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Climate change risk perception and adaptation to climate smart agriculture are required to increase wheat production for food security

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Highlights

- *Literate farmers are more aware of climate change as compared to illiterate farmers.*
- *The farmers emphasized the increase in both the summer and winter temperature.*
- *Rainfall is identified as a major climate threat in the study area.*
- *The farmers identified that the highest impact of climate change occurred during the harvest phase of wheat.*
- *The farmers stated that the limited adoption of climate smart agricultural practices is due to lack of knowledge and technological, economic, and other gaps.*

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Abstract

Climate change poses a serious risk to wheat farmers in many regions of the world. The present study was conducted in the Sialkot District, Punjab, Pakistan, to investigate climate change trends during the past thirty years and to determine farmers' knowledge and perceptions about climate change. The study also addresses the impacts of climate change on wheat production, current adaptation strategies, and limitations in adaptations to climate-smart agriculture (CSA) through a questionnaire-based survey. The historical weather data from the past thirty years indicated an increase in the mean annual minimum and maximum temperature and a decrease in annual total precipitation. Wheat productivity during the past thirty years showed an increasing trend but it was inconsistent. The respondents' perception of climate change indicated that the literate farmers and those with broad farming experience were more knowledgeable about the climatic effects on wheat production. However, the survey results showed that the age of the farmers did not affect their perceptions. The current management practices are primarily based on prior experiences (70%) and traditional practices (30%). The standard management practices to increase farm productivity include an increase in fertilizer use (70%), a decrease in manure use (24%), and intercropping or switching to other crop cultivations (60%). The farmers stated that their reasons for limited adaptation to climate smart farm practices (CSFP) were due to their lack of knowledge and skills (86%), lack of modern technologies (74%), economic constraints (78%), politics (86%), and social influences (74%). Based on the survey results, the study suggests that addressing these gaps can increase farm-level wheat productivity to increase resilience. This can be achieved by introducing state-of-the-art farming practices through farmer training and by providing institutional services with a focus on climate-specific farm consultation services, leading to climate-smart agricultural practices for improved food security.

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Introduction

Global food security is influenced by the effects of climate change on crop yield (Verma *et al*., 2022; Mittal *et al*., 2020; Robinson *et al*., 2015). Climatic variation in temperature and precipitation directly affects crop growth, grain yield, and crop health (Li *et al*., 2013; Green *et al*., 2018; O'Brien *et al*., 2021). Climate change has impacted both developed as well as developing nations. However, the developing countries are more vulnerable due to the compounding challenges of poverty, infrastructure, and technology (Lipper *et al*., 2014; Adimassu and Kessler, 2016; Hayhoe *et al*., 2018). The regions located between the mid to high latitudes have a positive impact of temperature increase on crop yield, whereas an increased temperature decreases the crop yield in dry and low-latitude regions (Ray *et al*., 2019; IPCC, 2022).

According to the Global Climate Risk Index report of 2020, Pakistan is 5th most vulnerable country in terms of global warming and climate change (Garg, 2021; Ahmad *et al*., 2015; CIAT, 2017). Pakistan has been ranked as 12th on climatic vulnerability and specifically on agriculture and livelihood (Awan and Yaseen, 2017). The changes in the patterns and intensity of precipitation (monsoon) and temperature are considerable challenges for the country's agriculture sector (Syed *et al*., 2022; CIAT, 2017; Abid *et al*., 2016). Agriculture contributes 9.1% to the national economy of Pakistan and involves 42% of the labour force, so a decline in agricultural productivity could result in an adverse impact on the livelihood of those directly and indirectly involved in agriculture (Abid *et al*., 2016; World Bank, 2017; GoP, 2019). Pakistan is the sixth most populous country and ranks 78 out of 113 countries in the Global Food Security Index (World Bank, 2017). Wheat is Punjab's leading staple food, with a total area under wheat cultivation of 9.74 M ha (2019-2020), while it accounts for 62% of the total dietary energy (GoP, 2020). As the population increases, Pakistan is projected to experience an increasing gap between the per capita demand and supply of wheat by the mid-century (2050), which could lead to local food insecurity and economic losses. Climate change will aggravate this situation if not efficiently managed (Zulfiqar and Hussain, 2014).

To increase agricultural production, a 70% increase in adaptative measures such as biotechnologies would be needed to create a more productive crop and ensure food security (Tester and Langridge, 2010). With the shift towards higher temperatures, wheat productivity in many parts of Pakistan may increase, making it possible to grow at least two wheat crop cycles per year with appropriate management and adaptation measures (CIAT, 2017). Farm-level adaptative strategies for climate change are based on understanding, perceptions, and adaptative practices of farmers that differ by culture, demography, and region. Farmers recognize the local indicators of climate change and the potential negative impact on yield. As a result, they have adopted strategies such as land use management, crop and cultivar diversification, livelihood change, increases in irrigation, and migration (Vedwan and Rhoades, 2001; Grothmann and Patt, 2005; Byg and Salick, 2009). Various studies have shown that a farmer's adaptative strategies are not merely based on their understanding and perception of climate change but are also influenced by economic, political, and social factors (Mertz *et al*., 2009a, 2009b; Battaglini *et al*., 2009; Li *et al*., 2013). Adopting climate change adaptation strategies contribute to a higher farm productivity and income (Arslan *et al*., 2015; Iqbal *et al*., 2015; Abid *et al*., 2016). The perception of farmers about adaptation to climate change and their barriers in adaptation are important to investigate as farmers might not adapt to climate change even if their agricultural yield and livelihoods are at a high risk (Chen and Whalen, 2016). Studies have shown that adaptation to climate change strategies can increase wheat yield as well as net farm income (Iqbal *et al*., 2015; Abid *et al*., 2016). Therefore, it is necessary to study the perception and understanding of farmers as well as barriers to adaptation to climate change at the regional level.

Although much has been done to adapt to climate change, studies need to be undertaken to understand both what has driven adaptations in the past and to focus on the future. The Punjab region of Pakistan is very sensitive to climate change, as the temperature in this region has increased in recent decades (Liu *et al*., 2007; Li *et al*., 2013), making it the focus of climate change studies. By considering the climate change risk to wheat productivity and the importance of adaptation to extreme weather conditions, the survey study was conducted with farmers in the Sialkot District, Punjab. The objectives of the present study were to determine climate change and yield trends in the study area during the past 30 years (1988-2018), to understand farmers' knowledge and perceptions of climate change, to identify strategies that farmers have taken to adapt to the effect of climate change on wheat, and to determine the barriers for implementing climate change adaptation measures.

Materials and methods

Study region

Punjab is Pakistan's major wheat production area with a total of 75.5% of farmland area, *i.e*., 6.96 M ha (Pakistan Statistical Bureau, 2019). The wheat-rice cropping system predominates in this region and the winter wheat crop, known as 'Rabi crop.' is sown during November and December and harvested in April or May. The present study was conducted in the Sialkot District of Punjab located around a latitude of 32.381°N, a longitude of 74.49°E, and at an elevation of 249 m above sea level with a total area of 3016 km^2 (GoP, 2017). There are four municipalities (Tehsils) in Sialkot and 152 villages (Figure 1). The land is plain and fertile for agriculture. Most of the area is rural, *i.e*., 74.2%, and only 25.8% is urban. The dominant crop in the region is wheat, grown on approximately 209,000 ha and with an annual average total production of 536,000 Mt (GoP, 2019). The weather pattern in this region varies from hot and humid during the summer to cold during the winter, with an average annual precipitation of 1000 mm. This study area was selected because climate change projections indicate a high vulnerability to extreme weather events such as flash floods, extreme heatwaves, and changes in precipitation patterns (Bashir, 2018).

Historical data collection

Meteorological data

The weather station in Sialkot is the only weather station in the study area with the longest available meteorological records. It is located at a latitude of 74.53°E, a longitude of 32.50°N and at an elevation of 2560 m. Long-term historical weather data from 1988 to 2018 for minimum and maximum temperature and precipitation were obtained from the Punjab Meteorological Department to analyse climate change trends.

Wheat production data

Wheat yield and production data for the Sialkot District were extracted from published reports of the Pakistan Statistical Bureau (PSB) for the period of thirty years *i.e.*, 1988 to 2018.

Farmer survey

A list of wheat farmers in the four municipalities in the Sialkot District was obtained from the local Agriculture Office. The farmers that were available during this time period were selected from stratified random sampling, *i.e.*, 13 different villages present in four municipalities, including four from Daska, two from Pasrur, two from Sambrial, and five from Sialkot 5 (Figure 1). A representative sample of farmers was chosen randomly from landowners who had more than ten years of farm experience, as these farmers are considered to have more experience in agriculture and might have observed changes in the local weather conditions due to climate change. The questionnaires were written in the local language so that the farmers could fully understand and respond to all the questions. A total of 185 questionnaires were randomly distributed in person among farmers (45-46 questionnaires in each municipality) between September and November of 2018. We selected this period for data collection because it coincided with the preparatory and sowing stages for wheat and, thus, farmers were easily approachable during the sowing phase. When the surveys were distributed, the purpose of conducting this study and questions were briefly explained in the local language. For those farmers who were illiterate, the questions from the questionnaire were discussed through an interview by a data collector. The questionnaires were collected in person the following day, with some flexibility in the return date. The return rate for questionnaires was 81%, *i.e.*, the total number of questionnaires that were returned was 150. After rejecting the invalid questionnaires (N=22) and incomplete questionnaires (N=28), the remaining questionnaires (N=100) were analysed.

The study frameworks and protocols developed for the questionnaire-based survey by Li *et al*. (2013) and Roco *et al*. (2014) were also considered during the preparation of the questionnaires in this study. However, these studies were conducted in a country that has different farming practices and farming knowledge of farmers, so the protocols were modified according to the local pro-

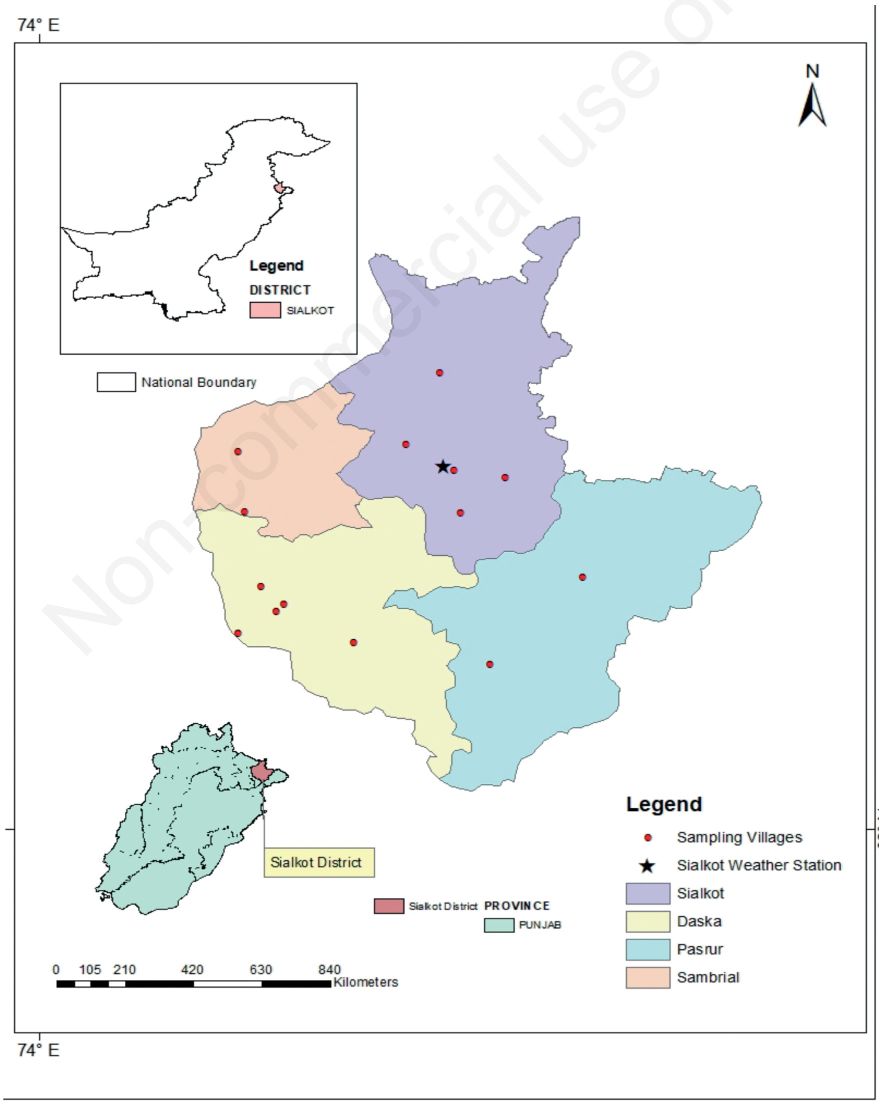

Figure 1. Map of the study area and the location of the villages that were surveyed.

cedures and farming practices in Punjab, Pakistan. The first section of the questionnaire solicited demographic information about the farmer's household, age, education level, farm experience, and household size. The second section asked about farmer's perception of climate variability and climate change and the perceived effect on his/her wheat production and yield. The response choices were purposefully designed to be simple and closed-ended. For example, when asked whether a farmer had observed any changes in average temperature and precipitation since 1988, the options were: i) increase; ii) decrease; and iii) no change. The responses to questions about a farmer's perception of the effect of climate change on different stages of wheat production, *i.e.*, sowing, germination, flowering, grain filling and harvest, were either 'Yes' or 'No.' The third section of the questionnaire queried the current adaptative strategies of the interviewed wheat farmers and the gaps in adaptation to climate-smart agriculture practices. The questions associated with knowledge and skills, technology, economic constraints, and political and social influences had simple 'yes' or 'no' response options.

Data analysis

Analysis of historical data

The historical data for annual climate and wheat yield were analysed using linear regression to infer trends in climate and wheat production and associated variability and their statistical significance. The software that was used for analysis included Microsoft Excel (Microsoft 2010) and Minitab.

Analysis of response data

Responses from the valid questionnaires (n=100) were analysed through percentage response of each variable to calculate farmers' beliefs about climate change, the effect and impact of climate change, adaptations that the farmer used, and limitations to implementing these adaptations.

Results

Temperature trend (1988-2018)

The mean annual minimum and maximum temperature in the Sialkot District have increased during the past 30 years (Figure 2). The mean maximum temperature in 1988 was 29.7±7.46°C, while in 2018 it was 30.8±8.04°C. The ten-year average showed that during the first decade from 1988 to 1997, the mean annual maximum temperature was 29.1±0.48°C. This average increased by 0.7°C to 29.8±0.04°C during the second decade, and it increased during the third decade by an additional 0.08°C to 29.89±0.08°C. During this period, the maximum winter temperature also increased, but fluctuations in the maximum year-to-year temperature were observed. Two of the largest fluctuations occurred in 1997, with a decrease in maximum temperature by 0.97°C compared to the previous year, followed by the second decrease of 1°C in 2014 (Figure 2A). The overall P-value of thirty years data indicates a significant increasing trend for maximum temperature (P=0.019).

The minimum temperature shows a fluctuating and gradually increasing trend. The lowest mean minimum temperature was observed in 1989 (15.2°C). The ten-year average indicated that during the first decade from 1988 to 1997, the mean annual minimum temperature was 16.0°C, which increased by 1.0°C to 17.0°C for the second decade, and by another 0.31°C for the third decade to a mean annual minimum temperature of 17.4°C. The significance level for the average minimum temperature was P≈0.00 (Figure 2).

Annual precipitation trend (1988-2018)

The total annual precipitation trend for the study area over the past 30 years showed a decrease in precipitation (Figure 3). The highest total yearly precipitation was observed in 1996 (1642±27.40 mm) with a second highest in 2003 (1604.9±41.32 mm). The ten-year data indicated that during the first decade (1988-1997), the mean total annual precipitation was 1,188 mm, which decreased to

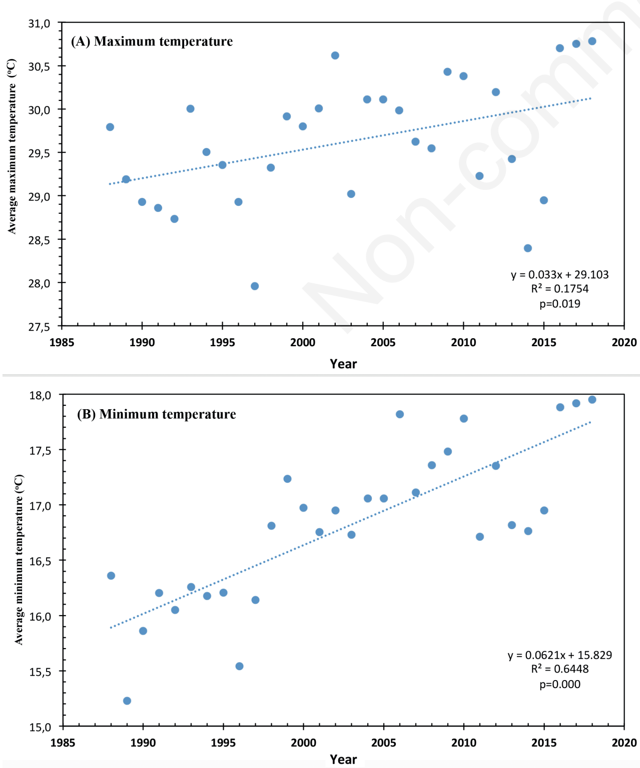

Figure 2. Average annual maximum (A) and minimum (B) temperature from 1988 to 2018 for the Sialkot District.

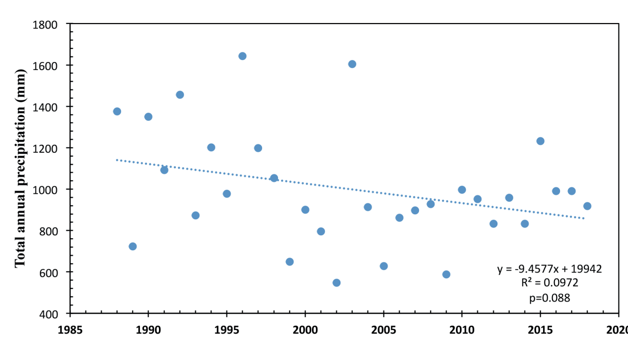

Figure 3. Total annual precipitation (mm) from 1988 to 2018 in the Sialkot District.

884.86 mm during the second decade (303 mm decrease from the previous decade), and it slightly increased to 930 mm during the third decade (2008-2017), which is 45.4 mm increase from the previous decade but lower than the first decade. The P-value of 0.088 indicates a significant decline in average precipitation. When compared to the temperature results, it was noted that the precipitation was high in years that had a relatively low air temperature, such as 1988, 1996 and 2014.

Wheat production

The total area cultivated with wheat in Sialkot increased from 175,000 ha in 1988 to 205,000 ha in 2018 (Punjab Agriculture Statistics, 2020). However, wheat production in this area showed a highly fluctuating trend. The lowest production was observed for three consecutive years, *i.e.*, 1993 to 1995, with a total annual production of 173,000 metric tons. However, during the last six years for which we were able to obtain wheat production data, *i.e.*, from 2012 to 2018, there was a gradual increase in production with the highest total production in 2018 of 536,000 metric tons (Figure 4).

The statistical analysis (Table 1) shows that correlation between the maximum and minimum temperature was positive (r=0.782; P≈0.000). Precipitation had a negative correlation with maximum temperature (r= –0.358; P=0.52) and minimum temperature (r = –0.526; P≈0.004). The correlation between wheat yield and maximum temperature was significant (r=0.418; P=0.021), while the correlation between wheat yield and minimum temperature was highly significant (r=0.454; P=0.012). Wheat yield and precipitation had a significant correlation (r=0.453; P=0.012).

Demographic profile of the farmers that were surveyed

The demographic characteristics that affect a farmer's perception, such as age, education, and farm experience, were analysed (Table 2). The age of the respondents ranged from 18 to 85 years, with most heads of household older than 60 years (44%). On average, 72% of the farmers had less than a primary education, with 16% having an intermediate level of education and 12% having some professional education. In the study area, the average landholding is 4.39 ha which is mainly owned by the farmers, although some of the farmland is also leased. A rice-wheat crop rotation is common, although some land is cropped with maize and sugarcane.

The farmers who had a basic education and schooling were classified as 'literate' (N=74) and those with no formal education were classified as 'illiterate' (N=26). Overall, 76% of farmers responded that they had observed a change in the local climate, while 24% answered that they had not observed any change weather or climate. Similarly, 17% of the illiterate farmers highlighted that they had noticed a change in climate, whereas 83% of the illiterate farmers perceived no answer on change in climatic parameters such as change in temperature and precipitation intensity, shift in the events as well as change in frequency of extreme rain and dry season events. The results indicated that the literate farmers (76%) perceived that the climate has changed over time compared to the illiterate farmers (17%), who did not perceive that the climate is changing. Farmers who have a moderate (21-39) to high (>40) number of years of farm experience reported that they had observed significant changes in weather patterns (Table 2).

With respect to age groups, most of the farmers that were interviewed were in the age group from 30 to 59 years (N=42), followed by the age group older than 60 years (N=38), while there

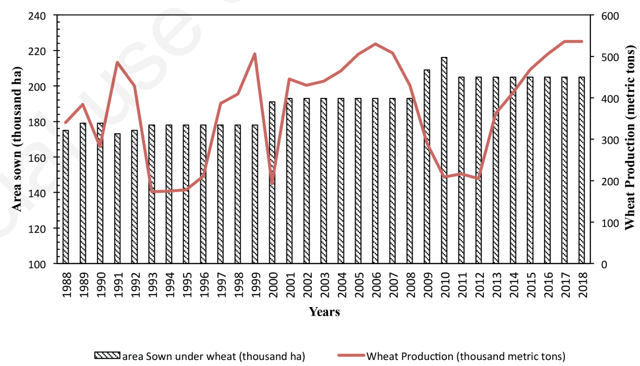

Figure 4. Total annual wheat production and area from 1988 to 2018 for the Sialkot District.

Table 1. Pearson correlation for weather conditions, including maximum and minimum temperature, precipitation, with wheat yield.

Parameters	Maximum temperature	Minimum temperature	Precipitation	Wheat yield
Maximum temperature	1			
Minimum temperature	0.782 0.000**	1		
Precipitation	–0.358 0.52	–0.526 0.004**	1	
Wheat yield	0.418 0.021*	0.454 0.012*	0.453 0.012*	1

Asterisks indicate significant correlation among variables: significant=*P<0.05, highly significant=**P<0.01.

Table 2. Demographic variables and farmers' perceptions.

Variables	Age			Education level*		Farm experience		
	18-29 (N=20)	30-59 (N=42)	>60 (N=38)	Literate (N=74)	Illiterate (N=26)	<20 years (N=10)	21-39 years (N=26)	>40 years (N=64)
Change	90%	85%	65%	76%	17%	17%	85%	90%
No change	10%	15%	35%	24%	83%	83%	15%	10%

*According to Pakistan's National Council for Justice and Peace (NCJP), a person is Literate if he can read and write his own name, whereas Illiterate is a person who lacks the ability to read and write his own name.

were 20 relatively young respondents in the age group from 18 to 29 years. Farmers in all three age groups stated that they had observed a change in climate, *i.e.*, 18-29 years (90%), 30-59 years (85%), and >60 years (65%). There were no statistical differences observed among farmers in the different age groups.

The results from the questionnaire indicated that the literate farmers who have more farm experience have observed more changes in climate and its impacts on the overall production potential of their farm. The farmers with more than 40 years of farm level experience (N=64) showed the highest concern related to climate change. Only 10% of the farmers with more than 40 years of farm experience stated that they had not observed any change in climate.

Wheat cultivars in study area

According to the survey, most of the farmers have grown the wheat varieties Faisalabad-2008, Sehar-2006, Shafaq-2006 and Punjab-2011, with other cultivars including Millat, Lasani and Galaxy during the past decade. The wheat cultivar Faisalabad-2008 was the most dominant sown in Sialkot, Daska, Sambrial and Pasrur with over 63.4%, 51%, 41% and 28.1%, respectively, of the studied area. The wheat cultivar Sehar-2006 was grown in Pasrur (34.7%), Sambrial (30.7%), Daska (27.9%), and Sialkot (19.5%), while the wheat cultivar Punjab-2011 was grown in Pasrur (20.7%), Sambrial (15.6%, Daska (13%) and Sialkot (11.6%) of the total wheat cultivation area. Similarly, the other wheat cultivars such as Millat, Galaxy and Lasani were grown in Sambiral (10.3%), Pasrur (8.2%), Sialkot (6.8) and Daska (5.6%). The respondents mentioned that during the past two decades, a variation in wheat varieties has been found as the new varieties have a higher productivity and early maturity as compared to the older varieties. However, cultivation of new varieties is challenging as new cultivar varieties have higher market rate as compared to the previous varieties. Therefore, the majority of the respondents prefer to purchase the old varieties.

There are three types of seeds available for planting in study area, including: i) *certified seeds*, which are certified and are considered best in terms of yield, heat, and disease tolerance as well as a higher quality of nutrients in the harvest grain; ii) *non-certified seeds*, which are basically saved by the farmers from their harvest and to be used for the following cropping season, seeds not certified or tested by laboratories; and iii) *a combination of both certified and non-certified seeds*, which is a mixture of certified or non-certified used by farmers based on their preserved stock from the previous year, market rates, and land ownership. The results from the survey indicated that in Daska non-certified seeds are mostly used for wheat cultivation (60%), followed by 26.5% of the respondents who used certified seeds, and 13.3% of respondents who use both certified and non-certified seeds (Figures 5 and 6). Similarly, in Sambrial most of the respondents used noncertified seeds (44.4%), followed by certified seeds (33.3%), and both certified and non-certified seed users (22.2%). However, in Pasrur and Sialkot most of the farmers use a combination of certified and non-certified wheat seeds, *i.e.*, 73 and 83.3% respectively, followed by certified seed users, *i.e.*, 25% and Sialkot 16.7%, respectively.

Farmers' perception of seasonal changes

The responses of the individual farmers to the seasonal climate and weather variability were diverse based on their personal experience, education, and observations (Figure 7). The farmers, in general, have observed that the weather patterns have changed during the past three decades, both in terms of intensity and frequency. The extreme weather, such as prolonged hot and humid summer and short cold winter season, have been delayed and the intensity of floods and droughts have become more severe. Farmers have started to pay more attention to the patterns of temperature and precipitation compared to other factors. The majority of farmers (73%) noted an 'increase' in both the summer and winter temperature, while 16% indicated a 'decrease' in temperature. However, 11% indicated 'no change.' Farmers mentioned that the recent

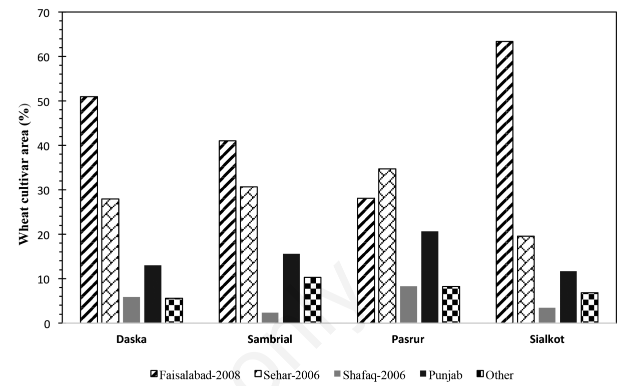

Figure 5. Wheat varieties grown in the study area.

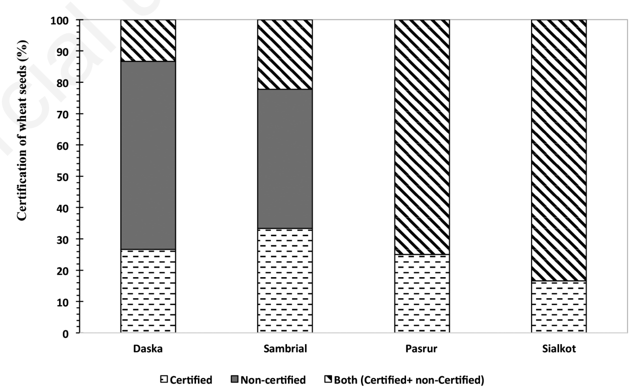

Figure 6. Certification of wheat seeds used in the study area.

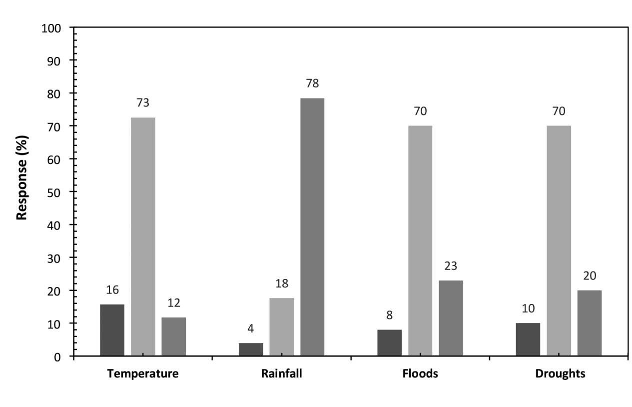

Figure 7. Farmers' perceptions about seasonal changes in weather conditions in Sialkot, Punjab.

summers were hotter and that the winters were less cold compared to the past. The majority of the farmers (78%) responded that, according to their observations, the precipitation in the area has 'decreased,' while 16% noted an 'increase', and only 4% mentioned 'no change'. Responses to the question about floods were similar, with 70% noting an 'increase', 23% a 'decrease', and 8% 'no change.' The farmers also observed that due to the 'increase' in precipitation, flash floods have increased during the monsoon seasons with a clear example shown recently in 2022. Responses for observations of droughts in the study area were that 70% of the farmers had experienced an 'increase', 20% have experienced a 'decrease', while 10% have not experienced a change in droughts.

Farmers' perception about the effect of climate change on wheat production

The farmers were asked to respond to the effect of climate change on their wheat crop, including sowing, germination, flowering, grain filling and harvest based on their personal observations and experience. The respondents were of the view that the variability of the seasons had an impact on the entire growth cycle of wheat. Most of the farmers (80%) marked 'Yes' to the question if they had observed an effect of the seasonal variation on sowing of wheat, while 20% indicated 'No' in that they had not observed any effect. The farmers who marked 'Yes' related this to the effects of extreme temperature and precipitation. Most of the farmers (82%) had observed an effect of weather during the germination stage of wheat, whereas only 18% stated that they had not observed or experienced any impacts. The farmers who reported the effects of climate change said that seed germination was earlier than previous decades due to a higher temperature. Similarly, 86% of the farmers responded 'Yes' to the question of the impact of weather on the flowering and grain filling stage. Ninety percent of the farmers reported that the variability in annual weather conditions adversely affects wheat at harvest and that the overall health of the wheat crop has declined. Most of the respondents (90%) also responded that they had observed variability in precipitation with respect to both the timing and intensity during the growth of wheat and, therefore, this had a significant impact on the average wheat yield in this region of the study area.

Current adaptative strategies of wheat farmers in the Sialkot District

Because wheat is the leading staple food in Pakistan, farmers pay more attention to its cultivation and management practices. Several factors that impact wheat cultivation, such as late sowing due to the previous crop, *i.e.*, rice, fodder, and seasonal vegetables. For seedbed preparation after the harvest of rice, some farmers have adopted zero tillage or minimum tillage practices, while others maintain conventional tillage practices. Conventional and minimum tillage practices significantly impact the soil attributes and, thus, can affect final crop yield. In the study area wheat farmers use cropping schemes based on their historical production experiences due to several internal and external factors such as the genetic variability of cultivars, edaphic factors, climatic factors and market conditions, About 70% of the farmers in the Sialkot District use the experience from previous years, such as cultivar selection, field operations, nutrient management, and pest control operations, as a reference for planning the following season, whereas the remaining 30% use their traditional method. The main modification that has occurred due to the change in weather conditions is a change in the planting date: the farmers mentioned that they had shifted to planting 10-15 days earlier compared to the past decades. This early sowing is due to the change in temperature because high temperatures during the booting and dough phase have led to the crop's early ripening. This in turn has caused smaller grains and an overall reduction in yield. The farmers have especially experienced this during this past decade with an abrupt change to a high temperature in March, leading to early ripening of wheat during early summer.

A large proportion of the farmers (70%) said that to increase the productivity of wheat, the use of fertilizers has increased. The farmers also mentioned that their fertilizer application has doubled compared to the past three decades due to the fertilizer responsiveness of new cultivars and a reduction of nutrients in the rhizosphere. A few farmers (24%) mentioned that their use of farm manure had decreased and, thus, the application of chemical fertilizers had increased. Different wheat varieties were another adaptative strategy in the study area. The survey also found that many farmers (60%) are willing to switch to other crops and vegetables on a rotational or permanent basis.

Limitations to climate change adaptation

The farmers responded to the barriers and limitations to climate change adaptation through simple questions that had multiple options. Eighty-six percent of farmers responded that they had limited access to information such as sowing techniques, integrated nutrients, and management for control of weeds, pests, and diseases, and field training for advanced management skills. The majority of the farmers (74%) adopted changes such as early sowing based on their own or their elders' experiences. Eighty-six percent of the respondents indicated a gap in the information provided by the government, as there is no proper guidance from the Department of Agriculture and other Governmental Departments. In particular, the respondents mentioned a gap in early warning systems by the Pakistan Meteorology Department. They also indicated that there are no training sessions or that there is no information dissemination that could assist them with proper management techniques and adaptation strategies. However, the authors noticed that yield was also impacted by the country's poor weather forecast system. In general, most of the farmers did not consider forecasts for wet weather events into their cultivating and harvesting plans and, thus, lost fractions of the crop yield. Seventy-four percent of the farmers indicated that they lacked advanced technology for tillage, harvesting and irrigation, which are important factors for proper field management, and that instead, they relied on traditional practices. Funding and loans from the government are also minimal. The economic constraints were also highlighted by a large number of the farmers (78%). This is due to a decrease in average income from wheat production, while the costs for irrigation water, seed, fertilizer, and transportation have increased. The market price for wheat is set by the government, while the high input and management costs also influence wheat production. Most respondents (80%) stated that the average yield is highly influenced by the political and social structure (74%). The farmers also said that political changes, such as the election of a new government and a modification of government policies for providing subsidies, loans, on-farm management training for farmers, and purchase and export of wheat to the urbanized areas, affect their decisions on how to manage their wheat production.

Discussion

Climate change and wheat yield

The analysis of thirty years of daily weather data from 1988 to 2018 for the Sialkot district indicates an increase in the average maximum (+1.66°C) and minimum (2.72°C) temperature and a decrease in annual precipitation of 444.4 mm from 2008-2018. The area sown under wheat has also increased from 175,000 ha to 205,000 ha, and total wheat production has increased from 34,000 metric tons to 53,600 metric tons. The fluctuation in wheat production was correlated with the variability in precipitation. The analysis results showed that both the maximum temperature and precipitation had a significant correlation with wheat production. The findings of Afzal *et al*. (2018) showed similar results, concluding that during the seedling stage, the minimum temperature (frost) has a significant impact on wheat production, while during the flowering, milking and dough stage, an increase in the overall temperature caused a decrease in wheat production. According to Ghanem (2010), 3°C temperature rise is predicted by 2040 in South Asian countries. Asseng *et al.* (2015) estimated a decline of 6% in wheat production with 1°C increase in temperature. The findings of Chaudhry *et al.* (2009) showed an irregular pattern in average annual rainfall indicating a decline in annual rainfall by 140 mm during 1901-1053 while this increased by 228 mm during 1955-2007. The findings of Munir *et al.* (2022) predict a decline of wheat yield by 2.81-31.0% under different climate change simulation models in Central Punjab Pakistan. Overall, the climate and wheat production analysis showed an evident change in temperature and precipitation during the study period and the associated impact on wheat yield and total production in the Sialkot district.

Local farmers' perceptions of climate variability and wheat yield

The average farmer in the Sialkot district owns about 2.92 ha, whereas the average farm size in Pakistan is 2.6 ha (CSA, 2017), categorized as small landholders (GoP, 2010). All participants selected for this study were male. Li *et al*. (2012) found that women are more engaged in household chores and participate to a lesser degree in farm activities than men, who are engaged in work both on and off the farm. Men in the study area have a greater decision-making power than females. Studies have shown that male farmers are more risk-averse than females (Liu, 2012; Cardenas and Carpenter, 2013). The representative farmers in this study were adults above 35 years of age. Several studies indicate a significant (positive) relation between age and attitude towards risk management (Deressa *et al*., 2010; Dadzie and Acquah, 2012; Rehima *et al.,* 2013; Saqib *et al.,* 2016). The educational status affects farmers' perceptions and practices. The results from this study are similar to the findings by Iqbal *et al*. (2016), Tavernier and Onyango (2008), Ullah *et al*. (2015) and Saqib *et al*. (2016) as this study found that the majority of farmers perceived climate change based on their personal experience and that their formal education influenced farmers' decisions related to climate change and climate variability (Figure 8). Their perception of the effect of the seasonal variability on wheat production was also consistent with historical data of wheat production in the study area. However, there were some exceptions as some farmers (20-30%) stated that they had not experienced any effect of the seasonal variability on their wheat yield. Thus, the current study's findings revealed that farmers had a perception that temperature, precipitation, and extreme weather events have an adverse impact on wheat yield, which could ultimately result in instability in crop production and affect food security in the region and Punjab.

There are fifty-eight wheat cultivar varieties recommended by Ayub Agricultural Research Institute (AARI), in irrigated areas of Punjab, Pakistan. Out of these, Faislabad-2008, Sehar-2006 and Punjab-2011 are being cultivated over most of the study area. The findings of AARI show that the 1000 kernel weight for Faislabad-2008, Sehar-2006 and Punjab-2011 is 43.2 g, 41.8 g and 44.7 g, respectively, which is lower as compared to the newer varieties such as Galaxy-2013 (45.63 g) and Chenab 2000 (45.9 g). Similarly, the protein percentage of Punjab-2011, Faislabad-2008 and Sehar-2006 are 13.7%, 12.6% and 12.9%, respectively, which is lower as compared to latest wheat cultivars such as: Anaj 2017 (14.5%) and Akbar (14%) (AARI, 2022). This comparison shows that the cultivation of wheat cultivars with a higher protein percentage and higher weight of kernels can be beneficial for the farmers. A similar study of Dawood *et al*. (2021) showed that the grain yield of cultivar Galaxy is higher, *i.e*., 5.4 t ha^{-1} as compared to Faisalbad-2008 (4.16 t ha^{-1}) and Sehar-2006 (3.43 t ha^{-1}). Similarly, the harvest index of Galaxy-2013 is higher (36.4%) as compared to Sehar-2006, and Faisalabad-2008, *i.e*., 32.78% and 30.53% respectively.

Factors influencing local farmers' decision-making for climate-smart farm practices

This research found that some farmers apply adaptative measures to cope with weather and climate factors, especially climate variability. Access to farm equipment, seed and fertilizers affordability, and lack of technical skills are the main constraints for the decisions made by smallholder farmers in the region. These constraints are associated with political, economic, and social contexts, especially agricultural policies. For sustainable wheat production and food security, adaptation and management strategies such as climate-resistant varieties and a change of the crop calendar using the 4R technology can also play significant roles (Ahmad *et al.,* 2018). A study by Shahzad *et al*. (2020), who examined 540 farmers and their decisions to adopt climate smart farm practices (CSFP) in three agro-ecological regions of Pakistan, showed that education has a positive and significant influence on adaptation strategies to mitigate climate uncertainty and can increase farm-level income (net returns). This emphasizes the importance of education for improving management practices by individual farmers. An increase in 7 to 15% in wheat yield is possible through appropriate CSFP (Challinor *et al*., 2014).

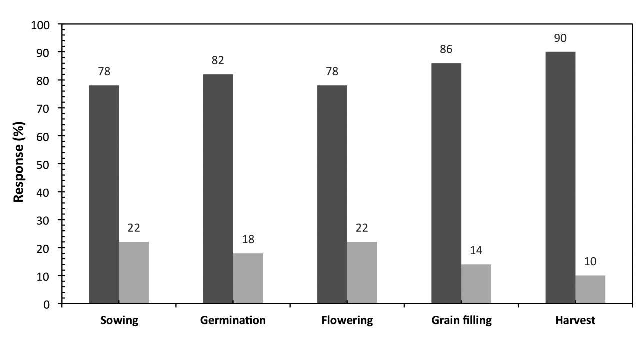

Figure 8. Perception of farmers regarding the effect of weather variability during the wheat growing season.

Adaptability of local farmers to climate change

Adaptation to new technologies and CSFP can increase yield and farm income in developing countries (Deschenes and Greenstone, 2007; Nhemachena *et al*., 2014; Yin *et al*., 2016), including changing inputs, shifts in the crop calendar, crop diversification, crop rotation, soil and water conservation, improved cultivars, and irrigation and fertilizer use efficiency (Tubiello *et al*., 2008; Shehzad and Abdulai, 2020). In developing countries, extension services provide access to training and expert guidance for farmers (Hellin, 2012; Shehzad and Abdulai, 2020). Most farmers in this study reduced their dependence on farming income by either moving to urban areas for their livelihood or from other farm income resources. Current research has shown that economic constraints are also obstacles to the adoption of CSFP (Figure 9). If CSFP is properly implemented by a farmer, it can increase wheat yield, increase farm income, reduce the potential impact of climatic change and variability, and improve the overall economic resilience of a farmer. Subsidies and funds from government and local agricultural departments to enhance agricultural production, training, agricultural machinery, and fertilizer application have reduced farmers' dependency solely upon farming. However, these practices may not fully buffer the impacts of severe weather conditions such as floods and droughts. For instance, there was little use for long-term weather forecasting by farmers in the study area. Therefore, a focus on how a forecast or tool could help a farmer respond to or prepare for specific on-farm risks could be a more effective strategy than talking about adapting to climate change more broadly (Loy *et al*., 2013). Policy makers and research institutions must consider farmers' attitude towards risk perceptions during the designing and implementation phases of policies. In addition, farmers must be equipped with risk management tools, including meteorological forecasting and information regarding crop management. Farmers must also have access to sufficient credit, market information, and more off-farm income opportunities that are needed for farmers to overcome financial constraints and risks at the individual farm level.

Advances and future directions

The perception of farmers regarding climate change and their adaptation practices to these changes are of global concern. This study used a questionnaire and an open interview method with smallholder farmers in Punjab, Pakistan, a developing country that is highly vulnerable to climate change (Mertz *et al*., 2009a, 2009b). The findings from this study indicate that farmers have some basic knowledge of seasonal variation and climate change, but their adaptative strategies are insufficient due to a lack of technology and skills and political, economic, and social factors. The farmers' adaptative strategies were not sufficient to overcome the effects of climate change as most farmers are still using traditional management practices or modifying their management based on their experience. Therefore, future studies should be conducted at three-year intervals to obtain more accurate results and can document farmers' management strategies and perceptions over time. Specific studies to analyse farmers' behaviours and gaps in climate change policy implementation are needed to obtain long-term data and to document the process.

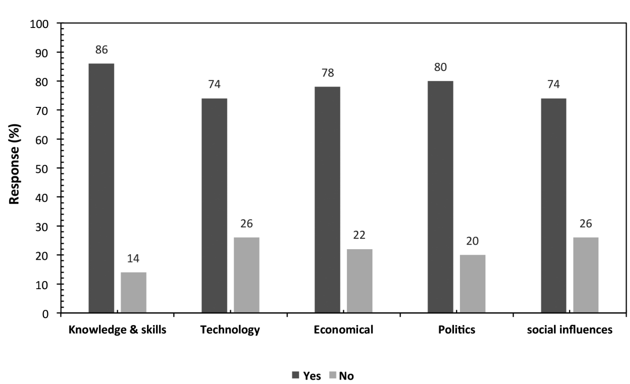

Figure 9. Farmers' barriers in adaptation to climate change practices.

Conclusions

This study showed that there has been a significant increase in the mean annual temperature and a decrease in precipitation over the past 30 years from 1988 to 2018 in the Sialkot district of Punjab, Pakistan. Total wheat production has increased during the same period, mainly due to an expansion of wheat acreage. However, the trend in wheat productivity fluctuates, which could result in a challenge for future food security. Overall, the understanding and perception of the surveyed farmers were consistent with the trends of the long-term weather and climate data. The adaptation practices of farmers were based on their indigenous knowledge and their own experience with only a minor influence of government strategies. Farmers also described barriers in the implementation of climate smart practices, such as their knowledge and skills, their technical capacity, and economic, political, and social constraints. Therefore, the application of modern knowledge, based on scientific research and international strategies could help improve the adaptation by local farmers to climate change in order to increase agricultural output and provide long-term economic sustainability for the individual farmer and food security for Punjab and Pakistan.

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