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Agricultural resource access, decision-making and women's empowerment in climate-vulnerable smallholder agriculture: evidence from Nepal and Bhutan

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Introduction: Building resilient agri-food systems in the face of climate change challenges requires addressing the gendered barriers that undermine farmers' adaptive capacity and limit women's empowerment. This paper examines how inequalities in access to agricultural resources, decision-making authority and information use shape gender-differentiated resilience among farmers in Nepal and Bhutan.

Method: Drawing on primary survey data from a random sample of 240 Bhutanese and 300 Nepalese farmers collected in 2022, the study identifies persistent disparities. Women face reduced access to mechanization, pesticides and credit, particularly in Nepal, and exhibit greater risk aversion in adopting new climate-smart and sustainable soil and crop management practices without assured financial benefits. Women are also more likely to adapt rather than strictly follow formal agricultural advice, but are more engaged in climate-smart practices such as composting. These findings highlight how gendered constraints limit women's ability to respond to climate-related stressors and their recognition as agents of adaptive change. The paper argues for gender-responsive strategies such as equitable access to resources, inclusive extension services and recognition of women's knowledge and decision-making roles as essential to building climate-resilient food systems. Empowering women in these domains enhances both individual resilience and the collective capacity of agri-food systems to withstand and adapt to climate risks.

KEYWORDS

gender-responsive resilience, climate shocks, women's empowerment, agricultural adaptation, resource access, decision-making, Nepal, Bhutan

1 Introduction

1.1 Background, research gaps and objectives

Climate change poses increasing risks to agriculture-dependent populations, particularly in low-and middle-income countries (Ozdemir, 2022; Saeed et al., 2023). In South Asia, where rural livelihoods are tied to the performance and stability of smallholder farming systems, the impacts of climate variability have destabilized food security, rural incomes, and

natural resource management (Rasul, 2021; Aryal et al., 2021; Ahmed et al., 2022). Specifically, in Nepal and Bhutan, rising temperatures, changing precipitation patterns and increased frequency of extreme weather events such as floods and droughts have introduced heightened uncertainty into already fragile agricultural systems (Singh et al., 2021; Poudel et al., 2023; Maharjan et al., 2025). These challenges affect farmers' abilities to plan, invest and sustain production over time. These disruptions have not been gender-neutral. In fact, climate shocks often magnify pre-existing social inequalities and disproportionately affect women's ability to participate fully in agricultural decision-making, access productive resources or build resilience within their communities (Southard and Randell, 2022; Md et al., 2022; Misra and Tewari, 2024).

The recognition that gender matters in climate adaptation is not new. Considerable attention has been paid to solutions for climate adaptation in agriculture, but there remains a critical gap in addressing the various dimensions of resilience, particularly those shaped by gendered power relations. As women's roles in agriculture have expanded particularly in Nepal, where male outmigration has led to the feminization of agriculture, this increased responsibility has not always been accompanied by increased empowerment or autonomy (Adhikari and Hobley, 2015; Slavchevska et al., 2020). Women may manage farms in practice while lacking legal land ownership, access to formal credit or recognition (Slavchevska et al., 2020).

Evidence from recent studies points to lingering challenges, including limited institutional capacity, weak accountability mechanisms and entrenched social norms that continue to restrict women's agency in agricultural systems (Devkota et al., 2022; Rana and Koirala, 2021; Dahal et al., 2022). Specifically, women continue to face limited access to climate-resilient technologies and do not have equal access agricultural information or advisory services tailored to their specific needs (Devkota et al., 2020). Financial services often remain out of reach due to collateral requirements that exclude them, and support for women-led organizations or cooperatives is minimal (Dhakal, 2019; Dhakal et al., 2021). These material barriers are compounded by social norms that restrict women's mobility, participation and authority in household and institutional decision-making (Holmelin, 2019). As a result, empowerment is frequently absent as both a condition for and a result of building resilient agri-food systems. Without addressing these constraints, resilience strategies risk reinforcing existing inequalities rather than overcoming them.

Empowering women in agriculture is increasingly recognized as a matter of social justice and a strategic necessity for enhancing adaptive capacity and achieving broader food system transformation (Visser and Wangu, 2021; Ruben et al., 2021; Asadullah and Kambhampati, 2021). Women's potential, however, is often constrained by structural inequalities in access to land, inputs, information, finance and authority (Manjula, 2021). In response, Bhutan and Nepal have been proactive in developing and refining gender equity and social inclusion policies within their agricultural sectors. These efforts are part of broader national strategies aimed at improving women's participation and addressing structural barriers in rural development. Progress is evident in declining Gender Inequality Index (GII) scores for both countries between 2010 and 2021 which is reflected in the gradual improvements in access to education and economic opportunities (UNDP, 2022). Arguably, some policy and programming focus has remained on integrating women as beneficiaries, rather than transforming the systems and structures that exclude them (Manjula, 2021). Thus, the gap between policy intent and lived realities remains significant.

Although research on gender in agriculture has expanded in South Asia, major gaps remain in understanding the link between gendered constraints and resilience outcomes particularly in terms of how unequal access to resources, decision-making power and information flows affect farmers' ability to respond to climate risks. There is also a scarcity of comparative studies that consider how different institutional and cultural environments influence these patterns and outcomes. This paper addresses these gaps by drawing on household survey data from Bhutan and Nepal to investigate how gender influences three interrelated dimensions of agricultural resilience, i.e., (I) access to and use of production resources, such as machinery, pesticides, and credit (II) attitudes and decision-making processes, including risk tolerance and openness to adopting new practices (III) access to and use of agricultural information, including engagement with extension services and adherence to professional advice (iv) adoption of climate-smart and sustainable agricultural practices. The study tests the hypothesis that gender disparities in these areas not only reflect existing inequalities but also constrain the potential for building inclusive and adaptive agricultural systems in the face of climate stress.

1.2 Conceptual framing of empowerment and adaptive capacity

This research is informed by the Gender and Development (GAD) approach (Muyoyeta, 2007), which highlights the socially constructed nature of gender roles and the structural inequalities that shape access to resources and opportunities. It also draws on household decision-making models particularly the collective and bargaining models to analyze how intra-household power dynamics influence agricultural decision-making and resource use. Together, these frameworks enable a critical interrogation of both individual agency and systemic constraint. In the agricultural context, the GAD approach makes clear that disparities in access to land, credit and inputs are shaped by gendered power relations and institutional norms (Tsige et al., 2020; Quisumbing et al., 2014). These disparities reflect underlying social structures that allocate resources and responsibilities unequally. GAD thus challenges the assumption that all farmers operate under equal conditions, highlighting instead how gendered norms shape both the opportunities and constraints faced by individuals.

Household decision-making models, particularly the unitary and collective frameworks, offer additional explanatory framework. The unitary model conceptualizes the household as a single decision-making entity, led by a head whose preferences dominate (Browning et al., 1994). In contrast, collective and bargaining models treat household members as individuals with separate preferences and unequal access to resources, resulting in negotiated outcomes (Donni and Chiappori, 2011). These models draws attention to how unequal access to land, credit and inputs reflects deeper gendered power relations, which in turn weaken women's capacity to contribute to and benefit from resilience-building efforts. They also underscore that decision-making is often contingent on bargaining positions, which are themselves influenced by broader gender norms.

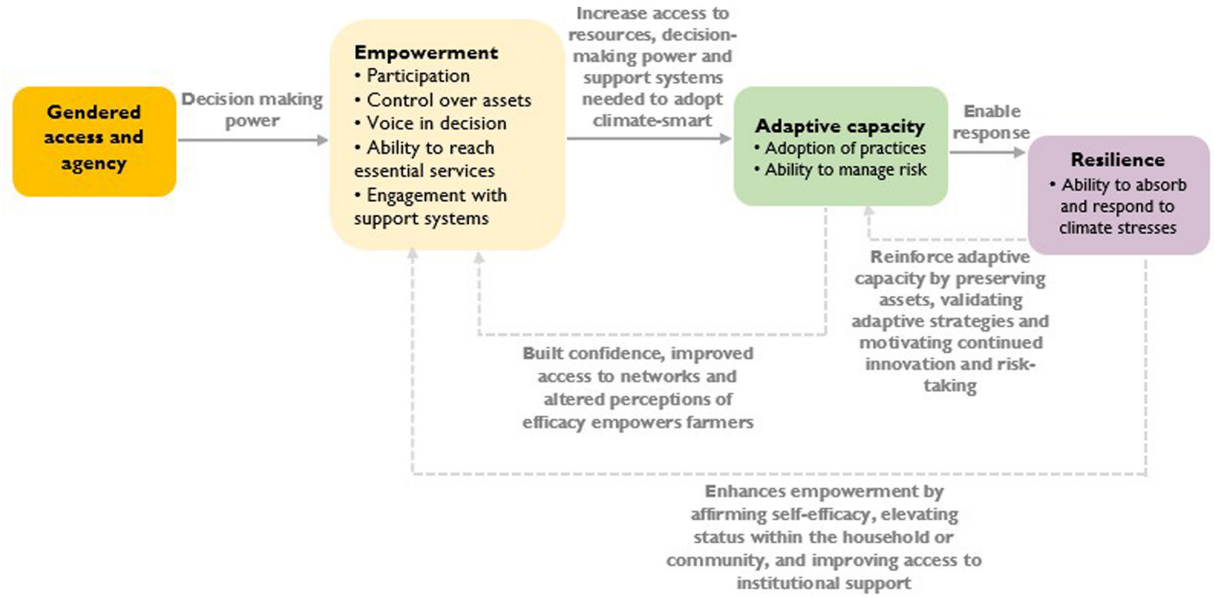

FIGURE 1
Conceptual framework.

The conceptual framework about the causal or theoretical pathways linking gender disparities to adaptive capacity and resilience is summarized in Figure 1. Gender disparities in access to resources, decision-making authority, and mobility play a foundational role in shaping adaptive capacity and resilience among smallholder farmers. The conceptual framework posits empowerment as a multidimensional construct, comprising access to assets, voice in decisions, ability to reach essential services and engage with support systems. These empowerment domains function as mediators linking structural gender disparities to adaptive capacity. For instance, control over agricultural inputs and land increases a farmer's ability to make autonomous decisions about fertilizer use, crop rotation, or mechanization. Likewise, participation in agricultural trainings and willingness to seek advisory support signal both an information advantage and a greater sense of agency. Adaptive capacity is defined here in behavioral and practical terms. It includes the adoption of practices such as composting, crop residue use, machinery use and organic fertilizer application. These practices reflect both awareness of climate risks but also the capacity to act despite uncertainty. Risk attitudes such as readiness to experiment with new practices or reluctance to change without guaranteed financial benefits serve as behavioral indicators of adaptive potential. Resilience, in this framework, is treated as a longer-term outcome linked to adaptive capacity. It includes the ability to maintain or recover productivity after climatic or economic shocks. The framework acknowledges feedback loops, where gains in adaptive capacity, for example, through successful practice adoption reinforce empowerment by building confidence, improving access to networks and altering perceptions of efficacy. These feedbacks are important because they suggest that empowerment is not static; it evolves with experience and success. Also, farmer who gains greater voice in household decisions may begin to take more initiative on the farm. If this initiative leads to improved outcomes, the result both increased resilience and empowerment. Figure 2 summarizes how these theoretical

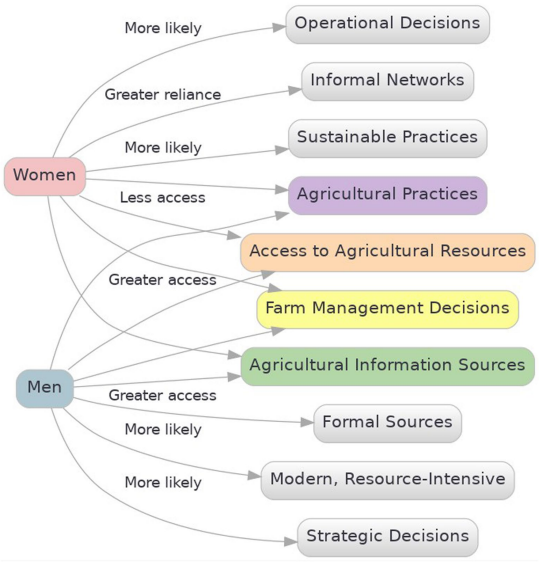

FIGURE 2
Hypothesized gender disparities in agricultural resource access and practices.

perspectives inform the study's hypotheses regarding gender disparities in agricultural resource access and use based on prior studies that women in climate-affected farming systems often face systematic barriers which in turn limit their ability to adopt or scale climate-smart practices.

The remainder of the paper is organized as follows. The Methods section sampling and methods used for data collection and analysis. This is followed by a presentation of key findings across the four thematic areas, i.e., resource access, decision-making, information use and practice adoption. The discussion section interprets these findings

in light of broader debates on gender, empowerment and resilience in South Asian agriculture as well as drawing policy implications. The final section concludes with recommendations for gender-responsive strategies to support climate adaptation and system transformation.

2 Materials and methods

2.1 Study area

Nepal and Bhutan offer compelling settings for examining agricultural resource access, decision-making, women's empowerment and resilience in smallholder agriculture. Both countries are highly exposed to climate risks and heavily reliant on small-scale, rain-fed farming systems (CIAT World Bank, 2017). Both countries are characterized by distinct topographies which range from subtropical lowlands to rugged mountain terrains. Nepal's geography is divided into three major regions. The Terai (lowland plains), the Hill region, and the Mountain region (Gurung et al., 2024). Many Nepalese farmers practice subsistence farming, with a recent shift towards cultivation of high-value cash crops (Holmelin, 2021). Soil erosion, difficult terrains, and unpredictable weather patterns are significant challenges for Nepalese farmers (Krupnik et al., 2021).

Bhutan also has varying altitudes that impact its agricultural practices. Farming in Bhutan is similarly constrained by steep slopes and a lack of extensive flatlands (Neuhoff et al., 2014). Bhutan has traditionally focused on maintaining environmental sustainability, which is embedded in its national philosophy of Gross National Happiness (Ansari, 2017; Wangmo and Iwai, 2018). Trashigang, a key agricultural district in eastern Bhutan, is characterized by its diverse agro-ecological zones, allowing farmers to grow a variety of crops like maize, millet, potatoes and vegetables (Akamatsu, 2012; Ansari, 2017). Subsistence farming is predominant with small, fragmented plots cultivated on steep slopes which makes mechanization challenging.

Notably, both countries differ in important ways in terms of socio-cultural norms, agricultural structures and policy frameworks. Nepal is characterized by entrenched patriarchal systems, with significant gender inequalities in land ownership, formal employment and representation (Balayar and Mazur, 2022). However, patterns of male outmigration particularly from the agriculturally productive Terai region have led to an increasing number of women managing farms, either as de facto heads of household or through joint decision-making with male relatives. This shift has increased the visibility of women in agriculture, but has not always translated into formal recognition or empowerment. Bhutan, by contrast, has a more matrilineal tradition in many regions, where land inheritance may pass through women (Pain and Pema, 2004; Sariyev et al., 2020). Bhutan's development philosophy, guided by Gross National Happiness (GNH), has explicitly included gender equity as a pillar, but gaps remain in operationalizing this commitment in rural agricultural systems.

2.2 Sampling and data collection

This study draws on primary household survey data collected in 2022 from smallholder farmers in Nepal and Bhutan. Eligible respondents in both countries met the following inclusion criteria. They had to be 18 years or older, currently own or rent farmland, grow at least one of five major crops in the region (rice, wheat, maize, potato, or chilli) and have been involved in farming decisions during the previous growing season. Local authorities in Bhutan and key informants in Nepal facilitated the sampling process by listings all households engaged in agriculture in their various locations. This was supported by the list maintained by agriculture extension officers which contain further details such as the size of land cultivated and type of land cultivated. The use of multiple lists ensured the sampling was not biased by the exclusion of certain farmers, which is often a risk in incomplete or outdated records. This approach also allowed for a precise identification of households for random selection within the multistage sampling framework.

In Nepal, data was obtained after multistage sampling across Koshi, Madhesh, and Far Western provinces (Figure 3). These three provinces were randomly selected out of the those that make up the Terai. The study focuses on the Terai due to its agricultural role. Within each province, four villages were randomly selected, and from each village, 25 farming households were also randomly selected. This resulted in 300 Nepalese farmers being surveyed. In Bhutan, the survey focused on Trashigang Dzongkhag. Trashigang has one of the highest number of households directly engaged in agriculture and also has one of the largest land areas used for agriculture (Figure 4). The farmers surveyed had different socio-economic backgrounds and farm sizes but shared similar types of crops grown. The survey through multistage sampling covered all the Chiwogs in selected Gewogs and data was obtained from 240 Bhutanese farmers who were also randomly selected. The sampling steps are summarized in Table 1.

Survey instruments were developed using best practices in farm household survey design, drawing on guidelines from the National Integrated Household surveys and similar large-scale agricultural surveys. Instruments were pre-tested with different cohorts of respondents per country to identify issues in clarity, sequencing and length. Feedback from the pre-test informed several modifications to improve comprehension and flow. Enumerator training was conducted in each country, covering survey protocol, ethical procedures and neutrality in questioning. Several potential biases were anticipated and mitigated through design and field protocols. Recall bias was minimized by limiting the reference period to the previous and most recent growing seasons. Social desirability bias was addressed through assurances of confidentiality, the use of indirect questioning techniques where it was appropriate and by explicitly informing respondents that there were no right or wrong answers. While the sampling design ensures internal representativeness within the selected regions of Nepal and Bhutan, findings are most directly generalizable to smallholder farming households in the Terai region and Trashigang Dzongkhag.

2.3 Analysis

The survey gathered information on the demographic and socio-economic backgrounds of the farmers, their access to and use of production resources, their attitudes and decision-making processes, their access to and use of information, and their adoption of various agricultural practices. The data collected were analyzed using chi-square test, *t*-test and logistic regression to understand whether gender differences exist in the sample. In the logistic

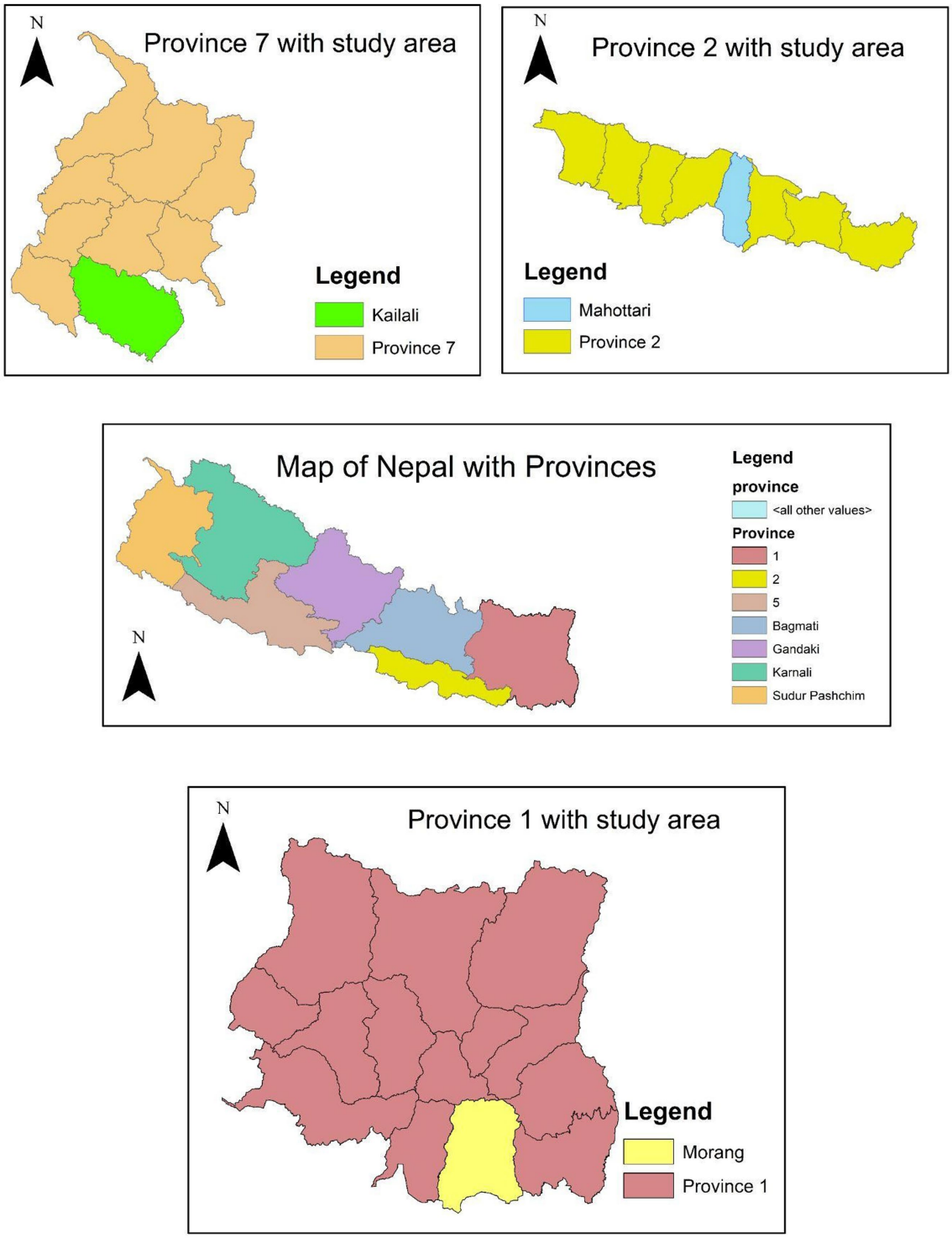

FIGURE 3
Nepal study area.

regression, the central explanatory variable of interest is whether the household is headed by a female, with additional controls included to account for demographic and farm-related factors. These include the farmer's age, years of formal education, farming experience, farm size and whether the farmer is a member of an agricultural organization. The four outcome variables capture different aspects of farming behavior, i.e., whether the farmer has access to mechanization, whether they incorporate fertilizer after application, whether they follow advice exactly as given, and whether they display high levels of risk aversion. These variables are selected to reflect resource access, responsiveness to agronomic

FIGURE 4
Bhutan study area.

guidance and individual behavioral tendencies relevant to farm management.

For each binary outcome ∈{0,1}, the model takes the form:

$$\log\left(\frac{P(Y=1)}{1-P(Y=1}\right) = \beta + \beta_1 \cdot FemaleHH + \beta_2 \cdot Age + \beta_3 \cdot Education + \beta_4 \cdot Experience + \beta_5 \cdot Member + \beta_6 \cdot FarmArea + \varepsilon i$$

Where,

Yi = Binary outcome variables (access to mechanization, whether they incorporate fertilizer after application, whether they follow advice exactly as given, and whether they display high levels of risk aversion, respectively)

FemaleHH = 1 if female-headed household, 0 otherwise
Age = Age of the respondent (years)
Education = Years of education
Experience = Years of farming experience
Member = 1 if member of a farmer organization, 0 otherwise
FarmArea = Farm size in hectares
ε = Error term (robust standard errors reported)

3 Results

3.1 Description of the farmers

Table 2 provides a summary of various demographic and socio-economic characteristics between male and female farmers in Bhutan and Nepal. In Nepal, female farmers are, on average, older than male farmers, with an average age of 50.1 years compared to 48.7 years for males. Male farmers have a higher average formal education of 5.4 years, while female farmers have 3.3 years. Male farmers have slightly more farming experience than

TABLE 1 Description of the sampling procedure.

Sampling steps	Nepal	Bhutan
Sampling area	All provinces in the Terai region	Trashigang Dzongkhag
Selection of primary sampling units	Three provinces randomly selected from Terai region provinces Koshi, Madhesh, and Far Western	Four randomly selected Gewogs (village blocks), Kanglung, Khaling, Thrimshing, Yangneer
Number of stages	Multistage sampling (2 stages)	Multistage sampling (2 stages)
Selection of villages/chiwogs	Randomly selected within each province	Randomly selected within all Chiwogs (villages) covered in the Gewogs
Number of villages/chiwogs	12 villages (Four villages per province)	Eight Chiwogs (Two per Gewogs)
Selection of households/farmers	25 farming households per village	30 farming households per Chiwogs
Total number of respondents	300 farmers	240 farmers

Source: Authors own.

TABLE 2 Characteristics of male and female farmers in Bhutan and Nepal.

Variable	Bhutan		Nepal	
	Male (56.7%)	Female (43.3%)	Female (14%)	Male (86%)
Age (years)	44.8	47.3	50.1	48.7
Education (years of formal)	3.1	1.3	3.3	5.4
Farming experience (years)	31.3	33.9	27.9	30.4
Farm size (acre)	0.67	0.72	0.59	0.48
Training				
Yes	15.2%	16.7%	15.8%	7.1%
No	84.8%	83.3%	84.2%	92.9%
Membership of organization				
Yes	14.5%	13.8%	23.1%	31.1%
No	85.5%	85.2%	76.9%	68.9%

Source: Authors own.

female farmers, with 30.4 years compared to 27.9 years for females. Farm sizes are generally larger for female farmers (0.59 acres) compared to male farmers (0.48 acres). A lower percentage of male farmers have received training (7.1%) compared to female farmers (15.8%). Male farmers are more likely to be members of an organization, with 31.1% reporting membership, in contrast to 23.1% of female farmers.

In Bhutan, female farmers are also slightly older than male farmers, with an average age of 47.3 years compared to 44.8 years for males. There is a difference in formal education years, with male farmers averaging 3.1 years and female farmers averaging only 1.3 years. Female farmers have more farming experience, averaging 33.9 years compared to 31.3 years for males. The average farm size is larger for female farmers at 0.72 acres, compared to 0.67 acres for male farmers. Training is marginally more common among female farmers at 16.7%, compared to 15.2% for male farmers. Membership in organizations is nearly equal, with 14.5% of male farmers and 13.8% of female farmers reporting membership.

3.2 Production resources access and use

Figure 5 shows a disparity in machinery use (i.e., small farm equipment and hand held or tractor driven) by gender, with males having a higher rate of usage at 92%, while females have a lower usage rate at 67%. This suggests that while a majority of both males and females use machinery, males are more likely to do so. Also, approximately 56% of males did not get a loan when needed compared to around 36% of females who did not get a loan when needed.

Table 3 presents a statistical comparison of production resource access and use between males and females in Bhutan and Nepal, using the Chi-square (χ^2) test. In Bhutan, there is no significant difference between females and males in the access and use of production resources except level of mechanization [$\chi2(2) = 6.49$, $p = 0.039$]. In contrast, in Nepal, a statistically significant difference is observed between females and males in the use of agricultural machinery [$\chi2(1) = 6.70$, $p = 0.01$], use of pesticides [$\chi2(1) = 5.67$, $p = 0.017$] and access to loans [$\chi2(1) = 4.86$, $p = 0.088$].

3.3 Farmers attitudes and decision-making

Figure 6 indicates that female farmers in Bhutan show a greater inclination towards lower risk levels. However, both genders show minimal willingness to engage with the highest risk level. A similar pattern is observed among Nepalese farmers. Also, compared to males, females in Nepal are less inclined towards

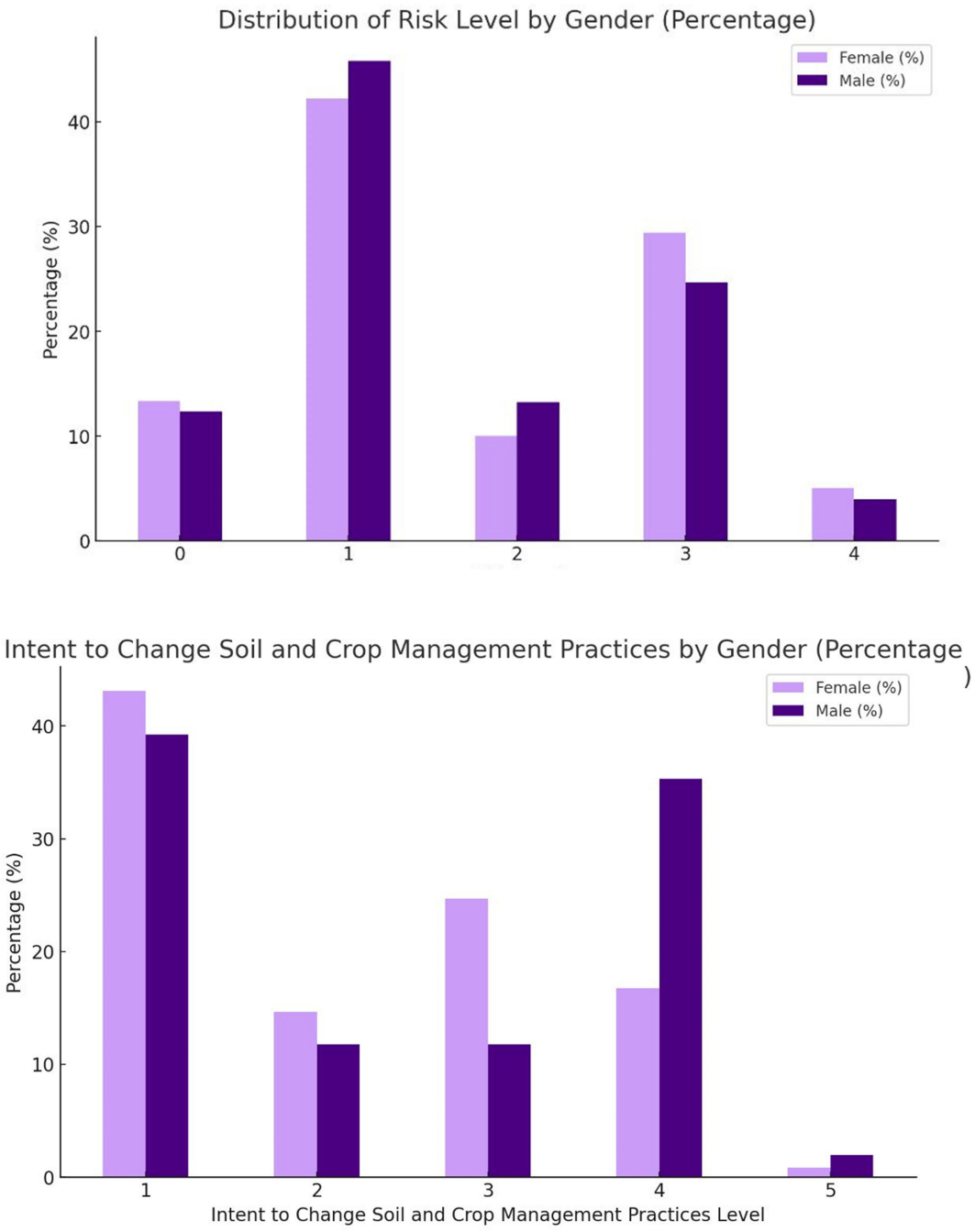

FIGURE 5
Risk taking and intent to change soil management practice by gender.

changing their soil and crop management practices except there was certainty their financial situation improves because of the change.

Table 4 reports the results of Chi-square tests assessing the significance of gender differences in various attitudes and decision-making processes related to farming in Bhutan and Nepal. In Bhutan, significant gender differences were observed in some attitudes towards farm decision-making practices. Specifically, there was a difference in how the decision is reached on fertilizer quantity use, [$\chi2(5) = 12.53$, $p = 0.028$] between males and females. Also, there was a marginally significant difference [$\chi2(4) = 8.34$, $p = 0.08$] in the general willingness to take risks, suggesting a variation in risk tolerance between genders in Bhutan.

In contrast, in Nepal, the results show gender differences in several farm decision-making attitudes. Females and males differed significantly in their propensity to maintain the status quo over trying new soil and crop management practices [$\chi2(4) = 12.83$, $p = 0.005$] their intentions to change practices contingent upon expected financial improvement [$\chi2(4) = 11.28$, $p = 0.024$] and the overall readiness to take risks [$\chi2(4) = 18$, $p = 0.003$].

TABLE 3 Gender comparison in the access and use of production resources.

Resource	Bhutan (male vs. female)			Nepal (male vs. female)		
	χ^2	DF	*p*-value	χ^2	DF	*p*-value
Tenure status of plot	1.47	2	0.481	0.54	2	0.463
Use machinery	0.03	1	0.852	6.70	1	0.010**
Level of mechanization	6.49	2	0.039*	0.88	2	0.645
Labor hors$^{\phi}$	−1.20	276	0.23	0.13	96	0. 900
Organic fertilizer	0.01	1	0.932	0.20	1	0.652
Use pesticides†				5.67	1	0.017**
Access to loans	2.12	1	0.146	4.86	1	0.088*

†No use by both genders, $^{\phi}$ T-test. *** Indicates significance at 1%. ** Indicates significance at 5%. * Indicates significance at 10%. Source: Authors own.

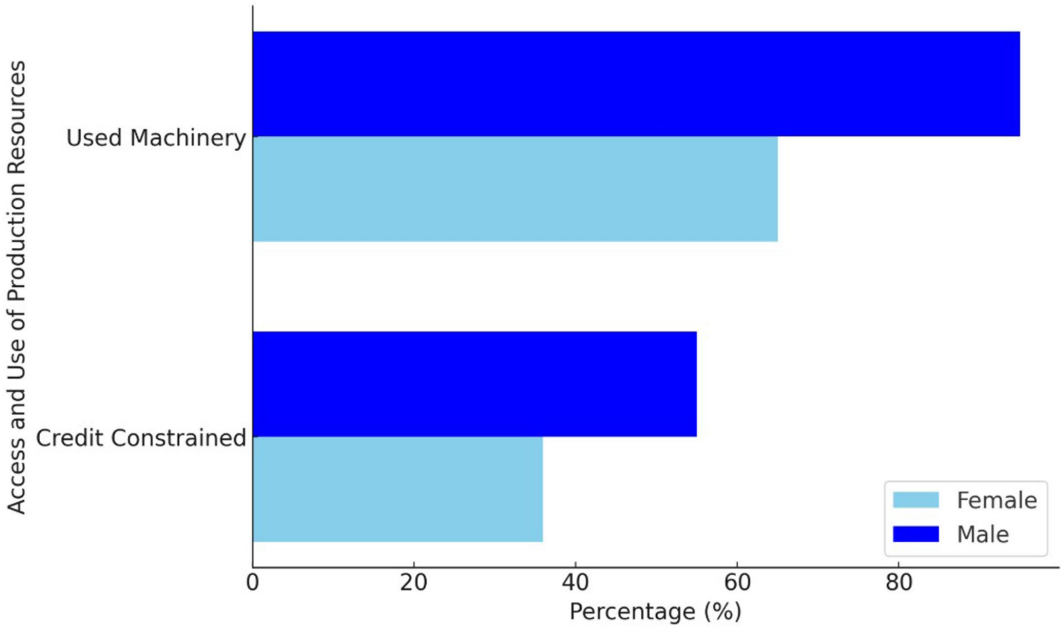

FIGURE 6
Percentage of machinery use and credit constrain by gender.

TABLE 4 Gender-based differences in attitudes and decision-making in agriculture.

Attitudes	Bhutan *(male vs. female)*			Nepal *(male vs. female)*		
	χ^2	DF	*p*-value	χ^2	DF	*p*-value
Maintain the status-quo rather than trying new soil and crop management practices	1.02	4	0.907	12.83	4	0.005***
Only intend to change soil and crop management practices if certain that financial situation improves because of the change	3.35	4	0.502	11.28	4	0.024**
Prepared to take risks generally	8.34	4	0.080*	18.00	4	0.003***
Decisions on quantity of fertilizer	12.53	5	0.028*	0.389	5	0.823

*** Indicates significance at 1%. ** Indicates significance at 5%. * Indicates significance at 10%. Source: Authors own.

3.4 Access and use of information

A smaller percentage of males (4%) use government guidelines compared to females (35%). In addition, a significant difference is seen in the use of guidelines from private companies, where males have a much higher percentage (89%) compared to females (65%). This indicates that males are more inclined to refer to materials provided by private companies. In terms of adherence to professional advice

regarding fertilizer use, a higher percentage of males (55%) appear to follow professional advice exactly compared to females (33%). This implies that a majority of females are more likely to modify advice after contact with professional rather than following it exactly.

Table 5 shows the results of Chi-square tests for gender differences in the access and use of agricultural information in Bhutan and Nepal. The findings show similarities in how men and women access and use agricultural information in these two countries. In Bhutan and Nepal, a significant gender disparity was observed in the in precision following external advice on fertilizer use [$\chi2(1) = 5.50$, $p = 0.019$] and [$\chi2(1) = 7.01$, $p = 0.008$]. Further, in Nepal, there was were statistically significantly different between gender in whether agricultural guidance or/tools was used for fertilization information [$\chi2(2) = 25.43$, $p < 0.001$].

3.5 Adoption of agricultural practices

Both males and females incorporate synthetic fertilizer after broadcasting in Bhutan and the same practice for organic fertilizer in Nepal. However, in Nepal, a higher percentage of females use this method (79%) compared to males (approximately 27%). The next most common method is broadcasting the fertilizer and then leaving it on the surface. In this category, more males than females use this method. Fertigation is the least used method by both genders. There is also a higher percentage of females than males that produced their own compost. Also, 63% of male farmers compared to 42% of females either incorporated crop residue into the soil or left it on the field as mulch.

Table 6 presents the results of Chi-square tests for gender differences in the adoption of various agricultural practices in Bhutan and Nepal. The findings reveal contrasts in how men and women engage with agricultural activities in these two countries. In Bhutan, a significant gender disparity was observed in the method of application for synthetic fertilizer [$\chi2(1) = 11.94$, $p = 0.063$]. In Nepal, there were statistically significant difference between gender in methods of organic fertilizer application [$\chi2(4) = 23.67$, $p < 0.001$], use of compost [$\chi2(1) = 11.85$, $p < 0.001$] and the use of crop residue [$\chi2(17) = 31.46$, $p = 0.018$].

3.6 Results assessing the potential confounding variables that might influence gendered outcomes

The logistic regression in Table 7 for and Bhutan and Table 8 for Nepal estimates gendered farmers behavior and structural constraints across the two countries. Each table reports odds ratios for four binary outcomes, i.e., access to mechanization, use of improved fertilizer methods, following agricultural advice exactly and a high risk aversion. Independent variables include gender of the household head, age, education, years of farming experience and total farm size. Farmer-organization membership was included in the Bhutan model but excluded from the Nepal model. This exclusion was due to the coefficient for farmer-organization membership in the mechanization model being unstable owing to complete or quasi-separation. In Bhutan, gender was statistically significant only in the model predicting whether farmers follow advice exactly. The odds ratio for female-headed households indicates they are significantly less likely than male-headed households to adhere strictly to extension recommendations. In contrast, the Nepal model show two notable gender effects. First, mechanization access is strongly gendered. Female-headed households are 94% less likely to have access to mechanization compared to their male counterparts. Second, in the

TABLE 5 Gender-based differences in access and use of information.

Attitudes	**Bhutan** *(male vs. female)*			**Nepal** *(male vs. female)*		
	χ^2	DF	*p*-value	χ^2	DF	*p*-value
Attended agric. Trainings	0.10	1	0.751	1.51	1	0.220
Actively seek help and advice when making decisions on the handling and use of fertilizers	0.28	1	0.594	0.05	1	0.815
Follow advice on fertilizer exactly	5.50	1	0.019**	7.01	1	0.008***
Used agricultural guidance or/tools for fertilization	3.47	2	0.324	25.43	2	0.000***

*** Indicates significance at 1%. ** Indicates significance at 5%. * Indicates significance at 10%. Source: Authors own.

TABLE 6 Gender disparities in the adoption of agricultural practices.

Technology/Practice	**Bhutan** *(male vs. female)*			**Nepal** *(male vs. female)*		
	χ^2	DF	*P*-value	χ^2	DF	*P*-value
Crops grown in rotation	11.60	10	0.313	0.77	10	0.979
Type of soil cultivation	3.36	2	0.186	3.31	2	0.346
Method of application for synthetic fertilizer	11.94	6	0.063*	4.33	6	0.228
Method of application for organic fertilizer	3.40	4	0.493	23.67	4	0.000***
Use compost	0.18	1	0.671	11.85	1	0.001***
Crop residue use	52.81	48	0.293	31.46	17	0.018**

*** Indicates significance at 1%. ** Indicates significance at 5%. * Indicates significance at 10%. Source: Authors own.

TABLE 7 Logistic-regression results for gender-related outcomes among farmers in Bhutan (odds ratios, robust s.e. in parentheses).

Variable	Access to mechanization	Incorporating fertilizer after application	Follow advice exactly	High risk aversion
Female HH head	0.98 (0.28)	0.95 (0.26)	0.37** (0.14)	0.75 (0.22)
Age (years)	1.02 (0.01)	1.00 (0.01)	0.98 (0.02)	1.00 (0.01)
Education (years)	0.99 (0.06)	0.96 (0.06)	1.05 (0.07)	1.06 (0.06)
Experience (years)	0.99 (0.01)	1.00 (0.01)	0.99 (0.01)	0.99 (0.01)
Farmer-org member	1.35 (0.55)	0.94 (0.37)	0.76 (0.41)	1.89 (0.76)
Farm area (ha)	1.04 (0.03)	1.06 (0.03)	1.04 (0.04)	1.02 (0.03)

*** Indicates significance at 1%. ** Indicates significance at 5%. * Indicates significance at 10%. Source: Authors own.

TABLE 8 Logistic-regression results for gender-related outcomes among farmers in Nepal (odds ratios, robust s.e. in parentheses).

Variable	Access to mechanization	Incorporating fertilizer after application	Follow advice exactly	High risk aversion
Female HH head	0.06** (0.06)	3.10 (3.27)	0.37** (0.13)	2.46 (1.20)
Age (years)	0.96* (0.02)	0.97 (0.02)	0.98 (0.01)	1.04** (0.01)
Education (years)	0.82 (0.19)	0.82** (0.05)	1.01 (0.07)	0.96 (0.07)
Experience (years)	1.12*** (0.02)	1.04* (0.02)	1.03** (0.01)	0.95*** (0.01)
Farm area (ha)	1.01 (0.02)	1.01 (0.01)	0.98 (0.01)	0.98 (0.01)

*** Indicates significance at 1%. ** Indicates significance at 5%. * Indicates significance at 10%. Source: Authors own.

case of advice-following behavior, women are also significantly less likely to follow formal agricultural advice exactly. This matches the pattern observed in Bhutan and suggests that female farmers in both countries tend to adjust or selectively apply recommendations rather than following them prescriptively.

4 Discussion

This study has shown that in both Bhutan and Nepal, there are gendered disparities in access to resources, information and decision-making authority which could constrain women's empowerment and the overall resilience of farming communities. While women have increasingly central roles in agricultural labor and management, particularly in contexts of male out-migration, they continue to face systemic and structural constraints that weaken their ability to adapt to climate variability and benefit from the ongoing transformation of agri-food systems. This discussion reflects on these empirical findings through the perspective of gender-responsive resilience, drawing implications for empowerment, policy design and adaptive capacity.

4.1 Gendered access to resources and the foundations of unequal resilience

The empirical evidence from this study reinforces a long-standing observation in gender and development research that unequal access to productive resources is a primary barrier to building climate resilience in agrarian societies. Across both Bhutan and Nepal, women's constrained access to agricultural inputs and technologies reflects deeper structural inequalities that shape who is able to adapt, invest and respond to climate risks. This finding is consistent with broader regional analyses (Quisumbing et al., 2014; Rola-Rubzen et al., 2020), which have emphasized that gender equality is both a matter of rights and a strategic necessity for enhancing adaptive capacity. When women lack the tools, information and decision-making authority needed to implement adaptive strategies, the resilience of entire farming systems is compromised.

In Bhutan, where matrilineal inheritance systems in some regions afford women relatively stronger land rights (Sariyev et al., 2020), one might expect more equitable conditions for access and control over productive resources. However, gender disparities in mechanization access indicates that legal entitlement alone is insufficient. Even in contexts where land ownership is more equitable, women's ability to convert land into productive advantage depends on whether they can access complementary inputs.

In Nepal, women's significantly lower use of machinery, pesticides and credit reflects a broader pattern of gendered exclusion from the formal channels through which technological and financial resources are distributed. While policies may nominally promote equal access, implementation often falls short due to entrenched assumptions within extension services, credit institutions and agricultural cooperatives that privilege male farmers as default beneficiaries (Manfre et al., 2013; Farnworth et al., 2019). The findings also support previous findings that many female farmers remain reliant on intermediated access through borrowing equipment through male relatives, attending training sessions only when invited by a spouse, or securing credit through informal guarantees thereby limiting their autonomy and decision-making capacity. This gender gap in access is particularly problematic when considered through the lens of climate resilience. As studies by Carr and Thompson (2014), Adzawla et al. (2019), and Kwauk and Casey (2022) have highlighted, resilience extends beyond technical inputs to the agency to use those inputs strategically in response to changing conditions. When women lack independent control over critical resources such as machinery or credit, their capacity to

implement adaptive practices (whether that means shifting planting dates, diversifying crops or adopting technologies) is significantly diminished.

The findings on credit access is contrary to conventional assumptions about gender-based financial exclusion. In Nepal, recent expansions in microfinance services have increased women's participation in formal lending schemes, challenging earlier characterizations of the access needs to be accompanied with autonomy to avoid undermining the long-term effectiveness of adaptation investments if women are unable to prioritize resilience-enhancing expenditures. Also, for women farmers managing small plots and balancing significant care responsibilities, credit alone may not enable the transition to climate-smart practices unless bundled as part of an integrated resilience strategy that simultaneously addresses structural barriers to agency and decision-making.

4.2 Decision-making, risk and the uneven distribution of adaptive capacity

The capacity to make strategic decisions under conditions of uncertainty is fundamental to climate resilience. This study finds that women's participation in critical farm decisions particularly those involving risk-taking and changes to established practices remains constrained by social norms, household power dynamics and asymmetries in access to information and resources. In Nepal, the female farmers express a significantly greater reluctance to alter soil and crop management practices unless there is a guaranteed financial benefit. Similarly, in Bhutan, women demonstrate lower willingness to take agricultural risks and a more cautious stance toward fertilizer use. While such behavior may be interpreted as a form of risk aversion, it is better understood as a rational adaptation to unequal conditions. Simmons et al. (2024), points out that women often face higher costs of failure. Without adequate safety nets or fallback options, trying a new practice that fails can have lasting consequences for a woman.

This pattern challenges the conventional assumption that women's reluctance to adopt climate-smart innovations is due to informational deficits or conservative mindsets. Instead, it aligns with the literature on bounded rationality and constrained choice, which emphasizes that decisions are made within specific contexts of constraint and opportunity (Musshoff and Hirschauer, 2011; Day, 2019). Also, resilience cannot be built through individual decision-making alone as it is also shaped by the institutional and collective spaces in which decisions are made. In both Bhutan and Nepal, women's participation in agricultural cooperatives and farmer organization remains limited. For climate resilience strategies to be effective, they must therefore address the availability of options as well as the distribution of authority over those options. Decision-making must be supported through structural changes that increase women's control over resources, reduce their vulnerability to failure and create institutional spaces where their preferences are taken seriously.

4.3 Unequal access to agricultural advice and information

Information is a critical input for climate adaptation. Timely, credible, and actionable agricultural information can enable farmers to adjust in planting dates, input application, or resource allocation in response to climatic changes. However, the effectiveness of such information depends on who receives it, how it is interpreted, and whether it can be acted upon. This study reveals important gendered patterns in the access and use of agricultural information in Bhutan and Nepal, particularly in relation to fertilizer guidance and adherence to professional advice. Male farmers were significantly more likely to follow formal recommendations exactly, while female farmers were more inclined to modify or reinterpret such advice based on their own context and experience. These findings point to asymmetry that reflects systemic inequalities in the framing, delivery and institutional credibility of information sources. As previous studies have documented (e.g., Rola-Rubzen et al., 2020; Medendorp et al., 2022; Naher and Karim, 2023), agricultural extension systems across South Asia either often default to male-centric modes of delivery, conduct trainings at times and places that exclude women, use male agents as intermediaries or treat male farmers as the primary clients. These patterns also reflect and reinforce gendered assumptions about who is considered a legitimate knowledge user.

This adaptive modification of formal advice should not be dismissed as a deviation from best practice. Rather, it may represent a form of situated knowledge grounded in lived experience, local conditions and labor requirement realities. The idea that farmers, particularly women, co-produce knowledge by integrating formal recommendations with contextual understanding is supported by work on adaptation using indigenous knowledge (Jiri et al., 2015; Wang, 2015). Women's modifications to fertilizer application, for example, may reflect careful observation of soil conditions, household labor constraints, or seasonal variability which may be factors often overlooked in standardized extension messages. This tendency to equate divergence from recommended practice with error reinforces a top-down model of knowledge transfer that marginalizes local expertise and fails to reflect the gendered realities of farming and possibly excludes women from being seen as innovators in their own right. As noted by Farnworth and Colverson (2015), closing the gender knowledge gap requires not only improving access to information but also transforming how knowledge is valued and whose knowledge counts.

At the same time, the study's finding that male farmers rely heavily on private sector guidance introduces a separate but related concern. Input dealers, fertilizer suppliers, and other agribusiness actors often serve as de facto extension providers, particularly where public systems are overstretched. While these sources may offer timely and product-specific advice, their recommendations could be arguably driven by commercial incentives. The widespread reliance on such sources by male farmers, combined with the exclusion of women from both public and private advisory systems, suggests a fragmented and uneven knowledge environment. In this context, promoting resilience requires more than expanding the volume of information available. It demands a deliberate restructuring of how agricultural knowledge is produced, validated and delivered. Gender-responsive extension, therefore, must address both the supply and demand sides of knowledge systems by ensuring that services are accessible to women, while also recognizing the value of the knowledge they already hold and generate. In practical terms, this means investing in female extension agents, designing training content that aligns with women's needs and constraints, and creating spaces for two-way knowledge exchange. It also requires mechanisms for quality control and accountability in private sector

advisories, to ensure that recommendations support both productivity and resilience goals. In both Bhutan and Nepal, this will entail working within existing institutional frameworks while pushing for reform where exclusionary practices persist.

4.4 Practice adoption and the hidden contributions of women to sustainability

The adoption of agricultural practices is often framed in terms of technological uptake and productivity gains. However, in climate-affected farming systems, it is equally critical to consider the sustainability and ecological impact of adopted practices. This study reveals that across gender, there was on major difference in the adoption of practices that enhance long-term environmental resilience in Bhutan. In Nepal, however, women were more likely than men to produce and use compost and retain crop residues. These practices are associated with improved soil health, moisture retention and nutrient recycling. These findings resonate with a growing body of literature that highlights the gendered dimensions of sustainability in smallholder farming. This also challenges the prevailing postulation that equates resilience with innovation only when it is technologically advanced or capital-intensive. The implications for climate-resilient food systems are significant. Supporting the kinds of practices that women already employ is cost-effective and enhances ecological and social resilience simultaneously.

4.5 Reframing empowerment as a pathway to resilience

Empowerment has often been framed in agricultural development discourse as a long-term social objective, secondary to more immediate goals such as productivity or efficiency. However, the findings of this study suggest that empowerment may be a foundational condition for achieving resilience and sustainable adaptation. In the face of growing climate variability, the ability of farming systems to adapt depends on the availability of technologies or inputs as well as whether those who manage agricultural decisions have the autonomy, authority and resources to use them effectively. For women in Bhutan and Nepal, this autonomy remains constrained in ways that reduce both their individual resilience and the adaptive capacity of the systems they support. The data reveal that although women are central to agricultural labor and often take on major responsibilities in production and resource management, their influence in decision-making remains limited. This pattern aligns with patterns documented in prior studies from South Asia (Nguyen et al., 2019; Shahbaz et al., 2022), which emphasize the persistent mismatch between women's visible participation in agriculture and their often-invisible roles in decision-making.

The significance of this comparatively low empowerment for climate resilience lies in the interactive nature of adaptation. Adaptive practices require farmers to respond flexibly to changing conditions, manage uncertainty, and sometimes make trade-offs between short-term gains and long-term sustainability. When women lack the power to make or influence such decisions due structural or normative barriers they are excluded from shaping the very strategies that determine the resilience of their households and communities. Empowering women for climate resilience require addressing economic, informational, decision-making and institutional barriers. This involves ensuring control over resources, tailoring information delivery, enabling meaningful participation in governance and reforming institutions so that gender equity becomes a driver of adaptation.

Some limitation of this study is that it does not assess within-group heterogeneity, particularly among female farmers. Intersectional factors such as land tenure security and access to social or institutional networks were not examined and may account for unexplored variation in the findings. Although random sampling was employed, there remains the possibility of sampling bias and selection effects. In addition, some responses especially from women may have been influenced by social or cultural factors that limited their willingness to speak openly during interviews. These factors may affect how some findings should be interpreted.

5 Conclusion

Women in Nepal and Bhutan face barriers in accessing resources, making decisions and receiving tailored information. They are also risk averse because the costs of failure are higher for them. In Nepal, these disparities are sharper. These inequalities affect productivity and inclusion and also constrain women's ability to adapt to a changing climate. Ensuring equitable access to productive resources for all farmers is crucial for resilience. Despite these challenges, in comparison to the past, more women are using machinery, more women than men adopt climate-smart practices like composting and there is an increase in women securing loans which suggests a shift in the right direction toward gender parity. However, further efforts are required to continue to address gender-based barriers particularly those that limit women's full participation and recognition in agriculture.

Policies and practices that promote gender equality in agriculture can lead to more sustainable use of productive inputs, consequently, contributing to better environmental and economic outcomes. The recommendations are empowerment must be treated as a precondition for resilience and not as an outcome that will eventually emerge. This means ensuring that women have autonomous access to credit, inputs and information. Also, extension systems must change how they engage with women. This includes training more female extension agents, designing communication channels that fit women's routines and creating platforms where women's practical knowledge can shape technical recommendations. Recognizing the different ways men and women access and process information can help in designing outreach and training that resonates with each gender and result in more informed decision making. Promoting gender-inclusive decision-making through pushing for norms that promote equitable recognition of different genders in farming can ensure that both men and women's perspectives are considered which will address disparities. Lastly, both Bhutan and Nepal need to build stronger accountability frameworks to track whether gender equity objectives are being met both in terms of participation but crucially in terms of control over outcomes.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found at: https://doi.org/10.5285/3b7a3e0b-48e5-4395-b4c6-79bb43ae31e3 and https://doi.org/10.5285/cd35ca67-8121-4a0d-81c9-c4a7fae25117.

Ethics statement

The studies involving humans were approved by the Social Science Ethics committee of Scotland's Rural College (Ethical Clearance Reference Number: 35218734) on 05/03/2021. Locally, Kathmandu University School of Medical Sciences Institutional Review Committee (KUSMS, IRC) approved the study in Nepal (number granted by the KUSMS, IRC is W01/20). In Bhutan, the necessary administrative permissions to conduct the survey at the proposed sites were secured from the District Administration under the Royal Government of Bhutan. Also, approval was obtained from the College Research Committee since no ethical board was available. Participants were informed of the anonymity and confidentiality of their data. Voluntary participation and use of the information obtained for non-commercial purposes only was sought. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

TB: Writing – original draft, Writing – review & editing. SD: Writing – review & editing, Writing – original draft. DT: Writing – original draft, Writing – review & editing. BN: Writing – review & editing, Writing – original draft. RJ: Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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