tanzania, similar to findings in Ghana by Martey *et al.* (2020) and in Pakistan by Imran *et al.* (2022), emphasizing the role of farmer education and financial resources. Furthermore, the studies by Amadu *et al.* (2020) and Ali *et al.* (2022) identify the perception of climate risks and the availability of resources as critical in Malawi, underscoring the need for policies that enhance resource allocation and climate risk management to foster CSA adoption.

The research extended into the dynamics of information access, market accessibility, and social capital, with studies like those by Nchanji *et al.* (2022) and Zizinga *et al.* (2022) showing how these factors facilitate the adoption of CSA practices in Uganda and Ethiopia. Mujeyi *et al.* (2021) and Phiri *et al.* (2021) further argue that training and supportive services boost the adoption in Zimbabwe, mirroring trends in Swaziland as noted by Sam *et al.* (2021), where government support plays a crucial role. These insights collectively advocate for integrated approaches that combine educational, financial, and infrastructural support to overcome barriers to CSA adoption.

Moreover, the inclusion of social networks and institutional trust as elaborated by studies in Ghana and Tanzania highlights their effectiveness in disseminating information and fostering community-level adoption, as observed by Kurgat *et al.* (2020). This approach is echoed by the findings of Imran *et al.* (2022), who stress the importance of addressing the perceptual barriers related to climate change to encourage proactive adaptation measures among farmers. Collectively, these studies underscore the necessity of a multifaceted strategy that addresses educational, financial, and cultural barriers, ensuring that CSA technologies are both accessible and effectively integrated into existing agricultural frameworks.

Figure 1: Conceptual framework



***Source*:** Authors' design (2023)

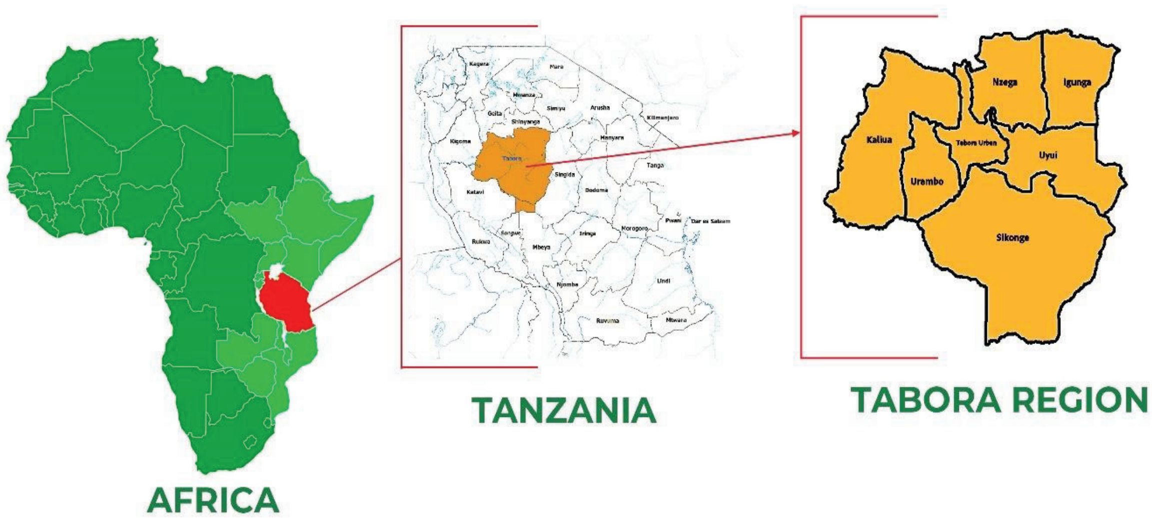
3. RESEARCH METHODOLOGY

This section provides an insight on the research methodologies utilised in the reported study. It provides a detailed explanation on the study area, research design, study population, sample size, sampling technique, data collection methods, and data analysis techniques deployed.

3.1 Description of the Study Area

The research was carried out in Tabora region located in Western Tanzania. The selection of the Tabora region was predicated upon its susceptibility to the impacts of climate change, as evidenced by previous studies (Denison-Johnston, 2023). Moreover, the region's reliance on agriculture as a primary livelihood strategy, with maize serving as a key staple crop, further justified its inclusion in the study. The study employed purposive sampling to select seven districts, with the aim of obtaining valuable insights and enhancing the overall clarity of the research. The districts encompass Nzega, Igunga, Tabora Municipal, Kaliua, Sikonge, Urambo, and Uyui.

Figure 2: Map of Tabora regions showing study areas (Tabora districts)



***Source*:** Authors' design (2023)

3.2 Research Design

The study employed a cross-sectional research design grounded in the positivist philosophy to collect quantitative data from smallholder maize farmers in Tabora region of Tanzania. This quantitative approach was chosen to objectively measure and analyse the factors influencing the adoption of CSA technologies and their impact on household income. By gathering data from a diverse group of farmers at a specific point in time, the study systematically examined socio-demographic, economic, infrastructural, and attitudinal variables.

3.3 Data Collection

The study utilized primary data to explore the impact of adopting climate-smart technologies on the welfare of smallholder farmers in the Tabora region. Gathering primary data provided real-time insights into the farmers' perceptions of these technologies, ensuring an accurate reflection of current attitudes and practices. To fulfil the study's objectives, the collected data encompassed quantitative metrics, which were gathered from an extensive sample of smallholder farmers using structured questionnaires. Data collection activity was conducted from May to July 2023, starting in Urambo district during the first week. Subsequent weeks saw data gathering extend to Uyui, Nzega, and Igunga, followed by Kaliua, Sikonge, and Tabora urban in the final three weeks. Throughout the data collection process, ethical considerations were strictly adhered to. Informed consent was obtained from all participants, ensuring they were fully aware of the study's purpose and their rights. Confidentiality was maintained by anonymizing respondents' information and securely storing all data. Participation was entirely voluntary, with no coercion or undue incentives provided to influence responses.

3.4 Sample size and Sampling technique

The study employed a multistage sampling method to obtain a representative sample of smallholder farmers across the seven districts in the Tabora region (*see* Figure 2). First, all seven districts were included to capture geographic diversity and variations in farming practices. In the next stage, we used stratified random sampling within each district, dividing them into sub-regions to ensure representation across various administrative areas and farming conditions. From the estimated total population of 2,269 smallholder farmers, the calculated sample size using the Yamane formula with a 4% margin of error, resulted in a target sample of 490 respondents. To ensure randomness, farmers were then randomly selected from each stratum within the districts, ensuring that each area contributed proportionally to the total sample. This process enhanced the representativeness and generalizability of the study findings by ensuring an unbiased sample distribution across the region.

3.5 Analytical Modeling

3.5.1 Modeling the determinants for the adoption of climate smart agriculture

The present study utilised the Multivariate Probit model to examine the determinants of CSA technology adoption among small-scale maize farmers in Tabora region, Tanzania. The selection of the Multivariate Probit model was motivated by its capacity to enable the concurrent estimation of multiple binary outcomes, thereby capturing the interdependencies that exist between the adoption decisions pertaining to various technologies. In the ordinary probit model, there is only one binary dependent variable Y and so only one latent variable Y^* is used. In contrast, in the bivariate probit model there are two binary dependent variables Y_1 and Y_2,

$$Y_1 = \begin{cases} 1 \ if \ Y_1^* > 0 \\ 0 \ otherwise, \end{cases} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

$$Y_2 = \begin{cases} 1 \ if \ Y_2^* > 0 \\ 0 \ otherwise, \end{cases} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

With

$$\begin{cases} Y_1^* = X_1\beta_1 + \varepsilon_1 \\ Y_2^* = X_2\beta_2 + \varepsilon_2 \end{cases} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

And

$$\begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \end{bmatrix} \Big| X \sim N\left(\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{bmatrix} 1 & \rho \\ \rho & 1 \end{bmatrix}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

Fitting the bivariate probit model involves estimating the values of β_1, β_2, and ρ. To do so, the likelihood of the model has to be maximized. This likelihood is:

$$L(\beta_1, \beta_2) = \left(\prod P(Y_1 = 1, Y_2 = 1 \,|\, \beta_1, \beta_2)^{Y_1 Y_2}\right)\left(P(Y_1 = 0, Y_2 = 1 \,|\, \beta_1, \beta_2)^{(1-Y_1)\,Y_2}\right) \ldots\ldots\ldots (6)$$

$$P(Y_1 = 1, Y_2 = 0 \,|\, \beta_1, \beta_2)^{(1-Y_2)\,Y_1}\, P(Y_1 = 0, Y_2 = 0 \,|\, \beta_1, \beta_2)^{(1-Y_1)\,(1-Y_2)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Now, substituting the latent variables Y_1^* and Y_2^* in the probability functions and taking logs gives

$$\sum (Y_1 Y_2 lnP\,(\varepsilon_1 > -X_1\beta_1, \varepsilon_2 > -X_2\,\beta_2) + (1 - Y_1)Y_2 lnP\,(\varepsilon_1 < -X_1\beta_1, \varepsilon_2 > -X_2\beta_2) + Y_1(1 - Y_2)lnP(\varepsilon_1 > -X_1\beta_1, \varepsilon_2 < -X_2\beta_2) + (1 - Y_1)\,(1 - Y_2)lnP(\varepsilon_1 < -X_1\beta_1, \varepsilon_2 < -X_2\beta_2)) \ldots\ldots\ldots\ldots\ldots (8)$$

After some rewriting, the log-likelihood function becomes:

$$\sum (Y_1 Y_2 ln\phi(X_1\beta_1, X_2\,\beta_2, \rho) + (1 - Y_1)Y_2 ln\phi\,(-X_1\beta_1, X_2\beta_2, -\rho) + Y_1(1 - Y_2)ln\phi(X_1\beta_1, -X_2\beta_2, -\rho) + (1 - Y_1)\,(1 - Y_2)ln\phi(-X_1\beta_1, -X_2\beta_2, \rho)) \ldots. (9)$$

Note that ϕ is the cumulative distribution function of the bivariate normal distribution. Y_1 and Y_2 in the log-likelihood function are observed variables being equal to one or zero. Therefore, for the general multivariate probit model it should always be referred to that $y_i = (y_1,\ldots,y_j)$, $(i = 1,\ldots,N)$ whereas j reflects the number of choices and i is the number of observations or individuals whose probability of choosing choice y_i is presented as;

$$Pr\left(y_i \middle| X_i\beta, \sum \right) = \prod_{AJ}\ldots\prod_{A1} fN\left(y_i^* \middle| X_i\beta, \sum\right) dy_1^* \ldots dy_J^* \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

$$Pr\left(y_i \middle| X_i\beta, \sum \right) = \prod 1_{y^*} \in AfN\left(y_i^* \middle| X_i\beta, \sum\right) dy_1^* \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

Where $A = A_1 \times \ldots \times A_J$

$$A_j = \begin{cases} (-\infty, 0\,] & y_j = 0 \\ (0, \infty) & y_j = 1 \end{cases} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (12)$$

The log-likelihood function in this case would be

$$\sum_{i=1}^{N} logPr\left(y_i \middle| X_i\beta, \sum\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (13)$$

Therefore, the log-likelihood function has been used in this study to provide estimates on the determinants of the smallholder farmers choice of the climate smart technologies in maize production in Tabora region.

3.5.2 Modelling effects of CSA on smallholder farmers' food security and incomes

This study utilised the IV Probit model to assess the impact of CSA on the food security of smallholder farmers. The food security status of smallholder farmers was considered as the dependent variable in this model, whereas CSA adoption was treated as the endogenous variable. The variable employed to mitigate the potential endogeneity of CSA adoption was the proximity to the nearest healthcare facility. The IV Probit model explaining this relationship is shown at equation 14;

$$FS = \beta_0 + \beta_1 CSA + \beta_2 CV + \varepsilon_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (14)$$

Whereas FS is household food security status, CSA are the technologies adopted and CV is control variables while ε_i is error term. On the other hand, the CSA adoption was instrumented by the use of distance to the nearest CSA promotion centre.

On the other hand, the effects of CSA technologies on smallholder farmers' income were examined using the Two stage least square (2SLS), of which the outcome variable is farming income, while endogenous and instrument were CSA technologies adoption and distance to the nearest CSA promotion centre respectively. The 2SLS model was estimated at two stages whereas the first stage is represented by equation 15

$$CSA = \gamma_0 + \gamma_1 Z_i + \gamma_2 CV + \varepsilon_i \dots\dots (15)$$

Whereas Z_i is instrumental variable (distance to the nearest CSA promotion centre) and CV are the control variables. Moreover, equation .... Also helped in providing the predicted values of CSA adoption.

$$Y = \delta_0 + \delta_1 CSA\_hat + \delta_2 Z_i + v_i \dots\dots (16)$$

Moreover, from Equation (16), Y represents the smallholder maize farmers' income while Z_i and v_i are instrumental variable and error term, respectively. Thus, the use of instrumental variable model helps to suppress the endogeneity issues and obtain reliable estimates on the effects of CSA technologies on smallholder farmers' food security and incomes.

In addition, to measure the risk perception of climate impacts among farmers, this study used a composite index. A survey was designed with questions covering critical dimensions of climate risk perception, including perceived severity, likelihood of occurrence, personal vulnerability, control over climate risks, and concern about climate impacts. Each question employed a 5-point Likert scale, where 1 indicated "Not Severe" and 5 indicated "Extremely Severe." Responses within each dimension were averaged to produce a score representing the level of perception in that area. These dimension scores were then combined by calculating an overall mean, creating a composite index for risk perception. This index provided a single, comprehensive value for overall climate risk perception, with higher scores signifying a greater perceived risk, thus allowing for the analysis of risk perception levels and their potential influence on adaptive behaviours.

4. RESULTS

The results of the study are divided into two sub sections of descriptive and inferential statistics. The descriptive statistics explains the general characteristics of the smallholder farmers and their perceptions towards the adoption of the climate smart technologies.

4.1 Socioeconomic Profile of Smallholder Farmers in Tabora Region, Tanzania

The results in Table 1 present a comprehensive socioeconomic profile of smallholder farmers in the Tabora region, revealing a nearly equal gender distribution with males accounting for 49.59% and females 50.41% of the population. Many of the farmers are married (60.41%), while single, widowed, and divorced farmers make up 11.02%, 20.00%, and 8.57%, respectively. Educational attainment among these farmers is predominantly at the primary level (58.57%), followed by secondary education (22.86%), with smaller proportions having college, vocational (5.71%), or university education (2.25%). Agriculture remains the primary sector of employment for 76.53% of the farmers, underscoring the region's heavy reliance on farming for livelihoods. In addition, over half of the farmers (53.87%) are members of farmers' organisations, which likely provide essential resources, knowledge, and support networks that enhance agricultural outcomes.

However, Table 1 also highlights significant challenges faced by these smallholder farmers. A substantial majority lack access to crucial resources, with 59.69% not having access to credit financing and 63.47% without access to crop markets. Similarly, irrigation infrastructure and extension services are unavailable to 62.04% and 62.86% of farmers, respectively, potentially hindering their ability to adopt and benefit from CSA technologies. These gaps indicate that, while there is a strong foundation in terms of gender balance, marital stability, and membership for farmer organizations, considerable barriers remain in accessing financial support, markets, and essential agricultural services. Addressing these deficiencies through targeted interventions could significantly enhance the capacity of smallholder farmers to adopt CSA practices, thereby improving food security and increasing household incomes in Tabora region.

Table 1: Description of socioeconomic profile of smallholder farmers in Tabora region

Variables	Category	Frequency	Percentage (%)
Sex	Male	243	49.59%
	Female	247	50.41%
Marital Status	Single	54	11.02%
	Married	296	60.41%
	Widowed	98	20.00%
	Divorced	42	8.57%
Credit financing availability	Available	198	40.31%
	Not available	292	59.69%
Crop market availability	Available	179	36.53%

	Not available	311	63.47%
Irrigation infrastructure availability	Available	186	37.96%
	Not available	304	62.04%
Availability of extension services	Available	182	37.14%
	Not available	308	62.86%
Membership in farmers' organisation	Members	264	53.87%
	Non-members	226	46.13%
Education level	No schooling	52	10.61%
	Primary education	287	58.57%
	Secondary education	112	22.86%
	College and vocational	28	5.71%
	University education	11	2.25%
Main sector of employment	Agriculture	375	76.53%
	Other sectors	115	23.47%

4.2 Available climate smart technologies in Tabora region

The utilisation of climate-smart technologies among smallholder farmers in various districts of the Tabora region is depicted in Table 2. The data presented illustrates the proportion of farmers within each district who have reported the utilisation of distinct climate-smart technologies. In Urambo district, study findings revealed that a minority of smallholder farmers, specifically 10%, reported engaging in intercropping as a farming practise. Additionally, 25% of the farmers practised crop rotation, while 35% utilised manure as a means of enhancing their agricultural activities. Furthermore, 20% of the farmers employed mulching techniques, and a similar proportion, 10%, adopted improved seeds in their farming practises.

Table 2: Climate smart technologies usage across smallholder farmers in Tabora region

CSA technologies	Districts						
	Urambo	Uyui	Nzega	Igunga	Kaliua	Sikonge	Tabora Urban
Intercropping	10.00%	5.00%	5.00%	12.50%	24.00%	15.00%	25.00%
Crop rotation	25.00%	15.00%	10.00%	11.50%	6.00%	20.00%	5.00%
Manure	35.00%	25.00%	25.00%	15.00%	30.00%	22.50%	12.50%
Mulching	20.00%	10.00%	5.00%	16.00%	5.00%	2.50%	12.50%
Improved seeds	10.00%	45.00%	55.00%	45.00%	35.00%	40.00%	45.00%

In Uyui district, the study results revealed that a small proportion of farmers, specifically 5%, engaged in the agricultural practise of intercropping. 15% of farmers were found to implement crop rotation as part of their farming methods. A quarter of the farmers, constituting 25%, utilised manure as a means of enhancing soil fertility. Furthermore, 10% of the farmers employed mulching techniques to conserve moisture and suppress weed growth. The largest proportion of farmers, comprising 45%, opted for the adoption of improved seeds as a means of enhancing crop productivity and quality.

In the Nzega district, study results revealed that 5% of farmers are engaged in intercropping, 10% implemented crop rotation, 25% employed the use of manure, 5% utilised mulching, and the majority, 55%, adopted improved seeds. On the other hand, in Igunga district, the results revealed that 12.50% of farmers engaged in the agricultural practise of intercropping, while 11.50% implemented the crop rotation technique. 15% of farmers in the district utilised manure to enhance soil fertility, while 16% employed mulching to conserve moisture and suppress weed growth. Furthermore, it was found that 45% of farmers had adopted improved seeds in their agricultural activities.

In Kaliua district, the study found that 24% of farmers reported engaging in intercropping, 6% practised crop rotation, 30% utilised manure, 5% employed mulching, and 35% adopted improved seeds. On the other hand, In Sikonge district, a study found that 15% of farmers engaged in the agricultural practise of intercropping, while 20% implemented crop rotation as a means of diversifying their crops. 22.50% of farmers in the district utilised manure as a method of enhancing soil fertility, while a smaller proportion of 2.50% applied mulching to conserve moisture and suppress weed growth. Furthermore, a significant percentage of 40% of farmers in the district adopted improved seeds to enhance crop productivity and resilience.

In the urban area of Tabora, a quarter of the farmers surveyed indicated their utilisation of intercropping, while 5% reported practising crop rotation. 12.50% of the farmers reported the use of manure, while the same percentage employed mulching. The majority, comprising 45% of the farmers, reported adopting improved seeds. The results of this study suggest that there are differences in the adoption and utilisation of climate-smart technologies among various districts. Certain districts demonstrated higher rates of adoption for specific technologies, such as enhanced seeds, whereas others displayed more varied adoption patterns across multiple technologies. These results provide guidance for implementing targeted interventions and policies aimed at promoting the adoption of climate-smart practises, considering the distinct requirements and preferences of farmers in individual districts.

4.3 Benefits of Climate Smart Agriculture among Smallholder Farmers in Tabora

The benefits of climate-smart technologies among smallholder farmers in Tabora region are illustrated in Table 3. For Urambo district, majority of farmers, specifically 57%, reported a notable increase in productivity. 47% of farmers mentioned an improvement in their resilience, indicating an enhanced ability to withstand and recover from various challenges. Furthermore, 65% of farmers indicated that they felt emissions had decreased, highlighting a perceived improvement in environmental sustainability. Moreover, a substantial majority of farmers, accounting for 75%, experienced improvements in food security, indicating an enhanced ability to access and maintain an adequate supply of nutritious food. Lastly, 42% of farmers reported lower production costs, suggesting a potential positive effect on economic efficiency.

Table 3: Benefits of Climate smart agriculture among smallholder farmers in Tabora

Benefits of CSA	Districts													
	Urambo		Uyui		Nzega		Igunga		Kaliua		Sikonge		Tabora Urban	
	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
Increase productivity	57%	43%	64%	36%	67%	33%	53%	47%	47%	53%	57%	43%	69%	31%
Enhance resilience	47%	53%	56%	44%	60%	405	48%	525	55%	45%	62%	385	53%	47%
Reduce emission	65%	35%	77%	23%	68%	325	75%	25%	60%	40%	65%	35%	73%	27%
Food security	75%	25%	80%	20%	77%	23%	60%	40%	55%	45%	60%	40%	78%	22%
Low production costs	42%	58%	55%	45%	52%	48%	38%	62%	35%	65%	42%	58%	88%	12%

Within Uyui district, a significant proportion of farmers, specifically 64%, reported a notable surge in productivity. 56% of these farmers acknowledged an improvement in their resilience to various challenges. Moreover, a substantial majority of 77% of farmers within the district observed a reduction in emissions. Furthermore, approximately 80% of farmers reported experiencing enhancements in food security, while 55% noted a decrease in production costs.

In Nzega district, a majority of farmers, specifically 67%, reported an increase in productivity. 60% of farmers mentioned experiencing enhanced resilience, while 68% observed a reduction in emissions. Furthermore, a significant proportion of farmers, 77%, reported improvements in food security. Lastly, 52% of farmers reported lower production costs. Moreover, for Igunga district, a majority of farmers, specifically 53%, indicated a notable rise in productivity. 48% of these farmers reported an improvement in their resilience, while 75% observed a reduction in emissions. Moreover, a significant proportion of farmers, accounting for 60%, experienced enhancements in food security. Lastly, 38% of farmers reported a decrease in production costs.

In Kaliua district, a survey revealed that 47% of respondents reported an increase in productivity. 55% of farmers mentioned experiencing enhanced resilience, while 60% observed a reduction in emissions. Furthermore, 55% of respondents reported improvements in food security, and 35% indicated lower production costs. Within Sikonge district, a majority of farmers, specifically 57%, indicated a notable rise in productivity. 62% of these farmers reported an enhancement in their resilience, while 65% observed a reduction in emissions. Furthermore, approximately 60% of the farmers experienced improvements in their food security, and 42% reported a decrease in production costs.

In Tabora urban, a significant majority of farmers, specifically 69%, reported a notable increase in productivity. 53% of these farmers mentioned experiencing enhanced resilience in their agricultural practises. Furthermore, a substantial 73% of farmers observed a reduction in emissions, indicating a positive impact on environmental sustainability. Moreover, an overwhelming majority of 78% of farmers reported improvements in food security, suggesting an increase in the availability and accessibility of food resources. Lastly, a significant proportion of 80% of farmers reported lower production costs, indicating potential economic benefits associated with their agricultural activities.

The results of this study illustrate the diverse advantages of climate-smart technologies in different districts. The utilisation of these technologies has been correlated with heightened productivity, bolstered resilience, diminished emissions, enhanced food security, and decreased production costs. The aforementioned advantages underscore the capacity of climate-smart practises to effectively tackle various obstacles encountered by small-scale farmers in the Tabora region. These challenges encompass the imperative for enhanced crop yields, heightened resilience to climate change, and the promotion of sustainable agricultural production.

4.4 Determinants of CSA technologies adoption among smallholder farmers in Tabora

The findings presented in Table 4 reveal that the adoption of CSA technologies among smallholder farmers in Tabora region is influenced by a complex interplay of socio-demographic, economic, infrastructural, and attitudinal factors. Gender dynamics play a significant role, as male farmers are less likely to adopt improved seeds compared to their female counterparts (-0.2280). This suggests that women may have better access to or a greater inclination towards certain CSA practices. In addition, age positively impacts the adoption of multiple CSA technologies; each additional year of age increases the likelihood of adopting crop rotation (0.1620) and mulching (0.3290), likely due to older farmers leveraging their extensive experience and knowledge to implement sustainable agricultural practices effectively.

Moreover, household size is a crucial determinant across all CSA technologies, with larger households significantly enhancing adoption rates (ranging from 0.014 to 0.4760). This positive relationship indicates that more extensive labour resources within larger households facilitate the implementation of diverse agricultural practices, making CSA technologies more feasible. Economic factors further underscore the importance of financial accessibility, as access to credit financing strongly boosts the adoption of all CSA technologies (ranging from 0.0806 to 0.4797). This highlights the critical role of financial support in enabling farmers to invest in the necessary inputs and technologies required for sustainable farming.

In addition, both farm size and farm income are positively associated with CSA adoption. Larger farms are more likely to adopt crop rotation (0.503) and intercropping (0.1502), while higher farm incomes significantly encourage the adoption of intercropping (0.1970) and improved seeds (0.3292). These findings indicate that farmers with more extensive landholdings and higher incomes possess the necessary resources and financial capacity to implement innovative agricultural practices. Market availability also plays a pivotal role; improved seed adoption is positively influenced by crop market availability (0.6704), suggesting that access to reliable markets encourages farmers to invest in high-yielding seeds due to the potential for better returns. In contrast, limited market access negatively affects crop rotation adoption (-1.0990), indicating that in the absence of robust markets, farmers may prefer traditional practices to maintain soil fertility.

The results in Table 4 also reveal that, irrigation infrastructure availability positively affects the adoption of intercropping (0.1652), crop rotation (0.2158), and manure application (0.0929). Reliable irrigation supports the implementation of diverse agricultural practices by ensuring a consistent water supply, which is essential for the success of CSA technologies. Extension services also significantly promote the adoption of certain CSA technologies. Crop rotation adoption is enhanced by the availability of extension services (0.1856), and improved seed adoption shows a strong positive relationship (0.1921). However, the adoption of manure application is negatively influenced by extension services (-0.2475), suggesting a potential misalignment between extension programs and farmers' needs regarding manure use.

The presence of Community-Based Organisations (CBOs) positively affects the adoption of all CSA technologies, with coefficients ranging from 0.1141 to 0.3603. CBOs likely provide essential support, information, and resources that facilitate the adoption of CSA practices. Secure land tenure policies are also instrumental in encouraging CSA adoption, significantly increasing the likelihood of adopting crop rotation (0.2721), manure application (0.2302), and improved seeds (0.2015). Secure land ownership provides farmers with the confidence to invest in long-term sustainable practices, knowing that their land rights are protected.

Farmers' attitudes towards CSA significantly influence technology adoption. A positive attitude towards CSA is associated with higher adoption rates of crop rotation (0.2106), manure application (0.1611), and improved seeds (0.2206). This highlights the importance of fostering positive perceptions and attitudes towards sustainable agricultural practices. Moreover, risk perception related to climate change positively affects the adoption of intercropping (0.0617) and farm size (0.0342). Farmers who perceive higher risks from climate variability are more motivated to adopt adaptive CSA strategies to mitigate these risks.

Table 4: Determinants of CSA technologies adoption among smallholder farmers in Tabora

Variables	(1) Intercropping	(2) Crop rotation	(3) Manure	(4) Mulching	(5) Improved seed
Sex (Male)	0.0281 (0.210)	0.2141 (0.974)	0.1109 (0.109)	-0.0639 (0.137)	-0.2280* (0.101)
Age	0.0060 (0.317)	0.1620** (0.0708)	0.1700** (0.0865)	0.3290** (0.15)	0.2580** (0.107)
Household size	0.2170** (0.014)	0.1944* (0.087)	0.2260* (0.095)	0.1990*** (0.017)	0.4760*** (0.004)
Credit financing availability	0.0806** (0.0299)	0.0969* (0.020)	0.2931*** (0.0426)	0.1992*** (0.0079)	0.4797*** (0.0061)
Crop market availability	0.0643 (0.1850)	-1.0990** (0.1732)	0.1380 (0.4948)	-0.2600 (0.6920)	0.6704*** (0.0774)
Irrigation infrastructure availability	0.1652*** (0.0103)	0.2158** (0.0238)	0.0929** (0.0010)	-0.0477 (0.0820)	0.0163 (0.0527)
Availability of extension services	-0.2852 (0.5341)	0.1856** (0.0471)	-0.2475* (0.1083)	0.1502 (0.3082)	0.1921*** (0.0045)
Availability of Community Based Organisation (CBOs)	0.2681* (0.1179)	0.1473* (0.0381)	0.1636** (0.0179)	0.1141*** (0.0431)	0.3603*** (0.0141)
Secured land tenure polices	0.1265 (0.0944)	0.2721** (0.0216)	0.2302** (0.0855)	0.0351 (0.0967)	0.2015*** (0.0142)
Attitude towards CSA (1=Positive attitude)	0.0979 (0.1273)	0.2106** (0.0731)	0.1611** (0.0071)	0.1603 (0.1166)	0.2206*** (0.0343)
Composite index of risk perception on Climate	0.0617** (0.0151)	0.0837 (0.0561)	0.1103 (0.0322)	0.2316 (0.1408)	0.3988 (0.0122)
Farm size	0.1502*** (0.0012)	0.503*** (0.0103)	0.2104** (0.0752)	0.3271 (0.2652)	0.0342** (0.0047)
Farm income	0.1970*** (0.0006)	0.1004 (0.4520)	0.2100** (0.0205)	0.2410 (0.4521)	0.3292*** (0.0100)
Non farming activities	0.1279* (0.0601)	0.3137 (0.4092)	0.4820** (0.1000)	-0.2310 (0.2348)	0.3300** (0.1040)
Land ownership	0.2807*** (0.0701)	0.4119*** (0.03006)	0.1061** (0.0108)	0.2100*** (0.03001)	0.3811 (0.02001)
Media (Radio/Television)	0.3133*** (0.0131)	0.1115*** (0.0014)	0.2011** (0.0015)	0.1410*** (0.0300)	0.4409*** (0.0155)
Easiness of using CSA	0.1851** (0.0413)	0.0152*** (0.0011)	0.1120** (0.0110)	0.1096** (0.0031)	0.1552** (0.0431)
Cost of CSA	0.0316** (0.0114)	0.1077*** (0.0145)	0.0834 (0.0651)	0.0154 (0.0742)	-0.2994*** (0.0064)
Membership in farm organisations	0.0903* (0.0140)	0.0450*** (0.0023)	0.1965 (0.3476)	0.6097 (0.7634)	0.497** (0.0155)
Constant	0.5683 (0.8932)	-0.5632*** (0.0061)	-0.1311** (0.0291)	-0.2643*** (0.0764)	0.7562*** (0.0007)

*** p<0.01, ** p<0.05, * p<0.1
Robust standard errors in parentheses

Furthermore, results in Table 4 show that the perceived ease of using CSA technologies significantly enhances adoption, with improved seeds having an ease-of-use coefficient of 0.1851 and intercropping at 0.0152. Reducing barriers through user-friendly technologies can boost uptake. Costs have mixed effects: lower costs promote intercropping (0.0316) and crop rotation (0.1077), while higher costs deter improved seed adoption (-0.2994), underscoring the need for financial incentives. Also, membership in farm organisation positively affects adoption of intercropping (0.0903), crop rotation (0.0450), and improved seeds (0.497). Media exposure through radio and TV significantly increases adoption, with coefficients from 0.1115 to 0.4409. Land ownership also promotes intercropping (0.2807), crop rotation (0.4119), manure application (0.1061), and mulching (0.2100), encouraging investment in sustainable practices.

4.5 Effects of CSA on smallholder farmers' food security and income

Results in Table 5 demonstrate that the adoption of Climate Smart Agriculture (CSA) technologies among smallholder farmers in Tabora region significantly enhances both food security and household income. Specifically, male farmers experience increases food security by 0.1429 and income by 0.1752, indicating that CSA practices may offer greater benefits to men. Marital status plays a crucial role: divorced farmers show a 0.1802 improvement in food security but a 0.1281 reduction in income, whereas cohabiting farmers achieve substantial gains of 1.0839 in food security and 1.0970 in income. Married farmers also benefit, with food security increasing by 0.1811 and income by 0.2618, reflecting the stabilizing effect of marital partnerships on agricultural outcomes. These findings indicate that while CSA technologies can enhance livelihoods, their impacts differ across gender and household types, emphasizing the need for targeted, inclusive interventions to ensure equitable access and maximize the benefits of CSA adoption.

Moreover, age negatively affects food security by 0.1504, suggesting that older farmers might face challenges in maintaining food security despite their experience. Conversely, age positively influences income, increasing it by 0.2373, likely due to accumulated knowledge and better resource management over time. Household size does not show a significant effect on food security but positively impacts income by 0.2199, indicating that larger households may have more labour to contribute to farming activities, thereby enhancing income.

Table 5: Effects of CSA on smallholder farmers' food security and income

Variables		Effects on food security	Effects on income
		IV Probit	2SLS
Sex (Male)		0.1429** (0.0165)	0.1752** (0.0411)
Marital status	Divorced	0.1802* (0.0317)	-0.1281* (0.0477)
	Cohabit	1.0839** (0.0042)	1.0970** (0.0198)
	Married	0.1811** (0.0310)	0.2618** (0.0511)
Age		-0.1504*** (0.0042)	0.2373*** (0.0149)
Household size		0.1067 (0.2341)	0.2199 (0.1926)

Credit financing availability	0.1456*** (0.0003)	0.1895*** (0.0012)
Crop market availability	0.02167** (0.0049)	0.0946*** (0.0000)
Irrigation infrastructure availability	0.1304*** (0.0067)	0.1809** (0.0103)
Availability of extension services	0.1642* (0.0432)	0.2309** (0.0734)
Farm size	-0.2562 (0.4062)	0.2015** (0.0425)
Farm income	0.5882*** (0.1007)	-
Non farming activities	-0.1733 (0.3277)	0.2185** (0.0923)
Land ownership	-0.0087 (0.2109)	0.1120** (0.0413)
Media (Radio/Television)	0.0714 (0.0937)	0.1600 (0.1708)
Easiness of using CSA	0.2551*** (0.0042)	0.1714** (0.0120)
Cost of CSA	-0.1710** (0.0011)	-0.1144*** (0.0010)
Membership in farmers organisation	0.1243*** (0.0081)	0.2501*** (0.0114)
Availability of Community Based Organisation (CBOs)	0.1011 (0.0944)	0.1942** (0.0144)
Secured land tenure polices	0.1602** (0.0316)	0.0973** (0.0104)
Attitude towards CSA (1=Positive attitude)	0.2143** (0.0510)	0.1901*** (0.0261)
Composite index of risk perception on Climate	-0.1518*** (0.0100)	-0.2210*** (0.0016)
CSA technologies — Intercropping	0.2201*** (0.0101)	0.1956** (0.0138)
CSA technologies — Crop rotation	0.1798 (0.2282)	0.2515** (0.0901)
CSA technologies — Manure use	0.2341*** (0.0101)	0.3148*** (0.0204)
CSA technologies — Mulching	0.1284 (0.3317)	0.0181** (0.0026)
CSA technologies — Improved seed	0.1691** (0.0036)	0.2715*** (0.0036)

****p<0.01, **p<0.05, *p<0.1*
Standard errors in parentheses

Economic factors such as credit financing availability and crop market access are crucial for improving both food security and income. Access to credit financing boosts food security by 0.1456 and income by 0.1895, highlighting the importance of financial resources in adopting and sustaining CSA practices. Crop market availability positively affects food security by 0.02167 and income by 0.0946, underscoring the role of market access in enabling farmers to sell their produce at better prices and thereafter invest in CSA technologies.

Infrastructure improvements, particularly irrigation infrastructure availability, significantly enhance both food security and income, with increases of 0.1304 and 0.1809, respectively. Reliable irrigation supports the consistent application of CSA practices, ensuring higher yields and more stable incomes. Furthermore, the availability of extension services contributes positively to food security by 0.1642 and income by 0.2309, demonstrating the importance of agricultural education and support in successful CSA adoption.

Operational factors such as the ease of using CSA technologies and the cost associated with them also play pivotal roles. The perceived ease of using CSA technologies increases food security by 0.2551 and income by 0.1714, suggesting that user-friendly practices encourage more farmers to adopt CSA methods. In contrast, higher costs of CSA technologies negatively impact both food security and income, with decreases of 0.1710 and 0.1144, respectively. This indicates that financial barriers can hinder the widespread adoption of certain CSA practices, necessitating strategies to reduce costs or provide subsidies.

Organisational support further enhances the benefits of CSA adoption. Membership in farmers' organisations increases food security by 0.1243 and income by 0.2501, while the availability of Community-Based Organisations (CBOs) positively affects income by 0.1942. These organisations likely provide critical resources, information, and support networks that facilitate the effective implementation of CSA technologies. Additionally, secured land tenure policies positively influence food security by 0.1602 and income by 0.0973, as secure land rights encourage farmers to invest in long-term sustainable practices without fear of land loss.

Farmers' attitudes towards CSA and their perception of climate risks also significantly impact outcomes. A positive attitude towards CSA enhances food security by 0.2143 and income by 0.1901, emphasizing the importance of fostering favourable perceptions towards sustainable agricultural practices. Conversely, a higher composite index of risk perception related to climate negatively affects both food security by 0.1518 and income by 0.2210, suggesting that heightened awareness of climate risks may lead to cautious or reduced agricultural activities in some cases.

Finally, the specific CSA technologies adopted have varied effects. Intercropping, manure use, and improved seeds consistently improve both food security and income, with increases of 0.2201 and 0.1956 for intercropping, 0.2341 and 0.3148 for manure use, and 0.1691 and 0.2715 for improved seeds, respectively. These technologies enhance soil fertility, increase crop yields, and provide more reliable harvests, directly contributing to better food security and higher incomes. However, crop rotation and mulching show mixed results, indicating that their effectiveness may depend on other contextual factors or the way they are implemented.

Generally, results have shown that the adoption of CSA technologies in Tabora region significantly enhances smallholder farmers' food security and income through a combination of socio-demographic, economic, infrastructural, and attitudinal factors.

Financial support, access to markets, reliable infrastructure, and strong organisational support are essential for maximizing the benefits of CSA practices. Fostering positive attitudes towards CSA and addressing financial and operational barriers can further promote the widespread adoption of these sustainable agricultural technologies, ultimately contributing to improved livelihoods and food security for smallholder farmers in the region.

4.6 Strength of Instruments

The present study employed instrumental variable analysis using the distance to the nearest CSA promotion centre as an instrument, chosen for its ability to influence exogenous variables without directly affecting the outcome variable, thereby satisfying the exclusion restriction. This instrument demonstrated strong relevance, with an R-squared of 0.7633 and a partial R-squared of 0.6518, and the first-stage regression was highly significant (p-value < 0.0001) as shown in Table 6. These findings confirm that the distance to the nearest CSA promotion centre is a valid and robust instrument, ensuring reliable estimation of the causal effects of CSA adoption on smallholder farmers' income and food security.

Table 6: First-stage regression summary statistics

Variable	R-square	Adjusted R-square	Partial R-square	Prob > F
Distance to nearest CSA promotion centre	0.7633	0.6896	0.6518	0.0000

Results in Table 7 show that the eigenvalue statistic for instrument strength was determined to be 73.57, which far exceeds all critical values across various levels of relative bias and Wald tests (e.g., the 2SLS relative bias critical value at 5% is 16.19 and the LIML Wald test at 5% is 16.47). This exceptionally high eigenvalue indicates that the distance to the nearest CSA promotion centre is a robust instrument, strongly correlated with the endogenous variables and effectively addressing potential weak instrument concerns. Consequently, we reject the null hypothesis that the instruments are weak, affirming the reliability and validity of the instrumental variable approach used in this study to estimate the causal effects of CSA adoption on smallholder farmers' income and food security.

Table 7: Instrument strength by eigenvalue statistic

	Critical Values			
2SLS relative bias	5%	10%	20%	30%
	16.19	14.02	10.21	8.17
	10%	15%	20%	25%
2SLS Size of nominal 5% Wald test	27.25	23.16	19.85	13.72
LIML Size of nominal 5% Wald test	16.47	11.74	9.85	5.18

eigenvalue statistic = 73.57

H_0: *Instruments are weak*

The falsification test results in Table 8 indicate that the distance to the nearest CSA promotion centre does not have a significant direct effect on the outcome variables of food security and household income. Specifically, the coefficient for distance in the food security model is 0.0213 with a p-value of 0.259, and in the income model, the coefficient is 0.0994 with a p-value of 0.162. Both p-values exceed the conventional significance level of 0.05, demonstrating that there is no statistically significant relationship between the instrument and the outcomes. These findings support the validity of using the distance to the nearest CSA promotion centre as an instrumental variable, as it does not directly influence food security or household income, thereby satisfying the exclusion restriction and ensuring that the instrument effectively isolates the causal impact of CSA adoption on the endogenous variables.

Table 8: Falsification test to rule out direct effect of instrument to endogenous variable

	Food security		Income	
	Coefficient	**p>t**	**Coefficient**	**p>t**
CSA Adoption	0.2239	0.010	0.2582	0.000
Distance to nearest CSA promotion centre	0.0213	0.259	0.0994	0.162
Constant	0.7057	0.076	0.8169	0.057

5. DISCUSSION

The findings presented in Section 4 illuminate the multifaceted impact of Climate Smart Agriculture (CSA) on smallholder farmers in the Tabora region of Tanzania, particularly in enhancing food security and increasing household incomes. The positive relationship between CSA adoption and improved food security aligns with existing literature, which underscores CSA's role in mitigating the adverse effects of climate variability on agricultural productivity (Ali *et al.,* 2022; Wekesa *et al.,* 2018). By integrating practices such as intercropping, manure application, and the use of improved seeds, farmers are better equipped to sustain and even enhance their crop yields under fluctuating climatic conditions. This is consistent with Chai *et al.* (2021), who found that integrated farming systems significantly boost food production while reducing environmental footprints.

Economic factors, notably access to credit financing and crop market availability, emerged as critical determinants influencing CSA adoption. This echoes the conclusions of Agbenyo *et al.* (2022), who demonstrated that financial accessibility is pivotal for farmers to invest in CSA technologies. Access to credit not only facilitates the procurement of necessary inputs but also enables farmers to undertake long-term sustainable practices without immediate financial strain. Moreover, the availability of reliable crop markets incentivizes farmers to adopt improved seeds and other CSA practices, as the prospect of better returns enhances the economic viability of these investments. This finding is supported by Bozsik *et al.* (2022), who highlighted the importance of economic stability and market access in improving food availability and farmers' livelihoods.

The study also reveals the significant role of infrastructural improvements, particularly irrigation infrastructure, in promoting CSA adoption. Reliable irrigation ensures a consistent water supply, which is essential for the success of various CSA practices, especially in regions prone to droughts and irregular rainfall patterns (Amadu *et al.,* 2020). This infrastructure not only supports higher crop yields but also contributes to more stable and predictable income streams for farmers, thereby enhancing their overall economic resilience. Angom *et al.* (2021) similarly emphasized that robust irrigation systems are fundamental in enabling farmers to implement and sustain CSA practices effectively.

Social and institutional factors, including the availability of extension services and the presence of Community-Based Organisations (CBOs), play a pivotal role in facilitating CSA adoption. Extension services provide essential knowledge and training, empowering farmers to adopt and optimize CSA technologies (Kurgat *et al.,* 2020). However, the negative influence of extension services on manure adoption in this study suggests a potential mismatch between the services provided and the specific needs of farmers, indicating a need for more tailored extension programs. The positive impact of CBOs underscores the importance of community support networks in disseminating information, sharing resources, and fostering collective action towards sustainable agricultural practices (Musafiri *et al.,* 2022).

Land tenure security significantly influences CSA adoption, as secure land rights encourage farmers to invest in long-term sustainable practices without the fear of land loss (Nkumulwa and Pauline, 2021). The findings corroborate the notion that secure land tenure policies enhance farmers' willingness to adopt practices like crop rotation and manure application, which require long-term commitment and investment. Kahimba *et al.* (2015) also noted that land tenure security is fundamental in promoting sustainable agricultural practices and improving farmers' economic stability.

Attitudinal factors, including farmers' positive attitudes towards CSA and their perception of climate risks, are crucial in driving adoption. Farmers who perceive higher risks from climate change are more motivated to adopt CSA practices as adaptive strategies to safeguard their livelihoods (Denison-Johnston, 2023). This aligns with the work of Sam *et al.* (2021), who found that positive attitudes and heightened climate risk perceptions significantly influence the adoption of sustainable agricultural practices. Encouraging positive perceptions through awareness campaigns and education can, thus, be an effective strategy in promoting CSA adoption.

Operational factors, such as the perceived ease of using CSA technologies and the associated costs, also play significant roles. The study highlights that user-friendly technologies are more readily adopted, while higher costs can deter farmers from implementing certain practices, such as improved seeds. This finding is consistent with Yigezu *et al.* (2018), who emphasized the importance of reducing financial and operational barriers to enhance technology uptake among smallholders. Providing subsidies or financial incentives for more expensive CSA technologies could mitigate these barriers and promote wider adoption.

Membership in farmers' organisations and media exposure are instrumental in enhancing CSA adoption. Being part of such organisations provides farmers with access to valuable information, resources, and support networks, fostering a conducive environment for adopting CSA practices (Udimal *et al.,* 2017). Additionally, media channels like radio and television serve as critical platforms for disseminating information about CSA technologies, raising awareness, and influencing farmers' perceptions and behaviours towards sustainable practices (Lipper *et al.,* 2014).

6. CONCLUSION

This study reveals that the adoption of Climate Smart Agriculture (CSA) technologies significantly enhances both food security and household incomes among smallholder farmers in Tabora region of Tanzania. Key determinants driving CSA adoption include socio-demographic factors such as gender and age, with female and older farmers more likely to adopt CSA practices. Economic factors, particularly the availability of credit financing and reliable market access, play crucial roles in facilitating CSA uptake, thereby boosting farmers' economic resilience and productivity. Infrastructural elements, especially the presence of irrigation facilities, further support the successful implementation of CSA technologies. In addition, attitudinal factors, including farmers' perceptions of climate risks and their positive attitudes towards sustainable practices, are essential in promoting CSA adoption. The instrumental variable analysis confirmed that the distance to the nearest CSA promotion centre is a valid instrument, as it does not directly affect food security or income, thereby ensuring the reliability of the causal relationships identified.

Overall, the findings underscore the importance of addressing socio-economic and infrastructural barriers to maximize the benefits of CSA, ultimately contributing to improved livelihoods and enhanced food security for smallholder farmers in the region.

7. RECOMMENDATIONS

To effectively promote the adoption of Climate Smart Agriculture (CSA) technologies among smallholder farmers in Tabora and other regions with similar characteristics, policymakers should prioritize enhancing the availability of credit financing. Access to financial resources is a critical determinant of CSA adoption, enabling farmers to invest in necessary inputs and technologies. Establishing affordable credit schemes, providing low-interest loans, and creating financial support programs tailored to the needs of smallholder farmers can significantly reduce financial barriers and encourage the uptake of sustainable agricultural practices.

Moreover, improving market access and reliability is essential for incentivizing farmers to adopt CSA technologies. Reliable crop markets not only provide better returns for high-yielding seeds and other CSA practices but also enhance farmers' economic resilience. Policymakers should focus on developing robust market infrastructure, facilitating better transportation networks, and establishing fair pricing mechanisms. Creating platforms for farmers to connect with buyers and ensuring timely access to markets can drive the economic viability of CSA investments.

Investing in irrigation infrastructure is another critical area that requires attention. Reliable irrigation systems support the consistent application of CSA practices, ensuring higher crop yields and more stable incomes for farmers. Government initiatives should aim to expand and maintain irrigation facilities, particularly in regions prone to droughts and irregular rainfall patterns. By ensuring a steady water supply, policymakers can help farmers implement diverse agricultural practices more effectively, thereby enhancing both food security and income stability.

Strengthening extension services and ensuring they are aligned with farmers' specific needs is vital for the successful adoption of CSA technologies. Effective extension services provide essential knowledge, training, and support, empowering farmers to optimize the use of CSA practices. Policymakers should invest in training extension agents, developing relevant educational materials, and fostering close collaboration between extension services and farming communities. Tailoring extension programs to address the unique challenges faced by farmers in the Tabora region can enhance the effectiveness of CSA initiatives.

Supporting Community-Based Organisations (CBOs) is also crucial for facilitating CSA adoption. CBOs play a pivotal role in disseminating information, sharing resources, and fostering collective action among farmers. Policymakers should provide funding and technical support to strengthen these organisations, enabling them to serve as effective platforms for promoting sustainable agricultural practices. In addition, securing land tenure policies can encourage long-term investments in CSA by providing farmers with the confidence to adopt sustainable practices without the fear of land loss. Ensuring secure land rights is fundamental to fostering an environment where farmers are willing to invest in and commit to CSA technologies.

Finally, fostering positive attitudes towards CSA through awareness campaigns and educational programs can significantly enhance adoption rates. Policymakers should leverage media channels, such as radio and television, to disseminate information about the benefits of CSA and successful case studies. Reducing the costs associated with CSA technologies through subsidies or financial incentives can also mitigate economic barriers and promote wider adoption. By addressing these multifaceted determinants through integrated policy interventions, stakeholders can create an enabling environment that supports the widespread adoption of CSA practices, ultimately leading to improved food security and increased incomes for smallholder farmers in Tabora region.

8. LIMITATION AND AREAS FOR FURTHER RESEARCH STUDY

Notwithstanding the valuable contributions and insights offered by this study, it is imperative to acknowledge its inherent limitations. The study's sample size was relatively small, potentially constraining the ability to generalise the findings to a wider population of smallholder farmers. Additionally, it is important to consider the potential impact of measurement errors in self-reported data pertaining to CSA adoption, food security, and income on the overall accuracy of the analysis. The consideration of external validity is crucial in assessing the generalizability of the findings, as they may exhibit context-specific characteristics and lack direct applicability to diverse regions or countries. Establishing a causal relationship between the adoption of CSA, food security, and income can present difficulties, and it is important to note that the timeframe of the study may not encompass the comprehensive long-term impacts of CSA adoption.

Finally, it is important to note that the findings of this study are constrained by the data sources and variables utilised, which may result in the omission of significant factors that could potentially impact the adoption of CSA and its subsequent effects. The aforementioned limitations underline the necessity for additional research endeavours that specifically target these concerns and offer more evidence regarding the factors influencing and consequences of Climate-Smart Agriculture within the context of smallholder farmers.

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