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RESEARCH ARTICLE

Gender differential in choices of crop variety traits and climate-smart cropping systems: Insights from sorghum and millet farmers in drought-prone areas of Malawi

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Societal Impact Statement

There has been limited research regarding the roles of gender and social networks in climate adaptation in African agriculture. The study examines how gender and climate risk awareness influence sorghum and pearl millet farmers' varietal trait and cropping system choices in Malawi. The findings reveal gender disparities in choices of crop variety characteristics. For male farmers, decisions on variety traits are primarily guided by quantity and economic benefits, while women focus on post-harvest quality and grain handling attributes. This work provides insights for developing gender-responsive crop varieties and climate-smart cropping practices tailored to societal needs and relations.

Summary

- Climate-resilient crop varieties and cropping systems are required to manage climate variability and to adapt to the increasing climate risks across Africa. Integrating gender perspectives on cropping technologies will assist in accelerating crop adaptation programs. Here, we focus on understanding gender-differentiated trait preferences and decision-making on cropping practices of sorghum and pearl millet producers in southern Malawi.
- The study employs a convergent mixed research methods design in which both quantitative and qualitative data were collected, analyzed, and interpreted.
- Our analysis reveals clear gender differences and preferences in crop traits and cropping systems. Male farmers prefer traits based on economic gains, notably yield and grain size. Female farmers target characteristics based on both agronomic and post-harvest grain characteristics to ensure the sustainability of household food intake. We also identify gender inequalities in decision-making regarding crop production practices and preferential access to knowledge in favor of male farmers.
- We show that gender norms and climate risk knowledge influence farmers' decision-making in selecting crop traits and practices, as well as accessibility to resources. Gendered inequality in decision-making goes beyond cropping practices

to socially constructed rules of resource accessibility and restricted mobility. We conclude that efforts to improve crop adaptation and resilience to climate change in vulnerable dryland regions must pay greater attention to the processes and relations between gender and climate change knowledge bases.

KEYWORDS
climate-smart, crop variety, cropping system, gender, phenotypic traits, preferences

1 | INTRODUCTION

Global food and nutritional security are profoundly impacted by climate change and its variability. Sub-Saharan Africa is one of the most vulnerable regions to high levels of climate risk and associated food system insecurity due to its heavy reliance on rain-fed agriculture and low adaptive capacity (Challinor et al., 2007; Ericksen et al., 2011). Risks are enhanced due to slow-paced plant breeding and varietal replacement cycles. There is an urgent need to develop climate-smart, sustainable crops and management systems to provide sufficient, nutritious food to support healthy population growth (Acevedo et al., 2020; Dhankher & Foyer, 2018; Namany et al., 2020). Sorghum and millet are nutritious and climate-resilient small-grain cereals. The crops are tolerant of multiple stresses, including drought and heat stress (Kholová et al., 2013), and have low carbon emission footprints relative to other major cereals (Dar et al., 2018). Until recently, the crops have been forgotten in terms of conservation, utilization, and research, and progress in breeding programs has lagged behind (Anunciacao et al., 2017). There is a growing interest in the re-inclusion of these local crop species and varieties into food production systems and increased investment in crop improvement programs to increase crop productivity (Jansson et al., 2018).

In terms of global production and utilization, sorghum and pearl millet are ranked 5th and 7th among important cereals, respectively (Bhagavatula et al., 2013). However, these crops are expected to have an increased importance in the current and future adaptation of agriculture to climate change globally (Kholová et al., 2013; Woomer & Adedeji, 2021). Sorghum and millet can substitute the major crops that are susceptible to drought and high temperatures while ensuring farm resilience and diet diversification (Hadebe et al., 2017). These grains are important in local food systems and are becoming increasingly significant for food industries, driven by the need for environmentally sustainable food crops and consumer demand for gluten-free products (Alavi et al., 2019; Anunciacao et al., 2017; Woomer & Adedeji, 2021). Gender and social concerns over decision-making on cropping choices are not considered exclusively in current climate adaptation strategies (Djoudi et al., 2016; Kakota et al., 2011). Mainstreaming gender equality in climate risk management is critical to achieving sustainable development in Sub-Saharan Africa (Teklewold, 2023).

Gender is a critical social cleavage through which climate-related impacts on agricultural livelihoods and community resilience are shaped (Carr & Thompson, 2014). Gender refers to the social relations between males and females and how they are constructed. Gender roles are dynamic and change over time and space (Acevedo et al., 2020). Incorporation of gender analysis in cropping technology and improvement programs that aim to develop community resilience to climate change is needed (Murray et al., 2016). As such, examining decision-making choices and how such decisions influence climate effects adaptation and the implications to communities is a global research priority (Chandra et al., 2018). Despite emerging literature on the importance of gender and climate change adaptation (Carr & Thompson, 2014; Vincent & Mkwambisi, 2017), women are still being excluded in agricultural decision-making at various scales and settings ranging from the household level to the implementation of agricultural development programs and projects (Dankelman & Jansen, 2012; Phiri et al., 2022).

Attention on intra-household dynamics, gender roles, and relations and how these shape farming decisions, including the views of women in male-headed households, has been the center of research recently (Acosta et al., 2020). The literature on gender and agriculture has mainly focused on gender gaps in agricultural productivity and agricultural technology adoption (Joe-Nkamuke et al., 2019; Teklewold, 2023; Tufa et al., 2022), especially for major crops in Africa. In sub-Saharan Africa, there is an increasing focus on identifying females' trait preferences within crop breeding to enable gender-responsive product development, for instance in maize (Cairns et al., 2022). However, such innovations are also needed for climate-resilient crops such as sorghum and millet, which have been neglected to date.

In this study, we focus on understanding the choices for crop variety phenotypic traits and climate-smart farming practices of sorghum and millet producers as influenced by gender and climate risk awareness in drought-prone areas of southern Malawi. To further understand household farming resource allocation, we examine the availability and accessibility of sorghum and millet seed and farming resources among male and female farmers. We finally explore the differences in opportunities and challenges for sorghum and millet production among female and male farmers. This study provides new insights for the development of gender-responsive crop varieties and climate-smart technologies that are specific to community needs. It addresses the need for a greater gendered research focus on forgotten crops and their inclusion in African food systems.

2 | RESEARCH DESIGN AND METHODS

2.1 | Study area

The study was conducted in the neighboring districts of Nsanje and Chikwawa, which form part of the Lower Shire Valley (Figure 1), in southern Malawi (a sub-Saharan African country). Both districts have a tropical climate with strong seasonality. The mean maximum temperatures are between 37°C in October and 27°C in June (Ibrahim & Alex, 2008). Both districts have unreliable and variable rainfall, with an average annual precipitation of 800–1200 mm, with over 90% occurring during the wet season from November to April (Bischiniotis et al., 2020). Chikwawa and Nsanje districts are drought-prone and represent the main traditional growing areas for sorghum and pearl millet in Malawi.

2.2 | Data collection tools and analysis

This study adopted a mixed-method approach that balances the examination of different phenomena, including perceptions and statements, with quantitative numerical data (Creswell et al., 2003). The approach involved a combination of individual farmer semi-structured interviews, focus group discussion (FGD), and expert stakeholder consultations.

2.2.1 | Household survey

The household survey employed a semi-structured questionnaire to collect both quantitative and qualitative data. A semi-structured questionnaire consists of both open-ended and closed questions, providing greater depth than is possible with a structured questionnaire as respondents are not limited to their choice of answers (Gubrium & Holstein, 2002). The Agricultural Extension Development Coordinator (AEDC) provided the sorghum and millet farming household list for each study site, which was categorized as male-headed households and female-headed households. Through a probability-proportional-to-size sampling approach (Skinner, 2014), a total of 152 households were sampled. The interviews were conducted in March 2021, and an additional 27 interviews were conducted in March 2022. For each sampled household, a household head was selected for the interviews. In the absence of the household head, the spouse, if available, would participate in the survey. The absence of men in households for other economic activities resulted in a higher number of female interviewees than males. In total, around 47.5% of male and 52.5% of female farmers participated in the survey (Table S1). It is worth noting that the female respondents are a mix of female household heads and spouses. Our study focused on the lived experiences of men and women in sorghum and millet production. These interviews generated data concerning the socio-economic characteristics of the

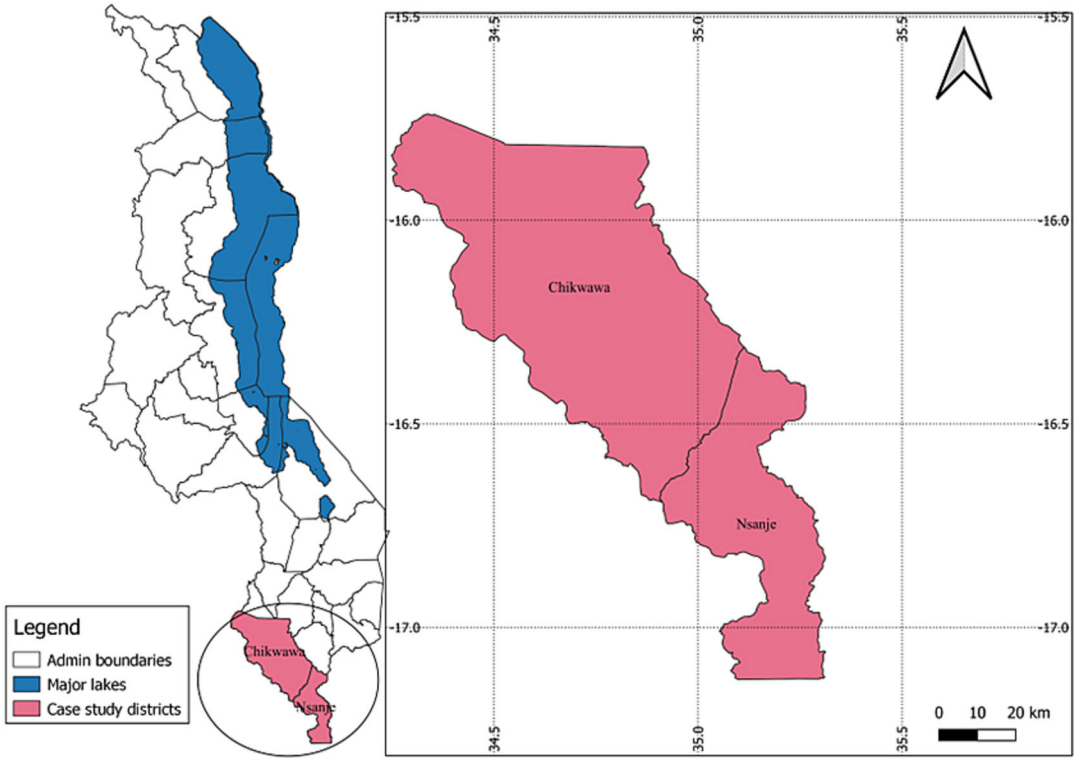


FIGURE 1 A map of Malawi showing the study locations (Chikwawa and Nsanje districts) denoted in red. These districts form part of the Lower Shire Valley in southern Malawi, a drought-prone area and the main growing sites of sorghum and millet. See Method S1 for detailed selection of villages within the districts. See Table S1 for detailed demographic characteristics of sampled households.

households, climate-smart cropping systems and choices for sorghum and millet production, available sorghum and millet varieties, varietal trait preferences for sorghum and millet among male and female farmers, and gender differences and challenges in access to, control over, and entitlement to resources among household members in sorghum and millet production.

2.2.2 | Key informant interviews

Two key informant interviews were conducted in each district with the AEDC and Agricultural Extension Development Officer (AEDO) for the section selected. AEDC coordinates the activities for the Extension Planning Areas (EPA), while AEDO coordinates the activities of the farmers within a particular section within the EPA. These are knowledgeable government staff and are the ones who interact with the farmers in their area most frequently. Key informant interviews help not only to frame issues before a survey is undertaken, but they can also assist in interpreting quantitative data by providing the "how" and "why" of what happened. Key informants were held prior to conducting the focus groups and household survey. This was done to facilitate the development of questions or concepts for the development of the questionnaires and interview guides. A flexible checklist with open-ended questions was used to interview them. This generated information on areas of climate-smart cropping systems and challenges farmers face in sorghum and millet production, including varieties grown in these areas. To gain a detailed understanding of the challenges and opportunities for the sorghum and millet seed systems, at least 10 individual expert stakeholder consultations were conducted, comprising seed companies, entrepreneurs, researchers, and Consultative Group on International Agricultural Research (CGIAR) centers who are working in the sorghum value chain.

2.2.3 | Focus group discussions

In each district, two focus groups were conducted, which were differentiated along gender lines, comprising about 10–12 participants per discussion group. The groups were divided based on gender to allow both males and females to discuss gender issues separately among their peers. FGD participants were randomly selected from the survey participants for in-depth discussion. In female groups, we purposely selected representation of females as either a spouse under male-headed households or female household heads to capture a diversity of intra-gender dynamics. AEDO, who works in the area, assisted in selecting the participants for the FGDs. A checklist with open-ended questions was used to evaluate the impact of climate change on sorghum and millet production over the years, climate-smart agricultural technologies/practices that farmers are using to adapt to the impact of climate change on sorghum and millet production, and varietal traits for sorghum and millet that male and female farmers prefer and the reasons for their preferences. Each FGD lasted between 60 and 90 min.

2.2.4 | Data analysis

Data collected from individual household interviews were subsequently digitized and processed in Microsoft Excel (2016 version) and Statistical Package for the Social Sciences (SPSS, version 26). The chi-square test was used to interpret the association between gender and variables collected in this study. This test is appropriate for our study because our data is in the form of frequency counts that occur in two or more categorical (nominal) variables. Analysis of data from focus groups was based on the approach of content analysis using thematic framework analysis (Ritchie & Spencer, 2002). This involved analyzing the data by examining the underlying themes in the text material that contains information about particular themes of the research. In the analysis, the data was sifted, charted, and sorted according to the key research issues and themes.

3 | RESULTS

3.1 | Gender and climate risk awareness influence farmers' decisions for production and the specificity of sorghum and millet variety

3.1.1 | The role of household decision-making on sorghum and millet production

Our study found that farmers have traditionally grown sorghum and pearl millet due to prolonged dry spells and frequent droughts experienced in Chikwawa and Nsanje. Approximately 90% and 80% of farmers interviewed grow sorghum and millet, respectively. Over 84% ($n = 126$) of respondents indicated that sorghum and millet are produced primarily for household food consumption and that surplus, if available, is sold. During the FGD, farmers emphasized that their experience with climate and weather past events shaped their decision on crops to grow.

> Sorghum and pearl millet are part of our traditional crops, and we choose to grow them because of their tolerance to heat, drought and can grow in poor soil fertility without the need for fertilizer or pesticides as other cereals.
>
> (Female respondent 4, Chikwawa)

Data revealed that 80% ($n = 121$) of respondents indicated that the head of the household decides what to cultivate and determines the land allocation for each crop. Under a quarter of respondents specified that the household head consults a spouse or decides together (Figure 2). Due to the patrilineal marriage systems in this region, men typically have control over household decision-making and planning.

The results further revealed a gender imbalance in agricultural land entitlement and farming resources. The p-value ($p < .004$) from the Pearson chi-squared test indicates a significant association between gender, agricultural land entitlement, and farming resources.

About 60% ($n = 91$) of farmers indicated that male farmers have agricultural land entitlement and control (Figure 2). The entitlement to land broadly influences the selection of and decision-making on cropping systems, with household head permission required for all household members to access the land. Similar trends are also observed in farm inputs and tools, where the male head of the household is mostly in control of farm inputs and associated tools. This implies that female farmers are disadvantaged by inequalities in control over and entitlement to production resources.

It was noted that although men make most of the decisions in married couples, women take a prominent role in the implementation of these decisions. Our study found that sorghum and millet are predominantly grown by female farmers. They are the ones present throughout farming seasons and experience the impacts of climate change and extreme weather events on the production of food crops more than men. Women emphasized that men are most concerned when there is an economic benefit to the product. In contrast, male farmers believe that their female partners are the main decision-makers when it comes to sorghum and millet crops, and they may occasionally make joint decisions (Table S2). FGDs reveal that occasionally, men leave the area for longer periods for casual employment, in some cases as a means for adaptation or coping mechanisms. They may also leave the household and reside on the islands in the Shire River for the cropping season to take advantage of fertile soils and moisture from marshes to grow crops such as maize, rice, and vegetables intended for sale. This can be particularly problematic when men are absent at key times of the year and fail to see the realities of farming. Those lengthy periods of absence also have implications on the availability of household family labor for food production and livelihoods. This was evident as over 94% ($n = 80$ male and $n = 87$ female) indicated reliance on family labor, especially on food crops, which women are mostly involved in.

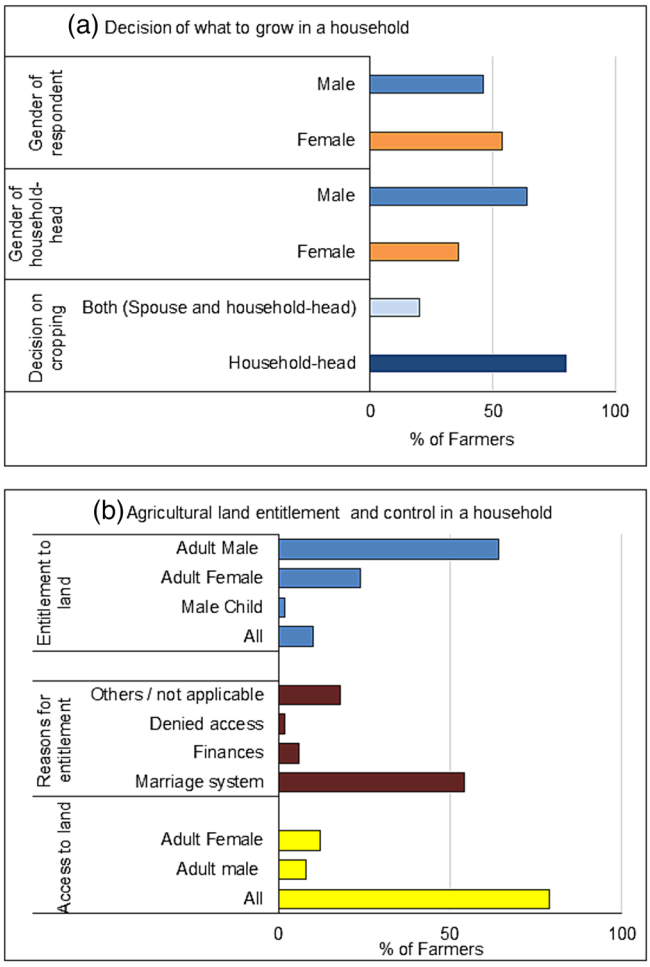


FIGURE 2 Graphs showing gender differences in farmers' land control and decisions on which crops to grow in Malawi. (a) The graph shows the gender of respondents, the gender of the household head, and who controls general cropping decisions in a household among study participants. (b) Shows agricultural land entitlement, control and accessibility by males and females in a household. The results are collective responses from Chikwawa and Nsanje districts ($n = 179$) of Malawi.

> You know women are responsible for making sure that there is food in the house. Millet and sorghum are grown for household consumption - we do not sell these crops, so it is their responsibility to grow food crops. Furthermore, women take a leading role in deciding specificity of the variety of sorghum and millet to grow.
>
> (Male respondent 2, Nsanje)

3.1.2 | Gendered differences in seed choices, variety ranking, and phenotypic traits preferences

Significant variations were observed in preferred seed choices among male and female growers (Figure 3). For example, females are more likely to grow improved varieties than landraces if they have desirable post-harvest traits. This is supported by the fact that 74% of farmers reported growing local varieties due to their availability and mainly from previous saved grain, while 43% reported choosing improved varieties (open pollination varieties) due to their higher yields and early maturity. A significant association was observed between crop variety preferences and the gender of the farmers (Figure 3). In the case of sorghum, it was observed that both female and male farmers preferred a local variety called *Thengeramanga* (38%) to other local landraces because of its drought tolerance and high-yielding attributes (Figure 3).

> We prefer Thengeramanga - this is a drought tolerant, produces more than one harvest despite its late maturing. It also has good flavour, resistance to storage pests, it yields more but produces small grains and late maturing compared to another local sorghum landraces called Wayawaya which has large grain size and, is early maturing.
>
> (Male respondent 8, Nsanje)

Among pearl millet varieties, around 37% of female and 40% of male farmers prefer *Mchewere*, a local landrace, for its stalk sweetness

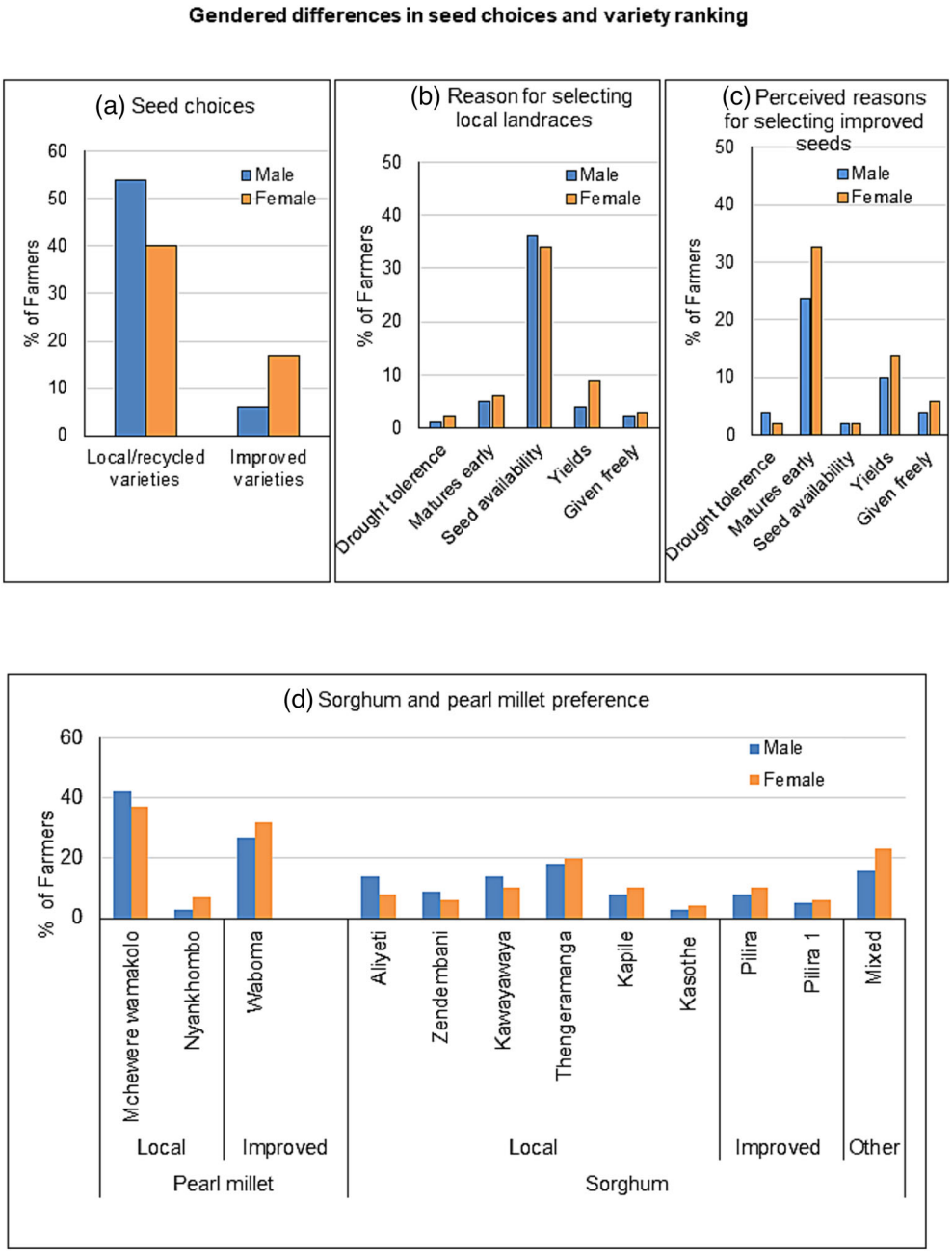
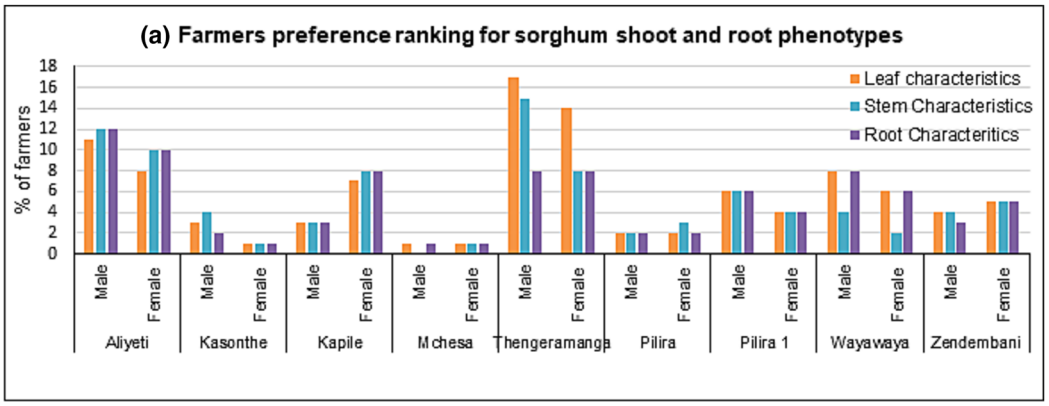


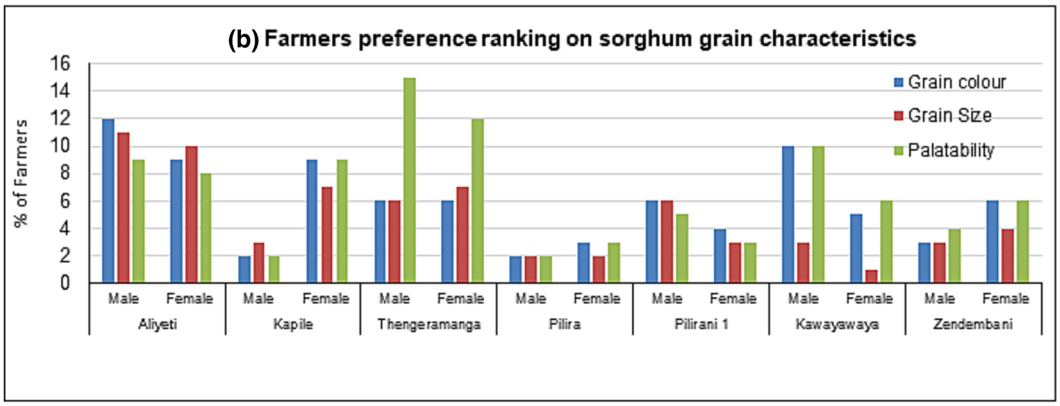
FIGURE 3 Graphs showing gendered differences in seed choices and variety ranking by sorghum and pearl millet farmers in Malawi. (a) Shows seed choices grown by gender 2019/2020 growing season. (b) Shows perceived reasons for the selection of seed of sorghum and pearl millet local landraces and (c) show variation in perceived reasons for the selection of seeds of sorghum and pearl millet improved varieties. (d) Highest ranked sorghum and pearl millet varieties/landraces grown and farmers preferences by gender. The results are collective responses from Chikwawa and Nsanje districts ($n = 179$).

and grain flavor. An improved variety, *Nyakhombo*, is desirable due to its high yield and early maturation.

> The local millet is more desirable because it has a very long stalk, that is sweet when eaten fresh (not dry) and it is palatable. Its grain reddish colour and taste are preferable to improved varieties.
>
> (Female respondent 1, Nsanje)

For sorghum and millet, yield, maturity, and drought tolerance are primary desirable traits, whereas pests and storage stability are secondary traits. In terms of phenotypes ranking, expressed as a count of votes was based on shoot characteristics (stem height and thickness), leaf characteristics (leaf branching angle, leaf shape and length) and root characteristics (root depthand root spreading). *Thengeramanga* was highly rated due to its deep roots, but farmers do not like its relatively long stem and lodging challenges (Figure 4). Male farmers emphasized more on the agronomic traits linked to yield and were market-oriented, while female farmers preferred postharvest characteristics including taste and long shelf life for household food intake sustainability. During the FGD, men emphasized that *Wayawaya* has a relatively large grain size compared with other local varieties, and so it is linked to higher yield gains. However, women pointed out the importance of flour quality after milling, for which they prefer *Thengeramanga*. Women were also typically interested in grain color, taste, and palatability, attributes that are relevant to the consumption of food and beverages.





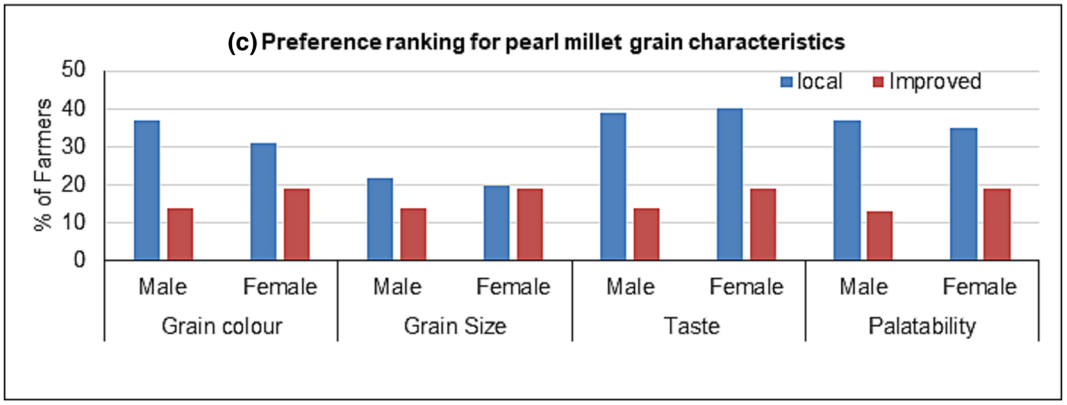


FIGURE 4 Graphs showing how Malawi farmers' preference ranking regarding sorghum and pearl millet phenotypic characteristics differ by gender. (a) Farmers preferences on shoot and root phenotypes for commonly grown sorghum varieties and the selection differs by gender. (b) Farmers preferred grain phenotypes among common grown sorghum local landraces and improved varieties. (c) Farmers preferred pearl millet grain phenotypes influenced by gender. The results are collective responses from Chikwawa and Nsanje districts ($n = 179$).

3.2 | Gender disparities affect sorghum and millet seed accessibility and availability among male and female farmers

The data show gender differences in access to quality sorghum and millet seeds, as well as availability challenges. We carried out a chi-squared test to understand this association. A significant relationship was observed between seed accessibility and gender ($p < .000$). Over 62% of men stated that they had the means to access seeds from seed distributors or local markets, compared with only 37% of female farmers. This disparity demonstrates that male farmers have greater access to high-quality seeds than female farmers. Most of the improved seed for sorghum and millets was sourced from organizations such as CGIAR centers (International Crops Research Institute for the Semi-Arid Tropics [ICRISAT], International Maize and Wheat Improvement Centre [CIMMYT]) and the Department of Agricultural Research Services (DARS), a government research institution, through extension workers or farmer delivery programs. Others obtain

improved seeds from informal local producers or multipliers whose seed quality is not paramount but nonetheless expensive, which female farmers mostly cannot afford. About 64% of female farmers, compared with 32% of male farmers, indicated that friends and family were their main sources of sorghum and millet seeds, mainly local landraces.

Regarding the availability of high-quality seed, there have been variations in the distance to access seed, as most local seed growers or sorghum distributors are further away from most farmers. While the average distance is 3.24 km, men indicated that they may travel more than 20 km to look for good seeds from agro-dealers or seed distributors. The distance can affect female farmers' access to quality seeds, as most lack access to transportation. It has been noted that sorghum and millet lack formal seed producers and markets relative to major grains such as maize, which makes the seeds unavailable. These barriers to the availability of improved varieties have an impact on the selection of a desirable variety that could enhance climate resilience.

3.3 | Variation of choices and knowledge on climate-smart cropping systems and technologies

3.3.1 | Farmer insights and broad understanding of climate-smart cropping systems

When farmers were asked what they knew about climate change and how sorghum and millet production had been shaped, one of the respondents in Nsanje stated that:

> We have seen dramatic changes in weather conditions for a very long time now. Despite that Nsanje has a long history of warmer climate, but it has now increased still. We have been having frequent heat waves, irregular rainfall patterns, and strong winds destroying the crops. Also, we have been having hunger due to the low production of crops. Currently, in low-lying areas, production cannot take place without pesticides- due to the increased pest and disease occurrences.
>
> (Male respondent 5, Nsanje)

This response was echoed by farmers from Chikwawa during an FGD, who explained the delay in planting due to the late onset of rains, which had been different from the past. The usual planting dates used to be November/early December, but in the 2021/2022 growing season, planting rains came in January, followed by heavy rains and cyclone Anna, which destroyed almost all crops.

3.3.2 | Association of gender and choices for cropping systems and technologies

Over the decades, farmers have been practicing several cropping systems where other techniques have been learned but mostly passed on from generation to generation (Chivenge et al., 2015). This study revealed that at least 56% ($n = 85$) of respondents practice monocropping for sorghum or pearl millet production, while 44% ($n = 66$) of the respondents indicated multiple cropping (mixed cropping or intercropping) as their primary cropping practice. The results revealed a significant ($p < .014$) association between the cropping system and gender in sorghum farming (Figure 5). About 27% of female farmers prefer multiple cropping to monoculture, and in contrast, 32% of male farmers choose monocropping. A similar pattern was also observed in millet, where 26% of female farmers practice multiple cropping compared with less than 20% of males.

According to the farmers' perceptions, the reasons for practicing monocropping include the following: 53% of respondents indicated that sorghum and pearl millet yield better and are easier crops to manage when grown as a sole crop. Nearly 12% of respondents pointed out that sorghum and millet crops are mainly grown on dry highlands or mostly infertile soils, where most other crops would not perform well (Figure 5). A further 7% of farmers explained that in most cases, sorghum growth habit and architecture included the crop's taller height, broader leaf shapes, and wider leaf angles, making it difficult for mixed cropping. It was evident that women utilize land as much as possible by having diversified crop enterprises for food self-reliance and diet diversification. It was observed that sorghum and millet are mainly intercropped with legumes such as common beans (red or white kidney beans, lima beans), cowpeas, and groundnuts. Farmers do recognize the benefits of mixed or intercropping for soil fertility improvement (21%, $n = 31$) and moisture conservation (15%, $n = 23$). However, most farmers in this study (59%) prefer intercropping sorghum with pearl millet or cowpeas, considering that both crops are adaptable to dry upland areas where it is not suitable for other food crops.

3.3.3 | Farmers' climate knowledge and gender influence on climate-smart cropping practices

Results revealed that there are many climate-smart cropping systems practices by farmers that provide multiple benefits in terms of productivity, resilience, and mitigation. However, most of the climate-smart technologies and associated practices are not well-defined by farmers, and in most cases, farmers self-define them (Chinseu et al., 2019; Dougill et al., 2021; Hermans et al., 2020). From the farmers' responses, two broad categories of practices were grouped, namely, conventional farming practices and conservation agriculture (Figure 6). The most perceived climate-smart technologies by the farmers included compost manure application, mulching, pit planting, construction of terraces, and selecting drought and early maturing varieties for drought adaptations. Our findings show that male farmers are likely to practice climate-smart technologies due to their access to farm inputs (manure and mulching) more than female farmers. Providing further evidence of gender-based disadvantages in the productive use of soil fertility inputs.

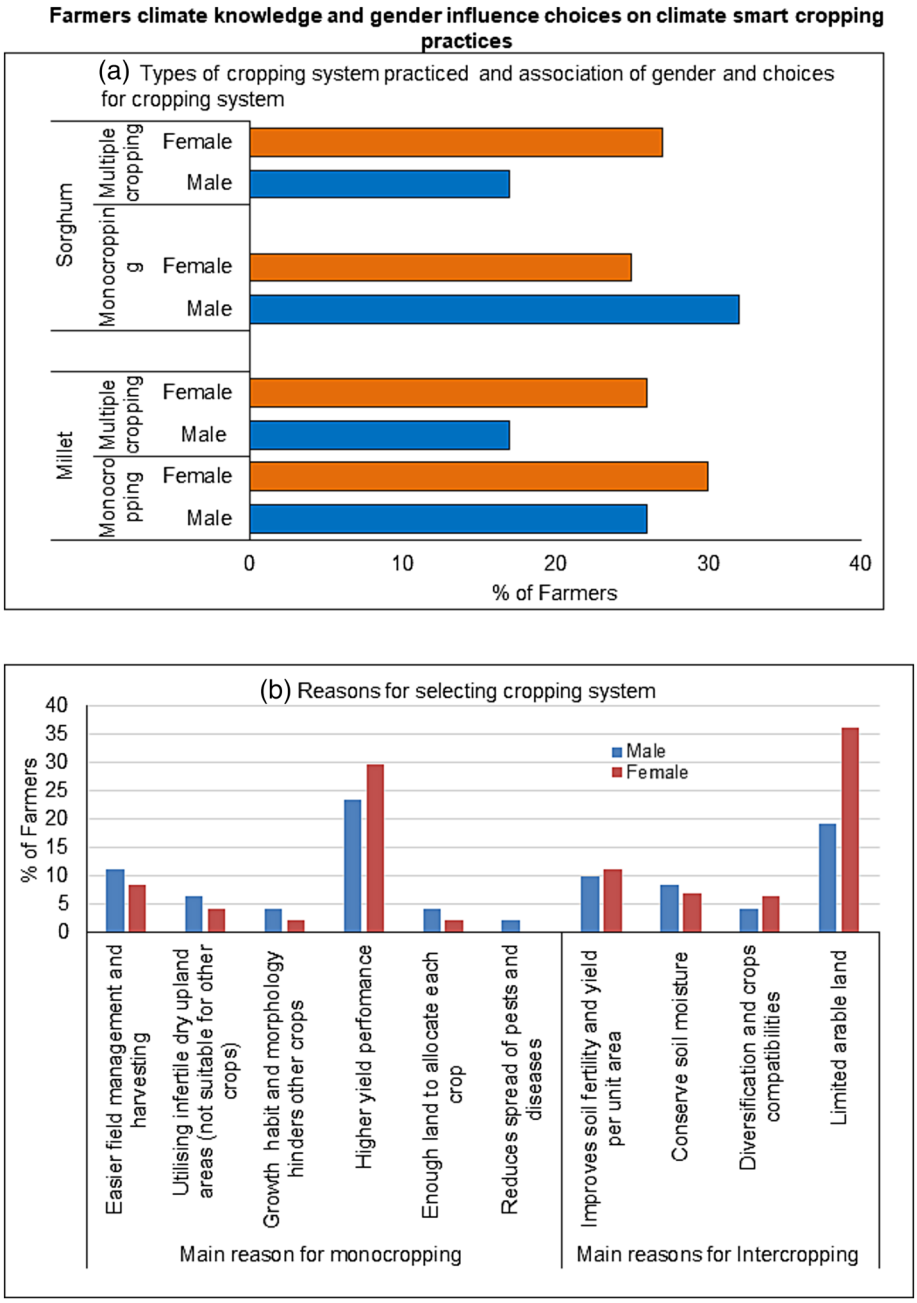


FIGURE 5 Graphs showing the association of gender and choices for cropping systems and technologies among sorghum and pearl millet farmers in Malawi. (a) The categories in the graph indicate the types of cropping systems commonly practiced in sorghum and pearl millet farming, and how gender influences the choices. (b) The reasons for the choices of sorghum and pearl millet cropping system by gender. The results are collective responses from Chikwawa and Nsanje districts ($n = 179$).

The study shows farmers have significant variation in their knowledge and choices of climate-smart technologies in relation to gender. In this study, nearly 19% ($n = 34$) of female respondents are not aware of climate-smart technologies in sorghum and millet farming, compared with less than 10% ($n = 18$) of male farmers. However, 37% and 32% of male and female respondents, respectively, are aware of CSA (Figure 6). This could be caused by inequalities in accessing farming training and extension services, with a focus on cropping systems and climate-smart education. Men indicated that in past years most women were not participating in/not involved in agricultural training, but that equality in entitlement and accessibility to these trainings is improving at a slow pace. The other knowledge gap could be due to education level. According to our data, 14% ($n = 26$) of the male respondents left school at the secondary school level, whereas only 4% ($n = 8$) of the female respondents left school at that level. There was no significant association between gender and source of knowledge, with 22% ($n = 40$) of male respondents and 16% females ($n = 30$) learning more from extension officers, followed by fellow farmers, which implies the importance of technology delivery services and channels for farmers access and adoption (see Figure S1).

Nearly 15% of respondents reported a lack of sufficient knowledge as one of the drawbacks to implementing CSAs in their fields. The study shows that 36% of farmers have limited resources to practice climate-smart cropping systems, for instance, a lack of sufficient land for crop rotation. Almost 20% perceived climate-smart technologies as costly, such as the construction of dams and pit planting. A further 30% indicated that most CSAs are labor-intensive and time-consuming. During FGDs with female farmers, it was stated that

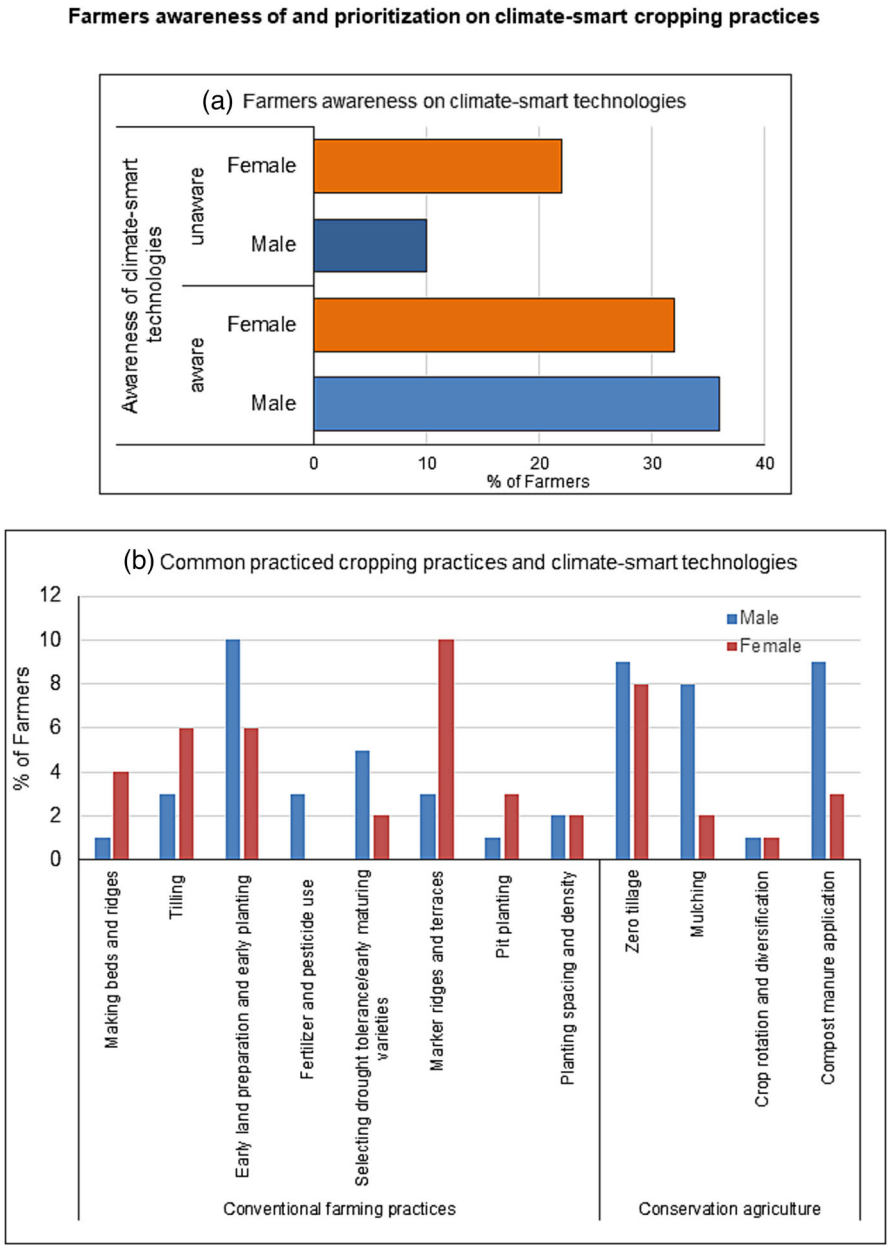


FIGURE 6 Graphs showing farmers' climate knowledge and gender influence choices on climate smart cropping practices in Malawi. (a) Shows sorghum and pearl millet farmers' awareness of climate-smart technologies and cropping practices. (b) Shows preferred climate-smart cropping practices for sorghum and pearl millet by gender. For farmers clarity the climate-smart practices were grouped as conventional farming practices and conservation agriculture. The results are collective responses from Chikwawa and Nsanje districts ($n = 179$).

labor requirements for some of the cropping practices, coupled with a lack of entitlement and control over land, affect their decisions on the technologies compared with male farmers. Other challenges include inaccessibility to improved sorghum and millet varieties and conflicting farming systems, for example, crop residues for mulching and livestock feed (Table 1).

3.4 | Differences in opportunities and challenges for sorghum and millet production among female and male: farmers and stakeholder perspectives

Stakeholders, including researchers, CGIAR representatives, and seed companies, outlined the potential of sorghum and millet as future crops in the context of community resilience to climate change. Tables 2 and 3 outline a summary of challenges and opportunities for sorghum and millets for climate adaptation and resilience that were gathered during household interviews and stakeholder consultations. The most mentioned challenges include seed accessibility for varieties with a wide range of desirable traits. Market availability, knowledge capacity on field and post-harvest technologies, and value addition are still lacking. Therefore, improved market accessibility and promotion of sorghum/millet recipes are some of the opportunities for commercialization of these forgotten crops enhance their utilization.

Another opportunity is the availability of natural genetic diversity within landraces, which can be used to select desirable traits for crop improvement. This was evident from the conservation unit both in situ and at the gene bank. According to the Department of Agricultural Research Services (DARS), there is a growing concern about integrating gender needs during the selection of sorghum breeding

TABLE 1 Farmers' perceived challenges associated with climate-smart technologies practiced in sorghum and pearl millet production across gender in Chikwawa and Nsanje districts of Malawi. Respondents had the opportunity to provide multiple responses to the question if applicable.

Challenges	% of male farmers	% of female farmers	% of total farmers
• Labor intensive and time consuming	13	17	30
• Lack knowledge and insufficient extension support	6	9	15
• Yield loss due to reduced plant spacing/density	5	0	5
• Increases pests' incidences when using mulching	3	0	3
• Limited resources for adopting the technologies	20	16	36
• Inaccessibility and unavailability of improved varieties	7	11	18
• Extreme weather events (flooding, dry spells) ruin technologies	9	10	19

TABLE 2 Farmers challenges on production, post-harvest handling, marketing, and access to support services for sorghum and pearl millet farmers in Malawi by gender.

	Gender of the household head									
	Sorghum					Millet				
Specified challenges	Male		Female			Male		Female		
Seed access	Freq.	Perc.	Freq.	Perc.	*p*-value	Freq.	Perc.	Freq.	Perc.	*p*-value
No	25.	29.1%	8.	11.1%	.006	19.	26.8%	8.	10.7%	.012
Yes	61.	70.9%	64.	88.9%		52.	73.2%	67.	89.3%	
Pest and diseases										
No	26.	30.2%	9.	12.5%	.008	31.	43.7%	25.	33.3%	.200
Yes	60.	69.8%	63.	87.5%		40.	56.3%	50.	66.7%	
Production technologies										
No	34.	39.5%	25.	34.7%	.533	31.	43.7%	33.	44.0%	.967
Yes	52.	60.5%	47.	65.3%		40.	56.3%	42.	56.0%	
Post-harvest handling and storage										
No	33.	38.4%	16.	22.2%	.029	28.	39.4%	24.	32.0%	.348
Yes	53.	61.6%	56.	77.8%		43.	60.6%	51.	68.0%	
Markets										
No	44.	51.2%	36.	50.0%	.884	39.	54.9%	44.	58.7%	.649
Yes	42.	48.8%	36.	50.0%		32.	45.1%	31.	41.3%	
Support services										
No	48.	55.8%	29.	40.3%	.052	36.	50.7%	30.	40.0%	.194
Yes	38.	44.2%	43.	59.7%		35.	49.3%	45.	60.0%	

materials (verbal communication, DARS representative on small grains [sorghum and millets]). Consultations with other crop researchers indicated that sorghum-improved varieties have been released in collaboration with ICRISAT, although availability is still low. According to our discussions with seed companies, for most of past breeding programs, initially, farmers were not involved in the selection of the plant and grain traits of the new varieties. Recent participation by farmers in trait selection has paid off in terms of varieties that perform well and are acceptable to farmers. Therefore, this is an opportunity for farmers to have desirable crop traits according to their priority needs.

4 | DISCUSSION

This study demonstrates that gender and climate risk awareness influence farmer decisions and choices for sorghum and millet varieties and cropping systems in Malawi. Our findings show that the control of such decisions is primarily influenced by societal and cultural norms and systems. We provide evidence that farmers' experiences with climate and weather events shape their decisions on crops and varieties to grow. Due to patrilineal marriage systems in southern Malawi, male farmers have greater control over household decision-making and

TABLE 3 Stakeholder perspective on challenges and opportunities for sorghum and pearl millet crop production in Malawi. The table shows collective responses from sampled stakeholders across sorghum and pearl millet value chain in Malawi.

Challenges	Opportunities
Limited access and availability of improved sorghum and pearl millet seeds.	There is a growing interest and investment in research and crop improvement for under-utilized crop species by research centers such as the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). Availability of diverse landraces in-situ and local gene banks creates a platform as novel sources of traits for crop improvement.
Limited knowledge and capacity related to climate-smart technologies.	Increasing investment in knowledge sharing platforms from government research services and the Consultative Group on International Agricultural Research (CGIAR) centers to farmers.
Unavailability of reliable formal markets for sorghum and millet grains and products.	Increased awareness of dietary diversification and the importance of sorghum and pearl millet-based products as gluten-free creates demand for food and feed.
Limited knowledge of post-harvest handling and value addition.	Potential diversity in recipes and products from sorghum and pearl millet.
Extreme and climate weather events including pests and disease incidences cause crop losses.	Growing interest to develop climate-resilient crops of desirable traits by breeders.

planning, which influences household food resilience and sustainability. Studies have indicated that in a household, female farmers consult partners and are more likely to report joint decision-making than male farmers on most major agricultural crops (Acosta et al., 2020; Van Campenhout et al., 2023). According to our findings for sorghum and millet farming, male farmers believe that women are the sole decision-makers. However, the entitlement to land also influences the selection of and decision-making on cropping systems. Our findings confirm results from other studies on gender inequalities in land ownership in Africa (Partey et al., 2020), indicating that female farmers' choices on cropping practices and varieties are influenced by entitlement to land and other resource accessibility.

Gendered inequality in decision-making goes beyond cropping practices to socially constructed rules of resource accessibility and restricted mobility. This study confirms gender disparities affect sorghum and millet seed accessibility and availability. The data show gender differences in access to quality sorghum and millet seeds, as well as availability challenges. These barriers to the availability of improved varieties have an impact on their selection of a desirable variety that could be suitable for a specific cropping practice for climate resilience.

The findings show trends in the importance of gender-differentiated choices on crop varieties. Understanding phenotypes such as plant architectural traits has an implication on desirable cropping systems and plays a significant role in crop improvement selection. Farmers' preferences are mainly guided by yield and grain characteristics. Yield, in terms of weight and grain size, is preferred by men, while women's interest is beyond yield to post-harvest-related attributes. Wanga et al. (2022) agree that incorporating farmer-preferred traits is key to the adoption of new-generation varieties in traditional sorghum-growing areas. Farmers' preference for local landraces over improved varieties confirms other studies that most landraces are well-adapted to low-input farming systems and possess essential quality traits (Orr et al., 2016). Despite farmers' desire for improved varieties each year, access to good seeds has been a significant challenge in both sorghum and millet growing areas across Africa (Okori et al., 2022). This is the case with many neglected local indigenous crops that do not have well-defined seed systems and value chains.

The findings further indicate significant variation in choices and knowledge on climate-smart cropping systems and technologies among male and female farmers. Farmers are aware of the changes in weather and climate over time in Malawi and that some places are more vulnerable. The high awareness of climate change was evident in how they narrated their experience with the past and recent climate variability, and the findings show consistency with other studies (Nkomwa et al., 2014; Partey et al., 2020). Although local knowledge is a relatively unexploited resource, it is useful for tracking past events and understanding the impacts of climate change on crop production and choices on climate-smart cropping systems (Labeyrie et al., 2021).

This study adds to the findings of Neufeldt et al. (2013) that most of these CSA cropping interventions are knowledge-intensive, location-specific, and require considerable capacity development. We provide evidence that the variation in knowledge on CSA between male and female farmers implies inequalities in accessing the information and training. We show that the increased knowledge of CSA and growing interest in under-researched crop species implies an opportunity for community climate adaptation, species conservation, enhancement, and crop improvement. The vast natural genetic diversity within sorghum and millet landraces is important for the selection of desirable traits and models for understanding climate-resilient crop species for rapid crop improvement. Apart from genotyping challenges, screening for phenotypes associated with superior agronomic traits has been a major bottleneck and costly for plant breeders (Song et al., 2021). Therefore, farmers' participatory selection of traits according to their climate change knowledge coupled with gender needs would guide the pre-selection of desired traits for crop improvement programs. Farmers, along with a multi-disciplinary team, should be involved in developing key traits for breeding pipelines. This is well aligned with the advancement of molecular biology and crop improvement technologies as an opportunity for plant breeders to identify and target desirable traits to meet societal family needs, thereby improving households' food and nutrition across low and middle-income nations.

5 | CONCLUSION AND POLICY IMPLICATIONS

This study focused on the assessment of sorghum and pearl millet crop production and to understand varietal phenotypic traits and cropping system choices and how they are influenced by gender and climate risk awareness in Malawi. These crops receive less attention but are very important as climate-smart crops as adaptations to warmer climates and prolonged drought periods. It is shown that the integration of gender and climate risk awareness influences farmer decisions for production and varietal trait phenotype choices for sorghum and millet. Understanding the diverse gender preferences for different varietal attributes is crucial for ensuring that farmers are involved in decision-making and selection.

The study discovers that new and crucial opportunities concerning sorghum and millet production should target female-headed households and women, as they dominate sorghum and millet production. While recommending a more participatory, farmer-oriented approach to developing climate-smart technologies. We also recognize the need for more socioeconomic research studies to be conducted across underutilized crop species. We conclude that efforts to improve crop adaptation and resilience to climate change in vulnerable regions must pay greater attention to the processes and relations between gender and climate change knowledge bases. The findings from this study offer intriguing considerations to inform government policy decisions and investment plans for gender-responsive, climate-smart adaptation strategies, and resilience programs in Malawi and sub-Saharan Africa.

AUTHOR CONTRIBUTIONS

Conceptualization: Sibongile Zimba and Andrew Dougill. *Implementation*: Sibongile Zimba, Charity Chanza, and Andrew Dougill. *Funding acquisition*: Andrew Dougill and Stefan Kepinski. *Supervision*: Andrew Dougill, Christine Boesch, and Stefan Kepinski. *Original draft preparation*: Sibongile Zimba. *Writing-manuscript*: Sibongile Zimba, Andrew Dougill, and Charity Chanza. *Review and editing*: Sibongile Zimba, Andrew Dougill, Charity Chanza, Christine Boesch, and Stefan Kepinski. All authors have read and agreed to the submitted version of the manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

Data supporting the findings of this study are available from the corresponding author upon request.

ETHICS STATEMENT

The research study forms part of the GCRF-AFRICAP project with Lilongwe University of Agriculture and Natural Resources which gained national ethical approval for AFRICAP household and vulnerability study of the project number BB/P027784/1. In both individual and focus group discussions, participants were required to sign a consent form, and those who were illiterate were permitted to give oral consent. The study participants consisted of adults who were over 18 years old.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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