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Looking up and going down: Does sustainable adaptation to climate change ensure dietary diversity and food security among rural communities or vice versa?

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Sustainable food systems are essential to ensure food security and mitigate climate change. Adaptation to climate change is part and parcel of sustainable food systems. Prior literature merely documented the climate-smart agricultural practices and explored the relationship with food security of adopters without taking the period of the strategies into account. Therefore, this study explored the factors affecting sustainable adaptation to climate change and created a further link between sustainable adaptation to climate change and the food security of rural households. The cross-sectional data were collected from 384 farmers through a face-to-face survey in Pakistan, selected by a multistage random sampling method. An ordered probit model and propensity score matching technique were used to analyze the data. Education, farm size, credit access, extension services, internet use for agriculture information, women's participation in farm-related decision making, and considering climate change a significant problem for agriculture were all positively influencing the sustainable adaptation to climate change at farms. The results indicated that farmers with a higher level of sustainable adaptation to climate change consumed more diversified diets and more daily calories as compared to those with a lower level of sustainable adaptation. Similarly, farmers with a lower level of sustainable adaptation to climate change had significantly lower food security than farmers with a high level of sustainable adaptation at their farms. This research indicated that farmers can gain food and nutrition benefits by becoming more sustainable adapters to climate change. This study has important policy implications for achieving sustainable development goals (SDGs) of zero hunger (SDG 2) and climate action (SDG 13) in developing countries.

KEYWORDS

SDGs, sustainable food systems, integrated resource management, ecological sustainability, food and nutritional security, food diversity

1. Introduction

Climate change is widely considered one of the key challenges to sustainable food systems and world food security (IPCC, 2014). The concentration of greenhouse gas (GHG) emissions, which are the primary cause of climate change worldwide, is increasing continuously despite mitigation efforts. Globally, GHG emissions have raised average temperatures and altered precipitation distribution (IPCC, 2018).

CO_2 emissions are continuously increasing in the atmosphere (Jackson et al., 2018), which has made the target of stabilizing global warming at 2 or 1.5°C difficult to achieve (Brown et al., 2019; Yang et al., 2020). As a result of the failure to develop an effective global framework to achieve the targeted level of global warming, 4°C of global warming by 2100 appears likely (Adger and Barnett, 2009; Parry et al., 2009). The continuous rise in warming and precipitation results in changes in the management of natural resources such as land and water, which subsequently affect agricultural productivity (Kurukulasuriya and Rosenthal, 2013). Similarly, the unavoidable rise in temperature has increased the chances of droughts, heat waves, uneven rainfall, floods, and other extreme events happening around the globe. The effects of climate change are already visible in different sectors, including agriculture (Arora, 2019). The changing climate severely affects crop productivity because these are very sensitive to temperature change (Mendelsohn and Dinar, 2009), which results in a decline in farm production and revenue (Mendelsohn, 2014). If the current trend of global warming and climate change continues, increasing crop losses in the future may contribute to lower food production and higher food prices, making it difficult to meet global food demand (Arora, 2019).

Climate change threatens food and nutrition security because it has negative effects that last for a long time. For example, it lowers agricultural productivity and destroys natural resources on farms. Climate variability, such as droughts and floods, etc., increases the chance of a poor harvest, which creates a situation of food insecurity. Similarly, water and land are the most critical resources for balancing farm production and the growing demand for food, and both are threatened by climate change. For example, with rising temperatures globally, the glaciers are melting at a high pace and the snow cover is disappearing quickly, which creates a shortage of water. Similarly, a temperature rise, on the other hand, generates many side effects for the crops as well as for the farm. It affects crop duration, changes pest survival and distribution, disturbs soil nutrients and mineralization, and affects fertilizer use efficiency (Jat et al., 2016).

Climate change has a significant impact on food security, farming, and the income of stakeholders all over the world. Lake et al. (2012) described that climate change has notable impacts on food and nutrition security, which is defined as "access to sufficient, nutritious, and safe food to sustain a healthy and active daily life." Summer temperature increases have serious implications for food production, potentially affecting nearly half of the world's population who live in the tropics and subtropics (Battisti and Naylor, 2009). Moreover, in light of the impacts of climate change on food and nutrition security as well as food diversity, a rise in prices due to the shortfall in farm production appeared. The crop prices are tending to increase more than the already published calculations (Easterling et al., 2007). For example, in 2006, climate vulnerability in the form of extreme weather contributed to the decline in world cereal production. Piesse and Thirtle (2009) described this decline in the yield of cereal crops as partly due to the rise in food prices globally. Similarly, in 2003, after the European heat wave, a 25% reduction in French fruit production appeared. Extreme weather events cause local and regional food shortages (Lake et al., 2012). Thus, the rise in prices due to the shortfall in food production under the impact of climate change diverts consumers toward low-cost and low-quality food items.

Agricultural production is dependent on the natural resources that are adversely affected by climate change and variability. This ultimately threatens food and nutrition security (Crumpler and Bernoux, 2020) at the local and regional levels. Moreover, the low probability of crop harvest (Tolossa et al., 2020), low chance of cultivating diversified crops on the farm, high agricultural business risk, and soil degradation are the outcomes of climate change (Makate et al., 2016). Thus, these adverse outcomes affect households' food and nutrition security as well as the food diversity of families (Jones et al., 2014).

With the growing concern of scholars and different stakeholders regarding climate change and its impacts on sustainable food systems, adaptation to climate change is inevitable (Berrang-Ford et al., 2011). Therefore, the necessity of adaptation to cope with climate change is becoming increasingly well known (de Coninck et al., 2018). Without coping strategies, the vulnerability and harshness of climate change will increase, and it will become a major challenge for securing food and sustainable agricultural development around the world (Fanzo et al., 2018; Haq et al., 2021). Climate change direct impact and vulnerability on food systems limited families' ability to meet their food and nutrition needs globally (Lobell et al., 2008). These adverse impacts of climate change on food systems are expected to grow continually. Therefore, climate change is one of the fundamental challenges that the agricultural and food systems face currently (Pielke Sr et al., 2007). All the stakeholders who participated in the food systems have multiple objectives, such as livelihood, profit, and securing food (Fanzo et al., 2018). Food systems are unstable worldwide and highly affected by demand-side drivers (changing consumption patterns, increasing urbanization, growing population, and income distribution) and food supply. All these demand- and supply-side drivers are associated with climate change (Godfray et al., 2010). Therefore, the food system is unable to control malnutrition and food insecurity, as evidenced by the 178 million stunted children, primarily in Africa and South Asia (Vermeulen et al., 2012). Thus, the food system incorporates all features of the food supply chain, from food production at the farm to the preparation and consumption of food at home (Fanzo et al., 2018). The climate-smart food system describes the efficient decision-making of producers and consumers to experience a "triple win" situation that increases food productivity with minimum food losses, reduces the emissions from agriculture, and implements adaptation strategies (Lipper et al., 2014). Adaptation, rather than mitigation, is widely regarded as a critical component of policy responses to mitigate the effects of climate change on agriculture, according to Deressa et al. (2009) and Gbetibouo (2009).

The adoption of climate-smart practices in agriculture can enable the farming community to withstand the detrimental effects of climate change and can make agriculture a more resilient and sustainable food system (Manda et al., 2016). Hundreds of such techniques and practices are available, including crop diversification, growing drought-resistant crops, integrated soil nutrient and fertility management practices (Faurès et al., 2013; Campbell et al., 2014), water harvesting, livestock diversification, and mixed farming (Shahbaz et al., 2020). Scholars concerning the vulnerability and unfavorable impacts of climate change on welfare, food, nutrition, and livelihood have largely favored the adoption of a sustainable food system (Makate et al., 2016). The adoption of climate-smart agricultural practices is based on three principles: (i) it should reduce the risk of climate change while improving income, food, and nutritional security; (ii) it should not hurt livelihoods or productivity; and (iii) the strategies and practices should be tailored to the area (Rosenstock et al., 2016).

A number of prior studies explored the factors influencing climate-smart agricultural practices and linked the adopted strategies with food and nutrition security all over the world, as well as in Pakistan. None of the studies considered the years throughout which the adopted practice has been applied by the farmers in determining the relationship between adopted strategies and food and nutrition security. Thus, this study goes one step further by taking into account the years of adopted strategies by constructing a sustainable adoption index and then creating a link between the food security of rural families and their sustainable adaptation to climate change. The current study has the following objectives: The first objective is to explore the practices being taken by the farmers to make their farms more resilient to climate change. The second objective is to explore the determinants of sustainable adaptation to climate change. The third objective was to analyze the effect of sustainable adaptation to climate change on food and nutrition security.

From a practical perspective, this paper offers a valuable methodology to take into account years of applied climate-smart agricultural practices for creating a link between sustainable adaptation and food security. The findings of this research will assist national and international agencies in their ongoing efforts to make agriculture a more sustainable food system and improve food security under a climate-changing scenario. So, all government agencies and international groups working to improve food security around the world, especially in developing countries, could benefit from this study.

2. Materials and methods

2.1. Study area and sampling technique

People in developing countries are more vulnerable to climate change and its consequences (Morton, 2007). Thus, poor people in developing countries are disproportionately affected by climate change because they rely on agriculture for income, food, and survival (Amole and Ayantunde, 2019). Similarly, Pakistan is a developing and agricultural country that is ranked as the world's seventh most affected by climate change (Kreft et al., 2016), with nearly 42 million (20.3%) of its population undernourished (Haq et al., 2021). During the last era, the country's average temperature has increased by 0.6°C (GoP, 2019). This rise in temperature and other climatic happenings such as floods, droughts, uneven rainfall, heatwaves, etc., affected agricultural productivity, crop yields, and water availability, which resulted in low farm produce in the country (GoP, 2019), decreasing the country's food security (Ahmed et al., 2008; Menhas et al., 2016). Similarly, most cereal crops are very sensitive to changes in temperature and climate. For example, wheat and rice are very sensitive cereal crops to temperature change and water shortage (Mahmood et al., 2019), and these make up more than half of the daily nutrition of rural families. Punjab has a major share in the production of grain crops such as maize, rice, and wheat, etc. (PBS, 2020). The targeted population of the current study was the rural population of Punjab, because this is the second-largest and most populated province of the country.

Punjab province has been bestowed with very fertile land, and it has a very expansive irrigation system. It has a very suitable climate for the cultivation of all types of field crops, and crop cultivation covers almost 10.81 million hectares (53% of the net sown area) of the total geographical area of the province. Among all provinces in the country, Punjab contributes the most to agricultural output ((Pasha, 2015)). Furthermore, it employs more than 42.30% of the province's labor force. The annual mean temperature remained in the range of 19.37 to 21.87°C (CCKP, 2022).

To determine the sample size for the current study, the following formula by Krejcie and Morgan (1970) was used:

$$n = \frac{X^2 \times N \times q \times (1-q)}{d^2 \, (N-1) + (X^2 \times q \times (1-q)}$$

Where n is the sample size, X^2 is the chi-square, and N is the population size (the total number of rural households in Punjab). Due to the large population of the province, we did not know the proportion of the population that adapted the practices, and we assumed that q = 0.50 was the maximum variability in sample size determination for the current study. Here, d describes the margin of error, which was assumed to be equal to 5%. Based on these values, a total sample size of 384 was acquired.

Multistage random sampling technique was employed in the current study to select the representative sample. In the first stage, three agro ecological zones, namely the rice-wheat zone, the maize-wheat zone, and the mixed cropping zone, were selected from the province. Each zone was made up of numerous small administrative units. To allocate the sample size to the lowest administrative unit, a top-down strategy was used in the current study. In the second stage, one district from each agro-ecological zone having the largest number of rural families or households was selected. In the third stage, we have selected two tehsils from one district and two union councils from one tehsil based on the number of rural households. The union council consists of several villages, and four villages were selected randomly from each union council. At the end, a total of 48 villages were ready to be approached for data collection. The total sample size was equally distributed among each village, and a total of 8 respondents from each village were selected randomly.

2.2. Data collection and survey instrument

The data collection was conducted through a well-designed questionnaire. A questionnaire survey is a systematic approach to collecting primary data (Sher et al., 2019). A face-to-face interview with respondents was conducted to collect the data. A well-trained and experienced team of female and male researchers was sent to the field of study. Before starting the interview, the researcher asked the respondents to give their consent verbally.

The questionnaire used for data collection was developed using insights derived from subject experts, researchers, and literature. The appropriateness of the questionnaire was confirmed before starting the survey. The questionnaire was reviewed extensively by five experts with research experience in climate change and food and nutrition security. Moreover, the pilot study was also conducted by interviewing 25 farm households. The questionnaire was finalized by incorporating the feedback of the experts and respondents. The final questionnaire was arranged in many sections. The first section consisted of the socio-economic characteristics of the respondents, such as education, age, experience, family size, etc. Questions regarding the adopted strategies being practiced in the study area were incorporated in the second section. The third section contained the standardized set of questions to measure the food security of the households. These standardized questions consisted of nine questions that considered all dimensions of food security (Kerr et al., 2019). The questions related to the measurement of food diversity were incorporated into the fourth part of the questionnaire. This section was adjusted according to the six different food groups existing in the country, i.e., (i) vegetables, (ii) fruits, (iii) cereals, (iv) meat and pulses, (v) fats and oils, and vi) milk and milk products (FAO and GoP, 2018). Seasonal availability of fruits and vegetables was also considered in this section and arranged accordingly. Thus, data from 42 food items were obtained for estimating daily energy intake and the food diversity of the rural families. Some food items, such as sweets, chocolates, biscuits, and cakes, were not incorporated in the questionnaire because they are only used on unusual occasions in the villages like weddings, birthdays, and the arrival of guests at home.

2.3. Outcome variables

2.3.1. Food diversity

We used the Simpson index for measuring food diversity. This index serves two purposes: it describes food diversity and it measures the nutritional adequacy of rural families (Ruel, 2003; Nguyen and Winters, 2011). Food diversity is very important for health because it provides the essential nutrients that are necessary for the growth of the human body. To maintain body growth and a healthy life, food diversity requires the consumption of food items from all six different food clusters. Consuming different food items from different food clusters describes the maximum level of food diversity. In the current study, food diversity was measured by considering the calorie share of each food cluster. The formula for measuring food diversity is as follows:

$$FD = 1 - \sum_{g=1}^{m} p^2$$

Where FD denotes the food diversity, p shows the calorie share of the i^{th} food cluster, m is the total number of food groups, and g is equal to 1 to 6. Therefore, resulting score of the food diversity index was in range of 0 and 1. This implies that the index value near 1 means higher food diversity and 0 means lower food diversity.

2.3.2. Daily energy intake

In the current study, the daily energy intake was also computed based on the daily calorie intake. The calorie intakes were measured from the quantity of each food item consumed by the household. For this purpose, the composite food table index was used to convert the consumed quantities of the food items into calorie and iron intakes. This table was prepared jointly by the government of Pakistan, and the Food and Agriculture Organization (FAO and GoP, 2001).

2.3.3. Food security

The household food security was measured by 9 different standardized questions, and a scale was used for categorizing the food security level of households: 1 for "food security," 2 for "mildly food insecure," 3 for "moderately food insecure," and 4 for "severely food insecure." In the current analysis, the "1" was assigned to food-secure households, while the mildly, moderately, and severely food-insecure households were numbered as "0." This method of measuring food insecurity was also adopted by Kerr et al. (2019).

2.4. Sustainable adoption index

The sustainable adoption index was measured by adapting the method used by Demiryürek et al. (2017) for calculating the innovation sustainability index. The method resulted in the "sustainable adoption index," which refers to the adapted and applicable practices of the respondents. The sustainable adoption index not only considers the adopted practices but also the years throughout which each adopted practice has been implemented by the farmer. Therefore, the index values increase, and the sustainability of the practices that the farmer has adapted increases accordingly. A higher value of the index means a higher level of sustainable adaptation to climate change by the farmer. The following formula was used to measure the "Sustainable adoption index."

$$\text{Sustainable adoption index (SAI)} = \frac{\textit{No. of adopted practices} \times \textit{No. of adopted years}}{\textit{Total number practices}}$$

The practices that the farmers adopted are crop diversification, farm diversification, improved seed varieties, changing planting dates, green manuring, crop rotation, crop covers, minimum tillage, drip irrigation, bed raising, solar panels, and agro-forestry. The resulting SAI value was in the range of 10.37 to 59.45. The cluster k-mean analysis was applied to the SAI, and three homogeneous groups of farmers were determined. The farmers with an SAI score of <20 were categorized as low-sustainable adopters (69 farmers, 17.97%). Those farmers with an SAI score in the range of 21 to 40 were named moderately sustainable adopters (173 farmers, 45.05%). The third group of farmers was classified as highly sustainable adopters (142 farmers, 36.98%), and they had scores >40. These groups of farmers were further used as the dependent variable of the ordered probit model.

2.5. Empirical analysis

The dependent variable was coded as 0 for farmers belonging to the low-sustainability adopter group, one for the farmer from the moderately sustainable adopter group, and two for the farmer in the highly sustainable adopter group. The ordered probit model for the current study was specified as

$$Z^* = \alpha' X_i + \varepsilon, \ \varepsilon \sim N(0, 1)$$
$$Z = 0 \ if \ Z^* \leq 0$$
$$Z = 1 \ if \ 0 < Z^* \leq \rho_1$$
$$Z = 2 \ if \ \rho_1 < Z^* \leq \rho_2$$

In this case, the dependent variable Z* is the probability of the rural family belonging to the category of sustainable adoption; α' is coefficient's vector to be estimated; X_i describes the independent variables' vector; ε is normally distributed error term [0, 1], Z depicts the observed dependent variable, which indicates the likelihood of the respondent having higher level sustainable adoption; and ρ describes the cut-off points that signifies the inclination. It emphasizes the natural ordering among the three groups of the dependent variable of the model.

2.5.1. Impact of sustainable adaptation to climate change on food and nutrition security

To estimate the average sustainable adaptation to climate change effect on food security, food diversity, and energy intake for three groups, we applied the propensity score matching (PSM) technique. The PSM pairs the treated (farmers with high sustainable adoption status), and control (farmers with low sustainable adoption status) groups according to their observable characteristics (Dehejia and Wahba, 2002). The assumption of common support was also confirmed for each outcome variable (food security, food diversity, and energy intake) before applying the kernel matching method. The common support assumption was satisfied for each outcome variable as there was a significant overlap among the propensity scores of the control and treated groups.

In the matching technique, the two highly interesting estimates are the average treatment effect on adapters (ATT) and the average treatment effect on non-adapters (ATU). Therefore, ATT describes how the average outcome would have changed if a respondent with a high level of sustainable adaptation to climate change had a low level of sustainable adaptation. Therefore, the ATT is used to compare the expected food security, food diversity, and energy intake outcomes of higher sustainable adoption with the counterfactual outcomes of lower sustainable adoption. The outcomes of higher sustainable adaptation to climate change are described as follows:

$$E\left(Y_{ik} \middle| I_i = k\right) = \beta_k X_{ik} + \alpha_k \lambda_{ik}$$

The counterfactual outcomes of lower sustainable adaptation to climate change instead of higher sustainable adaptation to climate change.

$$E\left(Y_{ij} \middle| I_i = k\right) = \beta_j X_{ik} + \alpha_j \lambda_{ik}$$

The average sustainable adaptation to climate change effect on food security, dietary diversity, and energy intake outcomes is conditional on a higher sustainable adaptation to climate change is as follow:

$$ATT = E\left(Y_{ik} \middle| I_i = k\right) - E\left(Y_{ij} \middle| I_i = k\right) = X_{ik}(\beta_k - \beta_j) + \lambda_{ik}(\alpha_k - \alpha_j)$$

The average sustainable adaptation to climate change effect is measured by calculating the difference between factual and counterfactual food security, food diversity, and energy intake scores or values. Therefore, we compared the food security index, food diversity index, and energy intake values of the households with higher sustainable adaptation to climate change with the households with lower sustainable adaptation to climate change. Consequently, the average treatment effect on all three variables is the difference between their two (factual and counterfactual) outcomes.

3. Results and discussion

3.1. Sample background

Socioeconomic characteristics provide important information about the samples' background and their abilities to counter climate change. The average age and education of the farmers were more than 41 and 8 years, respectively. Farmers were found to be rich in farming experience, with more than 20 years of working experience in the agricultural fields. Large family sizes are common in Pakistan, especially in rural areas, because of the joint family system (Shahbaz et al., 2020). In the study area, the average family size was nearly seven people. Agriculture is the mainstay of livelihood for a large majority of the population residing in rural areas of the country. More than one-third of the total family members were involved in agricultural activities for their livelihood in the study area. The average landholding was only 2.07 hectares. This may be because a large majority of the farming community in the country has land smaller than 2 hectares (Bryan et al., 2013).

More than two-fifths of the total farmers also mentioned agriculture as their primary source of livelihood. The reason may be that more than one third of the total Pakistani population is engaged in agriculture for their livelihood (GoP, 2021). More than half of the participating farmers in this study were owner-operators. Land distribution is highly skewed in Pakistan, and more than one third are tenant farmers with no agricultural land ownership

TABLE 1 Sample background.

Socioeconomic characteristics	Mean
Age (years)	41.35 (8.77)
Education (years)	8.56 (3.29)
Farming experience (years)	20.11 (7.67)
Family size (numbers)	6.77 (1.23)
Agricultural labor force (numbers)	2.33 (0.88)
Farm size (hectares)	2.07 (0.74)
Household head (1 = farmer is the household head, 0 = otherwise)	0.61
Main source of income (1 = agriculture, 0 = otherwise)	0.41
Tenancy (1 = farmer is owner cultivator, 0 = otherwise)	0.52
Credit access (1 = yes, 0 = otherwise)	0.34
Extension access (1 = yes, 0 = otherwise)	0.26
Internet use for agriculture information (1 = yes, 0 = otherwise)	0.21
Women participation in agricultural decision making (1 = yes, 0 = otherwise)	0.20
Training/workshop participation (1 = yes, 0 = otherwise)	0.11
Climate change is a significant problem for agriculture	0.89

The values in parenthesis are standard deviations. The standard deviations are presented only for continuous variables.

(GoP, 2015). A large majority of farmers (66%) mentioned credit accessibility issues during needy times. Extension services play a critical role in technology dissemination and creating awareness among farmers about climate change. But a large majority of the farmers mentioned that their farms were never visited by the extension agents. The Internet is also a source of information for the farming community, and they can access information about agricultural activities, market prices, and climate anytime (Mahmood et al., 2020). Only 21% of the farmers were using the internet to obtain agriculture-related information. The reason may be the lower education level of the farmers. Women are an essential part of agricultural activities, but their role in agricultural decision-making in the country is very limited. Moreover, women also play a critical role in ensuring food security and climate change adaptation (Asadullah and Kambhampati, 2021). Only one-fifth of the farmers stated that their women are involved in agricultural decisions. Cultural barriers and patriarchy in society are to blame for women's lower participation in agricultural decision-making. Similarly, only one-tenth of the farmers participated in the agriculture-related seminars and trainings. A large majority of the farmers (89%) consider climate change a significant problem for agriculture (Table 1).

3.2. Climate change adoption status

Farmers are well aware of the implications of climate change on agriculture. Therefore, they are adopting different strategies to minimize the climate change repercussions on agriculture depending on the capability and skills of farmers (Anser et al., 2020). Moreover, agriculture is labor intensive, and farmers use traditional strategies to minimize the impact of climate change in Pakistan (Shahbaz et al., 2021). Farm diversification was the most commonly adopted strategy by the farmers to minimize the impacts of climate change on the food system and make agriculture more resilient to climate change. This was followed by crop diversification, which was adopted by more than three-fourths of the farmers. Pakistan is facing one of the worst energy crises, and farmers are also confronting this problem in rural areas. The farming community is looking for new and cost-efficient solutions for sustainable food systems. Solar panels were the least adopted measure by the farmers. The use of solar panels for producing energy at farms reduces emissions and limits climate change. The green manure strategy was also adopted by more than two-thirds of the farmers. Pakistan has scarce water resources, and the adoption of water-efficient techniques is absolutely necessary for sustainable food systems and ensuring food security in the country (Razzaq et al., 2019; Ashfaq et al., 2020). The majority of the farmers (64%) adopted a traditional strategy (bed raising) to counter the implications of climate change on irrigation water (Figure 1). Drip irrigation was adopted by only a little more than 3%. Crop rotation is also important to maintain the soil fertility and nutrients necessary for better crop productivity. This practice was adopted by almost three-fifths of the total farmers. Improved seed varieties and changing planting dates were adopted by more than half and two fifths of the farmers, respectively, to counter the impacts of climate change on food systems.

3.3. Determinants of sustainable adaption to climate change

With a log likelihood ratio of chi square value of−756.40 and a probability of chi square value of <1%, the overall ordered probit model was significant (Table 2). Only seven explanatory variables out of a total of thirteen were significantly affecting the sustainable adaptation to climate change. The significant variables were education, farm size, tenancy, extension services, internet use for agriculture information, women's participation in agricultural decision-making, and considering climate change a significant issue for agriculture.

The education level of farmers plays a critical role in the adoption of measures to minimize the impacts of climate change on food systems. Education was found to be positively associated with sustainable adoption status. A 1-year increase in the education level of the farmers increases the likelihood of belonging to a higher sustainable adoption group by 1.79 times. Abid et al. (2015) also reported a positive relationship between climate change adaptation and farmer education. Farm size is an important indicator of a farmer's wealth. Farm size was also directly associated with the sustainable adoption status of the farmers. A one-hectare decrease in farm size reduces the chances of belonging to a higher sustainable adoption group by 1.14 times. The findings related to farm size and climate change adaptation are in line with the prior studies conducted by Belay et al. (2017) and Fadina and Barjolle (2018),

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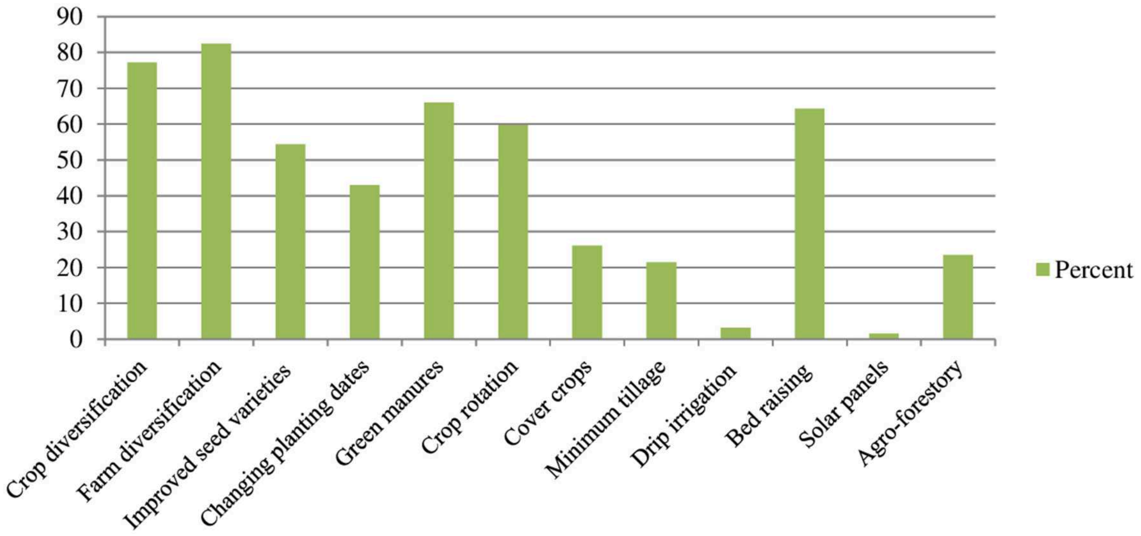

FIGURE 1
Climate change adoption status in the region.

TABLE 2 Determinants of sustainable adaptation to climate change.

Variables	Coef.	Std. errs.	Odd ratios
Education (years)	0.58***	0.36	1.79
Farming experience (years)	0.13	0.32	1.13
Agricultural labor force (numbers)	0.46	0.77	1.58
Farm size (hectares)	0.17**	0. 08	1.14
Household head (1 = farmer is the household head, 0 = otherwise)	0.33	0.29	1.39
Main source of income (1 = agriculture, 0 = otherwise)	−0.98	0.80	0.38
Tenancy (1 = farmer is owner cultivator, 0 = otherwise)	1.30*	0.17	3.67
Credit access (1 = yes, 0 = otherwise)	0.08	0.06	1.08
Extension access (1 = yes, 0 = otherwise)	1.01*	0.24	2.75
Internet use for agriculture information (1 = yes, 0 = otherwise)	0.09*	0.03	1.09
Women participation in agricultural decision making (1 = yes, 0 = otherwise)	0.96**	0.47	2.61
Training/workshop participation (1 = yes, 0 = otherwise)	0.26	0.43	1.29
Climate change is a significant problem for agriculture	0.65**	0.29	1.92
LR chi2	−756.40		
Prob > chi2	0.00		
Pseudo R2	0.69		

*, **, and *** represents significance level at 1%, 5% , and 10% respectively.

who also stated a positive association between landholding and the adoption of climate-smart agricultural practices.

The results also showed that an owner farmer is 3.67 times more likely to be in a higher sustainable adoption group than a tenant farmer. Extension services were also found to be positively influencing sustainable adaptation to climate change. The results of the study related to tenancy and climate change adaptation positively align with those of Iheke and Agodike (2016) and Fahad et al. (2020). A farmer with extension services is 2.75 times more likely to be in a higher sustainable adoption group than a farmer without extension services. Similarly, internet use for agricultural purposes was positively related to the sustainability of the adoption status of the farmers. Abegunde et al. (2019), Makate et al. (2019), and Mahmood et al. (2020) also reported a significant positive relationship between extension services and climate change adaptation. A farmer using the internet for agriculture information has 1.09 times more chances of belonging to the high sustainable adoption category as compared to a farm not using the internet for agriculture purposes. Thinda et al. (2020) and Antwi-Agyei and Stringer (2021) also found that information and communication technology can assist farmers to increase climate change adaptation on farms. Women's participation in agricultural decision-making also positively influences sustainable adaptation to climate change. A farm with the involvement of women in decision-making is 2.61 times more likely to be a sustainable adopter than a farm without women's participation in decision-making. These findings positively align with those of Shahbaz et al. (2022), who also found that women's empowerment in agricultural decision-making can enhance the adoption of climate change measures on farms. Similarly, a farmer who considers climate change a significant problem for agriculture is 1.92 times more likely to belong to a higher sustainable group than a farmer who does not consider climate change a significant problem.

TABLE 3 Sustainable adaptation to climate change impact on food security.

Sustainable adoption status		Average difference
High	Moderate	
0.67	0.59	0.08 (0.04)**
High	Low	
0.67	0.55	0.12 (0.06)**
Moderate	Low	
0.64	0.57	0.07 (0.03)*

* and ** represents significance level at 1% and 5%, respectively.

3.4. Impact of sustainable adaptation to climate change on food security

The results presented in Table 3 indicated that farmers with higher sustainable adoption status have higher levels of food security than farmers with lower sustainable adoption status. Another important result that can be extracted from the below findings is that all the farmers with higher sustainable adoption status would have had less food security if they had not belonged to a higher sustainable category. Another key finding is that the average difference between the food security of the high sustainable adoption group as compared to the low sustainable adoption group is higher than the average difference between the high sustainable adoption group as compared to the moderate sustainable adoption group. For example, belonging to a high-sustainability adoption group as compared to a moderate-sustainability group increases food security by 8%. Similarly, belonging to a high-sustainability adoption group instead of a low-sustainability adoption group can increase the farmers' food security by 12%. On the other hand, belonging to a moderately sustainable adoption group instead of a lowly sustainable adoption group can increase the farmers' food security by 7%. These findings also show that farmers in low-sustainable adoption groups can benefit more from food security by becoming highly sustainable rather than moderately sustainable. Previous literature (Brown et al., 2015; Douxchamps et al., 2016; Jat et al., 2016; Ali and Erenstein, 2017; Smith et al., 2020) also reported similar results as in this study: adaptation to climate change at the farm level positively contributes to the food security of rural households.

3.5. Impact of sustainable adaptation to climate change on food diversity

Dietary diversity is important for nutritional status and health. Fanzo et al. (2018) and Niles et al. (2021) reported that climate change will adversely affect food security and dietary diversity in rural households by negatively affecting food systems. Therefore, adaptation to climate change is necessary to maintain food security and dietary quality (diet diversity, nutrient density, and safety). Table 4 presents the impact of sustainable adaptation to climate change on the food diversity of the farmers. Farmers belonging to the high sustainable adoption group have (0.09) greater food diversity than the farmers in the moderately sustainable adoption category. Similarly, farmers belonging to the low-sustainability adoption group have lower food diversity than the farmers in the high-sustainability adoption group. A farmer in a low-sustainable adoption group can increase its food diversity by 0.10 by belonging to a moderately sustainable adoption group. Similar findings were reported in the previous relevant literature (Rahman, 2010; Kanter et al., 2015; Kumar et al., 2015), which found that adaptation to climate change at the farm level assists farmers in improving their daily dietary diversity.

TABLE 4 Sustainable adaptation to climate change impact on food diversity.

Sustainable adoption status		Average difference
High	Moderate	
0.71	0.62	0.09 (0.01)*
High	Low	
0.71	0.58	0.13(0.02)*
Moderate	Low	
0.65	0.55	0.10 (0.04)**

* and ** represents significance level at 1% and 5%, respectively.

TABLE 5 Sustainable adoption impact on daily energy intake.

Sustainable adoption status		Average difference
High	Moderate	
2489.60	2211.76	277.84 (47.87)*
High	Low	
2489.60	2145.43	344.17 (41.43)*
Moderate	Low	
2265.88	2221.56	44.32 (35.30)

*represents significance level at 1%, respectively.

3.6. Impact of sustainable adaptation to climate change on daily energy intake

The farmers belonging to the highly sustainable adoption group would have had less 277.84 kcal/day if they had belonged to the moderately sustainable adoption category. Similarly, farmers belonging to the low sustainable adoption group can increase their daily energy intake by 344.17 kcal by becoming highly sustainable adopters (Table 5). The results of the study corroborate with Haq et al. (2021), who also reported that farmers can increase their daily energy intake by adapting to climate change at farms. Issahaku and Abdulai (2020) also reported that adaptation to climate change at farm levels positively contributes to the food and nutrition security of the rural community. Additionally, the findings of this study are also in line with the study conducted by Amare and Simane (2018), who also estimated a positive relationship between climate change adaptation and daily nutrition intake.

4. Conclusion and policy recommendations

Climate change vulnerability has a negative impact on agriculture and food systems. The food system's demand and supply drivers are extremely vulnerable to climate change. From the time food is grown on the farm until it is consumed at home, it is threatened by the multifaceted effects of climate change. This causes instability in agricultural production and threatens the sustainability of food systems, which increase food insecurity; reduce food diversity, and lower energy intakes among rural inhabitants. Climate change adaptation has gained the primary support of stakeholders as the appropriate future trajectory to cope with the impact of climate change and enjoy secure food, more nutrition, a healthy diet, and required energy intakes. The current study is planned to explore the sustainable adaptation to climate change and its implications on the food security, food diversity, and energy intake of rural households. A sample size of 384 small farmers was interviewed by the trained and well-experienced researchers. The farmers were well experienced, and a large majority of them clearly understood the importance of climate change and its impact on agriculture.

Almost 12 sustainable practices were adopted by the farmers; among those, farm diversification was one of the most adopted practices by the small farmers, followed by crop diversification, green manure, bed raising, and crop rotation, respectively. The results of the ordered regression analysis described that the extension services were positively contributing to sustainable adaptation to climate change. Women's participation in agriculture and internet use for agricultural information was also positively associated with sustainable adaptation to climate change. Moreover, the farmers' perception about the significant impact of climate change on agriculture also contributes positively to sustainable adaptation to climate change.

The positive association between sustainable adaptation and food security, food diversity, and energy intake describes the importance of sustainable adaptation to climate change, which ensures secure, diversified, and full of nutrients food for rural households. The farmers with low sustainable adaptation to climate change consumed less diversified food, had a lower energy intake, and experienced higher food insecurity as compared to the farmers with high sustainable adaptation to climate change. This study has important policy implications for achieving sustainable development goals (SDGs) of zero hunger (SDG 2) and climate action (SDG 13) in developing countries.

The results of the current study have significant policy implications. First, this study describes the role of farmers' awareness and knowledge of climate change in minimizing the effects of climate change on sustainable food systems. Second, it also highlights the importance of extension services and internet for sustainable adaptation to climate change. The sustainable adaptation to climate change may also assist the government in making effective policies for addressing daunting challenge of food and nutrition insecurity in the country. Therefore, the government should increase awareness of sustainable food systems and climate-resilient agriculture benefits to cope with climate change in the country through serious awareness campaigns. Moreover, sustainable food systems should be promoted by raising awareness through extension services and short videos on the internet. Even though this study was conducted with the utmost care, it is not without limitations. First, the cross-sectional nature of the collected data does not allow for the development of a causal relationship between the sustainable adoption of climate change practices and the food diversity and nutrition of the households. Secondly, the food items used to estimate daily calorie consumption and food diversity did not include those that were not part of daily kitchen items in the country. Thirdly, the research included only farmers as participants in this study, which might not be representative of the whole rural population. Despite the study's limitations, the findings revealed important information about the implications of sustainable climate change practices on food diversity and the calorie consumption of farmers, and the findings will help to understand the implications of sustainable adoption on household nutrition.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by University of Education Lahore, Pakistan. The patients/participants provided their written informed consent to participate in this study.

Author contributions

SH and PS: conceptualization. SH, PS, AA, and NN: methodology, formal analysis, resources, data curation, and funding acquisition. PS, AA, BA, and NN: software and writing–original draft reparation. RN and NN: validation. BA and RN: investigation. SH, PS, AA, BA, and RN: writing–review and editing. All authors read and agreed to the published version of the manuscript.

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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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