Available online at www.agrifarming.org

DOI: http://dx.doi.org/10.18782/2582-7146.183

ISSN: 2582 – 7146

Current Research in Agriculture and Farming

Curr. Rese. Agri. Far. (2023) *4*(1), 8-22

Review Article

Peer-Reviewed, Refereed, Open Access Journal

Responses and Adaptations of Wheat to Climate Change in Pakistan: A Comprehensive Review

Ihtesham Arshad[1*], Zara Ali[1], Adnan Riaz[2], Areeba Naseer[1], Misbah Shafique[1], Adeeba Riaz[1], Jaweriah[1], Laiba Arzoo[1], Fizza Saleem[1]

[1]Department of Biotechnology, Faculty of Life Sciences, University of Okara, Okara 56300, Pakistan

[2]Department of Agronomy, College of Agriculture, University of Sargodha, Sargodha 40100, Pakistan

*Corresponding Author E-mail: ihteshamarshad86@gmail.com

Received: 10.02.2023 | Revised: 27.03.2023 | Accepted: 8.04.2023

ABSTRACT

The susceptibility of wheat to environmental changes is increasing at an ever-faster rate. This paper discusses trends of climate change, its effects, measurement methodologies, and adaptation alternatives in semi-dry and dry climates. In the wheat season, the temperature in Asia's mid-latitude could rise by 2.4 °C. According to several assessments, present varieties and production technologies will reduce the wheat output by 10 to 50 % in future climates. Climate change impacts have been quantified and adaptations developed using mechanical yield models, numerical models, field tests, and field trials in various locations. Wheat is mostly grown in irrigated and monsoon environments in semi-dry and dry areas of South Asia. Wheat is more vulnerable to climate change in dry regions than in semi-dry environments by the insufficient availability of moisture. Various solutions may be implemented in the agricultural systems in the future to mitigate climate change impacts on wheat production. In future climate circumstances, agronomic and breeding changes could potentially counterbalance or even improve wheat grain output.

Keywords: *climate change, wheat, Pakistan, temperature, carbon dioxide, simulation modelling.*

INTRODUCTION

Pakistan's agricultural economy is at risk due to climate change. The rank is twelfth among the world's nations, which are heavily influenced by environmental changes (Gorst et al., 2018). This country is sensitive to rainfall changes and variations in temperature. Due to changes in climate the temperature also increases which could mainly change biophysical relations for livestock/crops, forests/fisheries such as decreasing the growing time, aggregating moisture and thermal stresses, altering the species patterns, altering water necessities, changing soil physical characteristics, and growing the danger of infections and pests (Ahmed et al., 2016). The impacts of environmental variations in agriculture and other normal resources can be varied in different agricultural areas.

Cite this article: Arshad, I., Ali, Z., Riaz, A., Naseer, A., Shafique, M., Riaz, A., Jaweriah, Arzoo, L., & Saleem, F. (2023). Responses and adaptations of wheat to climate change in Pakistan: A comprehensive review, *Curr. Rese. Agri. Far. 4*(1), 8-22. doi: http://dx.doi.org/10.18782/2582-7146.183

This article is published under the terms of the Creative Commons Attribution License 4.0.

In dry western rocky regions, the method of de-glaciations can be increased by rising temperatures and disturbing water reservoirs on which our country depends for energy production and agriculture. These rocky areas are subjected to dangerous pressure due to different human and natural activities. Therefore, these areas have a continuous procedure of ecological degradation (Abid et al., 2019). The most important causes of human destruction in rocky regions are misuse of natural resources, removal of forests, and unmaintainable agricultural performance. It is expected that global climate change (i.e. rising temperature and rainfall changes) is expected to increase the continuous process of watershed deprivation and would truly threaten the sustainability of rocky regions and regular regions, generally in Pakistan and especially in Khyber Pakhtunkhwa (KP) (Ali & Erenstein, 2017). Some areas of the country around the higher latitude cover about 17% of the total area and they are less warm, so they can benefit from high temperatures. The high temperature can improve the growth of the crop and ingrain (Khan et al., 2016). The agricultural products are expected to increase in these areas due to increased temperature. Dual harvesting may also be possible in both winter and summer seasons. The style of forest species can change. Expected that the rapid growing species can substitute the conifers (Arshad et al., 2017). These areas are also susceptible to high levels of repeated flash floods, heavy loss of land, loss of agricultural characteristics, and living assets. In areas of the lower delivery line, climatic changes such as heat and water stresses, especially a rise in temperature will reduce the crop and livestock yield (Abid et al., 2016a). The risk of weather, such as drought and floods also influences lower latitude regions. Well-timed training and adaptations to change in climate are wanted, to reduce the harmful effects of environmental changes in all parts of the economy included agriculture, animal wealth, forests and water (Khan et al., 2020). Adaptations included transferring research, developing appropriate techniques, introducing appropriate species, and other management practices for agricultural products. Efforts are required to protect natural resources against the risk of weather, which is projected as the result of climate change (Hussain et al., 2020).

Climate Change and Wheat

Wheat is cultivated in the zones where irrigation and rainfall are high and the yields are low in sugarcane–wheat, rice-wheat, fallow-wheat, and cotton–wheat in these climates (Azmat et al., 2021). Weather aberrations are a major food security issue, particularly in South Asia. In recent years, global climate models have predicted that the temperature rise will occur from 1 to 3.7 degrees Celsius with symbolic changes in rainfall patterns over many land areas (Gul et al., 2020). In agro-food regions with different crops, the yield of wheat is expected to drop by 6-9% in the dry zone and semi-dry zone with an increase of only 1 °C. In addition, the studies explained that an elevation in the temperature of 2 °C can lead to a fall of 15.2% in wheat yield between 2040 and 2069. Various methods have been used to determine the environmental impact of wheat (Gul et al., 2019). For example, some research has been done in the laboratory on the enhancement of CO_2 emissions, temperature inclines tunnels, air conditioning and temperature controls enhancement, and dates of sowing seeds. The crop simulation models (CSMs) are an important tool for estimating the effect of climate change on various crops (Raza et al., 2019). The International Governmental Panel on environmental changes has used different varieties to measure the effect of environmental changes on agricultural. In Pakistan, few studies are used to evaluate the effect of environmental changes on wheat, and promote adaptations for different parts of the country (Anser et al., 2020). Measure the effect of environmental changes on wheat necessary for future wheat diversity, as well as for improving crop yields. In addition, measures should be adopted in making specific climate change adapting varieties of wheat to ensure our food security (Sonia, 2019). Improved varieties can minimize the susceptibility of wheat in a changing environment. Adaptations can also be made in the plant model, by changing plant characteristics, managing choices, and topsoil enhancement. Among the control options, sowing date, planting method, sowing rate, nourishment type, application plan, irrigation extent, and procedures may be assessed by numerous wheat models to enhance wheat production in upcoming climatic situations (Ahmad et al., 2021). The special seed varieties can be tested to evaluate their performance in a changing environment. The duration of a crop and phenology can help the wheat to work well in a changing environment (Jan et al., 2021).

Temperature and wheat

Accelerated temperature is a major reason for reduced yields of wheat in wheat-developing areas. Rising temperatures and heat stress are significant dangers to wheat yield during the grain-filling phase (Hussain et al., 2021). The elevated temperature impedes the growth and progression of wheat. For example, grain size remains small at 25 to 35 °C due to the limited duration of grain filling and the photosynthesis rate slower down above 30 Celsius temperature (Mahmood et al., 2019). In arid conditions (Lower precipitation), the rate of photosynthesis is consistently lower than in accessed water situations at 30 Celsius. In addition, an increase in tiller sterility is observed at 36 °C, and the index of wheat is lowered when the minimum temperature exceeds 14 °C. In Pakistan, rabi wheat is cultivated in the winter season (November to April), and it is getting smaller, and warmer, and poses new dangers to wheat yield (Mahmood et al., 2020). The lower and higher temperature in the mid of March is elevating, shortening the grain filling period, but increasing the grain filling rate of wheat. This cannot keep up with the more limited grain filling duration and is compensated at 21.3 ± 1.27 °C as the ideal temperature for filling grains (Asseng et al., 2017).

The yield of wheat reduced to 7% as the average temperature rose by 1 °C, and the propagative phase shortened, this affects the performance and collects the opposite value (Gul et al., 2020). Apart from the daytime temperature, the night temperature longevity from 14 to 23 °C also distresses spikelet productiveness, so the extension of the night temperature is an additional justification for the decrease in wheat yield. Newly global studies determined that a rise in 1 Celsius temperature could decrease wheat grain yields in major wheat-producing regions by 6% (Ali et al., 2017).

Carbon dioxide and wheat

During photosynthesis, plants absorb CO_2, which is converted into natural molecules. The natural molecules ultimately provide more than 95% of the biomass for harvesting and provide the energy that plants need for breakdown (metabolism) (Ahsan et al., 2020). CO_2 affects most plant cycles such as stomatal conductivity and photosynthesis rate. The concentration of CO_2 has increased since industrialization, and over time its rate is increasing more than expected. Increased CO_2 accumulation can alter various parts of plant physiology during free air carbon dioxide enrichment (FACE). Experimentations indicated that raising CO_2 (475-600) ppm resulted in a 40 percent increase in photosynthesis in several species of plants. (Demirhan, 2020). Generally, the grain and root storage capacity of cereals, wheat, and sugar plants improved by 12.5, 12.7, and 12.1%, respectively. For wheat, the CO_2 stabilization improved yield by 31 percent, biomass by 15-27 percent, and photosynthesis by 35 percent (Abbas, 2022).

Elevating CO_2 stabilization from 375 to 550 and 700 ppm increases wheat production, but this improvement is important in several climates that are more stressed by water access, such as semi-humid areas will be most important for wheat production with high levels of carbon dioxide (Khan et al., 2019).

The combined impact of temperature and CO_2 on wheat production

High CO_2 emissions will improve the yield of the crops and increase the negative effects of changes in global temperatures. Experiments in the field have shown that increasing carbon dioxide from 350-380 to 680-700 micromole mol^{-1} increases the rate of photosynthesis by 30 to 50 percent and wheat biomass by up to 15-30% which produces in winter (Sattar et al., 2020). Experts have cultivated wintertime wheat in the temperature slope tunnel and examined the mutual consequence of temperature and CO_2 enhancement. They found that the rise of temperature to 2.6 Celsius in the summer reversed the beneficial effect of 340 micromole mol^{-1} dispersion of CO2 emissions (Ali et al., 2019). Amthor (2001) investigated the cumulative consequence of temperature and Carbon dioxide in wheat. And, it was assumed that the combination of the elevation in Carbon dioxide from 300 to 350 micromole mol^{-1} and temperatures from 1 to 4 Celsius harmed wheat yield. High concentrations of CO_2 (550 ppm) promote entire dry material and crop yield up to 5 to 15 percent, but it also affects the quality of grains when the concentration of carbon dioxide is elevated to 450 ppm. In irrigated wheat, Carbon dioxide enhancement is useful in the existence of adequate nutrient concentration, but the absence of fertilization can be reduced the grains yield by 10-20%. The Global Atmospheric Model CSIRO's determined that the grains yield of 5 wheat varieties will reduce by 29 percent due to the increase in temperature in the semi-arid environment where the reduction will be 25 percent with the joint impact of temperature and increase in Carbon dioxide (Sultana et al., 2009).

Wheat and Climate Change: A Case Study of Pakistan

Pakistan's economy greatly depends on agriculture and wheat is the main donor. Agribusiness in Pakistan depends on rainfall and groundwater. The interface among metrological factors such as rainfall, air temperature, and crop development is additionally noticeable at some specific phenological phases (Chandio et al., 2020). Different weather conditions are used as input for yield production and crop display. Wheat is cultivated throughout Pakistan during the winter. Production of Wheat determines food security, which in turn strengthens the health sector and added the double value to other cash crops; mustard, cotton, and rice. During the last phase of wheat regular rains exaggerated wheat production negatively (Ali, 2017). In South Asia, environmental changes greatly influence Pakistan. Annual and pre-monsoon period day temperatures have raised meaningfully above 30 spots and the maximum raise was detected in March. The IPCC (2013) reported an increase in global temperatures of 0.12 Celsius per decade (Abid et al., 2016b). The fifth Assessment Report (AR5) by IPCC predicts that annual temperatures have increased over the past century, mainly in winter (November to March), with temperatures raised at 2.4 Celsius in central Asia. Moreover, a multi-model ensemble of CMIP5 projected that temperature will not rise rapidly in the future under both projections RCPs 4.5 and 8.5 for early, mid, and late century, but that temperature may reach above 2 C for the third decade, while mid-century and end-century could rise to 3 and 6 C under RCP 8.5 (Hussain et al., 2018). Under the RCP 4.5 emission scenario, post-downscaling studies show a 3–5 °C temperature rise in the summer season. Under RCP 8.5, the typical trend of summer temperature suggests a 4–6 °C rise by the end of the century (Qureshi et al., 2016). Under RCP 8.5, there is no substantial increase in winter temperature until 2038, but there is a sharp increase after 2042.

Methods for Climate Change Impacts Quantification

Various methods measure the effect of temperature on wheat around the world, for example, development chambers, temperature slope channels, temperature free-air organized enrichment systems, and planting dates (Liu et al., 2016). The main advantages and disadvantages of growing wheat seeds in chamber experiments are the high degrees of temperature control and limited root development paralleled to temperature slope channels and the field (Ray et al., 2019). Although the temperature gradient tunnel is an acceptable method for recreating field conditions for crops to better root development and considering the effect of temperature on the plant, the reduction of radiation power is the ultimate limitation. These types of studies are rare in Pakistan but few surveys can be found on sowing dates and stimulation modelling (Asseng et al., 2019).

Simulation Modeling

Worldwide, the vast majority of wheat varieties are produced in various forms. Normally, the simulation models relied on eco-biological procedures working in the plants. The stimulus models have a diverse standard of stimulation (Lobell & Asseng, 2017). The models respond differently to different climates, managements, and genotypes (Ahmed et al., 2018). Various models of crops discussed the evolution of genetically modified species in different climates. Although many studies have been done to measure the impact of environmental change by the modelling in local agriculture (Dettori et al., 2017). Table 1 shows a detailed assessment of the considered environmental changes in wheat in different parts of Pakistan by different stimulation methods (Fig 1).

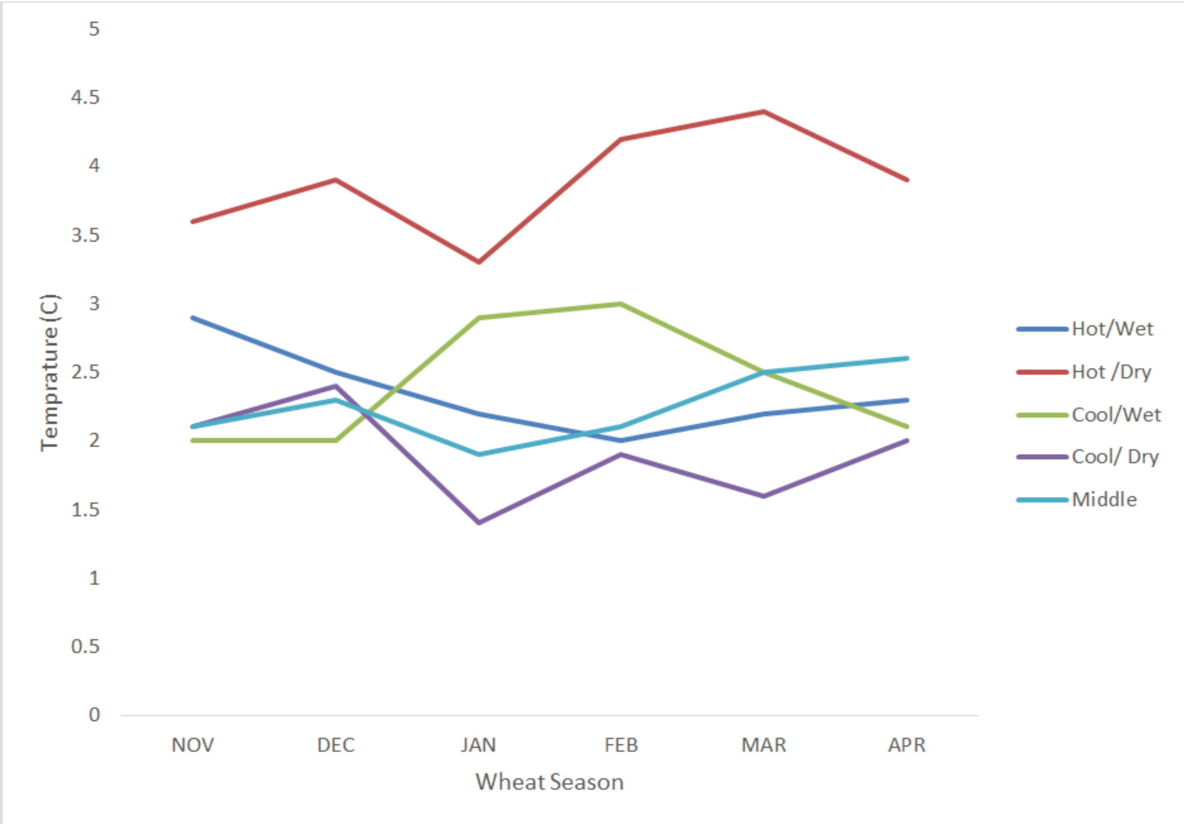


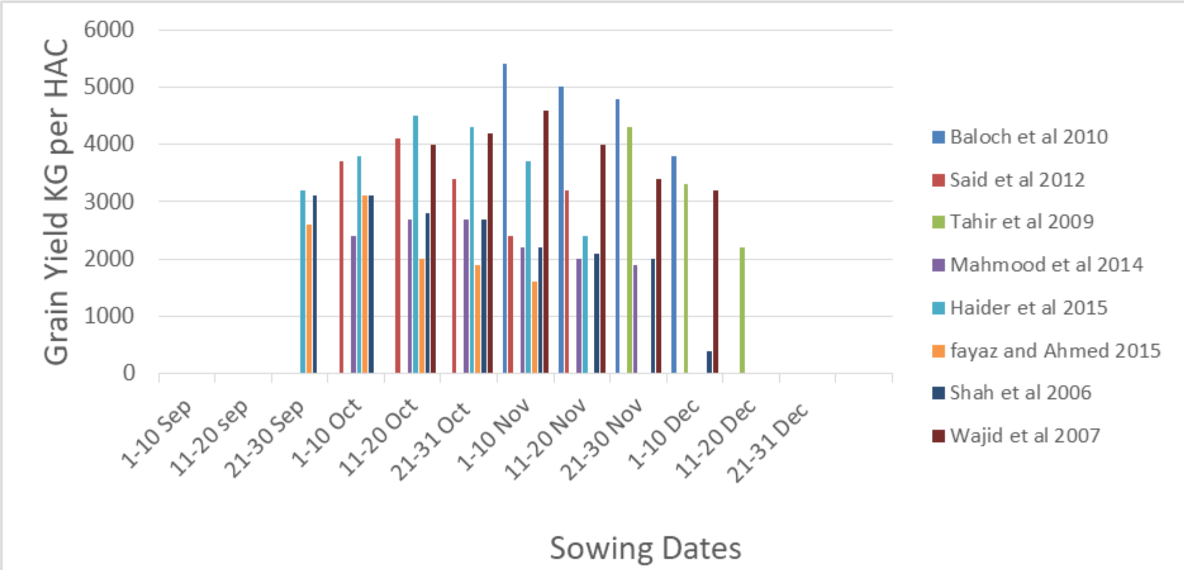
Fig 1 Increased in unpleasant temperature from 2038 through 2067 as paralleled to baseline records (1981-2011) at the dry climate of Pakistan for Hot/Wet, Hot/Dry, Cool/Wet, Cool/Dry, and some mid climatic situations (Hussain et al., 2018).

Field Test

Changing in sowing date and the selections can help to improve the crop yields. Dates of planting are a major factor in all crop managing practices (Haider et al., 2015). Planting dates have an impact on the length of the wheat plant, the area of leaves, the weight of grain, per spike grains, and the natural growth and development (Ahmed, 2015). Altering the dates of sowing, day span, and temperature which disturbs the major factors such as emergence, days to phenology, yield (weight of single grain and grains m-2), and constituents of yield (Mahmood et al., 2014). Planting time is of course an adjustment of environmental conditions as well as preproduction so that it can use these conditions for optimal development and progress (Abbas & Ahmad, 2018). The effect of sowing wheat yield is shown in Figure 2.

In addition to the planting test, in 2010–2011, 20 wheat varieties were subjected to 35–40 °C for 3 hours every day for five days continually in a chamber experiment, while control plants remained under normal circumstances in a complete randomized design with 3 replications (Said et al., 2012).

Fig 2 Effect of sowing dates on grain yield of wheat underneath various experimentations



Climate Change Effects Quantification results

Simulation Results

Crop yield simulations based on crop models seem to be unreliable in the face of future climate conditions. The evaluation of uncertainties in multi-model climate change projections is uncommon. Due to model design and parameterization differences, crop models performed effectively and differently with appropriate data in multiple situations (Jabeen et al., 2017). Crop models are often built on the interactive relationship between the environment, soils, crops, and management, all of which are connected in different models to provide output (Arshad et al., 2018). These errors in estimating the effects of climate change on wheat crops could be decreased by using multi-model ensembles to improve temperature and CO_2 correlations, potentially increasing the accuracy of crop model output (Luo et al., 2018). Table 1 provides a comprehensive overview of climate change studies on wheat in various locations in Pakistan using various simulation approaches.

Tentative Results

In the heavy rainfall region, lower temperatures in February and November have a high impact on wheat production, while rainfall in late March has a negative correlation with wheat production (Baloch et al., 2010). The future influence of temperature and rainfall on wheat was projected using three alternative scenarios, all of which suggested a decrease in the per capita production of wheat due to climate change (Tahir et al., 2009). In 2050, assuming a 3°C increase in temperature, per capita wheat production will be only 84 kilograms per year, down from 198 kilograms in 2012. As a result, climate change adaptation in the form of new varieties and improved management strategies would mitigate the effects of climate change.

Phenology and Germination

The first component that determines the initial crop position is germination. The quantity of plants in an area is depended on the germination percentage. Germination is impacted by a range of parameters, including seed health, soil moisture, temperature, aerial environment, and sowing technique, all of which can be influenced by changing the sowing date (Wajid et al., 2007). The optimal germination temperature for spring wheat is 22.1 to 29.8 °C, with minimum and maximum temperature thresholds of 2 and 32 °C (Shah et al., 2006). With increased temperature, germination normally increases up to a point and then drops. As a result, postponed sowing leads to a lower germination rate. The number of seedlings and germination count were relatively high in the first December seeding than in the 15^{th} and 30^{th} December sowing dates, with similar responses from diverse genotypes (Hassan et al., 2019). The low temperature caused a decrease in germination. The fluctuating sowing dates, which normally decrease from November to December, substantially impact the germination rate and count. However, there is a discrepancy between the top and lower temperature limits for germination, which may necessitate future research into sowing dates over a longer period (Aslam et al., 2017).

Under non-stressed conditions, wheat phenological development is influenced by atmospheric temperature, day duration, and genetic makeup. Wheat's temperature requirements vary from germination to maturity with ideal temperatures of 12.7 °C, 23.5 °C, and 22.3 °C for terminal spikelets, flower initiation, and grain filling (Nasrallah et al., 2019). The susceptibility of cultivars and species to elevated temperature varies depending on the phase of plant growth, but heat stress affects all reproductive and vegetative stages to some level (Shah et al., 2019). Flowering and grain-filling phases are the most sensitive to high temperatures among the several stages. The grain-filling stage is significantly impacted by high temperatures in Pakistan during mid-March (Aslam et al., 2017).

Yield and Yield Constituents

Engledow and Wadham (1923) reported estimating wheat output by assessing the components (grains spike-1, weight grain-1 and spikes m-2) a long time ago (Engledow & Wadham, 1923). However, grain m-2 and grain weight can be used to summarize yield components. High temperatures often damage late-sown wheat, reducing grain number, yield, and quality by altering the anthesis stage, which is the most vulnerable phase in wheat. The high temperature significantly impacts yield due to the increased rate of development, which reduces the rate of photosynthesis and has certain adverse effects on reproductive activities (Janjua et al., 2014). The inverse association between high temperatures and grain counts has a significant detrimental direct effect on grain yield. Wheat-approaching flowering has a temperature limit of 31 °C without reducing grain count; nevertheless, wheat susceptibility varies depending on the developmental phase, genotypes, and soil moisture (Ahmad et al., 2014). The low quantity of grains was caused by high temperatures that occurred twenty days before and ten days after the flowering stage, and five days before and two days after the flowering stage. Pollen sterility or infertile grains at 27 to 31 Celsius at mid-anthesis are mostly responsible for the drop in grain number (Tariq et al., 2014). Moreover, high temperatures have direct detrimental effects on pollen fertility, grain abortion, and rates of development, which hastens the formation of the double ridge and flowering, resulting in fewer spikelets per spike and grains per spikelet. The result of grain filling rate and period is grain weight (Hussain & Mudasser, 2007). The rate of photosynthesis for assimilation in stems and green leaves, uptake of the generated carbohydrates and nitrogen-containing substances in stems and leaves, and transportation towards the grains are all important factors in grain filling. Due to a decrease in photosynthetic activity at high temperatures, the grain-filling stage of wheat is extremely vulnerable to heat stress (Alvar-Beltrán et al., 2021). In Australia, for example, 75 wheat genotypes were subjected to shorter periods of extreme temperatures during the grain-filling stage, resulting in a reduction in grain weight of 23 to 37 percent due to shorter grain-filling time, and lower photosynthetic rates (Akbar & Gheewala, 2020). Grain filling is faster at high temperatures, but it cannot compensate for the reduction in grain filling time. Wheat grain filling time is reduced by 12 days when the temperature is raised by 5 degrees Celsius over 20 degrees Celsius. However, the overall susceptibility of these 2 phases is determined by genotype heat sensitivity. As a result, various genotypes of wheat are vulnerable to heat stress in different ways during late sowing.

Adaptations Choices

The main objective of climate change risk evaluation is to identify the adaptation solutions and assess their success in mitigating the unfavorable impact of climate change on a specific sector or region's long-term development (Zhu et al., 2013). Several reasons have hampered the healthy development of adaptation studies against impact assessments. Climatic changes effects on agriculture could be mitigated through a variety of adaptation strategies, including autonomous adaptations that require just management changes, such as changing planting dates or crop varieties and planned adaptations that require significant investment, such as the development of new wheat cultivars or expanding irrigation systems (Tanaka et al., 2015). Planned responses may offset climate change's negative effects on agricultural output. Farmers can withstand the consequences of climate change if government policies and management decisions are effective. Furthermore, climate-specific wheat adaptations must be developed to ensure our food security (Aryal et al., 2020). Wheat's vulnerability to climate change could be reduced as a result of the adaptations. Crop models can be adapted by modifying crop characteristics, management features, and soil amendments. Multiple wheat models can be used to assess planting dates, seed index, fertilizer, irrigation quantity, and procedures to improve wheat output in future climatic circumstances (Amir et al., 2020). Furthermore, wheat simulation models can be used to test alternative crop traits to see how they perform in shifting climates. Wheat can get the benefit from different crop duration and phenology options to perform better in various climates (Elahi et al., 2021).

Table 1 List of wheat climate change effect studies in different settings

S. #	Study area	Study objective	Weather condition	Methods of Quantification	Findings	Adaptation	Reference
1	Central Punjab	In a mixed-cropping system to analyze wheat productivity under change in climate	The weather condition is semi-arid	Ordinary least square technique	Wheat responds in different ways to rising temperatures from propagating to reaping	To find modern wheat varieties which can adjust against climate change	Ashfaq et al. (2011)
2	Pakistan	To reconnoitre the wheat production susceptibility in these areas	dry, sub-humid semi-arid, and Humid climate conditions	CERES-wheat model and CROPSIM-wheat	Higher temperature is not suitable for semi-arid, sub-humid, and arid, conditions because it reduced the yield. But beneficial in a humid zone.	Sowing date towards cold months	Sultana et al. (2009)
3	Pakistan	To determine a result of a change in climate on wheat productivity	Arid to humid	Vector Auto Regression model	Declines in the yield of wheat	Utilization of drought-resistant seeds and timely cultivation is useful	(Janjua et al. 2010)
4	Punjab and Sindh	Estimation of adaptation in the field	Arid to humid	Modeling, Di Falco et al.	Wheat may damage by climate	Yield increases 12% by adaptation	(Gorst et al. 2018)
5	Punjab	to analyze the climate change, impacts of climate change, and adaptations of the wheat harvesting system	Semi-dry to sub-humid	Modelling by APSIM-wheat and CERES-wheat	Declining in 16.2 per cent yield of grain	10% more nitrogen and ten days of initial sowing at the field	(Ahmad et al. 2015)
6	Pakistan	To study wheat productivity under the effect of climatic changes	Humid, sub-humid, arid, and semi-arid climate conditions	CERES-wheat model	There would be chances of a 5 to 6 % decrease in wheat production in the coming 70 years and shorting of wheat growing seasons	Modification in sowing window for wheat	(Iqbal et al. 2009)

Agronomic Adaptation

Crop Managing Choices

Among the several agricultural adaptations, the planting date is the most essential factor, as it is the adaptation of the wheat season to the weather conditions. Crop length, growth, development, and yield are largely determined by meteorological conditions (Ullah et al., 2018). Sensitivity to temporary changes in planting date is an important part of studying the effects of climatic components, especially maximum temperature and minimum temperature (HAYAT & AHMAD 2019). Planting density is also another adjustment strategy for wheat to adjust for climate change impacts, for example, low tillering can be compensated by a higher seed rate (Nasim et al., 2016).

Soil Managing

Soil is a vital part of the crop-growing environment. Maintaining soil fertility and organic material, boosting soil nutrients, increasing urea application, and improving soil water-holding capacity have all been described as valuable solutions for dealing with climate change consequences (Mohammad et al., 2012). The demand for urea in future climate change was simulated, and it was discovered that a 25 percent greater quantity of urea mitigated climate change, as indicated in Table 1. Kassie et al. (2013) recommended increased nitrogen for climate change mitigation and adaptation alternatives in Ethiopia and enhanced water conservation management and irrigation systems to increase climate resilience production system (Kassie et al., 2013). Organic material is a factor of excellent soil quality, as it promotes water holding capacity, availability of nutrients, microorganism habitat, and soil erosion resistance. High temperatures endanger the percentage of organic carbon in the soil in climate change scenarios (Khaliq et al., 2019).

Breeding Adaptations

The popular measures for ranchers to adapt to climatic fluctuations are to replace varieties with early maturing varieties as the rainy or storm season begins. We examined the effect of early and medium maturing variety selection on future environmental changes (Mondal et al., 2016). For C3 plants there is the possibility of using more CO_2 when the concentration of carbon dioxide is increased. Extra carbon dioxide usage can increase wheat yield and fix extra CO_2 to diminish climate change. Heat and temperature-resistant genotypes are intended to mitigate rational environmental changes and fluctuations (Liu et al., 2019). Farmers are increasingly replacing medium-maturing cultivars with early-maturing cultivars in areas where the main rainy season begins later to cope with current climate variability. Under future climate change scenarios, the impact of selecting an early- or medium-maturing cultivar was assessed. C3 plants can use more CO_2 when CO_2 levels are high. More CO_2 consumption can increase wheat yield while also fixing more CO_2 to help prevent climate change (Lopes et al., 2015).

CONCLUSION

Compared to other climatic elements, wheat is the most vulnerable to rising temperatures. According to much research, wheat is more vulnerable to temperature than carbon dioxide. In semi-arid and dry regions, water scarcity is becoming increasingly acute. At the agricultural and government levels, immediate adaptation strategies are required to enhance wheat yields in the face of future climate change. Planned breeding and autonomous adaptations are viable options that should be used in tandem to maximize wheat yield. Crop models and quantification of effects are the most advantageous implements to simulate the effects of climatic change on crops among numerous methods of climatic change, although all of these simulation models are not efficient and trustworthy. These crop models' simulations are typically different in similar climatic change scenarios. As a result, simulations of climatic change effect studies are suspect. It is proposed that more than one model be used to simulate climate change adaptations and consequences to produce more reliable results.

Conflict of interest

The authors declare no conflict of interest.

Acknowledgements

The authors acknowledge the Department of Biotechnology, University of Okara for providing the platform for this project.

REFERENCES

Abbas, Q., & Ahmad, S. (2018). Effect of Different Sowing Times and Cultivars on Cotton Fiber Quality under Stable Cotton-Wheat Cropping System in Southern Punjab, Pakistan. *Pakistan Journal of Life & Social Sciences 16*(2).

Abbas, S. (2022). Climate change and major crop production: evidence from Pakistan. *Environmental Science and Pollution Research 29*(4), 5406-5414.

Abid, M., Scheffran, J., Schneider, U. A., & Elahi, E. (2019). Farmer perceptions of climate change, observed trends and adaptation of agriculture in Pakistan. *Environmental management 63*(1), 110-123.

Abid, M., Schilling, J., Scheffran, J., & Zulfiqar, F. (2016a). Climate change vulnerability, adaptation and risk perceptions at farm level in Punjab, Pakistan. *Science of the Total Environment 547*, 447-460.

Abid, M., Schneider, U. A., & Scheffran, J. (2016b). Adaptation to climate change and its impacts on food productivity and crop income: Perspectives of farmers in rural Pakistan. *Journal of Rural Studies 47*, 254-266.

Ahmad, A., Ashfaq, M., Rasul, G., Wajid, S. A., Khaliq, T., Rasul, F., Saeed, U., Rahman, M. H. U., Hussain, J., & Ahmad Baig, I. (2015). Impact of climate change on the rice–wheat cropping system of Pakistan. In: Handbook of climate change and agroecosystems: The agricultural model intercomparison and improvement project integrated crop and economic assessments, Part 2. pp 219-258.

Ahmad, M., Siftain, H., & Iqbal, M. (2014). Impact of climate change on wheat productivity in Pakistan: A district level analysis.

Ahmad, M. J., Cho, G. H., Kim, S. H., Lee, S., Adelodun, B., & Choi, K. S. (2021). Influence mechanism of climate change over crop growth and water demands for wheat-rice system of Punjab, Pakistan. *Journal of Water and Climate Change 12*(4), 1184-1202.

Ahmed, M. (2015). Response of spring wheat (Triticum aestivum L.) quality traits and yield to sowing date. *PloS one 10*(4), e0126097.

Ahmed, M., Ijaz, W., & Ahmad, S. (2018). Adapting and evaluating APSIM-SoilP-Wheat model for response to phosphorus under rainfed conditions of Pakistan. *Journal of Plant Nutrition 41*(16), 2069-2084.

Ahmed, T., Scholz, M., Al-Faraj, F., & Niaz, W. (2016). Water-related impacts of climate change on agriculture and subsequently on public health: A review for generalists with particular reference to Pakistan. *International journal of environmental research and public health 13*(11), 1051.

Ahsan, F., Chandio, A. A., & Fang, W. (2020). Climate change impacts on cereal crops production in Pakistan: evidence from cointegration analysis. *International Journal of Climate Change Strategies and Management*.

Akbar, H., & Gheewala, S. H. (2020). Effect of climate change on cash crops yield in Pakistan. *Arabian Journal of Geosciences 13*(11), 1-15.

Ali, A. (2017). Coping with climate change and its impact on productivity, income, and poverty: evidence from the Himalayan region of Pakistan. *International journal of disaster risk reduction 24*, 515-525.

Ali, A., & Erenstein, O. (2017). Assessing farmer use of climate change adaptation practices and impacts on food security and poverty in Pakistan.

Climate Risk Management 16, 183-194.

Ali, S., Liu, Y., Ishaq, M., Shah, T., Ilyas, A., & Din, I. U. (2017). Climate change and its impact on the yield of major food crops: *Evidence from Pakistan. Foods 6*(6), 39.

Ali, S., Ying, L., Shah, T., Tariq, A., Ali Chandio, A., & Ali, I. (2019). Analysis of the nexus of CO2 emissions, economic growth, land under cereal crops and agriculture value-added in Pakistan using an ARDL approach. *Energies 12*(23), 4590.

Alvar-Beltrán, J., Heureux, A., Soldan, R., Manzanas, R., Khan, B., & Dalla Marta, A. (2021). Assessing the impact of climate change on wheat and sugarcane with the AquaCrop model along the Indus River Basin, Pakistan. *Agricultural Water Management 253*, 106909.

Amir, S., Saqib, Z., Khan, M. I., Ali, A., Khan, M. A., & Bokhari, S. A. (2020). Determinants of farmers' adaptation to climate change in rain-fed agriculture of Pakistan. *Arabian Journal of Geosciences 13*(19), 1-19.

Amthor, J. S. (2001). Effects of atmospheric CO2 concentration on wheat yield: review of results from experiments using various approaches to control CO2 concentration. *Field Crops Research 73*(1), 1-34.

Anser, M. K., Hina, T., Hameed, S., Nasir, M. H., Ahmad, I., & Naseer, M. A. U. R. (2020). Modeling adaptation strategies against climate change impacts in integrated rice-wheat agricultural production system of Pakistan. *International Journal of Environmental Research and Public Health 17*(7), 2522.

Arshad, M., Amjath-Babu, T., Aravindakshan, S., Krupnik, T. J., Toussaint, V., Kächele, H., & Müller, K. (2018). Climatic variability and thermal stress in Pakistan's rice and wheat systems: A stochastic frontier and quantile regression analysis of economic efficiency. *Ecological indicators 89,* 496-506.

Arshad, M., Kächele, H., Krupnik, T. J., Amjath-Babu, T., Aravindakshan, S., Abbas, A., Mehmood, Y., & Müller, K. (2017). Climate variability, farmland value, and farmers' perceptions of climate change: implications for adaptation in rural Pakistan. *International Journal of Sustainable Development & World Ecology 24*(6), 532-544.

Aryal, J. P., Sapkota, T. B., Khurana, R., Khatri-Chhetri, A., Rahut, D. B., & Jat, M. L. (2020). Climate change and agriculture in South Asia: Adaptation options in smallholder production systems. *Environment*, *Development and Sustainability 22*(6), 5045-5075.

Ashfaq, M., Zulfiqar, F., Sarwar, I., Quddus, M. A., & Baig, I. A. (2011). Impact of climate change on wheat productivity in mixed cropping system of Punjab. *Soil & Environment 30*(2).

Aslam, M. A., Ahmed, M., Stöckle, C. O., Higgins, S. S., Hassan, F. U., & Hayat, R. (2017). Can growing degree days and photoperiod predict spring wheat phenology? *Frontiers in Environmental Science 5*, 57.

Asseng, S., Cammarano, D., Basso, B., Chung, U., Alderman, P. D., Sonder, K., Reynolds, M., & Lobell, D. B. (2017). Hot spots of wheat yield decline with rising temperatures. *Global change biology 23*(6), 2464-2472.

Asseng, S., Martre, P., Maiorano, A., Rötter, R. P., O'Leary, G. J., Fitzgerald, G. J., Girousse, C., Motzo, R., Giunta, F., & Babar, M. A. (2019). Climate change impact and adaptation for wheat protein. *Global change biology 25*(1), 155-173.

Azmat, M., Ilyas, F., Sarwar, A., Huggel, C., Vaghefi, S. A., Hui, T., Qamar, M. U., Bilal, M., & Ahmed, Z. (2021). Impacts of climate change on wheat phenology and yield in Indus Basin, Pakistan. *Science of the Total Environment 790*, 148221.

Baloch, M., Shah, I., Nadim, M., Khan, M., & Khakwani, A. (2010). Effect of seeding density and planting time on growth and yield attributes of wheat. *J. Anim. Plant Sci 20*(4), 239-242.

Chandio, A. A., Magsi, H., & Ozturk, I. (2020). Examining the effects of climate change on rice production: case study of Pakistan. *Environmental Science and Pollution Research 27*(8), 7812-7822.

Demirhan, H. (2020). Impact of increasing temperature anomalies and carbon dioxide emissions on wheat production. *Science of The Total Environment 741*, 139616.

Dettori, M., Cesaraccio, C., & Duce, P. (2017). Simulation of climate change impacts on production and phenology of durum wheat in Mediterranean environments using CERES-Wheat model. *Field Crops Research 206*, 43-53.

Elahi, E., Khalid, Z., Tauni, M. Z., Zhang, H., & Lirong, X. (2021). Extreme weather events risk to crop-production and the adaptation of innovative management strategies to mitigate the risk: A retrospective survey of rural Punjab, *Pakistan. Technovation:* 102255.

Engledow, F. T., & Wadham, S. (1923). Investigations on yield in the cereals1. I. *The Journal of Agricultural Science 13*(4), 390-439.

Gorst, A., Dehlavi, A., & Groom, B. (2018). Crop productivity and adaptation to climate change in Pakistan. *Environment and development economics 23*(6), 679-701.

Gul, F., Ahmed, I., Ashfaq, M., Jan, D., Fahad, S., Li, X., Wang, D., Fahad, M., Fayyaz, M., & Shah, S. A. (2020). Use of crop growth model to simulate the impact of climate change on yield of various wheat cultivars under different agro-environmental conditions in Khyber Pakhtunkhwa, Pakistan. *Arabian Journal of Geosciences 13*(3), 1-14.

Gul, F., Jan, D., & Ashfaq, M. (2019). Assessing the socio-economic impact of climate change on wheat production in Khyber Pakhtunkhwa, Pakistan. *Environmental Science and Pollution Research 26*(7), 6576-6585.

Haider, M. M., Ahmad, A., Khaliq, T., & Shahbaz, M. (2015). Simulating the effects of sowing time on growth and yield of wheat in arid environment using APSIM-model. *Appl Sci Bus Econ 2*, 1-7.

Hassan, N., Irshad, S., Saddiq, M. S., Bashir, S., Khan, S., Wahid, M. A., Khan, R. R., & Yousra, M. (2019). Potential of zinc seed treatment in improving stand establishment, phenology, yield and grain biofortification of wheat. *Journal of Plant Nutrition 42*(14), 1676-1692.

HAYAT, R., & AHMAD, S. (2019). Biochemical, physiological and agronomic response of wheat to changing climate of rainfed areas of Pakistan. *Pak. J. Bot 51*(2), 535-551.

Hussain, J., Khaliq, T., Ahmad, A., Akhter, J., & Asseng, S. (2018). Wheat responses to climate change and its adaptations: a focus on arid and semi-arid environment. *International Journal of Environmental Research 12*(1), 117-126.

Hussain, J., Khaliq, T., Rahman, M. H. U., Ullah, A., Ahmed, I., Srivastava, A. K., Gaiser, T., & Ahmad, A. (2021). Effect of temperature on sowing dates of wheat under arid and semi-arid climatic regions and impact quantification of climate change through mechanistic modeling with evidence from field. *Atmosphere 12*(7), 927.

Hussain, M., Butt, A. R., Uzma, F., Ahmed, R., Irshad, S., Rehman, A., & Yousaf, B. (2020). A comprehensive review of climate change impacts, adaptation, and mitigation on environmental and natural calamities in Pakistan. *Environmental monitoring and assessment 192*(1), 1-20.

Hussain, S. S., & Mudasser, M. (2007). Prospects for wheat production under changing climate in mountain areas of Pakistan–An econometric analysis. *Agricultural Systems 94*(2), 494-501.

Iqbal, M. M., Hussain, S. S., Goheer, M. A., Sultana, H., Salik, K. M., Mudasser, M., & Khan, A. M. (2009). Climate change and wheat production in Pakistan: calibration, validation and application of CERES-Wheat model. Islamabad: Global Change Impact Studies Centre.

Jabeen, M., Gabriel, H. F., Ahmed, M., Mahboob, M. A., Iqbal, J. (2017). Studying impact of climate change on wheat yield by using DSSAT and GIS: a case study of Pothwar region. In: Quantification of climate variability, adaptation and mitigation for agricultural sustainability. Springer, pp 387-411.

Jan, I., Ashfaq, M., & Chandio, A. A. (2021). Impacts of climate change on yield of cereal crops in northern climatic region of Pakistan. *Environmental Science and Pollution Research 28*(42), 60235-60245.

Janjua, P. Z., Samad, G., & Khan, N. (2014). Climate change and wheat production in Pakistan: an autoregressive distributed lag approach. *NJAS-Wageningen Journal of Life Sciences 68*, 13-19.

Janjua, P. Z., Samad, G., Khan, N. U., & Nasir, M. (2010). Impact of climate change on wheat production: A case study of Pakistan [with comments]. *The Pakistan Development Review:* 799-822.

Kassie, B. T., Hengsdijk, H., Rötter, R., Kahiluoto, H., Asseng, S., & Van Ittersum, M. (2013). Adapting to climate variability and change: experiences from cereal-based farming in the Central Rift and Kobo Valleys, Ethiopia. *Environmental Management 52*(5), 1115-1131.

Khaliq, T., Gaydon, D. S., Cheema, M., & Gull, U. (2019). Analyzing crop yield gaps and their causes using cropping systems modelling–A case study of the Punjab rice-wheat system, Pakistan. *Field Crops Research 232,* 119-130.

Khan, M. A., Khan, J. A., Ali, Z., Ahmad, I., & Ahmad, M. N. (2016). The challenge of climate change and policy response in Pakistan. *Environmental Earth Sciences 75*(5), 412.

Khan, M. A., Tahir, A., Khurshid, N., Husnain, M. I. U., Ahmed, M., & Boughanmi, H. (2020). Economic effects of climate change-induced loss of agricultural production by 2050: A case study of Pakistan. *Sustainability 12*(3), 1216.

Khan, Y., Bin, Q., & Hassan, T. (2019). The impact of climate changes on agriculture export trade in Pakistan: Evidence from time-series analysis. *Growth and Change 50*(4), 1568-1589.

Liu, B., Asseng, S., Müller, C., Ewert, F., Elliott, J., Lobell, D. B., Martre, P., Ruane, A. C., Wallach, D., & Jones, J. W. (2016). Similar estimates of temperature impacts on global wheat yield by three independent methods. *Nature Climate Change 6*(12), 1130-1136.

Liu, J., Rasheed, A., He, Z., Imtiaz, M., Arif, A., Mahmood, T., Ghafoor, A., Siddiqui, S. U., Ilyas, M. K., & Wen, W. (2019). Genome-wide variation patterns between landraces and cultivars uncover divergent selection during modern wheat breeding. *Theoretical and Applied Genetics 132*(9), 2509-2523.

Lobell, D. B., & Asseng, S. (2017). Comparing estimates of climate change impacts from process-based and statistical crop models. *Environmental Research Letters 12*(1), 015001.

Lopes, M. S., El-Basyoni, I., Baenziger, P. S., Singh, S., Royo, C., Ozbek, K., Aktas, H., Ozer, E., Ozdemir, F., & Manickavelu, A. (2015). Exploiting genetic diversity from landraces in wheat breeding for adaptation to climate change. *Journal of experimental botany 66*(12), 3477-3486.

Luo, Q., O'Leary, G., Cleverly, J., & Eamus, D. (2018). Effectiveness of time of sowing and cultivar choice for managing climate change: wheat crop phenology and water use efficiency. *International journal of biometeorology 62*(6), 1049-1061.

Mahmood, N., Arshad, M., Kächele, H., Ma, H., Ullah, A., & Müller, K. (2019). Wheat yield response to input and socioeconomic factors under changing climate: Evidence from rainfed environments of Pakistan. *Science of the Total Environment 688*, 1275-1285.

Mahmood, N., Arshad, M., Kächele, H., Ullah, A., & Müller, K. (2020). Economic efficiency of rainfed wheat farmers under changing climate: Evidence from Pakistan. *Environmental Science and Pollution Research 27*(27), 34453-34467.

Mahmood, Z., Wahla, A. J., Mahmood, R., Ali, L., Nawaz, M. (2014). Impact of sowing time on yield parameters of selected wheat cultivars under rice-wheat cropping system of district Sheikhupura, Punjab. *Biologia 60*, 31-36.

Mohammad, W., Shah, S., Shehzadi, S., & Shah, S. (2012). Effect of tillage, rotation and crop residues on wheat crop productivity, fertilizer nitrogen and water use efficiency and soil organic carbon status in dry area (rainfed) of north-west Pakistan. *Journal of soil science and plant nutrition 12*(4), 715-727.

Mondal, S., Singh, R., Mason, E., Huerta-Espino, J., Autrique, E., & Joshi, A. (2016). Grain yield, adaptation and progress in breeding for early-maturing and heat-tolerant wheat lines in South Asia. *Field crops research 192*, 78-85.

Nasim, W., Belhouchette, H., Ahmad, A., Habib-ur-Rahman, M., Jabran, K., Ullah, K., Fahad, S., Shakeel, M., & Hoogenboom, G. (2016). Modelling climate change impacts and adaptation strategies for sunflower in Pakistan. *Outlook on Agriculture 45*(1), 39-45.

Nasrallah, A., Baghdadi, N., El Hajj, M., Darwish, T., Belhouchette, H., Faour, G., Darwich, S., & Mhawej, M. (2019). Sentinel-1 data for winter wheat phenology monitoring and mapping. *Remote Sensing 11*(19), 2228.

Qureshi, M. I., Awan, U., Arshad, Z., Rasli, A. M., Zaman, K., & Khan, F. (2016). Dynamic linkages among energy consumption, air pollution, greenhouse gas emissions and agricultural production in Pakistan: sustainable agriculture key to policy success. *Natural Hazards 84*(1), 367-381.

Ray, D. K., West, P. C., Clark, M., Gerber, J. S., Prishchepov, A. V., & Chatterjee, S. (2019). Climate change has likely already affected global food production. *PloS one 14*(5), e0217148.

Raza, M. H., Bakhsh, A., & Kamran, M. (2019). Managing climate change for wheat production: An evidence from southern Punjab, Pakistan. *Journal of Economic Impact 1*(2), 48-58.

Said, A., Gul, H., Saeed, B., Haleema, B., Badshah, N. L., & Parveen, L. (2012). Response of wheat to different planting dates and seeding rates for yield and yield components. *ARPN Journal of Agricultural and Biological Science 7*(2), 138-140.

Sattar, A., Sher, A., Ijaz, M., Ullah, M. S., Ahmad, N., & Umar, U. (2020). Individual and combined effect of terminal drought and heat stress on allometric growth, grain yield and quality of bread wheat. *Pak. J. Bot 52*(2), 405-412.

Shah, T., Latif, S., Khan, H., Munsif, F., & Nie, L. (2019). Ascorbic acid priming enhances seed germination and seedling growth of winter wheat under low temperature due to late sowing in Pakistan. *Agronomy 9*(11), 757.

Shah, W. A., Bakht, J., Ullah, T., Khan, A. W., Zubair, M., & Khakwani, A. A. (2006). Effect of sowing dates on the yield and yield components of different wheat varieties. *Journal of Agronomy 5*(1), 106-110. doi:10.3923/ja.2006.106.110

Sonia, K., Sadozai, N. P., Khan, A. U. & Jan & Hameed, G. (2019). Assessing the impact of climate change on wheat productivity in Khyber Pakhtunkhwa, Pakistan. *Sarhad Journal of Agriculture 35*(1), 284-292.

Sultana, H., Ali, N., Iqbal, M. M., & Khan, A. M. (2009). Vulnerability and adaptability of wheat production in different climatic zones of Pakistan under climate change scenarios. *Climatic Change 94*(1), 123-142.

Tahir, M., Ali, A., Nadeem, M. A., Hussain, A., & Khalid, F. (2009). Effect of different sowing dates on growth and yield of wheat (Triticum aestivum L.) varieties in district Jhang, Pakistan. *Pak. j. life soc. sci 7*(1), 66-69.

Tanaka, A., Takahashi, K., Masutomi, Y., Hanasaki, N., Hijioka, Y., Shiogama, H., & Yamanaka, Y. (2015). Adaptation pathways of global wheat production: Importance of strategic adaptation to climate change. *Scientific Reports 5*(1), 1-10.

Tariq, A., Tabasam, N., Bakhsh, K., Ashfaq, M., & Hassan, S. (2014). Food security in the context of climate change in Pakistan. *Pakistan Journal of Commerce and Social Sciences (PJCSS) 8*(2), 540-550.

Ullah, W., Nihei, T., Nafees, M., Zaman, R., & Ali, M. (2018). Understanding climate change vulnerability, adaptation and risk perceptions at household level in Khyber Pakhtunkhwa, Pakistan. *International Journal of Climate Change Strategies and Management*.

Wajid, A., Hussain, K., Maqsood, M., Khaliq, T., & Ghaffar, A. (2007). Simulation modeling of growth, development and grain yield of wheat under semi arid conditions of Pakistan. *Pak. J. Agri. Sci 44*(2), 194-199.

Zhu, T., Ringler, C., Iqbal, M. M., Sulser, T. B., & Goheer, M. A. (2013). Climate change impacts and adaptation options for water and food in Pakistan: scenario analysis using an integrated global water and food projections model. *Water International 38*(5), 651-669.