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ORIGINAL ARTICLE

Gender dimensions in the adoption of climate-smart agriculture technologies in response to climate change extremes in Benin

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Abstract

This study investigated the gender dimensions in the adoption of CSA technologies among smallholder farmers in Benin. A multistage sampling procedure was used in selecting 272 respondents for the study, comprising equal proportions of male- and female-headed households. Focus group discussions, key informant interviews, and structured interviews were used to obtain responses from interviewees. Descriptive statistics, principal component analysis, and multivariate probit regression model were used in analyzing the data. The results of the study showed that a higher percentage (89.0%) of women sourced information on CSA technologies from their family/peers compared to men (66.2%). Men adopted more CSA technologies than women. Specifically, the CSA technologies adopted by the respondents were crop rotation (92.7% women vs. 86.0% men), animal health services (44.9% women vs. 66.2% men), and organic fertilizer (46.3% women vs. 59.6% men), among others. These climate-smart agricultural technologies were further delineated into three broad packages, namely soil and water conservation practices (SWC), improved livestock management system (ILM), and improved crop production system (ICP). More men than women adopted SWC and ILM. On the other hand, women (94.9%) adopted ICP more than men (87.5%). Gender, age, farm size, land ownership, access to labour, project contact, climate change information, and livestock ownership are significant determinants of the adoption of CSA options among the respondents. The study reinforces the need to consider context-specific local factors and co-design gender-based solutions to extreme climatic threats with the local communities.

Keywords Adoption · Benin · Climate-smart agriculture · Gender · Multivariate probit model

Introduction

In sub-Saharan Africa, the agricultural sector remains a keystone for achieving the Sustainable Development Goals (SDGs) (Kofi & Adams 2020). Benin is among the countries in sub-Saharan Africa that depend primarily on agriculture. The agricultural sector in Benin employs more than 70% of its workforce and contributes 25% to the GDP of the national economy (World Bank 2017). Small-scale farming systems dominate agriculture in Benin with many communities heavily dependent on agricultural products for their livelihoods (Sossou et al. 2021). However, climate change evident in form of rising temperature, precipitation, and other extreme weather events has threatened food production. For small-scale farmers, this will alter the nutritional quality and reduce the availability of food thus leading to food insecurity (Bhattacharya 2019).

Due to their little adaptive capacity as a result of their limited material resources, small-scale farmers will experience the most adverse effects of climate change (Jawid 2020;

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Rahman & Anik 2020). Climate-smart agricultural practices (CSA) offer the possibility to increase the adaptive capacity of small-scale farmers. Climate-Smart Agriculture (CSA) is an approach that integrates the need for adaptation and the potential for mitigation into agricultural development strategies to promote food security (Asfaw & Branca 2018). Thus, it contributes to the joint achievement of three defined objectives, including increasing productivity to achieve food security, adapting and building resilience from the farm level to the national level, and reducing greenhouse gases emissions (CCAFS 2017).

The adoption of CSA technologies at the farm level is influenced by the contextual nature of such technologies (Mwongera et al. 2017) and requires that diverse options are developed for different contexts, including socially differentiated groups such as age and gender. It has been documented that a gender gap exists in agriculture such that women, especially those in female-headed households, have less access to advisory services, information, participation in community governance and social organization, financial capital, and productive resources in comparison with men (Cohen et al., 2016; Nelson & Huyer, 2016). In the context of climate-smart agriculture, this gender gap places women in a disadvantaged position when compared with men. Due to their different roles in the household and agriculture, women have different abilities and capacities to respond and adapt to climate change impacts when exposed to climatic shocks (Kristjanson et al. 2017; Huyer and Partey, 2020). Additionally, the different social status, economic power, and expectations of men and women could affect the adoption patterns of agricultural technologies (Murage et al., 2015). This could reinforce inequalities in the adoption and sustainability of climate-smart agriculture technologies. If implemented in a way that the needs and circumstances of women are taken into consideration, climate-smart agriculture technologies could be beneficial to women and thus bridge the gender gap.

Economic models of agricultural technology adoption often analyze the decision to adopt a single technology/practice, with little attention paid to analyzing multiple technologies whose adoption and economic impacts are potentially linked and which may perform better when adopted together (Ruzzante et al. 2021). In that sense, limited attention has been given to analyzing the adoption of multiple CSA technologies from a gender perspective in a constrained environment under extreme climate change effects (Bryan et al., 2021; Oyawole et al. 2020). Often, adoption studies fail to control for the interdependence of technologies, which may result in underestimating or overestimating the influence of various factors on the adoption decision (Khanna 2001; Wu & Babcock 1998) and the impacts of adoption.

Therefore, the goal of this study is to investigate the gender dimensions of the adoption of multiple CSA technologies in Benin. Benin provides a good case study because women are responsible for 60–80% of the agricultural activities in Benin (Dah-gbeto and Villamor, 2016) and are more vulnerable to the adverse impacts of climate change than their male counterparts (Dossou-Cadja & Akimabera 2020). Thus, the analysis of the gender dimension of climate-smart agriculture in Benin could improve the design and implementation of climate-smart agriculture interventions (World Bank et al., 2015). The paper is organized as follows: the conceptual framework is presented in the "Conceptual framework" section two. In the "”Material and methods" section, we present the study area, sampling procedure, and data collection. The results and discussion are presented in the "Results and discussion" section. Finally, we conclude the paper with some policy recommendations in the "Conclusion and policy implications" section.

Conceptual framework

The concept of gender is constantly evolving to meet the changing norms resulting from human interaction within societies (Reckelhoff 2023). What is meant by the term "gender" often differs from society to society, each with unique characteristics in terms of shared values, beliefs, and cultures. Broadly, the term "gender" is associated with roles and social constructs, as opposed to the biological sex of male and female (Garofalo & Garvin 2020). In theory, it refers to the different roles, responsibilities, and power relations between men and women in a given society (Hove & Gweme 2018; Kristjanson et al. 2017; Tsige et al. 2020). Accordingly, in the agrarian society of northern Benin, women and men are expected to play different roles which shape their decision to adopt new technologies. Building on the above definition, this study conceptualizes "gender" as the social roles played by men and women and the power relations between them, which have a profound effect on the adoption of climate-smart agricultural technologies. Moreover, while we acknowledge that the terms "sex" and "gender" are distinct concepts, their influence often overlaps as important determinants of innovation adoption literature in agriculture (Brown et al. 2017; Hirpa Tufa et al. 2022; Lokonon & Mbaye 2018; Teklewold 2023; Yahaya et al. 2018). Therefore, this study also uses sex-disaggregated data of farmers as a proxy to measure gender outcomes in the adoption of climate-smart agricultural technologies in northern Benin.

The process of undertaking a gender analysis of climate-smart agriculture technologies adoption is particularly crucial for achieving a sustainable world free of hunger and poverty. Indeed, gender-related factors are likely to affect various components of the food system, including food production, consumption, and distribution processes (Njuki et al. 2022). This study, given its scope and purpose, focuses on the food production system. Increasingly, changes in climate variability, including the frequency and severity of extreme events, pose significant threats to the food production system (Filho et al. 2022; Kumar et al. 2022; Mirón et al. 2023), resulting in lower crop yields, frequent pests and diseases, and high livestock mortality (Amouzou et al. 2019; Tonnang et al. 2022; Wing et al. 2021). While both women and men working in agriculture are affected by climate change, women are affected differently, making them more vulnerable to climate change than men. Numerous studies in Benin report situations in which women growing the same crops as men in their households, but on different plots, have significantly lower yields (Gbetondji & Nonvide 2019; Osei-Adu et al. 2015). Structural barriers, including lack of access to and control over productive resources and agricultural services, time constraints resulting from unpaid domestic chores, inequality in decision-making, and restricted mobility, all frequently account for gender gaps in crop productivity.

Moreover, gender also interacts with other forms of social differentiation categories (e.g. region, ethnic group, age, economic class, or religion) to define the extent to which women and men are vulnerable to climate change impacts. As such, how gender plays out in relation to vulnerability and resilience to climate change in Benin could be context-specific and nuanced. According to Dossou-Cadja and Akimabera (2020), women in Benin are about 1.1 times more vulnerable to climate change than men. They are particularly vulnerable to productive resources, including access to land, and education. In the Niger Basin of Benin, female-headed households invest relatively less than male-headed households in agriculture and livestock (Lokonon 2019), while in the coastal areas of Benin, women face enormous challenges in conducting income-generating activities due to coastal hazards, which increases their vulnerability to livelihoods (Yantikoua et al. 2023). Gender also influences youth participation in agriculture, with young men being more likely to invest in agriculture or agribusiness than their female counterparts (Akrong & Kotu 2022). Furthermore, Fulani women and allochtones in northern Benin face greater marginalization in access to land than autochtones and other ethnic groups (Bidou et al. 2018).

Efforts to increase the adaptive capacities of vulnerable groups in agriculture across the world have accelerated in recent years and have resulted in the adoption of climate change adaptation strategies. More recent efforts of governments and civil society organizations have emphasized “climate-smart agriculture” technologies. By definition, the climate-smart agriculture approach is based on three main pillars including (i) sustainably increasing the productivity and profitability of agriculture thereby ensuring food security, (ii) adapting and building resilience to climate risks, and (iii) mitigating greenhouse gas (GHG) emissions. While it is recognized that there are trade-offs between these three pillars of the CSA that contribute, in a broader sense, to the Sustainable Development Goals, it does not take into account the “higher level” trade-offs between the CSA and gender equality (SDG 5). Yet, gender inequalities can be reproduced in the way men and women access and benefit from CSA technologies use (Bryan et al. 2017; Tsige 2019). For example, evidence shows that women have less access to climate information in comparison to men. Yet, when women have access to information on climate-smart agriculture, they are more likely to adopt the practices (Twyman et al. 2014). Some CSA technologies, such as soil and water conservation, are less adopted by women due to increased labour requirements (Beuchelt & Badstue 2013; Nelson & Stathers 2009). This underscores the need to design or (re) adapt CSA technologies to meet women’s labour capacities. Participatory identification of women’s needs for CSA technologies can provide a roadmap for gender-responsive and climate-smart agriculture. Therefore, gender mainstreaming in CSA is paramount to improving the livelihoods of both men and women in rural areas. Moreover, for CSA to have a positive impact on men and women, gender equality targets must be deliberately introduced at the prioritization, design, planning, and implementation stages of climate adaptation programs (Roy et al. 2022).

Material and methods

Study site description

Benin is a West African country located in the tropical zone between the equator and the Tropic of Cancer. Its latitude ranges from 6°30′ to 12°30′ N and its longitude from 1° to 3°40′ E. Its total area is 112,622 km^2. The total population of Benin was estimated in 2013 to be 9.9 million, of which more than 50% are women. The country has 77 municipalities and seven agricultural development poles (ADP). Each ADP is administered by the Territorial Agricultural Development Agencies (ATDA). Indeed, the ADP is a framework for the development of various agricultural projects and programs in the country. It represents a development territory organized based on a limited number of priority agricultural sectors and municipalities to promote economic development in the territory. Small-scale farmers in Benin operate mostly (93.56%) on family farms. Such farms are characterized by high use of family labour (94.15%) and manual tools and equipment (80.3%), i.e. hoes, cutters, etc. The average farm size is 4.89 ± 2.20 ha.

The study was carried out in northern Benin. This region represents 73% of the country in terms of land area. Out of the seven ADPs in Benin, the Northern part of the country covers three ADPs including (1) Niger Valley, (2) South

Alibori-Borgou North-2KP, and (3) West Atacora. More precisely, the study was carried out in ADP 2 (South Alibori-Borgou North-2KP). ADP 2 covers 10 municipalities, while ADP 1 and 3 cover 2 and 3 municipalities, respectively. Besides, a decline in agricultural production in this pole 2 has been reported, owing to the loss of land fertility because of climate change. In particular, ADP 2 is among the sub-catchments that are severely vulnerable to climate change. Some climate change effects observed in ADP 2 are delayed rainfall, increased temperatures, droughts, and floods. Between 1990 and 2019, projections in the ADP2 indicated that the sub-catchments areas were vulnerable to climate change effects (Fig. 1).

Sampling procedure and sample size

The studied population comprised all small-scale farmers in northern Benin. A multistage sampling procedure was used to collect data from the respondents through a structured interview. The agricultural development pole 2 covers the municipalities of Kandi, Banikoara, Segbana, Gogounou, Kouandé, Kérou, Péhunco, Sinendé, Kalalé, and Bembérékè. In the first stage, four out of the 10 municipalities were randomly selected (Gogounou, Kandi, Sinendé, and Bembéréké). In the second stage, in each of the four selected municipalities, two town communities were purposively selected. The purposive selection was based on the intensity of

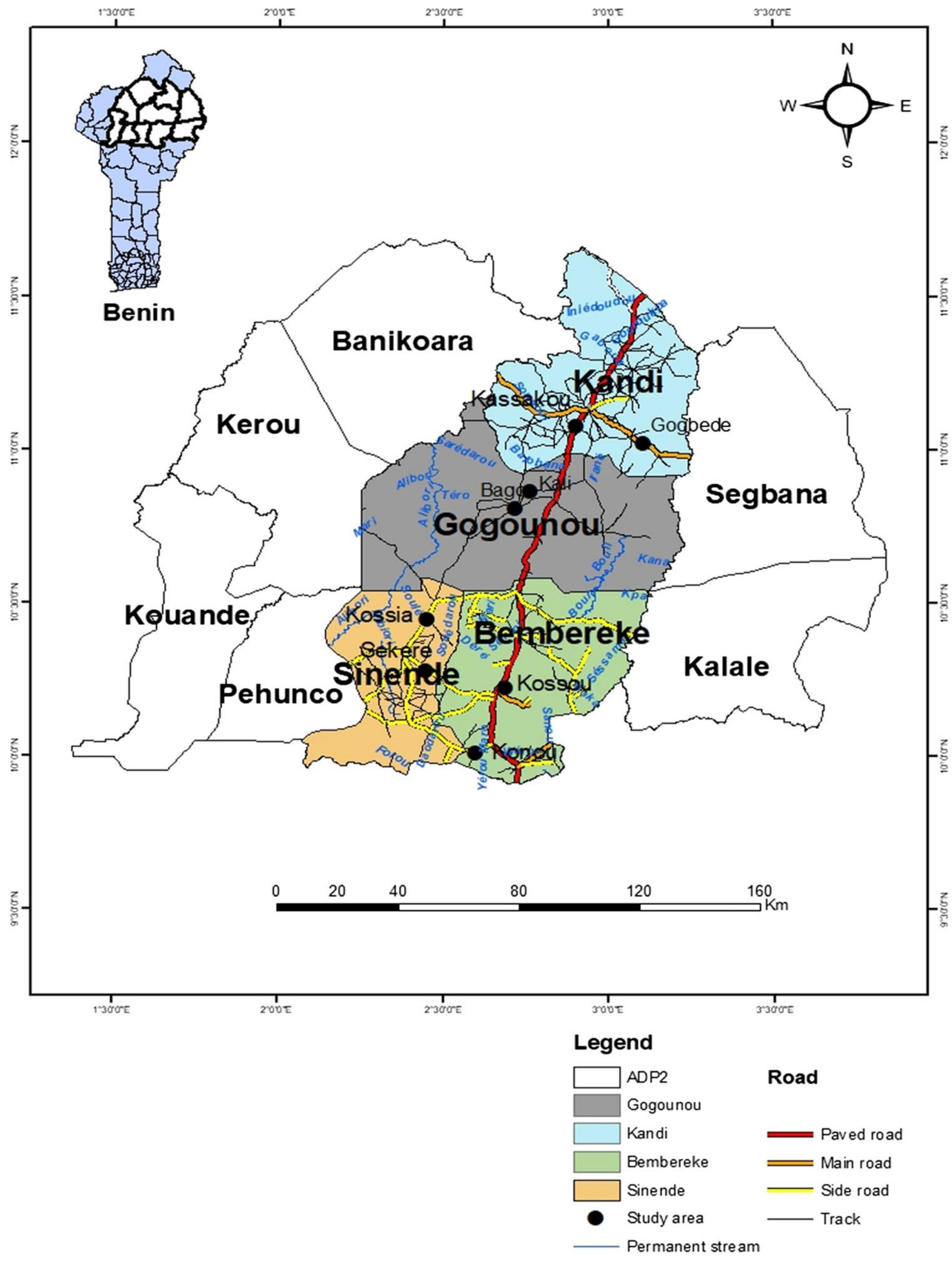


Fig. 1 Agricultural development pole (ADP) 2 showing the study area. Source: IGN 2000 et 2006 WGS84 UTM 31N

agricultural production activities and adverse climatic events (floods, soil erosion, droughts) over the past 10 years. In the third stage, one village was randomly selected in each of the eight selected towns. The selected villages were Bagou-Yagbo, Kale, Kassakou, Gogbede, Konou, Kossou, Kossia, and Serekè-Maro. In each village, 34 farm household heads were randomly selected. This gave a total of 272 respondents (comprising 136 male and female-headed households each).

Data collection

This study employed a mixed-method approach and relied on a combination of quantitative (structured interview) and qualitative (Focus Group Discussion and key informant interviews) data collection methods (Creswell & Clark 2017). The use of a mixed method reinforces the rigour and enriches the analysis and the results (Wisdom & Creswell 2013). Moreover, it helps to improve data reliability and validity through data triangulation. Focus Group Discussions provided qualitative data to explain the gender roles and adoption of climate-smart agriculture technologies in the study area. In total, 16 FGDs were conducted—two FGDs per village, with separate discussions held with women and men. The FGDs were recorded with the consent of the participants. The findings from the FGDs were triangulated with results from the key informant interviews to validate the conclusions of the study. The data from FGDs and key informant interviews complemented and informed the development of the structured interview instrument for collecting in-depth data on small-scale farmers. The interview of respondents from the study areas was conducted using a structured questionnaire. The objective was to collect gender-disaggregated information on the socio-economic and institutional characteristics of the respondents, their adoption of climate-smart agriculture technologies, and the sources of information on CSA technologies. Prior to collecting structured interview data, ethical approval was obtained from the Department of Agricultural Extension of the University of Nigeria Nsukka. Participants provided a written informed consent to participate in the study. In addition, written informed consent was obtained from all participants for specific data to be used in an open access publication. Data were collected in face-to-face interviews with the help of experienced and trained research assistants from the National Agricultural Research Institute of Benin (INRAB). All interviews were audio recorded and then transcribed into French language.

Study hypotheses and variables specification

The hypotheses of the study were that (i) there is no significant relationship between the gender of the household head and the socio-economic and institutional variables and (ii) the socio-economic and institutional variables do not significantly influence the choice of CSA options adopted by the respondents. Because a smallholder farmer can therefore use several CSA options simultaneously, our dependent variable is polytomous and represents CSA options including (i) soil and water conservation practices, (ii) improved livestock management system, and (iii) improved agricultural production system in response to climate extremes. Independent variables were selected based on theoretical background from the literature, expert consultations, and experiences of local farmers (Falco et al. 2011; FAO 2010; Kassie et al. 2010). The model variables assumed to influence the choice of CSA options by small-scale farmers are included in Table 1.

Data analysis

Descriptive statistics (frequencies, percentages, and means), nonparametric chi-square ($X2$) tests for two-way categorical associations, and *t*-tests were performed. A chi-square was also conducted to determine whether there is a significant difference between the use of CSA practices and the gender of the farmer and *t*-tests were used to test the relationship between gender and farm characteristics. Qualitative data were analyzed using thematic analysis while quantitative data were analyzed using Stata version 16.

Model specification and estimation strategy

In this study, a farmer is considered to be adopting a CSA practice if he or she had used the practice at least one planting season before the interview and was still using it at the time of the interview. In total, 13 CSA technologies were considered and they were measured using dummy variables. In other words, if a small-scale farmer has adopted a CSA technology, he/she is scored 1; otherwise, 0 (Appendix A). The selection of technologies before was guided by the CSA country profile for Benin. This was documented as part of the collaborative effort between the International Center for Tropical Agriculture (CIAT), the lead centre of the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), and the Food and Agriculture Organization of the United Nations (FAO) to identify country-specific baselines and entry points for scaling out CSA in West Africa.

In specifying the empirical model of the study, the CSA technologies used in northern Benin were first identified and their adoption rates estimated. Next, Principal Component Analysis (PCA) was used to identify both the number of CSA technologies and the "option/combinations" of CSA technologies adopted by small-scale farmers. The components were rotated so that a smaller number of highly correlated technologies would be placed under each component to facilitate the interpretation and generalization of a CSA option. In this study, PCA with oblique rotation (Oblimin) was used as it combines CSA technologies that are correlated, unlike PCA with orthogonal rotation (varimax or quart

Table 1 Variables influencing farmers' adoption decision

Variables	Description of the variables	Expected sign
Dependent variables		
Soil and water conservation practices	Dummy = 1 if farmer adopted, 0 otherwise	
Improved livestock management system	Dummy = 1 if farmer adopted, 0 otherwise	
Improved crop production system	Dummy = 1 if farmer adopted, 0 otherwise	
Independent variables		
Age	Age of the farmer in years	+/−
Education	Dummy = 1 if farmer is literate, 0 otherwise	+
Household size	Number of people eating in one pot	+
Cooperative membership	Dummy = 1 if farmer belongs to a cooperative, 0 otherwise	+
Access to credit	Dummy = 1 if farmer has access to credit, 0 otherwise	+
Extension contact	Dummy = 1 if farmer has contact with extension services, 0 otherwise	+
Project contact	Dummy = 1 if farmer has contact with projects, 0 otherwise	+
Access to climate information	Dummy = 1 if farmer has access to climate information, 0 otherwise	+
Farm size	Total land size in hectares	+
Livestock ownership	Dummy = 1 if farmer owns livestock, 0 otherwise	
Access to hired labour	Dummy = 1 if the farmer have access to labour, 0 otherwise	+
Land ownership	Dummy = 1 if farmer owns land, 0 otherwise	+
Off-farm income	Dummy = 1 if farmer has an off-farm source of income, 0 otherwise	+

max) (Duong & Duong 2008). Besides, the results of PCA with oblique rotation are more accurate for research involving human decision-making as it provides results that can be easily interpreted (Williams et al. 2010). Oblique rotation is chosen over varimax rotation when the observed correlations from the factor correlation matrix are at least 0.32 (Tabachnick et al. 2007). The result of the rotation yielded 3 principal components with eigenvalues > 1 by criterion. PCA was useful in reducing the dimensionality of the data without losing much information. This approach is superior to using a convenient grouping of technologies that would make it difficult to conclude about a group in cases where few practices could represent the entire group (Wekesa et al. 2018). Based on Filmer and Pritchett (2001), the general model for principal component analysis with oblique rotation for a set of n number of random CSA technologies is expressed as follows.

$$\begin{aligned} PC_1 &= a_{11}X_1 + a_{12}X_2 + \cdots + a_{1n}X_n \\ PC_2 &= a_{21}X_1 + a_{22}X_2 + \cdots + a_{2n}X_n \\ PC_{13} &= a_{131}X_1 + a_{132}X_2 + \cdots + a_{13n}X_n \end{aligned} \tag{1}$$

where a_{1n} represents the coefficient (weight/factor loadings) for the first principal component of the nth number of random CSA technologies. The order of the components ensures that the first principal component explains the greatest possible amount of correlation of the variables in the original data.

After grouping the CSA technologies, a multivariate probit (MVP) regression model was used to capture the factors that influence small-scale farmers' decision-making process for the adoption of CSA technologies combination/option. The MVP model was used because it models the influence of all explanatory variables on each CSA option by simultaneously estimating a set of binary probit models while allowing the error terms of these models to be correlated (Greene 2008). Several factors that may influence farmers' decision to adopt a CSA option were considered, including the socio-economic and institutional characteristics of small-scale farmers and their assets. In the estimation of the factors affecting the adoption of each CSA option, the dependent variable is coded as 1 = Use and 0 = Non-use. The MVP model for multivariate choice problems can be represented by two systems of equations. First, a system of equations with latent (unobservable) dependent variables is described by a linear function of a set of socio-economic (i) and institutional (j) characteristics of small-scale farmers as well as productive (k) resources (X_{ijk}) and normally distributed multivariate stochastic terms (ε_{ijk}). The empirical model for the multivariate probit regression is represented as shown below:

$$Y^*_{ijkm} = \beta_m X_{ijk} + \varepsilon_{ijk} \text{Where}(m = \text{SWC, ILM, ICP}) \tag{2}$$

where Y^*_{ijkm} denotes the latent dependent variables that can be represented by the expected level of benefit and/or utility from using the CSA option Soil and Water Conservation (SWC) practices, Improved Livestock Management (ILM), and Improved Crop Production (ICP),ε = error term; i = socio-economic characteristics of the small-scale farmer; j = institutional characteristics of the small-scale farmer, k = assets of the small-scale farmer.

The second system of equations describing the observable dichotomous household choice variables is as follows.

Table 2 Socio-economic and institutional characteristics of the respondents

Variables	Female-headed household ($N = 136$)		Male-headed household ($N = 136$)		t-statistic (sig)
	Mean	SD	Mean	SD	
Socio-economics					
Age	37.33	11.18	41.79	13.26	−2.9912***
Education	0.24	0.43	0.34	0.47	−1.8681*
Household size	9.68	5.55	11.14	6.87	−1.9114
Institutional					
Cooperative membership	0.51	0.50	0.65	0.47	−2.3529***
Access to credit	0.38	0.48	0.44	0.50	−0.9837
Extension contact	0.39	0.49	0.55	0.50	−2.6983***
Project contact	0.54	0.50	0.60	0.49	−0.9789
Access to climate information	0.95	0.21	0.99	0.086	−1.9206**
Assets					
Farm size	3.11	1.81	4.88	2.05	−7.5730***
Livestock ownership	0.65	0.47	0.84	0.36	−3.7191***
Access to labour	0.73	0.45	0.70	0.46	0.5346
Land ownership	0.74	0.44	0.87	0.33	−2.8053***
Off-farm income	0.78	0.41	0.74	0.44	−0.8466

Significance *at the 10% level, **at the 5% level, and ***at the 1% level of t-test estimates of mean comparisons

$$Y_{ijkm} = \begin{cases} 1 if Y^*_{ijkm} > 0 \\ 0 otherwise \end{cases} \tag{3}$$

where Y_{ijkm} is the adoption of the mth CSA option for the $ijkm$th small-scale farmer.

Results and discussion

Socio-economic and institutional characteristics

Table 2 shows the descriptive statistics of the socio-economic and institutional characteristics of the respondents differentiating between male- and female-headed households. Results from the t-test suggest that there are statistically significant differences for eight out of thirteen variables examined, namely age, education, cooperative membership, extension contact, access to climate information, farm size, livestock ownership, and land ownership.

From the table, the average age of male-headed households was about 42 years while that of female-headed households was 37 years. Previous studies reveal that the age of the farmers positively influences the adoption of new technologies, with younger farmers adopting more technologies (Marescotti et al. 2021; Paustian & Theuvsen 2016), arguably because of their risk-taking attitude (Ayinde 2016; Spicka 2020). Our findings revealed that more men than women were literates. It is expected that the variable education positively influences the adoption of climate-smart agriculture technologies. Many authors have reported that farmers' education levels significantly influence the adoption of CSA technologies (Nyang'au et al. 2021; Onyeneke et al. 2018; Sardar et al. 2021). The average household size in the study area is about ten people in female-headed households and eleven in male-headed households, above the average household size of seven in northern Benin (Bidou et al. 2018). This further implies that family farm labour will be relatively available for farm activities in the study area, potentially increasing the likelihood of adopting CSA technologies. Likely, soil and water conservation may require additional labour from the farmer, which is often provided by household members.

More male-headed households belong to a cooperative organization and have access to credit than female-headed households do. In addition, men have access to extension services more than women, although both, most women and men farmers have been in contact with different development projects in the past 5 years. Moreover, both men and women mostly discuss climate change and adaptation issues with their peers.

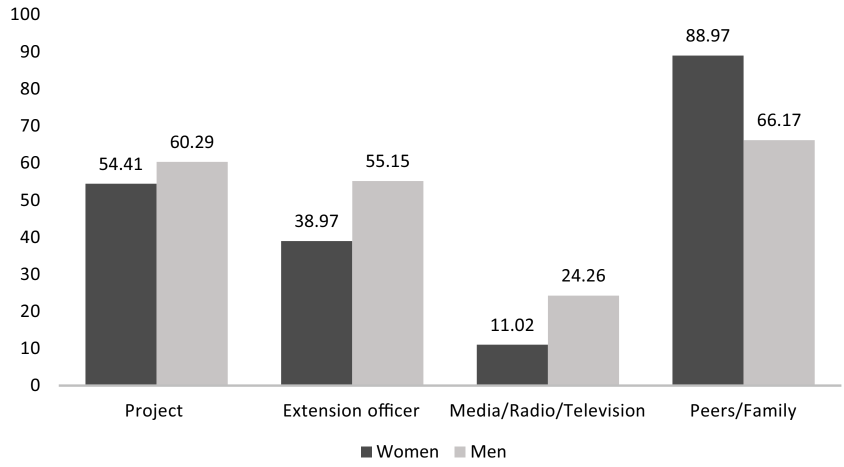
On average, women respondents (household heads) cultivate 3.11 hectares of land, while men cultivate 4.88 hectares of land. The majority of men and women rear livestock in addition to crop production. Regarding their accessibility to labour, the majority of respondents have access to labour with more women having access to labour than men. Most of the respondents own the land they cultivate and off-farm employment complements the revenues of the majority of the small-scale farmers.

Sources of information on climate-smart agriculture technologies

Overall, peers, family, and friends were the main sources of information on climate-smart agriculture technologies (Fig. 2). The majority (89.0%) of women and men (66.2%) use their peers, family, and friends to obtain information on climate-smart agriculture technologies, probably because they are easily accessible. Focus group discussions with men and women revealed that the exchange of information between peers and friends was a way to legitimize and verify the effectiveness of CSA technologies. This means that information the farmer receives from other sources may not be fully accepted if it is not clarified by their peers, family, and friends. Results from our work are in line with the work of Kalungu and Filho (2016) in Kenya who found that most smallholders tend to receive information about technologies from other farmers. Complementarily, it was reported in the work of Nguyen et al. (2021) in Vietnam that women were more willing to disseminate knowledge within communities through formal and informal channels than men. The finding also corroborated with the work of Weyessa (2017) in Ethiopia who found that farmer-to-farmer knowledge sharing contributed significantly to technology adoption by facilitating adopting farmers' access to a credible and reliable source of information on new technologies and access to improved seeds. As argued by Isaac et al. (2007), peer-to-peer knowledge exchanges have stronger effects in actively seeking agricultural knowledge. Already, the fact that the majority of CSA technologies are rooted in traditional local knowledge implies that farmers will be more familiar with certain CSA practices and will look to their peers for confirmation and updates of their current practices. However, given the complexity of knowledge and the fact that individuals who receive CSA knowledge from their peers have different capacities to absorb the knowledge they receive, realizing CSA learning outcomes may sometimes be difficult (Pratiwi & Suzuki 2017). As a key rule, successful knowledge transfers require a level of mutual understanding between the knowledge givers and receivers, which in turn requires reciprocal exchanges between the actors for successful learning to occur (Burt 2004).

Nevertheless, as much as 60.3% of men and 54.4% of women also source information on climate-smart agriculture technologies through development projects. Development projects in the area often provide training and disseminate practices on how to adapt to climate change impacts. However, relying solely on development projects for the dissemination of CSA technologies to farmers may be unsustainable since these projects are time-bound. Extension workers were the third most important source of information on CSA technologies, although the proportion of women (39.0%) who received information from extension agents was lower than the proportion of men (55.2%). Gendered institutional biases in extension service delivery have contributed to women's limited access to CSA information from extension agents. Also, we observed that women receive little attention from extension workers, probably due to their role in the household. Duffy et al. (2020) equally elaborated that although both male and female farmers obtained information on CSA through traditional extension, the gain was less for women; however, women farmers who interacted with farmers' leaders increased their knowledge on CSA. This result also strengthen those of Waaswa et al. (2021) among potato farmers as very few women rely on extension agents for awareness of CSA technologies. Innovative extension services that target both men and women in the study area should therefore be designed and delivered. On the other hand, relying solely on extension agents would not achieve wide dissemination of CSA technologies to small-scale producers. Extension agent–based approaches should often be complemented by farmer-led extension approaches. This because effective extension services require road infrastructure, the lack of which may prevent extension agents from reaching farmers in the most remote areas. Most farming communities are far from the district capital where most extension agents live. Extension agents therefore need transportation to reach

Fig. 2 Small-scale farmers' sources of information on CSA technologies



these communities. Unfortunately, many of them do not have their own transportation. In addition, the high ratios of extension agents to farmers lead to an increased workload for extension agents. When extension agents have too many farming communities to manage, the frequency of visits becomes lower and more irregular, which can reduce the effectiveness of extension advice. It is therefore important to improve the ratio of extension agents to farmers. At the same time, female extension agents need to be promoted if effective CSA learning outcomes for small-scale women farmers are to be achieved. Experiences have shown that women farmers feel more comfortable with female extension agents, since they are freer to discuss their problems with them and they can accommodate their meeting time preferences better than with male extension agents (Ragasa 2014).

Moreover, 11% of women and 24.3% of men rely on the media, including television, radio, and cell phones, to learn about CSA technologies. While acknowledging the role of the media in shaping smallholder farmers' knowledge of climate adaptation, as shown by Comoé and Siegrist (2015), many challenges remain limiting equitable access to CSA information. The low rate of media use could be explained by the fact that the media has limited coverage of CSA-related information that is specific to each socio-cultural context (Comoé & Siegrist 2015). Often, media tend to give general information. Also, gender inequalities in asset ownership, including radio and television, often result in women having limited access to agricultural information (Singh et al. 2018). There is a need for the media to design more programs in indigenous languages, especially for CSA-oriented content delivery. More efforts should be made to promote the organization of community media to complement the work of commercial broadcasting stations.

Adoption of climate-smart agriculture technologies

Table 3 presents the results of the adoption of CSA technologies by small-scale farmers. Overall, men adopted ten out of thirteen CSA technologies considered, more than women. On the other hand, women adopted two technologies more than men. More men than women adopted some technologies, such as agroforestry (52.2% men vs 41.2% women) and the use of organic fertilizers (59.6% men vs. 46.3% women). However, women adopted some technologies more than men, including crop rotation (92.7%) and mulching (55.2%). Our findings suggest that there are gendered differences in the use of CSA technologies in northern Benin, with men adopting more CSA technologies. This finding contends with those of Kalungu and Filho (2016) who found that male-headed households had higher technology adoption levels compared to female-headed households. However, the findings contradict those of Bernier et al. (2019) in Kenya and Oyawole et al. (2020) in Nigeria, who found that female-headed households are more likely to adopt CSA technologies than their male counterparts.

Our result further contradicts the findings of Oyawole et al. (2020) that men are more likely to adopt crop rotation than women and that women are more likely to adopt green manure and agroforestry than men. The relatively low adoption of agroforestry among women may be because women have small plots of land compared to men. Dhakal and Rai (2020) identified the limited land size as the main constraint to agroforestry adoption by smallholders. On the other hands, men are more likely to engage in agroforestry than women. This is due to the patriarchal rights intrinsically linked to land tenure security (Anugwa et al., 2020).

Table 3 Adoption of climate-smart agriculture technologies among small-scale farmers

Climate-smart agriculturetechnologies	Women ($n = 136$) %	Men ($N = 136$) %	Total	Chi-square
Improved crops varieties/drought-tolerant crops	47.8	50.0	48.9	0.1324
Crop rotation/crop diversification	92.7	86.0	89.3	3.1264
Agroforestry/planting trees	41.2	52.2	46.7	3.3224
Mulching/crop residues management	55.2	53.7	54.4	0.0593
Organic fertilizers (Compost/manure)	46.3	59.6	53.0	4.7813***
Contours ploughing	43.4	51.5	47.4	1.7841
Contour stone bunds	33.1	33.1	33.1	0.0000
Cover crops	48.5	55.2	51.8	1.1928
Drainage ditches	28.7	31.6	30.2	0.2793
Constitution of food reserves for the dry season	36.0	51.5	43.8	6.5882***
Pasture management and supplementary feedings	24.3	35.3	29.8	3.9558***
Seasonal movement of the livestock	19.9	39.7	29.8	12.8168***
Animal health services/use of vaccines	44.9	66.2	55.5	12.5199***

Fieldwork, 2021

*** Significant at 5% level

The study found a low proportion of women adopting organic fertilizer as compared to men, with a chi-square test revealing significant difference ($p = 4.7813$). This difference may be attributed to the small number of cattle owned by women. FGDs revealed that cattle manures were most available for men than women. Besides, women buy organic fertilizer and complement it with waste and small ruminant dung. This result is consistent with those of Abebe and Debebe (2019) and Avane et al. (2021). However, it contradicts the findings of Daadi and Latacz-Lohmann (2021) in Ghana who found that female-headed households are more likely to adopt organic fertilizer than male-headed ones.

Though men tend to adopt water management practices, such as contours ploughing, cover crops, or drainage ditches, more than women, the pace of adoption is relatively low for both men and women farmers, and the differences in adoption between men and women are not statistically significant. As in other areas, the low adoption of such practices may be due to the poor technical knowledge of farmers (Diptesh & Chauhan 2016; Saidur Rahman & Gupta 2015). Other reasons for the low adoption rate mentioned during FGDs include the labour-intensive requirements and high costs associated with these practices. Moreover, both women and men declared that stones are not always available for use and most of them used water management practices on the upper slopes.

Though the livestock-based CSA technologies were not highly adopted, there was a statistically significant difference between women and men in the use of all climate-smart livestock technologies. This implies that men adopted more climate-smart livestock technologies than women. Among livestock management practices, the use of animal health services/use of vaccines recorded a relatively high rate of use for men (66.18%) than women (44.85%). The high rate of animal health services/use of vaccines may be traced to the availability of veterinary extension services in the study area. During FGDs, women reported they received less veterinary extension services than their male counterparts. On the other hand, seasonal livestock mobility recorded the lowest adoption rate for both men (39.7%) and women (19.9%). This result complements those of Mujeyi et al. (2019) in Zimbabwe that livestock-based practices were not widely adopted among smallholders. This is because the unfavourable perceived effectiveness or the costs associated with its implementation.

Climate-smart agriculture technologies combination using principalcomponent analysis

The principal component analysis of the different CSA technologies shows that the three principal components explained 59.78% of the total variability in the data set (Table 4). The first component explained 39.24% of the variance and is correlated with six CSA technologies: mulching/crop residues management, organic fertilizers, cover crops, contours ploughing, contour stone bunds, and drainage ditches all with positive effects (component loadings). Thus, this component was named “Soil and water conservation practices”. Components 2 and 3 accounted for 11.28% and 9.26% of the variance, respectively. The second component was positively associated with four practices: the constitution of food reserves for the dry season, pasture management and supplementary feeding, the seasonal movement of the livestock, and animal health service/use of vaccines. Component 2 was named “Improved livestock management”. The last component was positively associated

Table 4 Principal Component Analysis of different climate-smart agriculture technologies

Climate-smart agriculture technologies	Comp1	Comp2	Comp3	Communalities
Improved crops varieties/drought-tolerant crops	0.215	− 0.164	**0.453**	0.504
Crop rotation	− 0.07	0.098	**0.621**	0.562
Agroforestry/planting trees	0.041	0.202	**0.391**	0.459
Mulching/crop residues management	**0.436**	0.019	− 0.263	0.647
Organic fertilizers (compost/manure)	**0.391**	0.117	− 0.255	0.665
Cover crops	**0.346**	− 0.072	0.233	0.562
Contours ploughing	**0.41**	− 0.176	0.128	0.549
Contour stone bunds	**0.402**	0.018	0.047	0.654
Drainage ditches	**0.344**	0.069	0.033	0.551
Constitution of food reserves for the dry season	− 0.006	**0.52**	0.036	0.73
Pasture management and supplementary feedings	− 0.063	**0.426**	0.166	0.499
Seasonal movement of the livestock	− 0.009	**0.525**	0.021	0.730
Animal health services/use of vaccines	0.179	**0.377**	− 0.146	0.660
Eigenvalues	5.1	1.466	1.20	
% of variance explained	39.24	11.28	9.26	
Cumulative %	39.24	50.52	59.78	

Bold font means the absolute value of correlation coefficients was ≥ 0.32

Table 5 Climate-smart agriculture technologiescombinations

Group of climate-smartagriculture technologies	Components	Women (*N*=136) %	Men (*N*=136) %	Total %
Improved crop production practices	Improved crops varieties Crop rotation Agroforestry/planting trees	94.9	87.5	91.2
Soil and water conservation practices	Mulching/crop residues management Organic fertilizers Cover crops Contour ploughing Contour stone bunds Drainage ditches	75.7	81.6	78.7
Improved livestock management	Constitution of food reserves for the dry season Pasture management and supplementary feeding Seasonal movement of the livestock Animal health services/use of vaccines	53.7	75.0	64.3

Fieldwork, 2021

with improved crop varieties, crop rotation, and agroforestry and it was named "Improved crop production system".

Table 5 presents the descriptive statistics of each component (% of people who adopted at least one of the components in the group). The most commonly used component was the improved crop production system with 94.9% of women and 87.5% of men using at least one unit of this component. The second most used component was soil and water management practices with 75.7% of women and 81.6% of men using at least a unit of this component. Finally, the least used component comprised improved livestock management, which includes the constitution of food reserves for the dry season, pasture management and supplementary feeding, the seasonal movement of the livestock, and animal health services/use of vaccines and was used by 53.7% of women and 75.0% of men.

Determinants of the adoption of different climate-smartagriculture technologies

The factors influencing the use of identified CSA options are presented in Table 6. The results of the multivariate probit model show that gender, age, household size, farm size, contact with a project, livestock ownership, access to labour, and land ownership significantly affected the adoption of different CSA options in the study area.

Improved crop production (ICP) practices are implemented by women ($z=-2.61$), older people ($Z=2.23$), farmers in contact with projects ($z=3.53$), those who have less access to climate change information ($z=-9.23$), and land owners ($z=2.37$). The tendency for women to adopt improved crop production practices more likely than men is because of the ease women have in implementing such practices and the quick return on investment they can get compared to their men counterparts. Besides, women are often allocated low-fertility land in the study area, thus making them more inclined to adopt improved crop production practices. A woman discussant affirmed, "Already the land we are given is very impoverished, and we have no other choice than to practise crop rotation so as not to tire the land too much. We have understood that the land too, is like a man who breathes and when he works he needs rest". In addition, due to their household chores and mobility restriction, women are often allocated lands close to settlements. Such lands are low-fertile which increases their tendency to use an improved crop production system option (Patel et al., 2014). This result further shows the potential of this option in promoting and empowering marginalized women as it not only offers a better synergy between productivity and adaptation but it is also beneficial in terms of financial and resource use efficiency (Mutenje et al. 2019; Oyawole et al. 2020; Sain et al. 2017).

The finding also reveals that being in contact with development projects has significantly increased the probability of an improved crop production system. It was found that households who participate in a project or agroforestry initiative were more likely to adopt agroforestry when compared to households who do not participate (Jha et al. 2021). Though efforts to promote sustainable agriculture have been made in the study area by various development organizations, there is still a need to continuously and vigorously support interventions through various innovation support services (extension, financial, inputs, etc.) if we are to increase the pace of adoption of CSA technologies. We also found that small-scale farmers with no access to climate change information were less likely to use improved crop production practices ($z=-9.23$). This further shows the extent to which weather and climate information drive the adoption of CSA technologies in the region (Djido et al. 2021; Tran et al. 2020). Our results further show that land ownership positively influences the use of an improved crop production system ($z=2.37$).

Table 6 Determinants of climate-smart agriculture options by small-scale farmers

Variables	Soil and Water Conservation (SWC)			Improved livestock management (ILM)			Improved Crop Production (ICP)		
	Coef	Std.Err	Z	Coef	Std.Err	z	Coef	Std.Err	z
Gender	0.089	0.229	0.39	0.139	0.219	0.64	−0.697	0.267	−2.61***
Age	−0.017	0.008	−2.22**	0.013	0.009	1.39	0.026	0.012	2.23**
Education	−0.071	0.215	−0.33	0.054	0.254	0.21	0.061	0.243	0.25
Household size	0.079	0.02	3.94***	0.024	0.016	1.49	0.036	0.03	1.22
Farm size	−0.048	0.056	−0.87	0.152	0.056	2.70***	0.024	0.058	0.42
Cooperative membership	−0.061	0.28	−0.22	−0.126	0.304	−0.42	−0.464	0.326	−1.43
Access to credit	−0.027	0.228	−0.12	0.048	0.217	0.22	0.058	0.224	0.26
Extension contact	0.253	0.277	0.91	−0.071	0.249	−0.29	−0.323	0.394	−0.82
Project contact	1.236	0.257	4.81***	0.346	0.246	1.41	1.051	0.298	3.53***
Climate change information	0.806	0.575	1.40	−1.023	0.377	−2.72***	−3.504	0.38	−9.23***
Livestock ownership	0.531	0.265	2.00**	2.568	0.339	7.58***	0.173	0.294	0.59
Access to labour	−0.663	0.272	−2.44***	0.303	0.223	1.36	0.328	0.26	1.26
Land ownership	−0.491	0.284	−1.73	0.288	0.253	1.13	0.742	0.314	2.37***
Off-farm employment	−0.2	0.244	−0.82	0.3	0.249	1.20	0.382	0.263	1.45
Constant	0.274	0.73	0.38	−2.822	0.657	−4.3***	2.597	0.57	4.55***
Wald chi2(42) = 61									
Prob > chi2 = 0.0000									
Likelihood ratio test of rho21 = rho31 = rho32 = 0: chi2(3) = 8.20008 Prob > chi2 = 0.0421									

*** Significant at the 1% level, ** significant at the 5% level

SWC soil and water conservation practices, *ILM* improved livestock management system, *ICP* improved crop production system

Evidence indicates that female land ownership promotes women's wealth and decision-making authority, which could be the pathways through which their land fertility is influenced (Chakrabarti 2018; Jha et al. 2021).

Soil and water conservation (SWC) practices are most likely to be implemented by younger people ($z = -2.22$), living in larger households ($z = 3.94$), with contact with projects ($z = 4.81$), with more livestock ($z = 2.00$), and less access to labour ($z = -2.44$). Soil and water conservation practices are labour intensive (Anuga et al. 2019; Moges & Taye 2017) and as such younger farmers as well as larger households could provide the necessary farm labour to implement labour-intensive activities such as contour stone bunds, contour ploughing, and drainage ditches. Similar findings have been found by Belachew et al. (2020) in Ethiopia and Moriaque et al. (2019) in Benin. Moreover, there is a higher tendency for larger households to use mulching and organic fertilizers than smaller households (Mwaura et al. 2021). Furthermore, livestock ownership also significantly influences the use of soil and water conservation. This result contends with those of Amare and Simane (2017) who also found that livestock ownership significantly influences the use of soil and water conservation practices as well as agronomic practices. Small-scale farmers with more livestock are likely to access organic manure which could increase their adoption of practices such as organic fertilizers (Getahun et al. 2021; Mairura et al. 2021). However, our finding that small-scale farmers with less access to farm labour were more likely to use soil and water conservation practices is surprising when compared to a previous study which found the opposite (Belachew et al. 2020). The probable reason might be that practicing some of the SWC technologies such as contour ploughing needs less demand of labour and requires a relatively low complexity approach to operate. Thus, CSA policy interventions to increase the adoption of SWC practices should target younger farmers, living in larger households, with more livestock, and should also provide training/information on less complex practices requiring low labour demand.

Finally, **improved livestock management (ILM)** practices were implemented by households with bigger farms ($z = 2.70$), less access to climate information ($z = -2.72$), and more livestock ($z = 7.58$). The finding is further consistent with those of Kifle (2021) in Ethiopia who also found that farm size positively influences the adoption of improved livestock feed. However, the finding contradicts findings by Njarui et al. (2017) in Kenya who found that households that owned larger pieces of land were more unlikely to adopt improved livestock feeding system with forage than households that had smaller pieces of land. The results further demonstrate the extent to which small-scale farmers valued climate information concerning managing climate risks in livestock production. The provision of climate information does not alone guarantee its integration in farm production decisions (Gitonga et al. 2020). Other forms of institutional support such as extension services, reliability of network connectivity, and communication infrastructure should be complementary. Households with more livestock would likely generate additional income needed to engage in improved livestock management practices. Hence, in order to increase the probability of adoption of ILM practices, CSA programs and policies should focus on providing information to farm households with more livestock and large farm sizes. While the provision of climate information to farmers is necessary, the provision of extension services and other forms of institutional support is important to encourage the adoption of ILM practices.

Conclusion and policy implications

The study reveals that the rate of CSA adoption in northern Benin is still low, with a lower proportion of women implementing CSA technologies than their male counterparts. In addition, women farmers have implemented CSA technologies that require little capital, which may be explained by their limited financial resources. Improved crop production systems were the most prevalent CSA technologies among both male and female farmers, possibly due to their low cost. Our results suggest that there is a need to empower farmers to gradually move to more capital-intensive practices. Gender, in particular, significantly influenced the use of the improved crop production system in this set of variables. This suggests that CSA programs and policy interventions should focus on improving equal access to CSA information and empowering women in household decision-making. This can be achieved by establishing policy measures that would enhance women's access to formal education and extension services. The existence of trade-offs and complementarities between CSA technologies suggests that policy and programmatic efforts on climate change adaptation affect the adoption of gender-sensitive CSA technologies. The contextual nature of these findings reinforces the need to consider local factors and design gender-responsive solutions in collaboration with local communities. This would include ensuring equitable access to CSA information and capacity building initiatives, as well as using transformative gender approaches to address cultural barriers to CSA technology adoption. Specifically, knowledge and information dissemination channels that design and deliver contextually relevant climate/seasonal forecast information that addresses the specific needs of rural and marginalized women should be established. Other measures include facilitating the creation of social networks among women in the community so that they can help each other in times of need.

The findings of this study should however be interpreted with some caution since we relied mainly on cross-sectional survey data and self-reported measures of gender-differentiated adoption of climate-smart agricultural technologies. A cross-sectional data limits us from rigorously providing a dynamic effect of gender-differentiated adoption of CSA technologies on risk exposure. Future research using panel data can help provide a more rigorous estimate of the dynamic effects of gender-differentiated adoption of CSA technologies. Additionally, our limited sample size of 272 households does not capture every farm household in northern Benin. However, our data collection approach of a random selection of farm household heads in the study communities that have experienced adverse climate extremes and the mixed-method research design improved the reliability of the study. Despite these shortcomings, we do not expect systematic bias in our study. Our study contributes to available literature on gender dimensions on the adoption of CSA technologies.

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Data Availability The datasets generated for this study are available on request to the corresponding author.

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