frontiers | Frontiers in Sustainable Food Systems

TYPE Original Research
PUBLISHED 03 October 2024
DOI 10.3389/fsufs.2024.1471238

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RECEIVED 26 July 2024
ACCEPTED 16 September 2024
PUBLISHED 03 October 2024

CITATION
Mustafa G and Alotaibi BA (2024) Fostering adaptation to climate change among farmers in Pakistan: the influential role of farmers' climate change knowledge and adaptive capacity.
Front. Sustain. Food Syst. 8:1471238.
doi: 10.3389/fsufs.2024.1471238

Fostering adaptation to climate change among farmers in Pakistan: the influential role of farmers' climate change knowledge and adaptive capacity

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Introduction: Adaptation to climate change (ACC) is imperative to avoid deleterious consequences of climate change in agriculture. However, the uptake of adaptation measures has been slow among farmers because of low adaptive capacity (AC) in developing countries, particularly in Pakistan. Farmers and their supporting institutions have been successful in introducing technological innovations to respond and adapt to environmental challenges. The present study intended to determine the impact of farming technologies, along with human, financial, social, physical, natural, and climate information resources that support AC and hence ACC.

Methods: The study collected data from 360 farmers in Punjab through a multi-stage random sampling technique. A binary logit model and odds ratio were used to identify the factors affecting ACC. The study also utilized correlation tests to show the correlation between each pair of variables included in the analysis.

Results: The results indicated that physical capital such as ownership of tube wells, transportation, and sowing and harvesting tools by the farmers builds farmers' AC and consequently determines the ACC such as change crop variety (CCV), change crop type (CCT), change planting date (CPD), soil conservation (SC), water conservation (WC), and diversification strategies (DSs). The findings also revealed that human capital (age, education, family size, and labor), financial capital (off-farm employment, access to the marketing of produce, and agricultural credit), social capital (farmers-to-farmers extensions, access to extension services, and the farm association membership), and natural capital (land ownership, tenancy status, and the location of the farm) were importantly related to farm households' ACC strategies. The odds (likelihood) of adaptation were higher for the users of farm technology as compared to non-users.

Discussion: The analysis conducted in this study showed that climate information resources amplify the adaptation to climate change: technology allows farming to be much more efficient, while climate change knowledge (CCK) self-motivates farmers to adopt more ACC measures. Our findings provide evidence that suggests the need to provide credits and financial support for farming technologies that speed up the ACC in the long run, while in the short run, climate information should be spread among farming communities.

KEYWORDS

adaptation to climate change, climate change knowledge, adaptive capacity, logit model, odds ratio

1 Introduction

Farm-level adaptations are considered a significant imperative driver of global-level adaptation endeavors (Coulthard, 2008; Srivastava, 2020). However, speed of adaptation has been very slow in Southeast Asian countries (Bahinipati and Patnaik, 2022; Zhuang, 2009), particularly in Pakistan (Ali and Erenstein, 2017; Ali et al., 2021; Mirza, 2011). Adaptation is not completely autonomous, as sometimes claimed (Fankhauser, 2017). Even if it is autonomous, it is not supposed to occur naturally (Tripathi and Mishra, 2017). It requires foresight, coordination, planning, and knowledge (Fankhauser, 2017). Given these challenges, the present study intended to determine adaption options and to investigate what can accelerate greater uptake of strategies related to adaptation to climate change (ACC) by farmers.

Farmers utilize various ACC strategies to adapt to climatic risks in agriculture. The ACC options such as change crop variety (CCV) (e.g., stress-tolerant crop cultivars), change planting date (CPD), and change crop type (CCT) (e.g., shifting to new crops because previously used crops might get severely damaged from climate change) could reduce the vulnerability to environmental variations (Smit and Skinner, 2002). Diversification strategies (DSs) (intercropping, animal rearing, and diversification of crop types and varieties) are another dominant approach used by farmers in response to climate change and the economic risks associated with these vagaries (Danso-Abbeam et al., 2021). Similarly, soil conservation (SC) and water conservation (WC) strategies are used by farmers in response to erratic rainfall and ever-increasing temperatures (de Sousa et al., 2018; Marie et al., 2020; Sinore and Wang, 2024). These ACC practices lower risk and hence minimize the severity of the impact of climatic change. Such adaptation measures are necessary for Pakistan as it is one of the countries in the Southeast Asian region that is severely impacted by climate change, particularly in terms of agriculture (Ali et al., 2021; Irfan et al., 2019). The study aimed to identify various factors that can accelerate these ACC options.

Communication, knowledge, education, and information sharing help farmers with proper ACC measures (Drafor and Agyepong, 2005). Even with limited resources, small farmers with adequate information can better address adaptation-related issues (Eise and Rawat, 2021; FAO, 2019). For instance, Belay et al. (2017) found that climate information is an important element of adaptation among Ethiopian farmers. Similarly, Piya et al. (2013) were of the opinion that climate change information plays a pivotal role in adoption practices among Nepalese farmers. The majority of the previous studies agreed that climate information is one of the determinants of adaptation (Ali and Rose, 2021; Ali et al., 2021; Khanal and Wilson, 2019).

Farmers construct their climate change knowledge (CCK) based on their past experience with climatic vagaries, how they perceive climate change, their interaction with local communities, their social values, and personal views, with limited scientific knowledge (Hundera et al., 2019; Nguyen et al., 2019). This creates critical gaps in the subjective measure of climate change. This needs to be addressed through scientific evidence and facts (Howe et al., 2019; Ringler et al., 2010; Silvestri et al., 2012). Farmers' CCK increases their access to climate change information, increasing their ability to adapt to climate change (Ricart et al., 2019). For instance, previous studies reported that farmers have a better understanding of climate change, which helps them in adaptation, ultimately leading to greater food security (Etana et al., 2021; Talanow et al., 2021). On the other hand, some studies claimed that farmers lack CCK (Ali et al., 2021; Asrat and Simane, 2017), and thus, there is no significant impact of CCK on adaptation measures (Owusu et al., 2017). This mixed evidence suggests that farmers' CCK needs to be validated based on scientific facts. Therefore, research in rural Punjab is necessary to understand farmers' knowledge and its impact on ACC strategies.

Access to information on climate change is often treated as a mere control variable while addressing factors affecting climate change adaptation (Alauddin and Sarker, 2014). It is usually restricted to conceptualization in terms of gaining information. The conceptualization of this information is dependent on factors such as the volume, channel type, and frequency of the information (Chetri et al., 2024). The current study addressed this gap by examining a broader conceptualization of education (volume), the members of farm organizations (FOs) in information exchange (channel type), and the access of farmers to extension services (frequency of information) and their contribution in the uptake of adaptation measures. For instance, previous studies found that education significantly determines adaptation strategies (Elahi et al., 2015). Similarly, studies reported that farmer-to-farmer extension through FOs plays a significant role in the implementation of farmers' adaptation plans (Abdul-Razak and Kruse, 2017; Chepkoech et al., 2020). In addition, Deressa et al. (2009) identified that access to extension services helps farmers with adaptation options.

Adaptive capacity (AC) is defined as the ability of a system to adjust to climatic variations, including climate variability and extreme-to-moderate potential damage, take advantage of opportunities, and deal with environmental damages (Adger et al., 2007; Intergovernmental Panel on Climate Change, 2014). Previous studies identified that a household's capacity to adapt is a critical factor in the adaptation process to climate change (Adger and Vincent, 2005; Dixon et al., 2014; Hogarth and Wójcik, 2016). It includes both tangible and intangible resources. To build AC, local-level resources are highlighted in the literature, with a primary focus on livelihood assets (Choden et al., 2020; Piya et al., 2012). Therefore, farmers with greater access to different forms of capital will have a greater capacity to adapt to climate change (Choden et al., 2020). The resource-based conceptualization of AC is frequently discussed in the literature. There is a growing consensus in the literature that the ACC is long-term if the AC takes human capital, social capital, financial capital, physical capital, and natural capital into consideration (Abdul-Razak and Kruse, 2017; Choden et al., 2020; Piya et al., 2012; Cuesta and Rañola, 2009; Ibrahim, 2014; Shirima et al., 2016).

Human capital can be defined as the stock of knowledge acquired through formal and informal education, including both on-the-job learning and work experience, skills, and other personal characteristics that increase their productivity (Botev et al., 2019). In the context of a farming system, it is the farmer's ability and skill set that may determine the level of awareness and knowledge of climate change vagaries and hence the capacity to cope with these impacts (Ali and Erenstein, 2017; Maiti et al., 2017). Previous studies have shown that education (Elahi et al., 2015), farming experience (Abdul-Razak and Kruse, 2017), household size (Defiesta and Rapera, 2014), and the number of laborers (Byrne, 2014) are the main sources of human capital that enhance farmers' AC and, consequently, their ACC. Similarly, social capital is crucial to enhancing community resilience (Suhaeb et al., 2024). Access to extension services is considered the most important asset contributing to social capital, enhancing farmers' AC (Chepkoech et al., 2020; Deressa et al., 2009). Community-based organizations are also sources of social capital that provide farmers with the knowledge and skills related to climate information, ACC, and relevant practices (Abdul-Razak and Kruse, 2017; Chepkoech et al., 2020). It has been found that membership in farm organizations (FOs) provides farmers with access to useful information for household ACC (Defiesta and Rapera, 2014). Therefore, membership in associations was a relevant indicator of social capital, as reported in previous studies (Abdul-Razak and Kruse, 2017; Yameogo et al., 2018).

Financial capital is defined as income sources, including the level, variability, and diversity of the sources, and access to financial resources that contribute to wealth (Williges et al., 2017). It is conceptualized as the ease of access to agricultural credit, which enhances ACC (Chepkoech et al., 2020). For instance, if farmers have access to agricultural credit, it helps them carry out different farm operations smoothly, such as the purchase of new seeds and other inputs (Deressa et al., 2009). Similarly, Williges et al. (2017) were of the opinion that access to off-farm income is an important source of financial capital. It influences ACC through the sufficient purchase of new technologies and inputs, which are often required for adaptation strategies (Egyir et al., 2015). Access to the marketing of produce also ensures the availability of financial capital for the next production cycle (Mustafa et al., 2021).

Farm machinery, such as irrigation infrastructure (e.g., tube well), the total number of assets owned by farmers, and access to agricultural machinery (e.g., a tractor and tools) are the most important assets contributing to physical capital (Egyir et al., 2015; Sherbinin et al., 2008). This physical capital is important for household ACC (Egyir et al., 2015; Eakin et al., 2011). For instance, access to farm machinery increases farmers' adaptive capacity. This enables farmers to exploit better farming technology and hence enhances adaptation to climate change (Defiesta and Rapera, 2014). The asset-based wealth approach is a better way to measure household wealth as compared to the income or consumption expenditure approach (Howe et al., 2008). This not only develops the adaptive capacity of farmers but also improves their overall well-being (Meinzen-Dick et al., 2013). Previous studies employed an asset-based approach to measure the wealth of farmers. Wealthy farmers tend to adopt more adaptation strategies. For instance, farmers who own livestock, tractors, harvesting and sowing machinery, and transportation tools, such as a car or a motorcycle, are more likely to adopt adaptation strategies. Moreover, wealthy farmers are able to invest in new technologies that support climate change adaptation.

Natural resources include land and its productivity, actions to sustain productivity, and water and biological resources that contribute to nutrition and income generation (Williges et al., 2017; Nawrotzki et al., 2012). The landholding is a high-ranked natural capital that increases farmers' capacity to adapt. For instance, Egyir et al. (2015) assumed that the farm size increases farmers' AC and hence ACC strategies. Tenancy status is another important natural capital that enhances the adaptive capacity of farmers. Ownership of land shows well-established property rights that empower farmers to make long-term investments in technologies for managing their resources (Meinzen-Dick et al., 2013). Similarly, Chepkoech et al. (2020) were of the opinion that ACC strategies depend significantly on farmers' geographical location.

The current study used human capital (farming experience and education), social capital (access to extension services, farmer-to-farmer extension, and membership in FOs), financial capital (access to credit and access to the marketing of produce), physical capital (tube well ownership and access to farm machinery, such as sowing, harvesting, and transportation tools), and natural capital (landholding, tenancy status, and the location of the farm) as factors for adaptive capacity. Although access to climate change information is in itself a resource, this important factor is frequently missed (Choden et al., 2020). CCK can be influenced by other capital resources discussed earlier. For instance, entitlements to resources empower farmers to have access to weather and climate information through different media (Maiti et al., 2017; Quiroga et al., 2020). This CCK further enhances farmers' adaptation decisions. For example, Chen et al. (2018) reported that access to weather information is a global determinant of ACC in terms of both diversification and intensification.

In a nutshell, based on the previous discussion, AC plays a key role in fostering ACC; however, there is limited research on it in Southeast Asian countries, particularly in Pakistan. Using AC through different forms of capital as a lens, the current study analyzed its impact on ACC. Therefore, our first objective was to determine the impact of AC on ACC through human, social, financial, physical, and natural capital resources to escalate the adaptation process. It may help the future potential of agriculture. Moreover, studies dealing with farmers' AC tend to follow the resource endowment perspective and ignore the role of information. Climate change information is in itself a resource like the other capital resources discussed earlier, whose nexus with ACC requires urgent attention. Therefore, the current study intended to determine the impact of adaptive capacity and climate change information on ACC. It is hoped that the adaptation–adaptive capacity relationship will be strengthened in the presence of climate change information.

2 Materials and methods

2.1 Research design

The current study used a quantitative approach. Primary data were collected from Punjab province (the most populated area in Pakistan) through a survey using a multi-stage random sampling technique. A structured questionnaire was developed for the interview. Information about climate change such as temperature, rainfall, and seasonal and weather patterns was collected to assess the farmers' climate change knowledge. Information about the rising sea level was removed from the questionnaire as there is no coastal area in Punjab. Moreover, questions related to the farmers' socio-economic information, the farm and farmers' characteristics, the households' access to different institutional services, and access to different farm machinery and tools were added to the questionnaire. The questionnaire was translated into Urdu and the local language (Punjabi) to remove communication barriers, if any. The farmers' anonymity was maintained, and the farmers were informed that the data would be only used for research purposes. Furthermore, invigilators were hired for data collection, and training regarding the survey was provided to them. Finally, data were collected from April 2023 to July 2023 at the time of wheat harvesting and rice sowing because most farmers are fully engaged in farming activities during this period.

2.2 Sampling technique

The study used a multi-stage random sampling technique. In the first stage, the southern and central zones of Punjab province were selected. In the second stage, two districts from each zone were selected randomly. From each district, two tehsils (sub-part of a tehsil) were elected in the third stage. In the fourth stage, nine villages were randomly selected. In the fifth and last stage, five farmers were selected for the survey. A total of 360 farmers were interviewed, as shown in Table 1.

2.3 Empirical estimates

The study used a logit regression model to identify the factors affecting ACC. Previous studies used a multinomial logit model (Piya et al., 2012); however, a binary logit model is best fitted when strategies are independently adopted. For instance, the decision to adopt change crop variety is entirely independent of soil conservation and the decision to adopt change planting date is not dependent on the change crop type. Following Onyeneke et al. (2018), the study used the binary logit model given below (Equation 1):

$$\ln\left(\frac{L_i}{1-L_i}\right) = \alpha + \sum_{i=1}^{18} \beta_i X_i + \varepsilon \tag{1}$$

where $\ln\left(\frac{L_i}{1-L_i}\right)$ represents the logit for the farmers' ACC strategies (e.g., L_i is the probability of the farmers adopting the i ACC strategy,

TABLE 1 Sampling technique.

Zone	Southern Punjab		Central Punjab	
Districts	Multan	Khanewal	Faisalabad	Lahore
Tehsils	2	2	2	2
Villages	9	9	9	9
Farmers	5	5	5	5
Total	90	90	90	90

while $1 - L_i$ is the probability of the farmers not adopting the particular strategy). We have six sets of ACC strategies, as shown in Table 2, with their mean, standard deviation, and minimum and maximum values. β_is represents the parameters to be estimated (it is the K × 1 vector of unidentified coefficients), X_i s is the 1 × K vector of other determinants influencing the farmers' ACC, and ε is the error term. The final form of the equation for the particular strategy is given below (Equation 2):

$$\begin{aligned}\ln\left(\frac{L_i}{1-L_i}\right) &= \alpha + \beta_1 CCK_1 + \beta_2 age_2 + \beta_3 edu_3 + \\ &\beta_4 FS_4 + \beta_5 labor_5 + \beta_6 ext_6 + \beta_7 FO_7 + \beta_8 FC_8 + \\ &\beta_9 AC_9 + \beta_{10} MP_{10} + \beta_{11} OFI_{11} + \beta_{12} TW_{12} + \\ &\beta_{13} TT_{13} + \beta_{14} ST_{14} + \beta_{15} HT_{15} + \beta_{16} land_{16} + \\ &\beta_{17} TS_{17} + \beta_{18} zone_{18} + \varepsilon\end{aligned} \tag{2}$$

The set of independent variables and their short forms, measurements, means, standard deviations, and minimum and maximum values are provided in Table 2.

The study also calculated the odds ratios. The equation used to calculate the odds ratios is given below (Equation 3):

$$\frac{p_i}{1-p_i} = \exp\left(\beta_0 + \sum_{i=1}^{18} \beta_i X_i\right) \tag{3}$$

The current study used the statistical software STATA to run the logit regression models for the selected adaptation strategies. The Wald chai-square statistics were applied to determine the goodness of fit of the model. It is a way to find out if explanatory variables in a model are significant. The study also determined the correlations among the selected variables that show the strength of their relationships, as shown in the Supplementary Table S1.

3 Results and discussion

The study found that the majority of the respondents respond to climate change vagaries through CCV (64%), CCT (54%), CPD (49%), SC (55%), WC (48%), and DSs (59%) strategies (Table 2). Their adaptation is rather slow compared to other developing countries (Silvestri et al., 2012; Chetri et al., 2024). Factors that determined the ACC strategies are given below.

3.1 Climate change knowledge and adaptation measures

Climate change knowledge (CCK) empowers farmers regarding adoption measures by providing information about the deleterious consequences of climate vagaries. The farmers were asked to report whether they had information about weather and seasonal changes, erratic rainfall, and the temperature in summer or winter, as well as whether they had heard about climate change. The study found that 75% of the respondents had CCK (Table 2). It was found that CCK significantly impacted all the selected ACC strategies (Table 3). For instance, CCK was significantly related to CCV, meaning that the farmers substantiated the climate vulnerability that helped them adapt

TABLE 2 Descriptive statistics of the selected instruments.

Variables and their short forms	Measurement	Mean	Standard deviation	Mini	Max
Change crop variety-CCV	1 if adopted CCV; zero otherwise	0.64	0.48	0	1
Change crop type-CCT	1 if adopted CCT; zero otherwise	0.54	0.50	0	1
Change planting date-CPD	1 if opted CPD; zero otherwise	0.49	0.50	0	1
Soil conservation-SC	1 if adopted SC methods; zero otherwise	0.55	0.50	0	1
Water conservation-WC	1 if WC methods used; zero otherwise	0.48	0.50	0	1
Diversification strategies-DSs	1 if DSs used; 0 otherwise	0.59	0.49	0	1
Climate change knowledge-CCK	1 if have CCK; zero otherwise	0.75	0.43	0	1
Human capital					
Age	Years	40.23	14.19	17	80
Education-Edu	Formal years of schooling	8.39	5.10	0	18
Family size-FS	Number	9.44	3.95	3	30
Labor	Number	2.88	1.77	0	15
Social capital					
Access to extension services-Ext	1 if have access to ext. services; zero otherwise	0.64	0.48	0	1
Farmers' organization-FO	1 if a member of FOs; zero otherwise	0.54	0.50	0	1
Farmer-to-farmer extension-FC	1 if farmers cooperate; zero otherwise	0.80	0.40	0	1
Financial capital					
Agricultural credit-AC	1 if have access to AC; zero otherwise	0.49	0.50	0	1
Marketing of produce-MP	1 if have access to MP; zero otherwise	0.44	0.50	0	1
Off-farm income-OFI	1 if have OFI; zero otherwise	0.31	0.46	0	1
Physical capital					
Tube well-TW	1 if have TW; zero otherwise	0.68	0.47	0	1
Transportation tools-TT	1 if have TT; zero otherwise	0.69	0.46	0	1
Sowing tool-ST	1 if have access to ST; zero otherwise	0.57	0.50	0	1
Harvesting tool-HT	1 if have access to HT; zero otherwise	0.56	0.50	0	1
Natural capital					
Landholding-Land	Number of acres	15.61	17.87	1	100
Tenancy status-TS	1 if an owner of land; zero otherwise	0.74	0.44	0	1
Zone	1 if central Punjab; zero southern	0.50	0.50	0	1

Own illustration through survey.

by using resilient varieties of crops. Moreover, the odds ratio revealed that the farmers who had CCK were 2.53 times more likely to opt for CCV as compared to those who did not have CCK (Table 4). The findings of the study are in line with those of previous studies, where researchers found that farmers' clear understanding of climate change significantly determined CCV (Elum et al., 2017; Singh et al., 2017). Similarly, CCK was also found to have a significant and positive impact on CCT strategies. The odds ratio showed that the farmers who had CCK were 2.55 times more likely to opt for CCT as compared to those who did not have climatic change knowledge.

Change planting dates (CPD) to a suitable timing to avoid extreme climatic events is one the simplest approaches to adapt to the effects of climate variability (Yegbemey et al., 2014). By adopting this approach, farmers can adjust the planting dates to operate in a time-efficient manner and avoid extreme weather shocks (Sacks et al., 2010). CPD has the potential to reduce crop failure due to water stress during the juvenile stage of crop development (Waongo et al., 2015). Similarly, Laux et al. (2010) estimated that CPD minimizes water stress during the entire growing period of crops. Such adaptation methods significantly improve crop production (Waongo et al., 2014; Wu et al., 2024). CPD is among the low-cost adaptation strategies that aim to alleviate crop water stress, increase the yield and yield stability of crops, enhance agricultural decision-making, and hence improve crop production (Waongo et al., 2015; Wu et al., 2024; Bassu et al., 2021; Chisanga et al., 2020; Li et al., 2022). Although it is a simple strategy, the majority of farmers give it the least preference (de Sousa et al., 2018). This might be one of the reasons why farmers do not have CCK. The current study found that the farmers who had CCK were more prone to adopt CPD. The odds ratio showed that the aware farmers were 3.92 times more likely to adopt CPD as compared to the non-aware farmers. Similarly, CCK significantly impacts SC strategies. The odds ratio showed that the farmers who had CCK were 3.09 times

TABLE 3 Determinant of the ACC strategies (dependent variables = ACC strategies; $n = 360$).

Variables	CCV	CCT	CPD	SC	WC	DS
Climate change knowledge	0.9295 (0.3641)*	0.9365 (0.3776)**	1.3655 (0.4337)*	1.1271 (0.4114)*	−1.1002 (0.4151)*	0.8694 (0.4329)**
Age	0.0549 (0.0121)*	0.0389 (0.0124)*	0.0097 (0.0115)	0.0088 (0.0130)	0.0066 (0.0096)	0.0127 (0.0122)
Education	0.1673 (0.0389)*	0.1123 (0.0403)*	0.0576 (0.0339)***	0.0456 (0.0413)	0.0879 (0.0388)**	−0.0314 (0.0396)
Family size	0.0369 (0.0410)	0.0036 (0.0395)	0.0906 (0.0393)**	0.0232 (0.0460)	0.0085 (0.0509)	0.1036 (0.0479)**
Labor	0.0763 (0.0966)	0.1064 (0.0866)	0.0766 (0.0743)	−0.2874 (0.1085)*	0.2794 (0.0862)*	0.0016 (0.0802)
Access to extension services	0.2752 (0.3306)	0.7700 (0.3410)**	1.0256 (0.3285)*	0.4285 (0.3653)	0.9611 (0.3659)*	0.4503 (0.3774)
Farmers' organization	0.1736 (0.3401)	0.0712 (0.3371)	0.0934 (0.3047)	0.1950 (0.3669)	0.6232 (0.3278)***	0.2068 (0.3635)
Farmer-to-farmer extension	0.9286 (0.4068)**	0.9924 (0.4756)**	0.8318 (0.3987)**	0.3818 (0.4758)	0.1772 (0.4100)	−1.9808 (0.5456)*
Agricultural credit	1.1989 (0.3444)*	0.7047 (0.3426)**	−0.2145 (0.3456)	0.8096 (0.3829)**	1.4454 (0.3157)*	0.5232 (0.4042)
Marketing of produce	1.1059 (0.3769)*	0.5140 (0.3705)	1.3473 (0.3363)*	0.4345 (0.3799)	−0.4625 (0.3729)	0.2115 (0.3793)
Off-farm income	0.0982 (0.4144)	0.4669 (0.3872)	−0.1243 (0.3361)	0.9874 (0.3878)**	0.0562 (0.3294)	1.7010 (0.3732)*
Tube well	−0.3662 (0.4183)	−0.0142 (0.4151)	−0.4492 (0.4140)	0.4129 (0.4403)	0.9506 (0.3946)**	0.3044 (0.4715)
Transportation tools	1.0691 (0.4463)**	−0.0771 (0.4652)	0.4296 (0.4079)	−0.1102 (0.5097)	0.1969 (0.3873)	1.1622 (0.4896)**
Sowing tool	−0.4925 (0.4565)	0.5213 (0.3910)	0.1835 (0.3882)	0.8364 (0.3699)**	−0.0523 (0.3735)	0.6388 (0.3635)***
Harvesting tool	−0.4344 (0.3720)	0.3470 (0.3722)	0.0196 (0.3286)	0.9636 (0.3739)**	0.4493 (0.3345)	0.1526 (0.4067)
Landholding	−0.0025 (0.0096)	0.0022 (0.0103)	−0.0016 (0.0086)	0.0355 (0.0168)**	0.0024 (0.0102)	0.0176 (0.0102)***
Tenancy status	0.3119 (0.4005)	0.6470 (0.3873)***	0.4208 (0.3441)	−0.6662 (0.4291)	0.2349 (0.3543)	−0.3141 (0.4055)
Zone	−0.0471 (0.3864)	1.3185 (0.3666)	−0.4320 (0.3292)	1.4516 (0.3792)*	−0.1072 (0.3805)	1.1109 (0.3769)*
Constant	−6.2963 (0.8571)*	−7.0337 (1.0312)*	−5.1590 (0.9305)*	−4.1761 (0.8206)**	−4.0894 (0.7838)*	−3.0956 (0.7632)*
Wald χ^2 k-1	132.19	116.74	100.61	109.92	93.96	113.17
Prob > χ^2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Pseudo R2	0.3616	0.3932	0.3165	0.4646	0.3226	0.4189
Log pseudo-likelihood	−150.6837	−150.6509	−170.5141	−132.5357	−168.8472	−141.6837

Values in parenthesis are robust standard errors, while *, **, and ***, respectively, show the level of significance at $p < 0.01$, $p < 0.05$, and $p < 0.10$. Moreover, the absence of these asterisks shows that there is no relationship between the dependent and independent variables.

more likely to adopt SC as compared to those who did not have CCK. The results are in agreement with those of previous studies (Belay et al., 2022; Sheikh et al., 2024).

CCK also significantly and positively impacts diversification strategies. The odds ratio showed that as the farmers' knowledge about climate increased, their probability to adopt DSs also increased by 2.39 compared to those farmers who did not have CCK (Table 4). The findings of this study are in agreement with those of previous studies (Chetri et al., 2024; Mohammed et al., 2021). For instance, Mohammed et al. (2021) found that farmers who used sources of climate information practiced diversification strategies, both farm and non-farm diversification.

The only strategy significantly and negatively impacted by CCK is WC. It means that as CCK increases, the probability of adopting WC as a measure decreases. For instance, Taylor et al. (2017) found that some farmers demonstrated a high level of CCK but did not engage in positive water conservation behaviors. This might be due to economic reasons as most farmers in Punjab are poor. Water conservation in Punjab is usually achieved through methods such as switching canal water timing with other farmers, furrow bed planting, laser land leveling, zero tillage, rainwater harvesting, and the installation of tube wells. These conservation methods are rather costly strategies. On the other hand, farmers who have plenty of water for crops hardly care about climatic shocks. Therefore, there is a negative relationship between CCK and WC strategies. Therefore, there is a need to integrate the concept of climate change. Our results are in contradiction with those of previous studies (Esham and Garforth, 2013; Everest, 2021).

3.2 Human capital and ACC measures

Age has a significant impact on the adaptation options such as CCV and CCT. It means that as farmers grow older, the probability of adopting the mentioned strategies increases. The finding is further underscored through the odds ratios, which showed that the probability of adopting CCV and CCT strategies increased by 1.06 and 1.04 times, respectively, with older farmers compared to younger farmers (Table 4). The consideration of age is a way of reflecting the importance of experience, as older farmers usually understand the necessity of ACC strategies. Therefore, their probability of adopting ACC strategies increases with age. The results are in agreement with those of previous studies (Elum et al., 2017; Belay et al., 2022; Sheikh et al., 2024).

Education empowers all people and especially encourages farmers to adapt to climate variations. This is evident from the results of the study, which suggested that education had a positive and significant

TABLE 4 Odds ratio of the selected ACC strategies.

Variables	CCV	CCT	CPD	SC	WC	DS
Climate change knowledge	2.53 (0.9225)*	2.55 (0.9632)**	3.92 (1.6990)*	3.09 (1.2699)*	0.33 (0.1382)*	2.39 (1.0326)**
Age	1.06 (0.0128)*	1.04 (0.0129)*	1.01 (0.0120)	1.01 (0.0131)	1.01 (0.0097)	1.01 (0.0124)
Education	1.18 (0.0459)*	1.12 (0.0451)*	1.06 (0.0360)***	1.05 (0.0432)	1.09 (0.0423)**	0.97 (0.0384)
Family size	1.04 (0.0426)	1.00 (0.0396)	1.09 (0.0430)**	1.02 (0.0471)	1.01 (0.0513)	1.11 (0.0532)**
Labor	1.08 (0.1043)	1.11 (0.0963)	1.08 (0.0800)	0.75 (0.0814)*	1.32 (0.1140)*	1.00 (0.0804)
Access to extension services	1.32 (0.4353)	2.16 (0.7365)**	2.79 (0.9160)*	1.54 (0.5608)	2.61 (0.9566)*	1.57 (0.5921)
Farmers' organization	1.19 (0.4046)	1.07 (0.3620)	1.10 (0.3350)	1.22 (0.4459)	1.86 (0.6112)***	1.23 (0.4470)
Farmer-to-farmer extension	2.53 (1.0295)**	2.70 (1.2832)**	2.30 (0.9160)**	1.46 (0.6971)	1.19 (0.4895)	0.14 (0.0753)*
Agricultural credit	3.32 (1.1423)*	2.02 (0.6931)**	0.81 (0.2790)	2.25 (0.8605)**	4.24 (1.3395)*	1.69 (0.6820)
Marketing of produce	3.02 (1.1390)*	1.67 (0.6195)	3.85 (1.2940)*	1.54 (0.5866)	0.63 (0.2348)	1.24 (0.4686)
Off-farm income	1.10 (0.4572)	1.60 (0.6176)	0.88 (0.2970)	2.68 (1.0409)**	1.06 (0.3484)	5.48 (2.0448)*
Tube well	0.69 (0.2901)	0.99 (0.4093)	0.64 (0.2640)	1.51 (0.6653)	2.59 (1.0209)**	1.36 (0.6392)
Transportation tools	2.91 (1.2999)**	0.93 (0.4306)	1.54 (0.6270)	0.90 (0.4565)	1.22 (0.4716)	3.20 (1.5654)**
Sowing tool	0.61 (0.2790)	1.68 (0.6586)	1.20 (0.4660)	2.31 (0.8537)**	0.95 (0.3544)	1.89 (0.6887)***
Harvesting tool	0.65 (0.2409)	1.41 (0.5266)	1.02 (0.3350)	2.62 (0.9801)**	1.57 (0.5243)	1.16 (0.4737)
Landholding	1.00 (0.0095)	1.00 (0.0103)	1.00 (0.0090)	1.04 (0.0174)**	1.00 (0.0102)	1.02 (0.0103)***
Tenancy status	1.37 (0.5470)	1.91 (0.7396)***	1.52 (0.5240)	0.51 (0.2204)	1.26 (0.4482)	0.73 (0.2962)
Zone	0.95 (0.3686)	3.74 (1.3701)	0.65 (0.2140)	4.27 (1.6190)*	0.90 (0.3418)	3.04 (1.1447)*

Values in parenthesis are robust standard errors, while *, **, and ***, respectively, show the level of significance at $p < 0.01$, $p < 0.05$, and $p < 0.10$.

impact on the majority of adaptation strategies, such as CCV, CCT, CPD, and WC (Table 3). In other words, educated people are more likely to adapt to climate change as compared to those who are less educated or illiterate. The odds ratios revealed that the educated farmers were 1.22 times more likely to adopt CV, 1.21 times more likely to adopt CT, 1.11 times more likely to adopt CPD, and 1.09 times more likely to adopt WC as compared to the less educated farmers (Table 4). These findings underscore the critical role played by education in fostering knowledge about rural areas and, consequently, ACC strategies among farmers. The results are in agreement with those of previous studies (Ali and Erenstein, 2017; Belay et al., 2022; Fadina and Barjolle, 2018).

Households of farmers with relatively large family sizes are more likely to take up new adaptation strategies when compared to households of farmers with small family sizes. Family size positively and significantly impacts CPD and DSs. The odds ratio showed that the farmers with a larger family size were more likely to opt for CPD and DSs. This might be because both strategies are labor-intensive and extra family members can be available to work on the farms. For instance, the results showed that the farmers with a larger family size were 1.12 times more likely to adopt CPD and 1.11 times more likely to opt for DS. The results are in agreement with those of previous studies (Marie et al., 2020; Deressa et al., 2009), which reported that a large family size allows the accomplishment of laborious tasks during peak seasons by having extra labor.

Labor is the most important human factor contributing to ACC strategies. It can be viewed from two angles. First, sometimes agriculture requires a greater number of workers to perform laborious farming activities. For instance, diversification of the farming business requires more workers. Therefore, it has a significant and positive impact on WC strategies. The odds ratio showed that the farms with a greater number of laborers were 1.32 times more prone to adopt WC strategies as compared to the farms with a smaller number of laborers. The results are in agreement with those of previous studies (Elum et al., 2017; Tikita and Lee, 2024). Second, soil conservation strategies, such as fertilization applications, do not require much labor. Therefore, a greater number of laborers may decrease the probability of adopting SC. The odds ratio revealed that the likelihood of adopting SC strategies decreased by 0.95 times for the labor-intensive farms as compared to the farms with a smaller number of laborers.

3.3 Social capital and ACC strategies

Social capital includes farmers' interpersonal networks, trust, and norms. Social networks among farmers build social capital. Such networks help farming communities achieve common social objectives. Studies have identified that farmers-to-farmers exchange of information and inputs, access to extension services, and association with FOs are important sources of social capital (Ali and Erenstein, 2017; Abdul-Razak and Kruse, 2017; Chepkoech et al., 2020; Yameogo et al., 2018). Farmers' ties become stronger when they share inputs, share climate information, lend money to fellow farmers in need, and exchange marketing information. For instance, social networks, such as farmers-to-farmers extension, are related to CCV, CCT, CPD, and diversification strategies. As farmers' cooperation among themselves increases, the likelihood of adopting CCV as an adaptation measure increases (Table 3). The odds ratio showed that as the farmers' own cooperation increased, their probability of opting for CCV (2.53 times), CCT (2.70 times), and CPD (2.30 times) increased compared to those farmers who did not cooperate with each other. Similar results were reported by previous studies (Chepkoech et al., 2020;

Esham and Garforth, 2013). On the other hand, the probability of adopting DSs was 0.14 times lower among the farmers who cooperated with each other compared to the farmers who did not cooperate with each other. This might have been because diversification strategies involve labor-intensive work and it is difficult for farmers to offer their labor services for free.

Access to extension services has a positive impact on the likelihood of adopting adaptive measures, such as CCT, CPD, and WC strategies (Table 3). The odds ratio showed that the likelihood of adopting CCT was 2.16 times higher for the farmers with access to extension services compared to those with no access to such services. Similarly, the farmers with access to extension services were 2.79 times more prone to adopting CPD compared to those with no access to such services (Table 4). Furthermore, farmers with access to extension services were 2.61 times more likely to adopt WC strategies. These results reveal that the extension department plays an important role in ACC. Pakistan has a well-established extension department. There is a complete hierarchy in the extension department, with each union council (sub-part of a tehsil) having its own team of agricultural officers and field assistants who meet farmers every fortnight. This team organizes farmers meeting every 15 days with farmers in the fields. These meetings are reported to the district agricultural officer. In addition, farmers can approach the agricultural officer and his team any time during office hours. On the same line, private companies (such as those providing fertilizer, seed, and pesticides) have a parallel system of extension services in Pakistan. The companies not only sell their products to farmers but also address the issues that farmers face in crop and livestock production. Therefore, the majority of adaptation strategies are positively and significantly determined by access to extension services. Our results are supported by those of previous studies (Abdul-Razak and Kruse, 2017; Belay et al., 2022; Tikita and Lee, 2024).

Farmers' organizations (FOs) are an important source of social networking. These help farmers in acquiring adequate information about adaptation options and other challenges faced by them. The likelihood of adopting WC strategies was found to increase among the farmers who were members of any FOs (Table 3). For instance, the odds ratio showed that the probability of adopting WC was 1.86 times higher for the farmers who were members of any FO as compared to non-members. Similar results were found in previous studies (Ali and Erenstein, 2017; Chepkoech et al., 2020; Yameogo et al., 2018).

3.4 Financial capital and ACC options

It has been found that a lack of financial management limits the adaptation (Linnerooth-Bayer and Hochrainer-Stigler, 2015). Therefore, any effort to enhance farmers' financial ability fosters the adaptation options. It has been found that agricultural credit availability, access to the marketing of produce, and off-farm income increase the financial capital of farming households (Deressa et al., 2009; Defiesta and Rapera, 2014; Williges et al., 2017; Egyir et al., 2015). The current study found that four adaptation strategies such as purchasing new crop varieties, adjusting crop calendars, and soil and water conservation strategies are significantly and positively determined by access to agriculture credit (Table 3). In our study, the likelihood of adopting CCV increased by 3.32 times among the farmers with access to credit availability compared to those with no access to credit. Similarly, as the farmers' access to credit increased, the probability of CCT also increased by 2.02 times (Table 4). Furthermore, the credit users were 2.25 times more likely to adopt SC strategies as compared to the non-credit users. Moreover, the results indicated that the farmers with access to agricultural credit were more likely to adopt WC strategies compared to - those without access to credit. The findings are in agreement with those of previous studies (Defiesta and Rapera, 2014; Egyir et al., 2015), which indicated that greater financial resources allow the acquisition of information and physical resources that are crucial in undertaking ACC strategies.

Usually, the government announces support prices for major crops such as wheat, cotton, and sugarcane. For instance, in the case of wheat, the government provides jute bags (bardana) to farmers, allowing them to pack their wheat and sell it at specific PASCO stations. This bardana is part of the marketing of produce. The results of the study indicated that access to the marketing of produce has a significant and positive impact on CCV and CPD. For instance, the farmers who had access to the marketing of produce were 3.03 times more likely to adopt CV and 2.03 times more likely to adopt CPD compared to those who did not have access to the marketing of produce. A similar situation has been reported in India (Chetri et al., 2024), where it was noted that farmers with access to financial systems such as the Kasan card significantly considered adaptation strategies.

Non-farm employment is significantly important in providing an alternative source of livelihood to farming households. It ensures the financial stability of farmers. Farmers can have enough funds in the case of crop failure. In many developing countries, income from non-farm activities significantly contributes to the total household income (Nagler and Naude, 2017). The current study found that off-farm employment is significantly related to soil conservation and diversification strategies. The odds of the farmers who generated income from non-farming activities was 2.68 more than that of the farmers who did not generate income from non-farming activities. Similarly, the likelihood of the former farmers adopting diversification strategies was five times more than that of the latter farmers. Diversification strategies are rather more influential because they require more financial resources to diversify crops, animals, and enterprises. Similar results were found in studies conducted in Nigeria (Danso-Abbeam et al., 2021), Sri Lanka (Esham and Garforth, 2013), and Benin (Fadina and Barjolle, 2018).

The previous discussion indicated that for the farming households with high financial resources, the likelihood of adopting ACC strategies was higher. It is clear from the results that financial stability helps farmers to take timely actions for the next production cycle, such as a timely purchase of inputs. Off-farm income and access to the marketing of produce ensure the availability of physical resources, such as access to farm machinery, and natural resources, such as the acquisition of more land.

3.5 Physical capital and ACC strategies

The study used four types of asset ownership as proxies for the wealth of farmers; tube well ownership, transportation tool ownership, and the possession of sowing and harvesting tools. These four significantly predict the majority of the adaptation strategies (Table 3). For instance, tube well ownership significantly impacted WC strategies. The odds ratio showed that the farmers with tube well ownership were 2.59 times more likely to adopt WC compared to the farmers with no tube well ownership (Table 4). The ownership of transportation tools such as a motorcycle, tractor, and car ownership significantly and positively impact CCV and DSs. This may be because new crop varieties and the diversification of crops and animals require frequent visits to nearby markets, and transportation tools are readily available to farmers for this purpose. For instance, the odds ratio showed that the farmers with transportation tool ownership were 2.91 and 3.20 times more likely to adopt CCV and DSs, respectively, compared to those who did not have these tools. Similar results were reported by Ali and Erenstein (2017).

The ownership of sowing tools significantly and positively impacted SC and DSs (Table 3). For instance, the odds ratio showed that the farmers with sowing tools were 2.31 times more likely to adopt SC strategies and 1.89 times more likely to adopt DSs, respectively, compared to those who rented sowing tools. Similarly, harvesting tools are not only a strong indicator of wealth but also help farmers adopt SC strategies. For instance, the odds ratio showed that the farmers with the ownership of harvesting tools were 2.62 times more likely to adopt SC strategies compared to those who did not own these tools and rented these tools. Most of the sowing and harvesting (particularly wheat) is done using tractors and other tools. Hence, if farmers have to rent such tools, they have to pay high rental costs. This is why the ownership of such farm machinery significantly contributes to the majority of the strategies. The existing literature described the same phenomenon (Sohail et al., 2022).

Based on the above discussion, it is clear that access to agricultural technologies ensures the undertaking of farm operations and farm-level adaptation strategies. The current study incorporated access to farm technologies such as tube well ownership, access to sowing and harvesting tools (either own ownership or rented), and transportation tools (e.g., a bike, car, or tractor). These technologies help farmers in smoothly conducting farm operations and likely facilitate the uptake of ACC strategies by farmers. Although various governments in Pakistan have subsidized tractors for farmers, there is a need to provide financial assistance for other transportation, harvesting, and sowing tools.

3.6 Natural capital and ACC measures

The land is a limited resource owned by farmers. Therefore, any increase in landholding will always motivate farmers to conserve soil by maintaining fertility and to diversify crop production by producing a variety of crops. For instance, the current study found that as the household land size increased, the probability to adopt soil conservation and diversification strategies also increased (Table 3). The odds ratio showed that the probability to adopt soil conservation and diversification strategies increased by 1.04 and 1.02 times, respectively, for large landholders and farmers who owned more acres of land compared to small landholders. The results are in agreement with those of previous studies (Fadina and Barjolle, 2018; Sichoongwe et al., 2014; Maggio et al., 2018).

Tenancy status has a significant impact only on CCT strategies. It means that for farmers who have their own land, the probability of adopting CCT as an adaptation measure increases. The odds ratio (likelihood) for the landowners was 1.91 times higher compared to the farmers who rented or leased the land. This indicates that well-established property rights encourage farmers to shift to new crops. Secure property rights also empower farmers to make long-term investments, such as trying profitable crops through credits by pledging their lands for loans. The results are supported by those of previous studies (Ali and Erenstein, 2017), which showed that landowners practice more ACC strategies compared to tenants.

The location of the farm is crucial to the adoption of ACC measures. The study found that central Punjab is more prone to adopting SC and diversification strategies. This may be because central Punjab has a greater tendency for diversification due to its proximity to many metropolitan cities, such as Faisalabad and Lahore. The odds ratio showed that the likelihood of adopting DSs was 4.27 times higher in central Punjab as compared to southern Punjab. Similarly, the probability of adopting diversification strategies in central Punjab was 3.04 times greater as compared to southern Punjab. A previous study also reported that ACC strategies are highly dependent on geographical locations (Chepkoech et al., 2020).

4 Conclusion

Farmers respond to environmental consequences through various adaptation to climate change (ACC) strategies such as CCV, CCT, CPD, SC, WC, and DS. The study reported the impact of different capital resources on these ACC strategies. The study found that physical capital, such as ownership of tube wells, transportation tools, and harvesting and sowing technologies, enhances farmers' adaptive capacity (AC), which significantly determines ACC strategies. Such tools reflect the wealth of farmers, and rich farmers are more likely to opt for ACC as an adoption measure compared to poor farmers. However, the majority of farmers lack access to these tools and hire these tools on rent at high costs. Therefore, the study recommends that farmers' ownership of these tools be increased through financial programs. For instance, while the Punjab government subsidizes bikes for students, this program should be extended to farming communities as well. Moreover, human, financial, and social capital resources also significantly impact ACC strategies. It is reiterated that financial capital should be strengthened by providing all farmers with more access to agricultural credit and the marketing of produce.

The findings revealed that CCK significantly impacts all ACC strategies. Climate change information has proven to be a global determinant of adaptation options. It is also a resource like other capital resources. It is clearly evident from the results that CCK self-motivated the farmers to adopt more ACC strategies. In the long run, there is a need to increase farmers' AC through physical and financial resources, while in the short run, climate change information should be spread among the farmer community. Moreover, entitlements to resources empower farmers to have access to weather and climate information. The findings of this study provide evidence that the ACC–AC relationship is strengthened in the presence of the climate information resource. The current study separately examined the impact of human capital (age, education, family size, and labor), financial capital (off-farm employment and access to the marketing of produce and agricultural credit), social capital (farmers-to-farmers extensions, access to extension services, and membership in farm organizations), physical capital (ownership of farm machinery), and natural capital (land ownership, tenancy status, and the location of farms) on adaptation choices. However, future studies can calculate the indices of these capitals and then estimate the impact of AC on ACC strategies.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the [patients/participants OR patients/participants legal guardian/next of kin] was not required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

GM: Conceptualization, Data curation, Formal analysis, Methodology, Software, Supervision, Writing – original draft, Writing – review & editing. BA: Data curation, Funding acquisition, Investigation, Methodology, Project administration, Resources, Validation, Visualization, Writing – review & editing.

Funding

The author(s) declare that financial support was received for the research, authorship, and/or publication of this article. This research was funded by King Saud University, Riyadh, Saudi Arabia, project number RSP2024R443.

Acknowledgments

Authors are thankful to King Saud University and the University of Education, Lahore, for supporting this research.

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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Supplementary material

Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2024.1471238/full#supplementary-material

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