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RESEARCH ARTICLE

Climate change and major crop production: evidence from Pakistan

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Abstract

Climatic changes are posing serious threats to crop production and food insecurity across the globe. This study explores the dynamic relationship between changing annual temperature and production of major crops such as wheat, rice, bajra, jowar, maize, barley, gram, sugar cane, mastered oil, and cotton in Pakistan from 2000 to 2019 through an eclectic production model. The estimated result of panel econometric analysis revealed a significant negative effect of rising temperature on selected crop production in the long run with an insignificant impact in the short run. Among other explanatory variables, the area under cultivation and fertilizer input have significant positive effects in both the long run and the short run. Improved quality seeds revealed insignificant effects and urging authorities to enhance quality research to develop climate change resilient crops. This study urges Pakistan to improve agriculture technology along with adopting other greenhouse gas mitigation, such as forestation and clean energy, and water conservation policies.

Keywords Climate change · Major crops · Agriculture sector · Panel cointegration · FMOLS · DOLS · Pakistan

Introduction

Climatic change is posing a serious threat to humanity and biodiversity by distorting productivity of the agriculture sector (Siddiqui et al. 2012; Ahmed et al. 2016; FAO 2020; Chandio et al. 2021). Many species of food crops are very sensitive to increasing average temperatures. The climatic changes associated with the increasing annual temperature, changing patterns of rainfall, floods, and depleting water reservoirs are affecting the production and exports of major agriculture crops (Appiah et al. 2018; Chandio et al. 2019; Abbas 2020). Agriculture is an important production sector of developing and least developed countries that provides income and employment to almost half of labor force and supplies raw materials to the industrial sector. The phenomenal increase in global population and stagnated performance of the agriculture sector are resulting continuous increase in global hunger and food insecurities. Ending hunger and food security is one of the core targets of SDGs.

Pakistan is one of the agrarian developing countries, which relies on the agriculture sector for the foreign exchange earnings, employment, and development of other manufacturing industries/sectors (Abbas and Waheed 2017). The international trade is concentrated on a few commodities such as cotton manufactures, leather, and rice that account for more than 70.8% of total exports (Govt. of Pakistan 2020). In recent decades, the major crops are witnessing highly sluggish and distorted growth performance in Pakistan. The distorted growth performance of major crops can not only reduce domestic income and employment, but also deteriorate the performance of related manufacturing industries along with the increasing food insecurity problem. This distortion in the performance of major crops, besides others, can be due to climate vulnerability and changes. According to IPCC (2012), crop production is very sensitive to climatic changes associated with increasing temperature, changing patterns of rainfall, and extreme weather events.

The average annual temperature of Pakistan is witnessing an increasing trend from 1997 onward with an average annual increase of more than 1°C (FAO 2020). Changing temperature can take various forms such as high day-time and low night-time temperature; duration and intensity of extremely cold and

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hot weather; and changes in average temperature. These changes can result in flooding, depletion of glaciers, plant diseases, and pest attacks that distort the productivity of major crops. The average annual temperature of Pakistan during the sowing season of major crops remains much higher than the threshold temperature discussed in Table 1 of Wahid et al. (2007). Siddiqui et al. (2012) and Ahmed et al. (2016) concluded that climate change-related crop diseases are harshly affecting agriculture sector productivity in Pakistan. The available literature mainly focused on CO_2 emission as a major indicator of environmental and climate change (Janjua et al. 2014; Chandio et al. 2019; and Chandio et al. 2021). The increasing concentration of GHGs emissions results from increases in average temperature, which can deteriorate the production of many food crops. Abbas (2020) investigated the effect of increasing annual temperature on the production of cotton by using contemporary time-series estimation technique. The findings revealed an insignificant effect of rising annual temperature on cotton production. Moreover, Jan et al. (2021) have recently explored the impacts of climate change (CO_2 emission) on the yield of selected cereal crops such as wheat and maize in the northern climatic region of Khyber Pakhtunkhwa (KP) of Pakistan from 1986 to 2015 by using the second generation of panel cointegration analysis. The findings show that the increased precipitation has a significant positive impact on cereal production (wheat and maize); whereas, rising average temperature has insignificant impact in the long run.

This study extends the scope of literature by exploring the effect of increasing annual temperature on the production of ten major crops in Pakistan, such as wheat, rice, bajra, jowar, maize, barley, gram, sugar cane, mastered oil, and cotton, from 2000 to 2019 by constructing an eclectic model that incorporates increasing annual temperature along with the area under crop, credit to the agriculture sector, fertilizer, and improved quality seeds as explanatory variables. Moreover, the crop-specific heterogeneities are addressed by using the PMG model that provides homogenous long-run estimates along with heterogeneous short-term elasticities. The long-run findings of the model are validated by using FMOLS and panel DOLS estimators. The modeling framework allows the effect of economic, policy, and environmental variables to devise policy to enhance the sustainable production of selected major crops.

The rest of this study is organized as follows. The "Performance of agriculture sector" section will review climate change and the agriculture sector of Pakistan, the "Literature review" section reviews selected literature, the "Methodological framework" section discusses methodological framework, the "Estimation results" section analyzes estimated results, and the "Conclusion and implications" section concludes the study with policy implications.

Performance of agriculture sector

Pakistan is an agrarian country of more than 20 million population with a higher population growth rate. The increasing population growth is increasing demand for food and enhances the importance of the agriculture sector to ensure food security.

Agriculture sector of Pakistan is the largest sector in terms of employment and source of income for the majority of the population living in rural areas. The development of the agriculture sector is important for the alleviation of poverty, increase food security, and uplift socio-economic structure. The performance of other important manufacturing sectors is dependent on the performance of the agriculture sector for raw material. Although the contribution of the agriculture sector to the GDP of Pakistan has gradually decreased to 19.3% in 2019, yet this sector has a lot of potentials to enhance its contribution through the efficient utilization of advanced agriculture technologies. It is producing a variety of cash and food crops such as wheat, rice, cotton, sugar cane, maize, paddy, pulses, fruits, vegetables, and other crops in an area of 23.45 million hectares in the fiscal year 2019–2020. Figure 1 reveals that the wheat is a highly cultivated crop that uses 34% of total cultivated land. It is followed by the cotton that is cultivated on 14% of the cultivated area.

Production of major crops

Pakistan is producing diverse crops among which wheat, rice, and maize are important food crops and cotton is major cash

Table 1 Description of variables

Abbr.	Variable name	Unit	Mean	Max.	J.B. stat[prob]
LnCROPS	Log of crop production	(000) Tonnes	7.197	11.331	15.4326[0.000]
TEMP	Annual temperature change	°C	0.691	1.279	9.937[0.018]
LnAREA	Log of area under cultivation	(000) Hectare	6.728	9.129	3.758[0.153]
LnFERT	Log of fertilizer input	(000) N/Tonnes	8.235	8.525	3.263[0.196]
LnSEED	Log of improved seeds	(000) Tonnes	5.699	6.405	13.701[0.001]

Source: Author's estimation

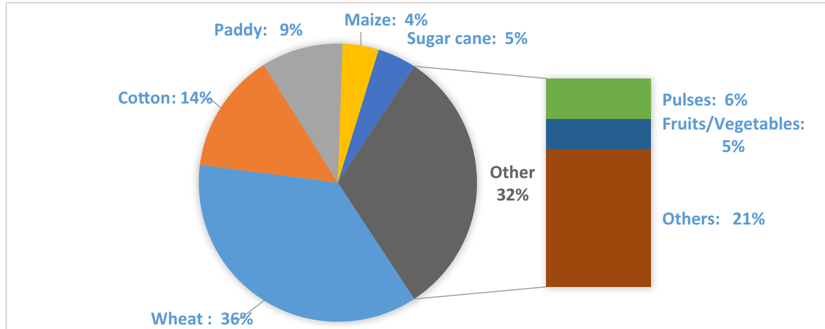

Fig. 1 Area under different crops in Pakistan, % of total cultivated land. Source: Authors' construction. Data has been taken from the Govt. of Pakistan (2020)

crop. The performance of these crops is important to ensure food security, employment, and foreign exchange. Cotton is an important cash crop of Pakistan with the largest value chain in the textile sector. Cotton and cotton manufactures are major exports that account for more than 50% of the total export receipt.

Figure 2 reveals that the cotton crop of Pakistan is witnessing a distorted production during the sample period. Total cotton production during 2000 was 1.83 million tonnes which have distorted to 1.56 million tonnes in 2019. This highly unsatisfactory growth performance of cotton crops is a matter of concern as it engages the largest workforce. Similarly, the production food crops such as wheat, rice, and maize are most important to ensure food security. Lower panel of Fig. 2 reveals that the wheat production remained highly stagnant from 2000 to 2019. The total wheat production in Pakistan was 20 million tonnes in 2000 which has increased to only 25 million tonnes in 20 years. Similarly, other important food crops, i.e., rice and maize also reported highly sluggish growth performance. The increasing population rate long with the stagnation in the production of food crops has the potential to aggravate the food security condition of the country.

The agriculture sector of Pakistan has the potential to export surplus production and earn large foreign exchange. The development of this crop is not only important for providing raw material to the textile sector but can reduce poverty and uplift socio-economic structure. The distorted performance of major agricultural crops may aggravate poverty, food security, and distort industrial performance. There are many factors that can explain the unsatisfactory performance of the agriculture sector such as limited credit, low research and development, lower agricultural technology, water availability, land ownership, and limited access along with deteriorating climatic conditions.

Climate change and major crops

Crops are highly vulnerable to climatic changes associated with the increase in annual temperature and changing patterns

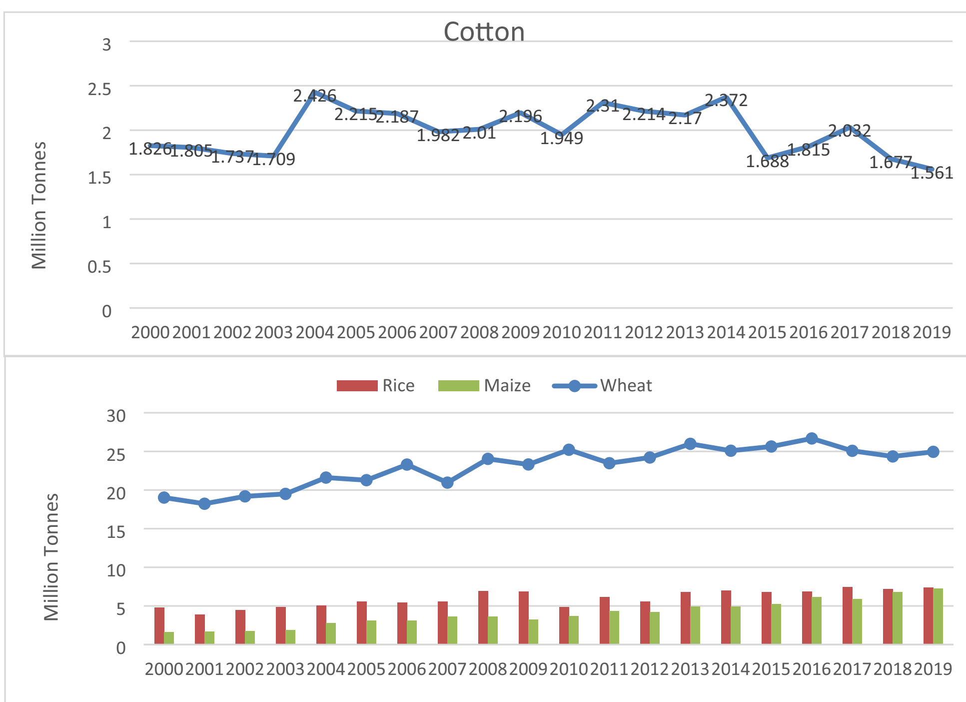

Fig. 2 Production of major cash and food crops. Source: Author's construction. Data has been taken from statistical appendixes of the economic survey of Pakistan, published by the Govt. of Pakistan (2020)

of rainfall (IPCC 2012). The increasing average annual temperature change has the potential to distort the productivity growth of major agricultural crops and aggravate food security conditions in Pakistan.

The increasing temperature can deplete frozen water reservoirs at Himalayan and Tibetan glaciers and increase water shortage if mitigating policies are not adopted (Abbas 2020). Figure 3 reveals that from 1960 to 1997, the average change in annual temperature was negative, which has exponentially increased after 1997 onward. This increase in average temperature can take many forms such as a change in average daytime temperature, change in time, intensity, and duration of extremely hot weather. The increase in temperature during the growing season results in excessive use of energy for respiration and lesser energy for their growth. According to Lobel and Field (2007) and Hatfield and Prueger (2015), 1°C increase in average annual temperature can distort yields of major cash and food crop species by 5 to 10%.

In recent years, Pakistan is witnessing the increasing frequency and intensity of heat shocks/stress, especially during the summer season. Heat stress can be fined as an increase in temperature beyond the threshold level that is causing inevitable damage to the development and growth of major crops. Hall (2001) considers heat stress as a major threat to crop production. Some crops are more tolerant of certain types of heat stress as compare to others. The increasing average annual temperature along with heat stresses increased the importance of heat stress-tolerant crops for sustainable agriculture. Moreover, increasing temperature also results in an increase in pest and weeds attack to major crops. With increasing global warming, insects of warmer areas move toward other areas. Similarly, invasive weeds restricted to warmers areas migrate toward colder areas (Hussner et al. 2010).

Literature review

Agriculture is an important sector that provides food, income, and employment to more than half of the population that is living in poor rural areas. The production performance of the agriculture sector can be influenced by many inputs along with the climatic changes associated with increasing annual temperature, precipitation, changing patterns of rainfall, and floods. This section reviews some recent literature on the effect of climate change on the performance of the agriculture sector that covers the overall behavior of existing empirical literature.

Zaied and Cheikh (2015) have explored the long-run and short-run effects of climate change on the production of the agriculture sector of Tunisia by using time series cointegration analysis. The findings of this study reveal that the increasing global temperature is distorting cereal and date production. Similarly, the findings of Attiaoui and Boufateh (2019) have also reported a significant negative effect of changing patterns of rainfall on cereal production in Tunisia; whereas, increasing annual temperature has a positive effect in the long run. Similarly, Chandio et al. (2020) investigate the effect of global climate change and CO_2 emission on the agriculture sector of Pakistan from 1982 to 2014 by employing the Johansen cointegration and ARDL bound approach. The findings show that the rising temperature and changing rainfall pattern have a significant negative effect; whereas, increasing CO_2 reveals a significant negative effect on agriculture production. Whereas, Chandio et al. (2020) found a negative effect of CO_2 emission and temperature on cereal production in Turkey from 1968 to 2014, the review of these studies shows a mixed effect of climate-related changes on agriculture production, across the globe.

The empirical literature in Pakistan has extensively explored the dynamics of climate change (CO_2 emission) on the performance of the agriculture sector. Among early studies, the effect of climate change on food production in four provinces of Pakistan is investigated by Ahmed and Schmitz (2011) by employing panel econometrics. The estimated results have revealed that climatic changes have a significant negative effect of lower intensity on crop production. Similarly, Janjua et al. (2014) examined the effect of changing climate on wheat production in Pakistan from 1960 to 2019 by using the ARDL bound testing approach. The findings have revealed that climatic changes do not effects wheat production capacity in the long run. In more recent studies Ahsan et al.

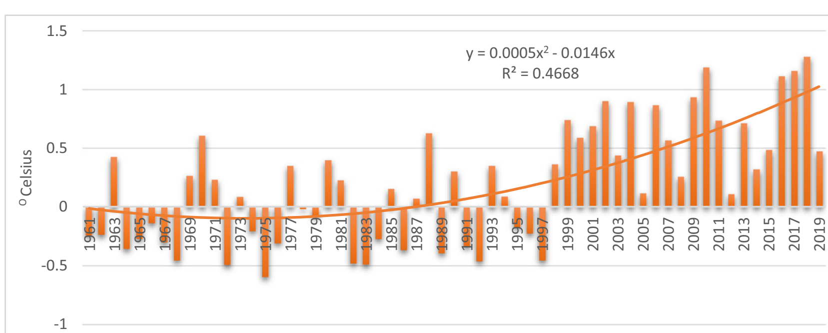

Fig. 3 Change in average annual temperature. Source: Author's construction. Data has been taken from the FAO Stat. (2020)

(2020) have explored the effect of CO_2, energy consumption, the area under cultivation, and labor force on cereal production in Pakistan from 1971 to 2014 by employing Johansen cointegration, ARDL bound testing approach, and Granger causality analysis. Estimated results show a significant positive effect of CO_2 emission on cereal production. Similarly, Chandio et al. (2019) examined the effect of carbon dioxide emission, average annual temperature, cultivated areas, and fertilizer inputs on rice production in Pakistan from 1968 to 2014. The findings revealed significant positive effect of CO_2 emission and increase in annual temperature on rice production. There is a strong positive correlation between CO_2 emission and average annual temperature change (IPCC 2012; World Bank 2013; Abbas 2020). Therefore, this model is suffering from strong multicollinearity bias. Later, Chandio et al. (2021) corrected by removal of temperature on their model to explore effect of CO_2 emission, financial development, and technological advancements (seed, fertilizers, etc.) on cereal production in Pakistan by using the ARDL bound testing approach for long-term relations from 1977 to 2014. The finding reveals a significant negative impact of CO_2 emission on the production of cereals in both the short run and long run; whereas, financial development and technical progress have a significant positive impact in both cases.

The increased level of GHGs emissions especially CO_2 is responsible for increasing average annual temperature along with extreme heat waves and heat strokes, (IPCC 2012; World Bank 2013). Many food crops are sensitive to increasing average temperature (Craufurd and Wheeler 2009; Long and Ort 2010; Luo 2011; FAO 2020). Abbas (2020) explored the effect of changing average annual temperature on cotton production in Pakistan from 1980 to 2018 by using the ADRL bound testing approach to cointegration analysis. Cotton is a vertical root crop that performs better in warmers conditions, but this study reveals an insignificant effect of temperature change on the production of cotton. In more recent studies, Jan et al. (2021) investigate the impacts of climate change on the yield of selected cereal crops such as wheat and maize in the northern climatic region of Khyber Pakhtunkhwa (KP) of Pakistan from 1986 to 2015 by using the second generation of panel cointegration analysis. The findings show that increasing precipitation has a significant positive impact on cereal production (wheat and maize); whereas, rising average temperature has an insignificant impact in the long run. The study urges for the increasing area under cultivation, development of irrigation system, and farmers' access to metrological information to lowering the drastic impacts.

The review of above-discussed literature reveals that the most of studies have focused on CO_2 emission as an indicator of climatic change and environmental degradation. There are a few studies on rising average annual temperature on some crop production and that are reporting mixed impact. Pakistan is producing a variety of crops, and there is a need for study that can explore the overall effect of changing average annual temperature along with other explanatory variables on production performance of major food and cash crops.

Methodological framework

This section explains the source and nature of data, model specification, and estimation techniques used to examine the short-run and long-run effect of increasing annual temperature along with other explanatory variables on the production of ten major crops such as wheat, rice, bajra, jowar, maize, barley, gram, sugar cane, mastered oil, and cotton.

Data description

The sample period of this study is from 2000 to 2019. The data are collected from various international and national open-data sources. The data of annual temperature change has been collected from FAO (2020); whereas, data of dependent variables and other explanatory variables are taken from the Govt. of Pakistan (2020). The descriptive statistics in Table 1 shows that the average annual temperature of Pakistan has increased by 0.691°C during the sample period with a maximum of 1.279 °C. The continuous increase in annual temperature during the sample period has the potential to distort the production of selected agricultural crops and distort food security conditions.

Model specification

The production of agricultural crops can be influenced by many variables besides annual temperature change such as the price of selected crops, water availability, the area under cultivation, price of substitute and complement goods, CO_2 concentration, quality of seeds, fertilizer input, credit availability, and improve quality seed. The unavailability of data from 2000 to 2019 has restricted the model to selected explanatory variables. Following Chandio et al. (2019) and Abbas (2020), the model constructed to examine the behavior of selected crop production is presented as follows:

$$\mathrm{LnCROPS}_{it} = \beta_i + \beta_1\mathrm{TEMP}_{it} + \beta_2\mathrm{LnAREA}_{it} + \beta_3\mathrm{LnFERT}_{it} + \beta_3\mathrm{LnSEEDS}_{it} + \mu_{it} \quad (1)$$

Equation 1 shows the panel regression model. The description of variables and their descriptive statistics are presented in

Table 1, while μ denotes white noise error term. The natural logarithm is used on all variables except annual temperature[1] change to normalize values and to address the potential heterogeneous problem that usually emerges in heterogeneous panel data. Crop production is highly vulnerable to climatic changes associated with a change in patterns of rainfall and an increase in annual temperature. The parameter β_1 is therefore expected to have a negative effect on the production performance of major crops. The area of under cultivation, fertilizer consumption, and improved quality seeds are agricultural inputs. The parameters (β_2, β_3, and β_4) are expected to have a significant positive effect on the production of selected major crops.

Estimation strategy

This section discusses the estimation strategy employed to explore the short-run and long-run effect of rising average annual temperature along with other explanatory variables on major ten crop production in Pakistan.

Panel unit root test

The selected panel variables are first subjected to a panel unit root analysis to explore the existence of unit root and order of integration. The order of integration is important for selecting an efficient cointegration technique to explore the existence of a long-run relationship between dependent and explanatory variables. This study employed both common root and individual root methods introduced by Levin et al (2002) and Im et al (2003). Levin, Lin, and Chu (LLC) unit root test assumes homogeneity of autoregressive unit-roots, whereas, Im, Pesaran, and Shin (IPS) unit root test propose heterogeneity of autoregressive coefficient dynamics. Traditional panel cointegration analysis requires all variables to integrate in the same order, that is $I(1)$; whereas, the ARDL approach to cointegration is applicable at varying order of integration from $I(0)$ to $I(1)$; whereas, not applicable at a higher order of integration, $I(2)$. The null hypothesis of these tests is the presence of unit root.

Panel PMG model

The result of unit root analysis of selected variables revealed varying order of integration, which implies that the traditional cointegration test can lead to potentially misleading inferences. Therefore, this study employs the panel pooled mean group technique proposed by Pesaran and Shin (1999). This technique is the panel version of the autoregressive distributed lag model of Pesaran et al. (2001) that has more superior explanatory power over alternatives. Besides exploring the existence of cointegration, this technique provides homogenous long-run estimates and captures dynamic short-term cross-sectional heterogeneities. The error correction term of the PMG model shows the existence of a cointegration relationship along with the adjustment mechanism of short-term disturbances.

The PMG model is sensitive to lag length selection. The optimum lag length is selected based on the minimum values of Schwarz Bayesian criteria. The unconstraint PMG version of the model in Eq. 1 is presented as follows:

$$\begin{aligned}\Delta \mathrm{LnCROPS}_{it} = {} & a_{0i} + \delta_1 \mathrm{LnCROPS}_{it-1} + \delta_2 \mathrm{TEMP}_{it-i} \\ & + \delta_3 \mathrm{LnAREA}_{it-1} + \delta_4 \mathrm{LnFERT}_{it-1} \\ & + \delta_5 \mathrm{LnSEED}_{it-1} \\ & + \sum_{k=1}^{n} \beta_1 \Delta \mathrm{LnCROPS}_{it-k} \\ & + \sum_{k=0}^{n} \beta_2 \mathrm{LnTEMP}_{it-k} \\ & + \sum_{k=0}^{n} \beta_3 \Delta \mathrm{LnAREA}_{it-k} \\ & + \sum_{k=0}^{n} \beta_4 \Delta \mathrm{LnFERT}_{it-k} \\ & + \sum_{k=0}^{n} \beta_5 \Delta \mathrm{LnSEED}_{it-k} + \mu_{\mathrm{it}} \qquad (2)\end{aligned}$$

where k shows optimally lag length selected based on the minimum value of Schwarz criterion. The significant and negative value of the error correction term reveals the existence of cointegration.

Sensitivity analysis

The sensitivity of long-run estimates of the PMG model is explored by estimating long-run coefficients using the fully modified ordinary least square (FMOLS) of Pedroni (2000) and dynamic ordinary least square (DOLS) regression techniques. These models address potential serial correlation and provide long-run estimates. If the sign and significance level of long-run estimates remains the same then the results will be considered robust; otherwise fragile.

Estimation results

This section discusses estimation results and establishes a short-run and long-run relationship between changing average annual temperature and major crop production in Pakistan.

[1] Average annual temperature data is not used as logarithm for two reasons. First, it remains the same for all cross-sections. Second, values are taken in terms of annual change in temperature.

Result of unit root analysis

The result of panel unit root analysis performed to explore stationarity dependence level and order of integration is reported in Table 2. The estimated result of the LLC and IPS unit root test reveals varying orders of integration. Crop production is stationary at a level with constant according to LLC unit root results, while PS unit root results show integrated at first order. Whereas, average annual temperature change fertilizers and improved quality seed input are stationary at a level according to both panel unit root test results. The panel unit root test results urge the use of panel cointegration proposed by Pesaran and Shin (1999) to explore dynamic short-run and the long-run relationship between the dependent variable and explanatory variables.

Result of PMG model

The estimated result in Table 3 reports cointegration along with the dynamic short-run and long-run estimates of selected explanatory variables on crop production in Pakistan that is investigated by using the panel pooled mean group (PMG) model.

The estimated long-run results of the PMG model revealed that the annual temperature change has a negative effect on major crop production in Pakistan at a 10% significance level. The finding revealed that by 1°C increase in annual temperature can distort crop production by 0.014%. The findings of the long-run effect of climate change are consistent with Chandio et al. (2019), Abbas (2020), and Chandio et al. (2021). It implies Pakistan to take increasing temperature and heat stress seriously and adopt policies to mitigate the emission of greenhouse gases and adopt climate-resilient agriculture for sustainable production of major crops.

The long-run effect of the area under cultivation revealed a significant positive effect of high intensity as a 1% increase in area under cultivation increases production of selected major crops by 1.14%. The area under cultivation depends on the availability of water for irrigation. The increasing temperature is depleting frozen water reservoirs. There is a need for many small and large dams to conserve water during peak summer and monsoon. Similarly, the estimated result of fertilizer intake revealed significant positive effects in the long run; whereas, the input of improved quality seed has an insignificant effect. One percent increase in fertilizer input can increase in the production of selected crops by 0.176%, whereas, the improved quality seeds revealed an insignificant impact on the productivity of selected crops in both the short run and long run, which implies that either the existing supply or quality of improved seeds is not sufficient to influence the overall production behavior of selected crops.

Moreover, the dynamic error correction term is negative and statistically significant at 1% level showing convergence of model with a modest speed of adjustment. The findings thus validate the existence of the established cointegration relationship among variable of the model.

Sensitivity analysis of long-run estimates

The result of sensitivity analysis of estimated long-run coefficients of panel PMG model performed by using fully modified ordinary least square (FMOLS) and dynamic ordinary least square (DOLS) is reported in Table 4.

The result of sensitivity analysis revealed that the sign and significance of long-run coefficients estimated using FMOLS and DOLS are consistent with the PMG model estimates. The findings thus validate the robustness of the PMG model.

Conclusion and implications

This study investigates the effect of increasing average annual temperature along with other explanatory variables on the production of ten major crops in Pakistan such as wheat, rice, bajra, jowar, maize, barley, gram, sugar cane, mastered oil, and cotton from 2000 to 2019. The panel data unit root tests,

Table 2 Result of panel unit root analysis

	Levin, Lin, and Chu (LLC) unit root test				Im, Pesaran, and Shin (IPS) unit root test			
	I(0)		*I*(1)		*I*(0)		*I*(1)	
	C	*C & T*	*C*	*C & T*	*C*	*C & T*	*C*	*C & T*
LnCROPS	−1.371*	0.239	−6.127*	−4.583*	0.396	−0.348	−7.159*	−5.890*
TEMP	−6.967*	−3.590*	−7.788*	−6.942*	−4.706*	−3.006*	−8.364*	−5.999*
LnAREA	−0.216	−2.560*	−6.965*	−6.153*	0.384	−0.596*	−7.152*	−5.799*
LnFERT	−2.135*	5.452	6.153	5.604	−2.491*	−0.754	−3.537*	−2.027**
LnSEED	−1.363***	−4.728*	−8.395*	−6.769*	−1.161	−2.073**	−6.860*	−4.815*

Source: Author's estimation. Note: * and ** show significance at the 1% and 5% level, respectively

Table 3 Result of panel PMG model. Dependent variable: ΔLnCROPS

Variable	Coefficient	*t*-statistic	Probability
Long-run equation			
TEMP	−0.014	−1.409	0.098
LnAREA	1.140	14.793	0.000
LnFERT	0.176	1.998	0.048
LnSEED	0.153	1.351	0.125
Short-run equation			
ECM_{t-1}	−0.521	−4.902	0.000
ΔTEMP	−0.001	−0.012	0.991
ΔLnAREA	0.891	2.663	0.009
ΔLnFERT	0.012	0.232	0.817
ΔLnSEED	−0.076	−1.370	0.173
Constant	−1.398	−3.538	0.001
Mean dependent variable	0.013	S.D. dependent variable	0.184
S.E. of regression	0.130	Akaike info criterion	−2.328
Sum squared residuals	2.314	Schwarz criterion	−1.272
Log likelihood	296.764	Hannan-Quinn criterion	−1.901

Source: Author's estimation

panel PMG model, panel FMOLS, and panel DOLS are employed to analyze the nature of long-run and short-run relationships. The estimated long-run results reveal that the increasing annual temperature has a significant negative effect on the production of major crop; whereas, the area under cultivation and fertilizer inputs revealed a significant positive effect of high intensity.

The major climate-related concern for the South Asian countries, especially India, Nepal, and Pakistan, is depleting the Himalayan glacier, which is a major source of freshwater for drinking, cooking, and irrigation. The deforestation around glaciers due to tourism or construction sector demand can enhance the pace of glaciers depletion; attempts should be taken to stop deforestation along with plantation of trees to restore nature around glaciers. Moreover, average annual temperature change has a significant negative effect on the production of major crops in the long run. It implies that besides depleting glaciers, the increasing average annual temperature is also distorting the production performance of selected crops. In this regard, the successful implementation of SDGs can provide a durable (long term) solutions to these and other issues. Pakistan has initiated various policies to enhance forestation to absorb greenhouse gases, such as "billion tree tsunami" initiative. It should facilitate the development or adoption of climate-resilient agriculture technology. The arid lands need proper water storage facilities to store maximum rainwater as the area under cultivation depends on it. Moreover, the development of physical

Table 4 Result of sensitivity analysis. *Dependent variable: LnCROPS*

Variable	FMOLS			DOLS		
	Coefficient	*t*-statistic	Prob.	Coefficient	*t*-statistic	Prob.
LnTEMP	−0.024	−1.591	0.084	−0.022	−1.457	0.093
LnAREA	1.462	13.403	0.000	1.374	12.525	0.000
LnFERT	0.421	1.999	0.047	0.399	1.911	0.058
LnSEED	0.039	0.530	0.597	0.021	0.272	0.786
Adjusted *R*-squared		0.995			0.995	
S.E. of regression		0.157			0.156	
Long-run variance		0.035			0.039	
S.D. dependent variable		2.161			2.152	

Source: Author's estimation

and financial infrastructure can be beneficial for rural areas and agriculture sector development.

This study urges future research to observe the effect of increasing average annual temperature on frozen water reservoirs at Karakorum and Himalayan ranges as the livelihood of South Asian nations is dependent on it. Second, future research is recommended to figure out the reasons for the insignificant effect of improved quality seeds on the production of major crops in Pakistan.

Abbreviations *FMOLS,* Fully modified ordinary least square; *DOLS,* Dynamic ordinary least square; CO_2, Carbon dioxide; *GHGs,* Greenhouse gases; *IPCC,* Intergovernmental Panel on Climate Change; *PMG,* Pooled mean group; *FAO,* Food and Agriculture Organization of the United Nations; *GDP,* Gross domestic product; *ARDL,* Autoregressive distributed lag model; *LLC,* Levin, Lin, and Chu; *IPS,* Im, Pesaran, and Shin

Author contribution The solo contribution of corresponding author.

Data availability The data of this study is taken from open sources of data, which can be provided on request.

Declarations

Ethical approval Not applicable

Consent to participate Not applicable

Consent to publish The author has given final approval of this version to be published.

Conflict of interest The author declares no competing interests.

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