Enhancing Food Security among Smallholders through Climate-Smart Agriculture in Tanzanian Arid Regions

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ABSTRACT

The role of the agricultural sector in ensuring food security among smallholders in developing countries cannot be overemphasized. However, climate change is becoming one of the biggest challenges in the agricultural sector. Climate-smart agriculture (CSA) has been proposed as an approach to mitigate some of the threats emanating from climatic changes and guide agriculture management in the era of climate change. This study aimed to (a) assess the CSA practices and technologies and their impacts on household food security among smallholders in Tanzania's arid and semi-arid agroecological zones and (b) to show how smallholder production adopts and challenges the promotion of CSA. Dodoma region in Tanzania was used as a case study. The methodology used qualitative and quantitative approaches and in-depth key informant interviews, focus group discussions (FGD), field observations, and household surveys were employed to generate data. The main findings include (i) smallholders play a crucial role in maintaining natural assets by improving soil quality and humidity; (ii) different practices and technologies are adopted by different smallholders where those cultivating smaller farms use new drought-resistant seed varieties, crop mixing sunflower with millet, sorghum, and maize, and irrigation using the local charco dams to improve household food security; (iii) smallholders cultivating relatively larger farms adopt technologies such as constructing terraces for soil conservation, precision fertilization, improved crop varieties, boundary trees, and hedgerows to improve crop yields and manage climatic challenges. Additionally, we show that interventions on CSA do not use smallholders' differentiation inclusively as they are focused on areas and farmers where they are likely to succeed rather than where its impact would be useful on the overall use of the CSA practices and technologies to ensure food security at the household level.

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1. INTRODUCTION

The role of the agricultural sector in ensuring food security in developing countries cannot be overemphasized (Pawlak & Kołodziejczak, 2020). In Tanzania, for example, the sector employs about 60% of the country's labour force and is considered essential for food security, economic growth, and poverty alleviation. (URT, 2015). However, climate change has become one of the challenges impacting the agricultural sector in the 21st century and has become an increasing threat to food security systems (Zimmermann et al., 2018). It is anticipated that climate change is likely to continue reducing agricultural productivity and thus raising production costs (FAO, 2021; Negera et al., 2023).

Globally, the economic losses from climate change impacts on agriculture are estimated at US$200 million annually (CIAT & World Bank, 2017). The recent AR6 IPCC report 2023 indicates that extreme climatic events such as severe flooding and drought are more likely to intensify, with more impacts likely to be observed in water availability and food production amongst other areas (IPCC, 2023). To combat some of these climatic impacts, climate-smart agriculture (CSA) was coined and proposed in 2009 as an approach to guide agriculture management in the era of climate change (Lipper et al., 2018).

Scaling up CSA interventions presents numerous challenges emanating from the existence of diverse farming systems, limited finances, high costs of agricultural inputs, and technology (Kirina et al., 2022; Makate, 2019; Neufeldt et al., 2015). Recently, numerous efforts have been made to address issues that hinder CSA upscaling in Africa substantially (Ayorinde Ogunyiola & Vij, 2022). Nevertheless, there is a lot to be desired on challenges about the inclusion or exclusion of local knowledge in CSA interventions and inconclusive evidence on how these interventions target differentiated smallholders in rural areas with implications for CSA adaptation (Ayorinde Ogunyiola & Vij, 2022; Hellin & Fisher, 2019). Consequently, this raises the question of how differentiated smallholders are likely to adopt and possibly scale up CSA strategies. (Kirina et al., 2022). This study aimed to answer this question by understanding the adoption of CSA practices and technologies among differentiated smallholders and the impacts of these technologies and practices on household food security in Tanzania's arid and semi-arid agroecological zones.

1.1 Literature Review: CSA and Smallholder Production

CSA is described as an integrated approach to address climate change and food security challenges by increasing agriculture productivity and reducing greenhouse gas emissions (USAID, 2019) while reducing smallholders' vulnerability and building resilience (Lipper et al., 2018; Negera et al., 2023). Interventions in CSA are expected to provide globally applicable principles on managing agriculture for food security under climate change that could provide a basis for policy support and recommendations by multilateral organizations, such as the UN's FAO (Lipper et al., 2018). This is more crucial in the current context, where smallholders have become increasingly vulnerable to multiple stressors (Batenga et al., 2023; Räsänen et al., 2016). A CSA intervention relies on its ability to leverage synergies between its adaptation and mitigation potentials (Lipper & Zilberman, 2018). Here, CSA intervention strategies may include practices such as irrigation and water management, soil and nutrient management, farming crop (seeds) tolerant to stress, agroforestry and intercropping, deploying crop rotation and mixed systems, pest and disease management, crop insurance and loans to farmers, and provision of climate information services (FAO, 2017; Sain et al., 2017).

While CSA usually involves technical and technological adaptations, the smallholders are expected to play a vital role in learning and adapting these farming practices to help them cope with climatic variability and changes and increase production to ensure food security within the household (Ayorinde Ogunyiola & Vij, 2022; Kalinga et al., 2021). In this case, scaling up CSA technologies and practices among the smallholders is considered to present an opportunity to build resilience in the agriculture sector, improve productivity and farmer incomes, and contribute to climate change mitigation (AU, 2014). This opportunity is perceived to be crucial to the agricultural sector in developing countries like Tanzania, which are dominated by smallholder farmers who practice rain-fed mixed farming by employing local technology and adopting a low-input and low-output production system (Lipper et al., 2018; URT, 2017).

Recently, the role of smallholder differentiation in agricultural transformation in Africa has been increasingly notable (Oya, 2007; Pauline et al., 2023; Wineman et al., 2020). In this case, the role of rising wealthier smallholder farmers and middle farmers has increased the agency of the smallholders in improving productivity (Ponte & Brockington, 2020; Sulle, 2017). Studies in farmer-led irrigation offer a good example of the increasing agency of smallholders in irrigation and water management as they play a crucial role in developing climate-smart (irrigation) practices (de Bont, 2018a; de Bont et al., 2019; Veldwisch et al., 2019; Woodhouse et al., 2017). Nevertheless, the agency and engagement of smallholders are limited by the extent to which smallholders' knowledge is acknowledged and included in irrigation and other CSA-related interventions (Ayorinde Ogunyiola & Vij, 2022; de Bont, 2018b).

In Tanzania, the government has made numerous efforts to create a favourable environment for adoption, explicitly naming CSA as a policy priority (FAO, 2017; URT, 2016). These efforts include the National Climate-Smart Agriculture Programme (2015–2025) and The Climate-Smart Agriculture (CSA) guideline, which envisions strategies for making the agricultural sector climate-smart by 2030 (FAO, 2017). The guideline distinguishes between fishing, aquaculture, and livestock and crop subsector. In the crop sub-sector, which is also the focus of this study, numerous CSA strategies and technologies[1] are proposed. However, adoption of CSA among smallholders is considered relatively low as the adoption was determined by other dynamics among the smallholders, such as availability of resources and accumulation of assets (Bongole et al., 2021).

[1] These CSA strategies have been previously mentioned in this section and they include rainwater harvesting and irrigation, soil and water conservation, terracing, agroforestry, conservation agriculture, soil fertility management, crop management and crop insurance.

The decision to adopt CSA practices in Tanzania was likely to be made when smallholders were keeping livestock and involved in diversified production, specifically, when females were involved in the control of farm resources and where the household had enough resources for cultivation (Kalinga et al., 2021; Kurgat et al., 2020). Similarly, natural assets like the size of the farm and its location in terms of its proximity to water resources and household and soil fertility were also crucial (Ndesanjo & Asokan, 2023). Among those who have adopted CSA, there is notable complementarity in adopting different agricultural technologies and practices, as adopting one technology influences another (Ogada et al., 2020). However, smallholder differentiation remains increasingly crucial with implications on both assets (Brockington et al., 2018; Brockington & Noe, 2021; Ponte & Brockington, 2020; Wineman et al., 2020) and household food security (Kazungu & Kumburu, 2023). The evidence of increasing differentiation among the smallholders, which are part of such smallholder dynamics, has mixed outcomes in Tanzania as elsewhere in Africa, with some accumulating and some losing out (Ameur et al., 2017; Greco, 2015; Sulle, 2017). The Tanzanian drylands have a long history of food shortages and insecurities, and the adoption of CSA is likely to differ among differentiated farmers (Liwenga, 2003). Nevertheless, little is known about adopting CSA in Tanzania's arid and semi-arid areas. Similarly, evidence on how smallholder production systems challenge CSA promotion and on-farm adoption in the semi-arid areas in the country remains scant.

This study explored how CSA adoption impacts household food security among smallholders in Dodoma, Tanzania's arid and semi-arid agroecological zones. We aimed to get a nuanced understanding of how different smallholders use the CSA practices and technologies to ensure food security at the household level. We consider the recent researches that point towards increasing differentiation among the smallholders as smallholder production becomes increasingly commercialized (Fibæk, 2021; Komakech & de Bont, 2018; Sulle, 2017). In this case, assets that smallholders own are considered crucial in influencing the agrarian dynamics (Brockington et al., 2018; Howland et al., 2019; Östberg et al., 2018) and predicting household food security (Alinovi et al., 2010). While productive assets (such as tractors, power tillers, and land), financial assets (farm size, age, education, and income), and human assets are considered crucial, some have further pointed towards the importance of natural assets such as soil quality, humidity, and technology change in improving food security (Apanovich & Mazur, 2018; Pinstrup-Andersen & Pandya-Lorch, 1998)Based on the importance of these natural assets, we analysed different practices that farmers use to maintain them. Similarly, we analysed different practices and technologies that farmers have adopted to improve crop yields and manage climatic challenges and how these have contributed to enhancing household food security.

1.2 Statement of the Problem

Climate-smart agriculture (CSA) was coined in 2009 and proposed as an approach to guide agriculture management in the era of climate change. African agriculture is predominantly smallholder production, and the smallholder production system plays a crucial role in national and household food security. In this case, CSA adoption is crucial among smallholders as they tend to rely heavily on the available natural assets in their environment that are highly affected by climatic changes. As such, climate change poses serious threats to smallholder agriculture and food security on the continent and elsewhere globally, where smallholder production is dominant. To smallholder production systems, adopting CSA technologies and practices is considered the first line of defence against the impacts of climate change. This is because crop failure due to erratic climate shocks incidents, such as drought (shortage of rainfall) and flooding (excessive rain), increases the risk of a more extended period of hunger and more severe livelihood hardship for smallholders' livelihood globally (UNFCCC, 2014).

Despite the importance of CSA in Tanzania, adoption of CSA among smallholders remains relatively low (Bongole et al., 2021). Numerous efforts, including establishing a CSA guideline, have been put in place by the government to make the agricultural sector climate-smart by 2030 (FAO, 2017; URT, 2016). However, scaling up CSA poses numerous challenges, some of which are associated with dynamics among the smallholders, such as differences in the availability of resources and accumulation of assets. Moreover, little is known about how scaling the current CSA interventions targets differentiated smallholders in rural areas with implications for CSA adaptation. This is particularly problematic in dry lands with a long history of food shortages and insecurities (Liwenga, 2003).

Therefore, this study assessed how CSA adoption impacts household food security among the smallholders in Tanzania's arid and semi-arid agroecological zones. Using Dodoma, one of the arid regions, as a case study, we specifically sought a nuanced understanding of how CSA interventions target and differentiate smallholders with implications on household food security.

1.3 Research Objectives and Questions

1.3.1 General Objective

The general objective of this study was to assess the adoption of climate-smart agricultural (CSA) practices and technologies and their impacts on household food security among smallholders' production systems in Tanzania's arid and semi-arid agroecological zones.

1.3.2 Specific Objectives

The specific objectives of the study were as follows:

a) To identify CSA technologies and practices that have been adopted in the study area.
b) To examine the barriers that limit differentiated smallholder farmers in employing available CSA technologies and practices.
c) To determine the effect of CSA technologies and practices on household food security.

1.3.3 Research Questions

To meet the specific and general objectives, the study is guided by the following questions:

a) What CSA technologies and practices have been adopted in the study area?
b) What barriers do differentiated smallholder farmers face when employing available CSA technologies and practices?
c) How do CSA technologies and practices affect household food security?

2. RESEARCH METHODOLOGY

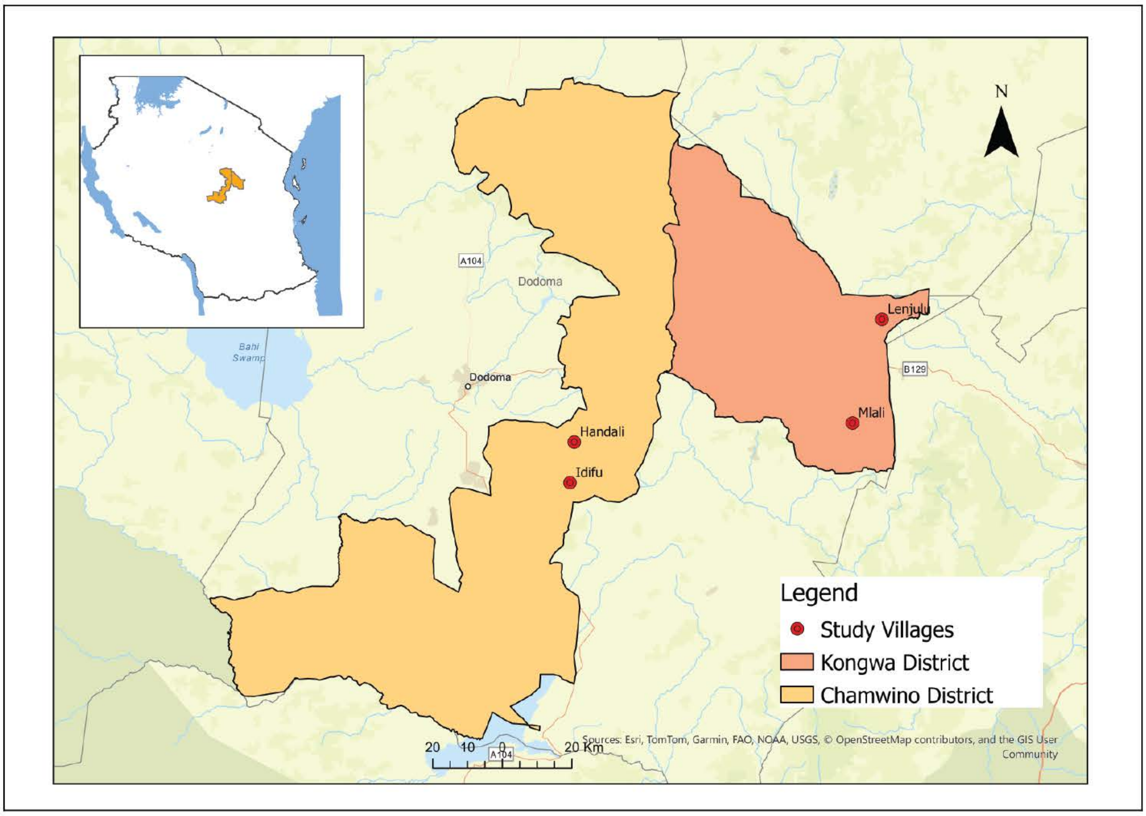
2.1 Study Approach and Design

In this study, mixed qualitative and quantitative approaches were employed to generate the data and triangulate the interpretation of data and results to enhance the reliability and validity of findings. In the qualitative approach, two in-depth key informant interviews were conducted in Chamwino and Kongwa district offices. Four focus group discussions (FGD), one for each of the four study villages, were conducted mainly to identify CSA interventions that have been conducted and CSA strategies used by the smallholders within the districts. In the quantitative approach, researchers and enumerators conducted the household survey based on a structured questionnaire interview in all four villages to understand the CSA technologies and strategies used and their impacts on household food security. In this case, an explanatory research design was appropriately applied. The binary logistic and linear regression models designed as explanatory models were used to determine the magnitude of the relationship between the "CSA adopters" as the dependent variable and selected demographic, socioeconomic, and farmers' characteristics as independent variables that characterize the adoption of CSA practices and technologies.

2.2 Description of the Study Area

This study was conducted in four villages, namely, Handali, Idifu, Lenjulu, and Mlali, in Kongwa and Chamwino districts in the Dodoma region, Tanzania, as shown in Figure 1. The selection of the region was influenced by the fact that Dodoma, being one of the dry agroecological areas in Mainland Tanzania characterized by the most expansive land (1,898,275 ha) used by smallholder farmers for agricultural activities, is vulnerable to food insecurity (Duda et al., 2018; URT, 2021). Despite this vulnerability, the region lags and is regarded to have less than half (45.3%) of the agricultural households practicing conservational farming, one of the practices linked to CSA. Conservational agriculture is the primary preposition for agricultural production in Tanzania, involving the use of applicable agronomic practices that improve crop production and conserve soil fertility, and is historically crucial for increasing agriculture productivity (Mkonda & He, 2017; Sosoveli et al., 1999; URT, 2021). In this case, the area enabled us to follow and unpack CSA adoption among the smallholders in the arid and semi-arid ecological zone as they cope with climatic stresses that impact their agricultural production and household food security. Furthermore, the dominance of smallholder production in the area was crucial in analysing smallholder differentiation as they compete with one another to access inputs, labour, and markets, as well as opportunities presented by CSA interventions.

Figure 1. Map of Dodoma's arid agroecological zone showing the study villages in Kongwa and Chamwino Districts



2.3 Sampling Techniques and Sample Size

A purposive sampling technique was employed to select the districts and respective villages based on their crop and livestock production potential to show the climate change variability and effect of CSA practices and technologies on food security. In this case, we prioritized villages based on the available CSA practices where two of the villages selected (Mlali and Handali) were considered to have CSA interventions. In contrast, the remaining two villages (Lenjulu and Idifu) were considered not to have a particular intervention, but there were notable climate-smart strategies developed and used by smallholders. The notable CSA interventions mentioned in villages where there had been active interventions include donor-funded drip irrigation and the use of manure due to the presence of cattle kept by the villagers in Handali. Similarly, interventions in Mlali included more intercropping, agroforestry, and terracing through an intervention called 'Kisiki hai.' This is a method of regrowing trees and enabling new naturally occurring plants to grow. Broadly, this is Farmer-managed Natural Vegetation Regeneration (FNVR).

We employed a simplified formula to calculate the sample size according to Yamane (1967) to determine the sample size for a given population. This formula is handy when dealing with large populations. The formula is:

$$n = \frac{N}{1+N(e)^2} \text{ .... (1)}$$

Where:

- *n* is the sample size,
- *N* is the total population size,
- *e* is the precision or margin of error level, expressed as a proportion (for example, a 5% margin of error would mean *e* =0.05).

This formula allows for a quick estimation of the sample size needed for a survey or study, assuming a simple random sampling method and a confidence level of approximately 95%.

Therefore, the calculated sample size was: $2000/(1+2000^{0.05})=333$

During the survey, we were able to gather data from 320 farmers. However, it is worth noting that 13 farmers were not available to participate. Despite this, we could still gather significant data from the remaining participating farmers. The respondents were selected using simple random sampling, where random numbers (=RANDBETWEEN formula) from Ms. Excel were employed using the list of villagers from the village and sub-village resident list.

2.4 Data Sources and Collection Tools

This study collected primary data using different approaches, including a household survey, interviews with key informants, focused group discussions, and field observations. In-depth interviews and FGDs were used to collect the qualitative data. The in-depth interviews were conducted through face-to-face conversations with a total of four key informants in Chamwino and Kongwa district offices, where two agricultural officers, one from each of the two districts, were interviewed. In-depth interviews were used as an entry point to identify areas and types of CSA intervention and practices found in the districts. We visited farmers' lands and other areas where CSA technologies were implemented to observe field practices.

To gather qualitative data, we used Focus Group Discussions (FGDs). We planned for these discussions with the help of village leaders, who informed the selected participants. Participants were selected based on their knowledge of the village dynamics, including the CSA interventions and training provided within the villages. In total, we conducted 4 FGDs with different types of farmers, with each session comprising 10 participants of mixed gender and age. We collected information about the perception of climate change, its effects on farming, and its influence on adopting climate-smart practices through these FGDs. We further used FGDs to gather information about the collection and dissemination of climate information to explore the existing CSA interventions and CSA strategies used by the smallholders within the study villages.

On the other hand, the quantitative data collection was also conducted in all four villages. In this case, researchers and enumerators conducted the household survey using a structured questionnaire interview. The questionnaire data aimed to understand the impacts of CSA strategies on household food security and identify barriers that smallholders face in the adoption of different CSA technologies within the study villages.

2.5 Data Analysis

2.5.1 Qualitative Data Analysis

The qualitative data obtained from Focus Group Discussions (FGDs) and Key Informant Interviews (KIIs) were transcribed, and transcripts were manually analysed using thematic analysis. This involved coding and categorizing concepts based on their dimensions, which were then used to generate inductive themes (Boyatzis, 1998). Additionally, a narrative analysis method was applied to extract direct responses from participants where necessary. This method helped better understand the participants' intentions or the actual context in cases where the initial responses were insufficient (Riessman, 1993).

2.5.2 Quantitative Data Analysis

2.5.2.1 Factors Affecting the Adoption of CSA Practices and Technologies

The binary logistic regression (BLM) model was used to identify and interpret the main socio-economic factors affecting the adoption of CSA practices and technologies on food security in the study area. Binary logistic regression is most beneficial in modeling the event probability for a categorical response variable with two outcomes. The model is a powerful statistical tool to determine the effect of multiple explanatory variables on the dependent variable while holding any number of other independent variables constant. The binary Logistic Regression procedure is used to determine factors more likely to affect the adoption of CSA practices and technologies. The specified generalized linear model can be written as follows:

$$\text{Logit}\,(\pi(x_i)) = \log\,(\pi(x_i)/1 - \pi(x_i)) = \beta_0 + \beta_1 x_{1i} + \ldots + \beta_p x_{pi} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

or

$$\text{In}\,(p/1\text{-}p) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_p x_{pf} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where, p = probability of event occurring and p/1-p = odds ratio

This study's response (dependent variable) Y represents the CSA practices and technologies. Farmers are expected to perceive that the adopted CSA practices and technologies contribute to farm income and household food availability. Therefore, it is measured as a dummy variable, with a numeric value of 1 if farmers adopt CSA and 0 if there are no adapters. The explanatory variables (independent variables) in the regression model are hypothesized to affect the smallholder farmers' adoption of CSA practices and technologies and combined effects of various factors such as household demographic, socio-economic, and institutional characteristics. The identification of explanatory variables to examine their impact on adoption will be based on reviewing related literature and past research findings.

The study used IBM SPSS Statistics Version 20 to analyse the cross-sectional data and perform all the required tests by analysing the regression model. Confidence intervals and odds ratios (Exp(B)) were presented. The odds ratio tells us about the change in "odds" being in one of the dependent variable categories for every unit increase of any given variable in the model. The Cox and Snell R Square and the Nagelkerke R Square are referred to as "pseudo-R-squared statistics," as reported by Hosmer and Lemeshow (2001). The Logistic regression models passed the goodness of fit tests as recommended by Pallant (2007) and Hosmer and Lemeshow (2001).

2.5.2.1 Selection of Independent Variables

The variables were chosen based on a review of relevant literature to encompass potential factors linked to adopting CSA technologies and practices. Table 1 describes these variables and their sources.

Table 1: Description of variables selected that influence the adoption of CSA technologies and practices.

S/No.	Variables	Description	Sign	Source
1.	CSA awareness	1 if the household head is aware of CSA practices	+/0	CIAT; World Bank. (2017), Mashi et al., (2022), Aturihaihi et al., (2022) and Kpadonou et al., (2017)
2.	Sex of household head	2 if the household head is male and 1 if is a female	+/0	Mutombo & Musarandega, (2023), Luu (2020), Kifle et al., (2022)
3.	Marital status of household head	1 if the household head is married	+/0	Bekabil & Bedemo (2015), Oduntan & Obisesan (2022), Nkonki-Mandleni et al., (2018), Ojoko et al., (2017 and Chavula et al., (2023), Egeru et al., (2022) and Aryal et al., (2018)
4.	Number of adults in the household	Continuous, number of household members between 15 and 65 years old	+	Kpadonou (2017), Chamberlin & Sumberg (2021) and Mukasa (2018).
5.	Education level of household head	Categorical (1=No formal education, 2=Primary education, 3=Secondary education and 4=College education)	+	Mutombo & Musarandega, (2023), Saha et al., (2019), Luu (2020), Mazhar et al., (2021), Serote (2023), Brüssow et al., (2017) and Kpadonou et al., (2017)
6.	Age of household head	Continuous, age of household head in years	+	Mutombo & Musarandega, (2023), Luu (2020), Kifle et al., (2022), Serote (2023), Brüssow et al., (2017) and Kpadonou et al., (2017)

7.	Experience of household head	Continuous, number of years spent in farming	+	Mutombo & Musarandega, (2023), Kifle et al., (2022), Mazhar et al., (2021), Serote (2023),
8.	Farm income	1=On farm	+/0	Mutombo & Musarandega, (2023), Kifle et al., (2022), Abegunde (2022), Waaswa et al., (2021), Sisay et al., (2023) and Agbenyo et al., (2022)
9.	Farm size	Continuous, total size of landholding in acres	+	Mutombo & Musarandega, (2023), Luu (2020), Kifle et al., (2022), Mazhar et al., (2021) and Kpadonou et al., (2017)
10.	Access to extension services	Continuous, number of household contacts with public extension services in the previous year	+	Saha et al., (2019), Luu (2020) and Kifle et al., (2022), Nakazi & Sserunjogi (2023), Abegunde (2022), Makate et al., (2019) and Onyeneke et al., (2018)
11.	Distance of output markets	Continuous, distance to output market in kilometres	+	Kifle et al., (2022), Mazhar et al., (2021), Saha et al., (2019), Luu (2020), Sisay et al., (2023)

Data was collected through the administration of a structured questionnaire. The information collected on farmers' CSA practices is based on the World Bank model. Respondents were asked to indicate (yes/no) to the stated CSA practices. This was to give an overview of the nature of acceptance of CSA and the individual practices that farmers mainly were employing. The individual variables were then computed to form the overall CSA dichotomous variable, thus, yes (1/adopting) and no (0/not adopting) for the binary logistic regression.

We gathered data on farmers' socio-economic factors indicating their likelihood of adopting CSA practices and technologies. Our data was collected from 320 farmers, both adopters and non-adopters. Of the 320 farmers, 200 were adopters, and 120 were non-adopters. We used the data from a random sample of 200 adopters to create a logistic model while setting aside the remaining 120 farmers for validation. Finally, we used the model to analyse the likelihood of the 120 non-adopters adopting CSA practices and technologies.

The explanatory (independent variables) in the regression model is hypothesized to affect the smallholder farmers' adoption of CSA practices and combined effects of various factors such as household demographic, socio-economic, and institutional characteristics. Based on the review of related literature and past research findings, eleven potential explanatory variables (CSA awareness, sex of the household head, age of the household head, number of adults in the household, education level, farm size, farming experience, farm income, access to extension services and distance to market) were considered as significant factors and examined for their effect on adoption.

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3. STUDY RESULTS

3.1 Farmers' Profile

Table 2 presents a detailed overview of various demographic and socio-economic characteristics of a selected group of farmers. The data covers a wide range of factors, including adoption rates, gender, marital status, education level, awareness of Climate Smart Agriculture (CSA), number of adults in the household, age, farming experience, monthly income, farm size, extension contacts, and distance to market. The key highlights of the data reveal that farmers who participated in the study adopted CSA practices (62.5%), were male (62.8%), married (79.1%), and had primary education (76.2%). Additionally, the data covers a wide range of farming experiences, with some farmers having up to 50 years of experience and others having less than five years. The ages of the farmers also varied significantly, with some being as young as 18 years old and others as old as 78 years old. In terms of income levels, the data shows that farmers earned between 50,000Tshs and 1,000,000 TAS per month, with the majority earning less than 500,000Tshs per month. The farm sizes also varied, with some farmers owning less than an acre of land while others owned more than 10 acres. Also, the data reveals that most farmers had contacts of extension services, indicating they were likely receiving support from extension workers.

Table 2: Descriptive statistics of model variables.

Variable	Frequency		Percent	
Adoption				
Adopters	200		62.5	
Non-adopters	120		37.5	
Sex				
Male	201		62.8	
Female	119		37.2	
Marital status				
Married	253		79.1	
Single	67		20.9	
Education level				
No formal education	76		23.8	
Primary education	244		76.2	
	Min.	**Max.**	**Mean**	**SD**
Awareness to CSA	0	1	0.79	0.408
Number of adults in farmer's household	1	8	2.50	1.282
Age	19	67	46.85	12.356
Farming experience	1	35	19.87	9.072
Average monthly income	30,000	3,000,000	416,250.00	580,712.809
Farm size	1	52	6.54	6.992
Extension contacts	0	8	1.81	2.039
Distance to market	0	35	18.33	13.048

3.2 Factors Influencing the Utilization of CSA Technologies and Practices

We selected and used a wide range of variables (see Table 1) from questionnaire data to run a theoretical binary logistic regression model to quantitatively establish the influential factors. Table 3 shows the results of the regression analysis.

Data was first prepared before running the analysis. We used a random sample of the 320 CSA adopters to create a logistic regression model to determine the impact of various factors on the uptake of CSA practices among farmers in the study area, setting the remaining farmers aside to validate the analysis. Setting the random numbers allowed us to replicate the random selection of cases in this analysis. We *validated* cases that could be used to create the model: farmers who adopted CSA practices. However, 200 cases were corresponding to CSA adopters in the sample.

We performed the computation only for adopters. The values *validated* the randomly generated Bernoulli variates with probability parameter 0.7. We *validated* only cases with non-missing values, that is, for farmers who previously adopted CSA practices. Approximately 70 percent of the farmers who adopted CSA practices were validated. These farmers were used to create the model. The remaining farmers who adopted CSA practices were used to validate the model results.

After building the model, we determined whether it reasonably approximates the behaviour of data using Hosmer and Lemeshow Test. The Hosmer-Lemeshow statistic indicates a poor fit if the significance value is less than 0.05. Here, the model adequately fits the data because the Hosmer-Lemeshow statistic is 0.772.

Table 3: Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	.000	0	.
2	4.869	8	.772

3.3 Factors that Influence the Adoption of CSA Technologies and Practices.

We used a diverse range of variables (refer to Table 1) obtained from questionnaire data to conduct a quantitative theoretical binary logistic regression analysis to establish the influential factors. The results of the regression analysis are presented in Table 4.

Table 4: Factors influencing the adoption of CSA technologies and practices

Independent variable: Adoption of CSA technologies and practices			
Independent variables	**B**	**Sig.**	**Exp(B)**
CSA Awareness (CSA aware)	2.837	0.012	17.581
Sex of household head (Sex hhead)	-0.394	0.612	4.384
Marital status of the household head (Marital)	0.073	0.731	1.097
Number of adults in the household (Adults No)	3.261	0.015	0.048
Education level of the household head (Education)	1.562	0.037	4.694

Age of the household head (Age)	3.135	0.027	0.978
Farming experience of the household head (Farming experience)	2.483	0.024	2.625
Average monthly farm income of household (Average income)	1.538	0.006	4.358
Farm size of household (Farm-size)	1.724	0.047	4.727
Number of extension contacts (Extension)	3.263	0.007	6.826
Distance to output market (Distance market)	-0.368	0.635	1.064
Constant	22.624	1.000	0.000
Cox and Snell R Square=0.572			
Nagelkerke R Square=0.639			
$p \leq 0.05$			

The study's results reveal that several factors significantly and positively affect the adoption of CSA. However, a few factors, including sex, marital status of household heads, and distance to market, have no significant effect on the adoption of CSA. Accordingly, we found that awareness is significantly and positively associated with adopting CSA practices and technologies. Awareness is also essential in shaping farmers' decisions toward the intensive use of SWC practices (Kpadonou et al., 2017). Wall (2007) proposes that the successful adoption of conservation agriculture depends on raising awareness in the community about the problems of soil degradation. However, in the face of immediate problems of poverty, food insecurity, and poor agricultural productivity, soil degradation may be readily downgraded from their list of priorities (Giller et al., 2009).

Furthermore, participants in the focus group discussion stated that there is awareness of the smallholder farmers towards CSA and that local communities have previously practiced and were well aware of some CSA practices such as physical soil and water conservation activities such as terracing, cultivating improved varieties, applying animal dung, crop rotation, and water harvesting through the use of charco dams prior and during the current interventions. FGD participants believed that despite the importance of farmers' awareness of CSA, the decision to adopt CSA practices within the community depended on those with better income and knowledge about CSA practices that they could apply. In this case, the participants pointed out that CSA interventions face problems of poverty, food insecurity, and poor agricultural productivity. As many intervention projects are for a short period, they usually target wealthier and successful smallholders known as ‘champion’ farmers rather than the poor ones.

Furthermore, the coefficient associated with the number of adult household members is positive and significant. This suggests that the number of adults living in the household can influence the labour supply since many CSA technologies require manual labour (Kpadonou et al., 2017). It has been found that the level of education of the head of the household positively impacts the adoption of CSA (Conservation Agriculture) technologies. This is because higher education is generally associated with better access to information on improved technologies and higher productivity (Norris & Batie, 1987). Previous studies have also shown a positive correlation between the level of education of the head of the household and the adoption of improved technologies (Lin, 1991; Deressa et al., 2009). The results of this study are consistent with these findings.

There is a noticeable difference in farmers' adoption of CSA technologies based on their age. This suggests that older farmers are more likely to understand the importance of these practices and implement them than younger farmers. However, a study by Kifle et al. (2022) found that age did not affect the adoption of CSA practices in Ethiopia. Moreover, during FGDs, it was mentioned that current CSA interventions also focus on raising awareness among youths, mainly by forming youth groups and farmers' field schools famously known as 'mashamba darasa' in Swahili. In this case, apart from the number of adult members in the household, the adoption of CSA was also influenced by differences in factors such as the level of CSA awareness among farmers, experience that these farmers had, and access to extension services that was mainly prioritized through farmers'-field schools.

Farming experience is significant and positively affects the adoption of CSA technologies. It was mentioned during FDGs that the experience that farmers had depended on the number of years that one had been farming, training received, cultivated crops, and type of farming practiced. It was further mentioned during FGDs that farmers were likely to venture into a new experience (either a new crop or farming technology) if new technologies become readily available and new opportunities are discovered. For example, participants mentioned how new seed varieties that are drought resistant are currently adopted, with some farmers opting to crop mix sunflower with millet, sorghum, and maize as it has provided new opportunities due to growing demand while adapting to climatic variabilities. The level of farming experience of the head of the household increases the possibility of undertaking different CSA technologies since experienced farmers are knowledgeable and better informed on CSA (Deressa et al., 2009). Since CSA is context-specific, farming experience is crucial to identify and practice locally smart technologies (Kifle et al., 2022). Thus, farmers could accumulate this lifetime wisdom through practices, where the acquired experience becomes an indispensable factor in identifying locally smart practices. Tabbo et al. (2016) also indicated the importance of experience in shaping farmers' perceptions and taking appropriate action.

On-farm income was found to be significant. This was also mentioned during interviews and FGDs as participants noted that farmers were also differentiated based on their income from farming, which ultimately affected how much they re-invested into farming. Those who could benefit better from on-farm income were mentioned to be those able to afford fertilizers and improved seeds, which were fast maturing with relatively higher yields, and some were constructing terraces for soil conservation. In this case, the on-farm income of the farmers significantly predicted the adoption rate of CSA practices, as also reported by Kifle et al. (2022). Socioeconomic factors like farmers' on-farm income have been essential determinants of technology adoption (Waaswa et al., 2021).

A larger cultivated farm provides more opportunities for farmers to practice CSA techniques. Within the study villages, FGD participants mentioned that the smallholders cultivating larger farms were relatively wealthier than others and, therefore, could adopt new available technologies. However, the types of technologies that they could adopt were considered, in some cases, different from those adopted by those cultivating smaller farms. For example, one of the FGD participants in Idifu mentioned that due to a water shortage in the local charco dam, irrigation technologies were mostly adopted by farmers cultivating in smaller farms (about 1 – 4 acres) rather than farmers cultivating in large farms. Technologies commonly adopted by those cultivating relatively larger farms (about

10 acres or more) were mentioned to be terraces, precision fertilization, improved crop varieties, boundary trees, and hedgerows. Studies on the adoption of agricultural technologies indicate that farm size has both positive and negative effects on technology adoption, making the effect of farm size on technology adoption inconclusive (Bradshaw, 2004). However, because farmers with larger farms tend to be more financially stable, it is hypothesized that they are more likely to adopt CSA practices. Larger farms have a greater chance of adopting different CSA technologies. This finding is consistent with other studies (Bryan et al., 2009), which have found that farmers with larger cultivated land are more likely to adopt CSA practices. The positive effects of farm size on adopting different CSA technologies are due to the higher opportunities available for farmers to apply CSA practices in their fields. Studies have shown that farm size or cultivated land positively affects the adoption of CSA technologies.

The results depict that access to extension services has statistically and significantly affected the adoption of CSA technologies. Access to extension services determined the adoption of CSA technologies in the study area. During FGDs, respondents in all study villages mentioned a shortage of extension officers, and they usually depend on one from the ward. Consequently, the extension officers prioritize 'progressive' farmers[2], who are referred to as 'champion farmers' within the study villages. These farmers usually are given training and are therefore responsible for encouraging others to adopt CSA. In this case, FGD participants believed that interventions and extension services favour wealthier and middle-income farmers more than low-income farmers. Besides extension, information sources positively influence adoption, including other farmers, media, and local meetings (Luu, 2020). However, the agricultural extension service is a formal source of information for producers based on the contact with extension agents and farmer groups (Tessema et al., 2013). Access to extension services could provide an upper hand in improving farmers' capacity to adopt CSA.

3.4 Challenges of Using CSA Technologies

The difficulty of utilizing CSA technologies was explored. Given that not all farmers adopt technology, only adopter farmers were asked how difficult it is to put it into practice. Their opinion was captured by 1 = easy, 2 = slightly difficult, 3 = very difficult. Following that, the frequency was multiplied by the score (1, 2, or 3) to obtain the total weighted score, which was then divided by the total sample of adopters (200) to obtain the weighted mean score (WMS), and a ranking order was assigned based on the weighted mean score.

As shown in Table 5, planting trees in separate plots is the most effective practice, with a weighted mean score (WMS) of 2.89, followed by the use of organic manure. The ranking descends to crop residue management, which has a WMS of 1.09 and is the least complex practice to implement. The ranking is based on the level of resources required, with less resource-intensive practices at the bottom. Resource constraints, such as limited capital and labour, are the main reasons for the low adoption rates of these practices (Amadu et al., 2020). The lack of access to land, labour, and financial capital can act as a significant barrier to the adoption of resource-intensive practices like

[2] Progressive farmers are commercial farmers who are usually prioritized in interventions as they are considered relatively well-off and able to be as an example for others to follow.

conservation agriculture (Bell et al., 2018; Brown et al., 2018) and the construction of physical infrastructure for soil and water management (Paustian et al., 2016; Pradhan & Ranjan, 2016). Therefore, we expect that resource-intensive CSA categories, such as physical infrastructure practices, will have a higher adoption rate if they receive more support, which can reduce transaction and other costs.

During the focus group discussions, participants reported several reasons for their challenges in using CSA practices. These reasons include high costs and long distances to farms, mainly when using organic manure. Additionally, pests were mentioned to prefer improved varieties and crops (hybrid seeds); thus, the lack of other inputs, such as fertilizers, poses a challenge when using hybrid seeds. Small land holdings and limited access to labour and capital were also identified as challenges.

Table 5: Farmers' level of difficulty practicing CSA technologies.

	Easy (%)	Slightly difficult (%)	Very difficult (%)	Total weighted score	Mean weighted score	Rank
Planting trees in separate plots	11 (5.5)	0	189 (94.5)	578	2.89	1
use of organic manure	10 (5)	15 (7.5)	175 (87.5)	565	2.825	2
Use of terraces	15 (7.5)	37 (18.5)	148 (94.5)	533	2.665	3
Pest resistant varieties	22 (11)	39 (19.5)	139 (69.5)	517	2.585	4
Water retaining/harvesting pits	24 (12)	48 (24)	128 (64)	504	2.52	5
Establishing forests	6 (3)	86 (43)	108 (54)	502	2.51	6
Drought/heat tolerant varieties		106 (53)	89 (46)	484	2.42	7
Drought/heat tolerant crops	21 (10.5)	87 (43.5)	92 (46)	471	2.355	8
Use personal experience to predict weather events	36 (18)	62 (31)	102 (51)	466	2.33	9
Fast maturing varieties/crops	14 (7)	126 (63)	60 (30)	446	2.23	10
trees	23 (11.5)	117 (58.5)	60 (30)	437	2.185	11
Access and use weather information services	38 (19)	110 (55)	52 (26)	414	2.07	12

Rainwater harvesting	6 (3)	179 (89.5)	15 (7.5)	409	2.045	13
Use of improved hybrid seeds	15 (7.5)	167 (83.5)	18 (9)	403	2.015	14
Land fallowing	48 (24)	103 (51.5)	49 (24.5)	401	2.005	15
Crop rotation	41 (20.5)	118 (59)	41 (20.5)	400	2	16
Intercropping	9 (4.5)	191(95.5)	0	391	1.955	17
Planting in the early season	58 (29)	107 (53.5)	35 (17.5)	377	1.885	18
Improved crop varieties	59 (29.5)	125 (62.5)	16 (8)	357	1.785	19
High yielding varieties	44 (22)	156 (78)	0	356	1.78	20
Crop diversification	89 (44.5)	94 (47)	17 (8.5)	328	1.64	21
Reduced/minimum tillage	100 (50)	100 (50)	0	300	1.5	22
Planting trees along field boundaries	141 (70.5)	59 (29.5)	0	259	1.295	23
Crop residue management	191 (95.5)	0	9 (4.5)	218	1.09	24

3.5 Household Food Security

Household food security was measured using the Household Food Insecurity Access Score (HFIAS) (Coates et al. 2007 and Deitchler et al. 2010). The HFIAS consists of four levels of severity based on a recall period of the previous four weeks (30 days). The four severity options represent a range of frequencies (0 = not at all, 1 = rarely, 2 = sometimes, 3 = often). The association between the farmers' CSA adoption and household food security was determined according to four food insecurity categories established by Coates et al. (2007).

Table 6 shows the percentage of households experiencing various food insecurity conditions based on the Household Food Insecurity Access Score (HFIAS). This score is determined by responses to nine frequency-of-occurrence conditions (FIC1 to FIC9). Most households rarely worry about food (57.5%), while a smaller percentage sometimes or often worry, and a large portion rarely or sometimes cannot eat preferred foods, with 15% often facing this issue. A majority sometimes eat limited varieties, indicating dietary diversity issues, while half of the households rarely eat food they do not want to eat. Eating smaller meals is relatively common, with a notable percentage often eating smaller meals. Again, a considerable number rarely or sometimes eat fewer meals. Having no food of any kind in the household, going to sleep hungry as well, and going day and night without eating are rare occurrences for most households.

Overall, the data suggests varied levels of food insecurity, with concerns like eating fewer varieties of foods and smaller meal portions being more common. In contrast, extreme conditions like going a day without food are less frequent. This reflects different levels and aspects of food insecurity within the sampled households. In a study of validation of the HFIAS measurement instrument in Tanzania, Knupeel et al. (2020) similarly documented a reduction in the quality and quantity of food as a first response rather than expressing a worry about food shortage. Similarly, it was noted that the capacity of local people to utilize food depends on their access to acceptable food, including varieties available to make choices (Babatunde, 2020).

Table 6: Percent of household food security conditions (n=200).

HFIAS conditions (FIC1-FIC9)	**Frequency of occurrence (%)**			
	Not at all	**Rarely**	**Sometimes**	**Often**
Worry about food (FIC1)	5	57.5	30.5	7
Unable to eat preferred foods (FIC2)	0	48	37	15
Eat a few varieties of foods (FIC3)	2.5	34.5	56	7
Eat food they did not want to eat (FIC4	19	50.5	23.5	7
Eat smaller meals (FIC5)	41.4	21.7	29.8	7.1
Eat fewer meals in a day (FIC6)	24.1	39.2	29.6	7
No food of any kind in the household (FIC7)	48.7	44.2	7	0
Go to sleep hungry (FIC8)	44.7	48.2	7	0
Go day and night without eating (FIC9)	56.6	43.4	0	0

Results in Table 6 show the distribution of CSA adopters' households according to four food insecurity categories. Please note that the category "Food secure" is not indicated in the table because its score is 0. Categorizing the total Household Food Insecurity Access Score (HFIAS) into different levels of food insecurity, such as "Food secure," "Mildly food insecure," "Moderately food insecure," and "Severely food insecure," typically involved defining score ranges that correspond to these categories (Coates et al., 2007).

- **Food Secure:** Households with a total HFIAS score of 0 are often categorized as "Food secure." This means they have no reported experiences of food insecurity in the reference period.
- **Mildly Food Insecure:** Households with a low but non-zero HFIAS score, typically in the range of 1 to 7, are often classified as "Mildly food insecure." This category represents households with occasional or minor food access challenges.
- **Moderately Food Insecure:** Households with a moderate level of food insecurity may have HFIAS scores ranging from 8 to 14. These households experience more frequent and severe food access problems, which may affect their food quality, variety, or quantity.
- **Severely Food Insecure:** Households with HFIAS scores of 15 or higher are often categorized as "Severely food insecure." This category includes households facing

significant food access challenges, including running out of food, skipping meals, or going without food for extended periods.

The results indicate that no household is entirely food secure. Of all households, 53 are considered "Mildly Food Insecure," representing 26.5% of the total. The majority of households, accounting for 66.5%, are "Moderately Food Insecure," with a total of 133 households. The remaining 14 households, 7% of the total, are considered "Severely Food Insecure."

The data offers insights into how CSA affects food security. Of the households that have adopted CSA practices, 66.5% are moderately food insecure, like the 2020 Global Food Security Index (GFSI) scores for Tanzania, where moderate food security is a concern. The fact that 26.5% of households fall in the mildly food insecure category suggests that CSA practices may positively impact food access to some extent. However, the presence of 7% of severely food-insecure households is of concern, highlighting the need to address other factors that may not be fully addressed by CSA practices alone. Nevertheless, the adoption of CSA practices is positively associated with household food security in terms of per capita annual food expenditure (Hasan et al., 2018).

Similarly, in India, Gosh (2019) found that farmers using CSA adaptation strategies achieved higher output, yield, and return than those who did not. Although CSA practices can be helpful, they are not enough to combat the challenges of food insecurity. This distribution underscores the need for a more in-depth analysis of the effectiveness of CSA practices and the integration of additional strategies to combat food insecurity more effectively.

Table 7: Distribution of CSA adopters' households according to food insecurity categories

Food insecurity category	Frequency	Percent
Mildly food insecure	53	26.5
Moderately food insecure	133	66.5
Severely food insecure	14	7
Total	**200**	**100**

It is important to consider the following limitations when interpreting this study's results. Firstly, the data was collected only once during the dry season, so this study cannot establish causality; it only establishes associations between variables and accounts for seasonal changes in food insecurity. Secondly, the seasons often affect food availability, so this should also be considered. Lastly, since there is no widely accepted standard for measuring household food insecurity, it is challenging to discuss the external validity of the HFIAS.

On the other hand, this study has several strengths, such as using a relatively large sample size and a simple random sampling method to select households. Moreover, the HFIAS instrument used in this study is valid and reliable in measuring household food insecurity among impoverished households in rural Tanzania (Knueppel et al., 2010).

4. CONCLUSION

In this study, we explored the impacts of CSA adoption on household food security among smallholders in arid and semi-arid agroecological zones. The aim was mainly to get a nuanced understanding of the CSA practices and technologies used by differentiated smallholders to ensure food security at the household level. The study shows that smallholders positively perceived CSA interventions, and more than half of the respondents adopted some practices that are currently considered CSA practices, with some adopting these practices before the interventions. In this case, smallholders were considered to play a crucial role in maintaining the natural assets by improving soil quality and humidity. CSA adoption is dependent on the respondents' awareness, the number of adult members in a household who could provide labour, experience in farming, on-farm income, and the size of the farm. The study's findings further highlight that resource constraints are a significant barrier to CSA adoption. These barriers include financial and human resources such as limited capital and labour for the construction of physical infrastructure for soil and water management, and lack of access to land and water. The level of food insecurity was found to be varied but moderate, with concerns like eating fewer varieties of foods and smaller meal portions being more common than extreme cases of going a day without food or having no food of any kind in the household.

With increased adoption of CSA within the study villages, most households rarely worry about food. However, we indicate that no household is completely food secure, and most households were only moderately food secure. This implies that improving food security requires more effort from the low-income smallholders than the middle and wealthier 'progressive' farmers, who are currently prioritized as ‘champion farmers’ as they are likely to succeed during the interventions. Therefore, areas and farmers where the interventions are likely to succeed are preferred rather than where its impact would be helpful on increasing the overall use of the CSA practices and technologies to ensure food security at the household level. We argue that differentiation among smallholder farmers should be used inclusively, and more efforts that favour the low-income smallholders should be set to ensure that they have access to resources. Also, their knowledge should be considered to design more participatory interventions that are more likely to increase the adoption of CSA practices and technologies to ensure food security at the household level.

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