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Determinants of finger millet farmers' choice of adaptation strategies to climate change in northern Uganda

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Abstract

Weather variability has had great negative impacts on crop production in rain-fed agricultural systems that dominate sub-Saharan Africa. Consequently, farmers usually undertake several climate change adaptation strategies to cope. This study assessed climate change adaptation strategies developed by finger millet farmers and the determinants to their choice of adaptation strategies in Kitgum District. This was achieved through a cross-sectional study involving 370 randomly selected smallholder farmers from Kitgum district. Data was collected using structured questionnaires, focus group discussions as well as key informant interviews. Collected data was analyzed using thematic analysis in the case of qualitative data and multivariate regression analysis in the case of quantitative data. Results showed that majority of finger millet farmers perceived weather variability in terms of decreased rainfall levels, prolonged dry spells, and unpredictable precipitations within the last twenty years. The visible effects include low yields of finger millet, poor seed germination, general millet failure causing low production, and increased food insecurity. The most common adaptation strategies were planting different types of crops to cater for failed crops, planting millet early to take care of the shortened length of the rainy season, and farmers adopting drought-resistant varieties of finger millet. Choice of these climate adaptation options depended on gender of household heads, age, size of land owned, education levels, belonging to a farmer group, and access extension service. The findings of this study imply that more effort is to improve the dissemination of weather-related information, provide training on climate-smart agriculture, and boost adaptation planning at the grassroots to empower millet farmers in the effort to increase millet production while practicing appropriate adaptation strategies to the effect of weather variability.

Keywords Climate, Weather, Rainfall, Finger millet, Production and adaptation

1 Introduction

Extreme weather conditions, attributed to climate change have frequently affected global agricultural production [1]. These extreme weather conditions include unusual temperature increases as well as low or high rainfall [2, 3]. The impact of the predicted future



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climate on food security would then continue to grow. Thus, there is a general consensus that climate change would continue to affect crop production if the trend continues [4–7]. With the food security still a challenge in developing countries including sub-Saharan African (SSA) countries, climate change is expected to exacerbate the challenge [8–11]. This is likely to be through the effect of climate change on precipitation. This implies that SSA where agriculture is largely rain-fed, is likely to experience significant yield declines [12–15]. The yield decline would result from alterations in the length of the growing seasons due to increased rainfall variability. Research has shown that, with climate change, even previously relatively drought tolerant crops such as finger millet, sorghum and maize are not spared [16–20].

These changes in climate have had a significant impact on crop production throughout most of Africa, and it has largely affected all farming practices [17, 21–24]. The research of Adhikari et al. [22] as well as Gornall et al. [23], noted that variability in climate seems to have indicated dynamics in agricultural practices and alternative approaches to increase yields for food security and livelihoods. Studies by Atube et al. [25] and Sahoo and Moharaj [26] reported that farmers in various communities, especially smallholders, had different adaptation approaches to address the impacts of climate change. In the same way study conducted by Azare et al. [27] also reported the alternative approach in agricultural practices. Adoption of climate change adaptation strategies has been shown to have differential effects on crop yields [28–34].

With many farmers perceiving climate change as being manifested in decreased precipitation [3], an understanding of which climate adaptation strategies are used by farmers is important. In smallholder production systems, options for climate change adaptation include planting drought tolerant crops [25]. One such crop is finger millet that is widely cultivated by smallholder farmer in several African countries [19, 35–40]. For instance, in northern Uganda, finger millet is cultivated as staple food, supporting livelihoods by providing food, ingredient for local brew as well as income. Finger millet is also preferred for its nutritional relevance [41, 42]. Despite millet being a relatively drought tolerant crop, information of what factors drive adoption of other climate adaptation strategies in addition to millet would help in encouraging climate change adaptation. This information is critical in understanding which adaptation strategies are usually used in conjunction with millet as a drought tolerant crop.

The findings of this study uniquely contribute in addressing unexplored areas in climate adaptation research by focusing on finger millet production which is among the staple crops in the sub-Saharan African region. By identifying specific socio-economic, environmental, and cultural factors that influence adaptation strategies used by smallholder farmers, it addresses a critical gap in understanding how local farming communities can respond to climate variability [3]. This study highlights the necessity for tailored interventions that consider the unique socio-economic and environmental contexts of smallholder farmers, offering insights that could enhance resilience in similar agricultural settings. Despite studies conducted on climate change adaptation in northern Uganda, a significant knowledge gap remains regarding the specific adaptation strategies employed by farmers cultivating drought-prone crops like finger millet. While previous studies have explored general climate change adaptation measures [25, 43–47], they often lack a nuanced understanding of how farmers adapt to climate variability in the context of specific crops, such as finger millet. A critical question arises: when a farmer

chooses to cultivate a drought-tolerant crop like finger millet as an adaptation strategy, what other complementary strategies are they likely to adopt to enhance their resilience to climate-related stresses? Thus, the study assessed climate change adaptation strategies among finger millet farmers in Kitgum district and the factors that determine their choice of adaptation strategies to climate millet in Kitgum District.

1.1 Theoretical perspectives

This research is grounded in the Vulnerability to Climate Change Theory [48]. According to the theory, the impacts of climate change on agricultural productivity, food security, and rural livelihoods are influenced by the vulnerability of communities to climate-related shocks [49]. Climate change is projected to increase weather variability, leading to more frequent and severe climate-related disasters, such as droughts, floods, and heatwaves [50, 51]. To reduce their vulnerability, farmers and rural communities adopt various adaptation strategies, including crop diversification, soil conservation, and agroforestry [46, 48, 52]. The effectiveness of these adaptation strategies in achieving desired outcomes, such as improved agricultural productivity and food security, depends on various factors, including access to climate information, institutional support, and socio-economic characteristics [28, 53, 54]. This study aims to contribute to the understanding of the relationships between weather variability, climate change, adaptation strategies, and outcomes in the context of finger millet farming in northern Uganda.

2 Materials and methods

2.1 Study area

This research was conducted in Kitgum district, located in northern Uganda (Fig. 1). Kitgum lies in the generally drier cattle corridor of Uganda [55–57]. The district covers a total land area of 4042 km square in which 96% is covered by savannah grass land and only 4% is covered by mountain ranges. Kitgum district is located between 975 to

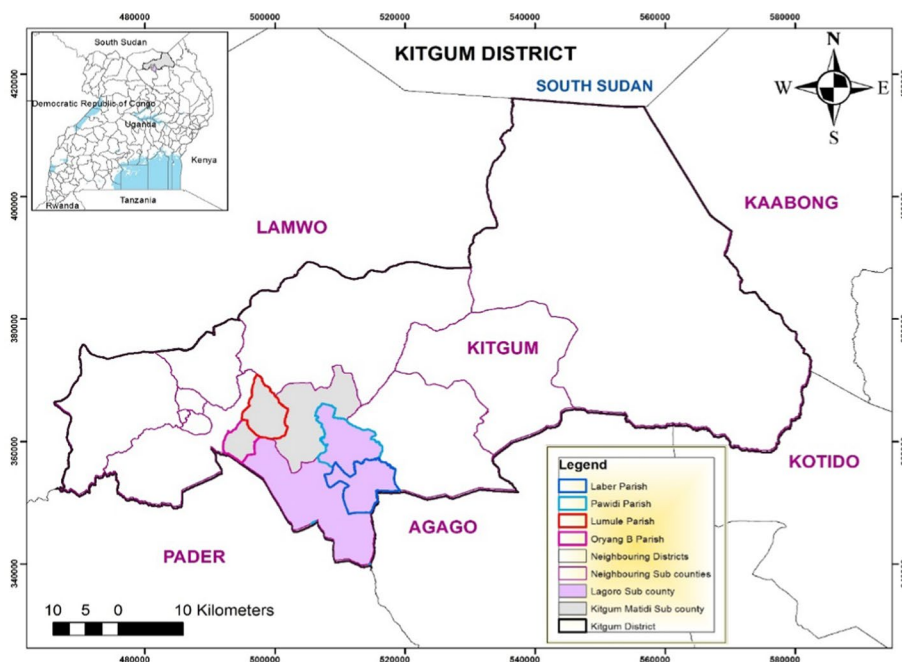


Fig. 1 Map of Uganda showing the study area in Kitgum District (Source GIS)

1524 altitude above sea level (ASL). The landscape is mostly flat with some small part which is hilly. The farming system in Kitgum district is predominantly subsistence in nature and small-scale livestock rearing. Kitgum district lies between 32° E and 34° E and latitudes 2° N and 4° N bordered by Lamwo district to the north, Kaabong district and South Sudan to the eastern side. As of mid-2021, the district population was 226,700. Kitgum district experiences a savannah grassland climate with temperatures ranging between 15 to 33°C and an average rainfall estimate of 1197 mm annually. The area has a dry season that lasts for four months from mid-November to late March, while the wet season start from April to early November which is a unimodal rainfall type, more favorable for growing cereals compared to other crops. The most common types of soil in Kitgum are sandy, brown, loamy and black clay soil which is found around the hilly areas. Majority of the agricultural workforce in Kitgum district consists of farmers who primarily practice subsistence farming with total reliance on rainfall. The most common type of food crops grown in Kitgum include finger millet, maize, sorghum, simsim, and groundnuts, meant for both food consumption and economic reasons.

2.2 Sampling procedure and sample size determination

A multistage sampling method was used to derive the sample used in this study. The choice of Kitgum District and Kitgum-matidi and Lagoro sub counties for the study were driven by the area's diverse environmental conditions, vulnerability to climate change, and unique socio-economic contexts, including its recent history of civil unrest. The study employed a stratified and random sampling methods to ensure a representative sample that captures the variability among farmer characteristics, such as agricultural practices and demographic factors. By carefully selecting the sample size based on statistics, the study aimed to provide insights applicable not only to Kitgum but also to other similar regions in Uganda facing climate-related challenges. This approach enhances the understanding of adaptation strategies among smallholder farmers, contributing valuable knowledge for future interventions. A purposive selection of Kitgum district was made because finger millet is one of the major crops produced by the local farmers and also because Kitgum district lies in the generally dry cattle corridor of Uganda [57]. Using the simple random sampling (SRS) technique, the researcher Selected Kitgum-matidi and Lagoro sub counties for the study. From each of the selected sub-counties, two parishes were randomly selected, making a total of four parishes for the study. These parishes selected were Lumule and Oryang from Kitgum matidi Sub-County and Pawidi and Laber Parish from Lagoro Sub-County. Every village in the selected parishes was included in the sampling frame. From the sampling frame, five villages were randomly selected from each of the parishes, making a total of 20 villages for the study. The sampling units for the study were the households that cultivated finger millet as one of the crops cultivated in the area of study. The respondents for the study were the household heads of the selected finger millet-cultivating households. From the household population of 39,959 in Kitgum district, using the Krejcie and Morgan [58] at a confidence level of 95% and a margin of error of 5%, a sample size of 370 households was proportionately selected from the villages for the study. Prior to data collection, this study obtained informed consent from selected participants. Only those farmers who voluntarily consented to participating in the study were included in the study.

2.3 Data collection methods and instruments

Data was collected using a triangulation of data collection methods and instruments to capture information that describes the actual situation among finger millet farmers in Kitgum district. The survey was conducted using household questionnaires, key informant interviews (KII), and focus group discussions (FGD) depending on the kinds of data required for the objectives of the study. The Questionnaires, Key informant interviews guide and Focus Group Discussions guide were used to collect data to determine adaptation strategies used by finger millet farmers to weather variability, and factors that influence choices of adaptation strategies by farmers to weather variability. By employing both FGDs and interviews in this study, we were able to achieve a comprehensive understanding of the adaptation strategies used by finger millet farmers to address weather variability, along with the factors that influence their choices. Each household interview using questionnaire lasted between 15 to 20 min. A total of four focus group discussions were conducted in the four parishes, one per parish. Each focus group was composed of 10 participants and lasted for about 1 h and 30 min.

The Key informant interview (KII) method was used to capture in-depth information from agricultural extension workers on the common adaptation strategies practiced by finger millet farmers to adapt to weather variability. Each key informant interview session lasted about 20 min.

2.4 Definition of variables

Dependent variables are the adaptation strategies adopted by finger millet farmers (1 if adapted, 0 otherwise, Table 1). The independent (explanatory) variables included household characteristics of the respondents: gender, age, level of education, farming experience, land ownership, Farmland size cultivated, farmer group membership, access

Table 1 Definitions, description, and variables used in the regression

Variables	Definitions	Unit of measurement and values	Apriori expectation
<i>Dependent variables</i>			
Adaptation strategies	Adaptation options	Dummy, 0 = not using the adaptation strategy 1 = using the adaptation strategy Adaptation strategies considered in this study included planting of drought-resistant varieties, Planting disease resistant varieties, planting different types of crops and irrigating the crops planted	NA
<i>Independent variables</i>			
Gender	Gender of household head	Dummy variable, 0 = Female 1 = male	±
Age	Age of household head	Continuous variable (in years)	+
Level of Education	Level of Education of household head	Categorical variable, 1 = Non, 2 = Primary, 3 = Secondary, 4 = Tertiary	+
Farming experience	Number of years of farming by household head	Continuous variable (in years)	+
Land Ownership	Ownership of land by household	Dummy variable, 1 = Household owns land, 0 = otherwise	+
Farmland size cultivated	Size of land cultivated by household	Continuous variable (in acres)	+
Farmer group membership	Belonging to farmer group	Dummy variable, 0 = No, 1 = Yes	+
Extension services	Access to extension services	Dummy variable, 1 = has access to extension service 0 = otherwise	+

to extension services, (Table 1). In this study, adaptation strategies considered among others are planting drought resistant varieties where the farmers planted finger millet varieties that are resistant to drought and the farmers despite experiencing drought would still have good harvest. Planting disease resistant varieties here meant farmers planted finger millet varieties that are resistant to infections by diseases such that despite increased incidences of diseases burden resulting from weather variability, finger millet farmers would still have good harvest from their gardens. Change of crop planting date here meant farmers did not necessarily follow specific dates when finger millet seeds were usually planted, but waited for when the rains have started falling for them to plant millet seeds. This would enable millet to thrive when there is adequate rain for its growth and maturation resulting to good harvest.

2.5 Data analysis

In the analysis of data, both qualitative and quantitative approaches were used. Qualitative data was analyzed using qualitative content analysis. Specifically, qualitative data was analyzed following thematic analysis where the responses are organized into major themes and sub-themes for interpretations. Themes and sub-themes followed climate change adaptation approaches used by the farmer. In the case quantitative data, collected questionnaire data was captured using Statistical Package for Social Scientists (SPSS) v26 statistic package, and then later analyzed using descriptive and regression analysis. Specifically, means, and frequencies were used to obtain summary statistics for farmer characteristics as well as climate change adaptation strategies used, while, a binary logistic regression model was utilized to assess the factors influencing the choice of climate change adaptation strategies among finger millet farmers. The logistic regression model is particularly suitable for this analysis because the dependent variable i.e., the choice to adopt or not adopt specific adaptation strategies is dichotomous.

The binary logistic regression model is mathematically presented as:

$$\text{logit}(p) = \ln(p/1 - p) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_k X_k$$

where:

p is the probability of adopting a specific climate change adaptation strategy.

$\text{Logit}(p)$ is the log-odds of the probability of adoption.

β_0 is the intercept term (constant).

$\beta_1, \beta_2, \dots, \beta_k$ are the coefficients.

$X_1, X_2, \dots, X_k$ are the independent variables representing the factors influencing the choice of adaptation strategies.

3 Results

3.1 Summary statistics of farmers' characteristics

Explanatory variables included socio-demographic characteristics of respondents such as gender, age, level of education, farming experience, land ownership, size of land owned by the household, belonging to the farmer group and access to extension services, are presented in Table 2. Results indicate that majority of finger millet farming households in the study area were headed by females (59.5%), which demonstrates the unique dynamics of common cultural norms and practices in the African context. This study therefore revealed that women had the freedom to perform their roles to the

Table 2 Socio-demographic characteristics of respondents

Variable	Category	Frequency (n)	Percentage (%)
Gender	Male	150	40.5
	Female	220	59.5
Age	(Youth) 18–35	143	38.6
	(Adult) 36–59	155	42.0
	(Elders) 60+	72	19.4
Level of education	None	40	10.8
	Primary	223	60.3
	Secondary	78	21.1
	Tertiary	29	7.8
Farming experience	1–5	178	48.1
	6–10	47	12.7
	11–15	39	10.5
	16–20	20	5.4
	20 Above	86	23.2
Size of land owned	Less than an acre	107	28.9
	1–5 acres	193	52.2
	6–10 acres	59	15.9
	11–15 acres	5	1.4
	16-Above	6	1.6
Belonging to farmer group	Yes	68	18.4
	No	302	81.6
Access to regular extension services	Yes	43	11.6
	No	327	88.4
Have access to extension services	Yes	95	25.7
	No	275	73.3

best of their ability, even when they were household heads. Over 38.6% of the household heads were within the age brackets of the youth (18–35 years). The findings, also indicated that the majority (60.3%) of household heads that grew finger millets attained only the primary level of education. This study shows that the majority (48.1%) of the respondents had been growing millet for between one and five years only, followed by those who grew millet for over twenty years (23.2%), while the other experience categories for millet farming were well below 15%. The study also indicated that all the households owned land that they used for cultivation. The majority (52%) of the respondents in the study owned between one and five acres of land. The study further revealed that only 18% of millet farmers in the study area belonged to farmer groups, while 12% of the household heads interviewed received agricultural extension services, and finally, 26% of the households regularly received weather information.

3.2 Adaptation strategies used by finger millet farmers to weather variability

The findings showed that finger millet farmers in Kitgum district practice some adaptation strategies to cope with and mitigate the effect of weather variability; therefore, the main strategies developed were planting different types of crops to cater for failed crops, which ranged higher and were represented by 96.2% of the respondents, followed by 76% of the millet farmers who plant millet early to make use of the shortened length of the rainy season. Finger millet farmers also practice some small-scale irrigation in response to drought, and this category was accounted for by 69% of the respondents. The study also revealed that those farmers who have adopted drought-resistant varieties of finger millet were 58.1%, while those who have adopted disease-resistant varieties of finger

millet were represented by 52.2% of the respondents. And lastly, very few farmers were able to plant trees around their millet farm to improve the microclimate and reduce soil erosion. Those trees act as wind breaks and were represented by 35% of the millet farmers (Fig. 2).

3.3 Factors influencing millet farmer's choice of climate change adaptation strategies

Binary logistic regression analysis was used to establish factors that influence the choice of adaptation to weather variability by finger millet farmers in Kitgum district. Results showed that gender and age of household head significantly influenced farmer adaptation to weather variability. Other variables that had a significant influence on adaptation to weather variability were the size of the land owned by households, members of the household belonging to a farmer group, and the fact that members of the household frequently listen to weather information on social media.

3.3.1 Effect of gender on adaptation to weather variability

Gender of household heads among finger millet farming households in Kitgum district had a significant influence on their adaptation to planting drought-resistant millet varieties and practicing water conservation as adaptation strategies to the effects of weather variability. The study, as shown in Table 3, established that male household heads were less likely to plant drought-resistant ($p = 0.044$) millet varieties but were more likely to practice water conservation ($p = 0.001$) as adaptation strategies to the effects of weather variability than their female counterparts in the strategy of practicing water conservation, which was done more by the males as an adaptation strategy to weather variability than the females.

3.3.2 Age of household head

The analysis underscores a significant relationship between the age of the household head and the diversity of crop types planted during the millet cropping season, with younger households ($p = 0.023$) more likely to engage in varied cropping strategies to adapt to weather variability. This trend aligns with similar findings in Sub-Saharan Africa and parts of Asia, where younger farmers tend to experiment more with diverse systems to enhance resilience against climate change. Additionally, the labor-intensive

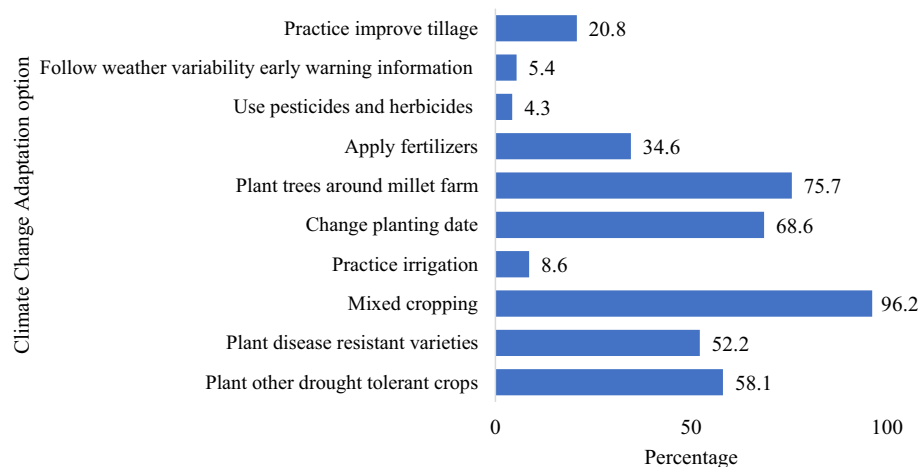


Fig. 2 Farmers' adaptation strategies to weather variability in Kitgum District

Table 3 Multivariate logistic regression model parameter estimates on predictors of climate adaptation options of millet farmers in Kitgum district

Independent variables	Other drought tolerant crops		Disease resistant varieties		Crop diversification		Irrigation		Agro-forestry		Apply fertilizer		Use pesticide		Increased tillage/soil nutrients/water conservation	
	Coef.	p-value	Coef.	p-value	Coef.	p-value	Coef.	p-value	Coef.	p-value	Coef.	p-value	Coef.	p-value	Coef.	p-value
Gender	-0.476	0.044	-0.228	0.334	0.425	0.489	-0.138	0.743	0.183	0.470	-0.853	0.171	0.068	0.894	0.940	0.001
Age	-0.162	0.273	-0.102	0.487	0.854	0.023	-0.174	0.516	-0.311	0.052	0.368	0.338	-0.031	0.926	0.149	0.432
Educ	-0.43	0.794	-0.073	0.654	0.191	0.661	0.060	0.847	-0.029	0.870	-0.027	0.952	-0.228	0.535	0.353	0.498
Experience	-0.001	0.993	0.036	0.635	-0.191	0.309	-0.105	0.460	0.132	0.114	-0.373	0.080	-0.162	0.347	0.069	0.490
Owens land	-0.876	0.456	-0.177	0.863	-17.667	0.999	18.191	0.999	-0.933	0.389	16.941	0.999	17.241	0.999	-0.833	0.489
Size land owned	-0.084	0.564	-0.261	0.076	-0.121	0.748	0.209	0.430	-0.422	0.006	0.405	0.315	-0.231	0.425	-0.130	0.468
Farmer group	-0.017	0.955	0.159	0.600	0.935	0.392	0.220	0.647	0.902	0.004	-0.439	0.529	0.203	0.729	0.461	0.183
Extension service	0.295	0.455	0.194	0.620	17.612	0.998	0.378	0.488	-0.061	0.108	0.789	0.281	0.325	0.619	0.043	0.921

nature of cultivating finger millet appears to favor younger farmers, who typically have the physical capacity and resource availability to invest time and finances for effective crop management, while older farmers may face limitations that restrict their agricultural practices. These insights underscore the importance for policymakers to recognize demographic trends when developing agricultural adaptation strategies. By providing targeted support such as training, financial resources, and technology access, successful adaptation approaches can be scaled up in regions facing similar climatic challenges, ultimately contributing to improved food security and resilience in vulnerable agricultural communities worldwide.

3.3.3 Size of land owned

Findings showed that the size of land owned by households significantly influenced households' choices of tree planting as an adaptation strategy to weather variability. The study revealed that millet farmers who owned less land were less likely to plant trees ($p = 0.006$) as an adaptation strategy to weather variability than their counterparts who owned more land. Since tree planting requires a standard spacing between the trees to be at least three meters and above, depending on the type and species of trees one is planting, a farmer has to only opt for tree planting as an adaptation strategy to weather variability when there is enough land left amidst growing other crops. The study found that the size of the land owned by individual household farmers significantly influenced tree planting as adaptation strategies to weather alteration in the area.

3.3.4 Belonging to farmer group

Our analysis revealed that belonging to a farmer group had a significant influence on tree planting as an adaptation strategy to weather variability. This means that millet farmers in Kitgum district who belong to the farmer group were more likely to plant trees ($p = 0.004$) as an adaptation strategy to weather variability than those millet farmers who did not belong to the farmer group. It is a well-known practice in many farming communities that most service providers, such as non-governmental organizations, the private sector, and government programs, are all channeled to the grassroots through group members other than individuals in the community. This put the farmer groups at an advantage in adapting more efficiently to weather conditions than their counterparts, who do not subscribe to farmer groups. Those who belong to farmer groups have access to extension services such as training of farmers on new farming methods, farm tools, information on weather forecasts, supplies of farm inputs, and application of bylaws regarding good farming practices. Use and application of the bylaws put in place to regulate the tree cuttings, in that each person is allowed to cut from his or her own garden. This improves the conservation effort at the local level.

4 Discussions

4.1 Adaptation to weather variability

The findings on adaptation strategies, therefore, emerged that very few of the adaptation strategies were being applied by millet farmers in Kitgum, majority of these farmers plant different crops to cater for failed crops. Followed by those farmers who plant their millet earlier to make use of the shortened length of the rainy season. The practice of mixed cropping and early planting as a common adaptation strategy is in agreement with

the qualitative data collected by focus group discussion and key informant interviews respectively. It appeared that most millet farmers lack weather-related information, and some extension services at the grassroots level to boot up appropriate adaptation options. This finding is in agreement with a study done in Ethiopia by Getahun et al. [59] which found the common adaptation strategies as: changing the planting date.

The analysis revealed that some farmers were practicing small-scale irrigation in response to drought. This practice of irrigation by a few farmers could be because the system is expensive, demands technical expertise, and is usually labor-intensive. In addition, the study revealed that few millet farmers adopted the planting of drought-resistant varieties. And very few were planting disease-resistant varieties of finger millet as their adaptation strategies to the effects of weather variability. The planting of drought-resistant and disease-resistant varieties was not common, mostly because procurement of the above seeds is expensive for millet farmers, and the production of millet is slowly decreasing. However, to improve food security, millet growing should be increased. This finding corresponds with the previous study by Wang et al. [60] in their study on the effect of climate change on the yield of cereals, which found that to address food security, millet growing should be increased to reduce the impact of global warming.

4.2 Determinants to choices of adaptation strategies

Gender of household heads significantly influences the adaptation strategies employed by finger millet farming households in Kitgum District, particularly in planting drought-resistant varieties and practicing water conservation to mitigate the effects of weather variability. This aligns with comparative studies from similar climatic contexts, such as research in Ghana showing that female-headed households are more adept at adopting drought-resistant crops compared to their male counterparts [61]. Conversely, findings from Uganda by Atube et al. [25] suggest that male-headed households tend to engage more in water conservation practices, potentially due to the physical demands of creating and maintaining water-holding channels essential for growing millet. The predominance of females in agricultural tasks within the Acholi community, where they manage planting and weeding while males take on more strenuous water conservation efforts, highlights the gendered division of labor in agricultural practices. These insights underscore critical implications for policy and practice: to enhance agricultural adaptation strategies, interventions should target both men and women, recognizing their distinct roles and capacities. This dual-focused approach could include training programs tailored to women on water conservation techniques and encouraging male involvement in crop management, potentially leading to more balanced and effective adaptation strategies that can be scaled up in other regions facing similar climatic challenges.

Age of the household head significantly influences the choice of crop types planted as an adaptation strategy to weather variability, with younger farmers demonstrating a greater propensity to diversify their cropping practices than their older counterparts. This observation aligns with findings from other regions facing similar climatic and socio-economic challenges, such as studies in West Africa that show younger farmers are more innovative and willing to experiment with different crops, thereby improving their resilience to climate variability [25, 45, 62, 63]. The requirement for additional capital investment in diverse crop planting—beyond just finger millet—often poses a greater burden on older farmers, who typically juggle multiple household responsibilities and

may lack the financial flexibility to invest in new seeds and pest management strategies. Furthermore, the study reveals that the labor-intensive nature of millet cultivation necessitates significant time and energy, leading to higher yields among youthful farmers who can either manage the workload more effectively or afford to hire additional help, thereby reinforcing existing disparities based on age and economic status. These comparative insights underscore the importance of tailoring agricultural policies that empower younger farmers through access to financial resources, education, and technical support, while also recognizing the need for targeted assistance for older farmers. Such an inclusive approach could facilitate the scaling up of successful adaptation strategies across various regions, ultimately strengthening community resilience to climate change.

Land size significantly influenced household decisions to engage in tree planting as an adaptation strategy to weather variability, reinforcing findings from similar climatic and socio-economic contexts where larger landholdings positively correlate with increased tree planting [25, 43–45]. This relationship suggests that households with more land are better positioned to incorporate tree planting amidst their other agricultural activities, as this practice requires sufficient spacing—typically a minimum of three meters between trees—depending on the species. For instance, research in East Africa has highlighted that households with extensive land are more likely to diversify their farming systems by integrating trees, which can enhance soil fertility, provide shade, and create windbreaks, thereby improving overall crop resilience. This therefore means, to scale up effective adaptation strategies, there is a need for policies that promote equitable access to land and resources, including support for smaller landholders. Initiatives such as agroforestry programs could be developed to optimize land use, enhance biodiversity, and improve resilience across diverse farming systems, ultimately facilitating broader adaptation measures in regions similarly affected by climate variability.

Belonging to a farmer group significantly enhances the adoption of tree planting as an adaptation strategy to weather variability, a finding that corroborates with studies conducted in similar climatic and socio-economic settings, where collective organization among farmers has been linked to improved access to resources and knowledge [64]. Farmers affiliated with groups benefit from shared experiences, peer learning, and capacity-building initiatives facilitated by various stakeholders, including governmental and non-governmental organizations, which tend to direct their support more effectively through these collective entities rather than individual farmers. This structure not only fosters a stronger support network but also ensures that essential services, such as agricultural extension training, weather forecasts, and modern farming inputs, are more readily accessible to group members. As evidenced in agricultural communities across Sub-Saharan Africa, such collective engagement enhances resilience against climate shocks by facilitating better information exchange and resource allocation. This implies that promoting the formation and strengthening of farmer groups should be a key strategy in scaling up successful adaptation efforts. Policymakers could focus on enhancing the capacity of these groups, thereby enabling them to leverage more significant resources, implement comprehensive adaptation strategies, and ultimately bolster community resilience to climate variability throughout similar regions.

Access to weather information significantly influenced finger millet farmers in Kitgum District in adopting a range of adaptation strategies, such as planting disease-resistant

varieties, practicing irrigation, cultivating trees for windbreaks and soil stabilization, applying fertilizers to enhance yields, using pesticides for pest control, and implementing water conservation methods. These findings align with numerous studies in similar climatic and socio-economic contexts, which emphasize that farmers' adaptability to weather variability is often contingent upon their access to timely and relevant information [62, 63, 65, 66]. For instance, research in East Africa has shown that improved access to climate information enables farmers to make informed decisions that enhance resilience and optimize resource management. This underscores that finger millet farmers with reliable weather information are considerably more equipped to implement effective adaptation strategies compared to those with limited access. This suggests that enhancing farmers' access to weather information, through participatory communication channels or technology-driven dissemination methods, should be a priority for agricultural and climate resilience initiatives. By fostering a more informed farming community, policymakers can facilitate the scaling up of successful adaptation practices, thereby improving agricultural productivity and resilience in regions facing similar climate challenges.

5 Conclusion

The objectives were to identify the adaptation strategies employed by smallholder millet farmers in response to climate variability, as well as to examine the factors influencing their choice of these strategies. The findings indicate that the predominant adaptation strategy among smallholder millet farmers is mixed cropping, whereby millet is cultivated alongside other crops within the same cropping season. Additionally, practices such as agroforestry wherein shade trees are integrated with crops in household gardens and the modification of planting dates are widely adopted. The results further reveal that the selection of adaptation strategies is significantly influenced by several socio-economic factors, including the farmer's age, gender, landholding size, and membership in farmers' associations. Furthermore, respondents unanimously indicated that access to extension services and timely weather information is crucial in enhancing awareness and promoting the adoption of climate change adaptation strategies. These insights underscore the need for targeted interventions to support smallholder farmers in improving their adaptive capacity in the face of climate variability.

Findings underscore the critical need for enhanced dissemination of weather-related information and the integration of climate change adaptation training into agricultural extension services. By prioritizing these initiatives, policymakers can significantly improve farmers' capacity to respond to climate challenges. Additionally, strengthening grassroots climate adaptation planning is essential for empowering millet farmers. This localized approach not only facilitates tailored solutions that resonate with community needs but also fosters greater resilience among farmers. Ultimately, these strategies can lead to increased climate adaptation and higher millet production, offering valuable insights for scaling successful adaptation efforts in other regions facing similar climate-related challenges. Integrating weather-related information into agricultural programs can be achieved through mobile alerts that provide real-time forecasts, establishing community weather stations for localized data, and organizing community workshops that combine weather forecasting with climate adaptation training. Additionally, creating demonstration plots to showcase weather-informed practices and partnering

with meteorological services for up-to-date information can empower farmers to make informed decisions. These strategies collectively enhance resilience and foster better adaptation to climate challenges.

6 Study limitations

The following limitations are acknowledged; The cross-sectional design only captured a snapshot of adaptation strategies at a single point in time, neglecting dynamic changes in adaptation strategies over time. Additionally, the study relied on self-reported data, which may be subject to biases and recall errors. The study focus on finger millet farmers in Kitgum District also limits generalizability to other crops and agro-climatic zones. Finally, the lack of objective measures, such as observational data or satellite imagery, to validate self-reported adaptation strategies is a notable limitation.

Several measures were taken to ensure that these limitations do not affect the findings for this study: The study employed triangulation of data sources, combining surveys, focus group discussions, and key informant interviews to validate self-reported data and reduce biases and recall errors. The survey instrument was pilot-tested and validated, and data quality control measures, such as data cleaning and checking for inconsistencies, were implemented. Statistical analysis techniques were used to identify patterns and relationships in the data, and the findings were contextualized within the specific geographic and cultural context of Kitgum District. Finally, the study explicitly acknowledged its limitations, providing a transparent and honest account of the potential biases and limitations of the research design and methodology.

Acknowledgements

We are grateful to all the respondents who participated in the study and provided all the relevant information for this study, Kitgum district administration, and the agricultural extension workers for supporting the study.

Author contributions

In producing the manuscript, FA, CO, LRL, DMO and CNO participated in designing the study; OC and FA participated in collecting field data. FA, CO, and LRL participated in analyzing and presenting the data. FA, CO, LRL, DMO, and CNO wrote the initial drafts of the manuscript. All the authors read and approved the final manuscript.

Funding

There was no funding from any organization that supported this study.

Data availability

The datasets used for this current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

Ethical approval to conduct this study was obtained from the Gulu University Research Ethics Committee (GUREC). The study was conducted in accordance with the principles outlined in the Declaration of Helsinki (World Medical Association [WMA], 2013). Prior to data collection, informed verbal consent was obtained from all participants. Only consenting participants were included in the study.

Consent for publication

The authors all agreed that this manuscript be published.

Competing interests

The authors declare no competing interests.

Received: 22 October 2024 / Accepted: 23 June 2025

Published online: 14 July 2025

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