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Impact of Climate Change on Citrus Production in Pakistan: Challenges, Economic Implications and Adaptation Strategies

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ABSTRACT

The production of citrus fruits is one of the key elements of the agricultural economy of Pakistan, playing an important role in economic growth, job creation, and foreign exchange income. Pakistan is considered one of the largest citrus producers in the world, and kinnow mandarin is one of the main citrus fruits that it exports. But the adverse impact of climate change on citrus plantations in key areas of their cultivation has become more evident. Higher temperatures, precipitation fluctuations, lack of water supply, smog pollution, and increased cases of pests have had a negative impact on citrus crop yield, quality, and marketability. The current research focuses on the influence of climate change on the productivity of citrus fruits through analysis of primary data collected from 150 citrus producers in Punjab, Pakistan. A questionnaire survey was used for assessment of the respondents' views about the effect of climate change, their coping strategies, and yield. It has been found that the increase in temperature, changes in rainfall pattern, and scarcity of irrigation water reduce the productivity of citrus farming along with the quality of the fruits. From the regression analysis results, it is found that temperature variability negatively impacts the yield the most ($\beta = -0.41$; $p < 0.01$); the second one is water scarcity ($\beta = -0.36$; $p < 0.01$); the third one is changes in rainfall pattern ($\beta = -0.29$; $p < 0.05$), and the use of climate smart practices – proper irrigation schedule, mulching and pest management – positively affect the productivity ($\beta = 0.44$; $p < 0.01$). The proposed model explains about 61.9% of the variance in productivity of citrus, which shows the important role of climate change in this regard. All the four hypotheses have been validated. It has been concluded from the study that building adaptive capacity of the farmers, using climate resilient technologies and efficient water management policies will be needed to sustain the citrus industry of Pakistan in future.

Introduction

It is pertinent to mention that the role of agriculture in Pakistan's economy still remains pivotal in terms of its contribution to GDP and employment of labour in the sector. Among agricultural crops, horticultural crops have attracted much attention in view

of relatively high economic gains from these crops, and citrus fruits in particular kinnow mandarin has been identified as one of the most significant export crops in the country. Punjab province is responsible for nearly 95% of the total production of citrus in Pakistan and the districts of Sargodha and Bhalwal, along with adjoining areas, enjoy the advantages of suitable agro-climatic conditions, which include mild winters and enough sunshine for fruit development.

It is unfortunate to state that these agro-climatic conditions are getting disrupted due to climate change, which is considered as one of the most crucial threats for the agriculture of developing countries. In fact, the climate changes are posing serious threat to the agriculture in Pakistan as it is one of the most susceptible countries in the world to the changing environment. Rising temperature, changes in precipitation patterns and occurrence of extreme weather conditions are making agriculture quite difficult for farmers in Pakistan.

There is national-level evidence to show that climate variables significantly influence the yields of Pakistan's major food crops (Ali, Liu, Ishaq, Shah, Ilyas, & Ud Din, 2017). There are projections that due to climate change, the water availability required for irrigation agriculture in Pakistan will decline because of changing patterns of glacial melt and precipitation (Baocheng, Jamil, Bellaoulah, Mukhtar, & Clauvis, 2024). In light of the fact that citrus is an economically valuable, perennial and water intensive crop that thrives in semi-arid belts, there is reason to believe that the aforementioned national level pressures may manifest themselves in a particularly significant way for kinnow farmers, but little evidence exists at the farm-level to support such a conjecture.

Despite the magnitude of the issue, there are no empirical, farm-level studies to quantify the impacts of climatic variables in terms of lower productivity in Pakistan's citrus belt, while few research works incorporate climatic variables, production outcomes and adaptation behavior in the same framework. This paper tries to fill this gap through empirical analysis of primary survey data of 150 citrus farmers in Punjab and estimates the impact of climatic stressors (temperature, rainfall variability, water availability and pest occurrence) on productivity.

Literature Review

Climate change has altered the way agriculture is done across the globe, and there are specific crops that depend on the climate, like citrus crops, which have been particularly affected due to changes in temperatures and rains (IPCC, 2023).

International studies prove that citrus production is very temperature-sensitive, as floral induction happens during low temperature and drought stress, while high temperatures affect flowering physiology, fruit-set, carbohydrates formation, and respiration (Agusti, Reig, Martinez-Fuentes, & Mesejo, 2022) in the regions where citrus production takes place in South Asia as winters have become shorter and the chilling period remains unfulfilled (Nawaz, Abbasi, Hafiz, Khalid, Ahmad, & Aftab, 2019).

In the case of Pakistan, for instance, on-site analyses of kinnow orchards in Punjab (in the cities of Sargodha, Toba Tek Singh, and Vehari) indicate that variations in moisture and temperature lead to poorer quality of the fruits and poor fruit-bearing capacity, with warmer regions witnessing higher incidence of premature dropping of fruits and biennial bearing of fruits compared to the cooler production areas (Nawaz et al., 2019). Supporting this evidence from orchard level is the district level analysis of Citrus reticulata Blanco production in tehseil Bhalwal of Sargodha, which constitutes the heartland of Pakistan's kinnow belt and has seen changes in fruit production and its spatial variation owing to climate change.

Apart from the temperature variations, fluctuations in rainfall levels constitute an additional vulnerability factor as irregular rainfall with dry phases and rainy phases with heavy rains has become a common phenomenon in the agricultural areas of Pakistan, which adversely impacts the trees due to their requirement for consistent moisture during their life cycle.

Another associated limiting factor is that of water stress, especially in the production zones of Pakistan that are semi-arid. Pakistan has already been identified as one of the most water-stressed nations around the world, and as temperatures rise, evapotranspiration will further reduce water availability and raise costs of irrigation for production (Baocheng, Jamil, Bellaoulah, Mukhtar, & Clauvis, 2024). Since water irrigation through canals and wells plays a key role in the production of citrus fruits in Pakistan, any variations in water supply will inevitably influence productivity.

The impacts of climate change also include the changing dynamics of pests and diseases in citrus orchards. Increased warmth and humidity result in faster pest reproduction cycles and increase the presence of diseases like cancer and the Huanglongbing (citrus greening), whose impact has been strongly linked to temperature, rainfall, and humidity in orchards in Pakistan (Sajid, 2026), as well as fruit fly infection.

In addition, there is the problem of air pollution and smog during seasons in Punjab. Reduction in photosynthesis caused by low levels of solar radiation due to the smog causes a decline in color, sugar content, and uniform ripening of the fruit. These aspects play an important role for the commercial value of both local market products and export products (Goheer, Hassan, Sheikh, Malik, Uzair, & Satti, 2025).

As a result of these stressors, the effect is not only economic but also agronomic – reduced productivity and quality cause income loss for farmers and for exports and, therefore, the competitiveness of citrus export is extremely dependent on pricing, quality and trade relations between countries (Hayat, Naeem, Mustafa, Alhafi Alotaibi, Traore, & Anwar, 2024). This leads to declining profitability and growing tendency to grow other crops instead of citrus. In terms of sustainability, this tendency is highly negative.

Another weakness is varietal structure of the crop. The citrus production in Pakistan is still largely based on kinnow varieties which have poor heat and drought resistance. Moreover, there is a lack of breeding efforts to develop climate-resilient rootstocks and cultivars.

However, there are some approaches to climate-resilient agriculture that could help to This trend is backed up by additional evidence from Pakistan, whereby adopting more climate adaptation practices positively results in higher food security and reduced poverty levels for the adopters compared to non-adopters (Ali & Erenstein, 2017); collective actions from smallholder communities improve local adaptive capacity in Punjab (Jabbar et al., 2023); climate-stress perceptions in rain-fed farming communities in Punjab lead them to alter their cropping calendars and use of inputs (Bakhsh & Kamran, 2019); and the awareness of the climate change problem among the farmers themselves is a predictor of adaptation (Mustafa & Alotaibi, 2024). A systematic review of 62 Pakistani studies indicates that changes in cropping practice, farm management and diversification form the main adaptation approaches throughout Pakistan depending on the availability of information, credit, and extension support (Saddique et al., 2022).

Nevertheless, the current literature review reveals that the previous work on the topic mostly analyses either the physical impacts of climate change on the quality of citrus or socio-economic aspects of adaptations but does not focus on the interrelationship of climate change, production impact, and adaptations in one farm-level study model, especially for the citrus region of Punjab. The present research paper attempts to fill the gap in literature through an empirical study of primary survey data using the multiple regression approach.

The following Table 1 presents a summary of the literature review discussed above and illustrates the context of the present farm-level regression analysis.

Table 1. Summary of Key Reviewed Studies

C	Scope / Location	Method	Key Finding
Nawaz et al. (2019)	Sargodha, Toba Tek Singh, Vehari (Punjab)	Field-based orchard assessment	Warmer districts show greater premature fruit drop and more pronounced biennial bearing.
Bashir & Mobeen (2018)	Tehsil Bhalwal, Sargodha	Meteorological production trend comparison (2009–2015)	Long-term temperature and rainfall trends are linked to shifts in citrus production and its spatial pattern.
Agusti et al. (2022)	Global (review)	Literature review	Elevated temperature disrupts flowering, fruit-set, and carbohydrate accumulation in citrus.
Baocheng et al. (2024)	Pakistan (national)	Secondary/hydrological data analysis	Water availability for irrigated agriculture is projected to tighten under climate change.
Goheer et al. (2025)	North-eastern Punjab districts	Geospatial analysis of smog trends	Seasonal smog reduces solar radiation, affecting fruit colour and ripening uniformity.
Sajid (2026)	Pakistan (citrus orchards)	Field monitoring	Huanglongbing severity correlates with temperature, rainfall, and humidity.
Hayat et al. (2024)	Pakistan (citrus exports)	Two-way fixed-effect panel model	Export competitiveness is highly sensitive to price, quality, and trade-relationship factors.
Ali & Erenstein (2017)	Pakistan (multi-province, n = 950)	Probit / CLAD / PSM	Adaptation-adopting farmers show higher food security and lower poverty.
Bakhsh & Kamran	Rain-fed Punjab	Cross-sectional survey	Farmers adjust cropping calendars and input

(2019)	Jabbar et al.	Punjab (smallholders)	Cross-sectional survey	use in response to perceived climate stress.
(2023)	Mustafa & Alotaibi	Pakistan (farm households)	Survey / structural analysis	Collective action among smallholder groups strengthens local adaptive capacity.
(2024)	Saddique et al.	Pakistan (62-study systematic review)	PRISMA systematic review	Farmers' climate-change knowledge significantly predicts adaptation uptake.
(2022)	Khan et al.	Pakistan (cash-crop growers)	Survey / regression	Changing cropping practices and farm-management adjustments are the dominant national adaptation responses.
(2022)	Khan et al.	Pakistan (cash-crop growers)	Survey / regression	Awareness and information access are key determinants of adaptation adoption; non-adopters show lower productivity.
This study (2026)	Sargodha and major citrus districts, Punjab (n = 150)	Survey + multiple regression	Temperature rise is the strongest negative predictor of citrus productivity; adaptation practices significantly offset climatic stress.	

Note: Table compiled from the studies cited in Section 2 (Literature Review).

Methodology

Research design

The research utilized a quantitative, cross-sectional survey research design to explore the impact of climate change on the productivity of citrus in Pakistan. Farmers involved in citrus production in Pakistan filled out a standardized questionnaire containing information related to climate, productivity, and adaptation.

Study Area

This research was conducted in the important citrus producing districts of Punjab, particularly in Sargodha district, which is known to be the hub of citrus production in the country. Being a semi-arid region with hot summers and unpredictable rainfall, the growth of citrus in this region is very much exposed to the changing climate.

Sampling Procedure

Multistage sampling techniques were applied: (1) purposive sampling for selecting the important citrus growing region; (2) selection of tehsils and villages from the selected region; (3) random selection of farmers growing citrus, and (4) simple random sampling of 150 citrus growers.

Approach to Data Collection

Primary data were collected using interviews with pre-tested structured questionnaires in 2025 during the crop production season. The questions were divided into four categories: (i) farmers' socioeconomic attributes; (ii) perceptions regarding climate change; (iii) citrus production and yield; and (iv) coping strategies and management practices. Secondary climatic data was gathered from the Pakistan Meteorological Department.

Measurement of Variables

Dependent	Citrus Yield	Tons per acre
Dependent	Fruit Quality	Farmer perception scale (1–5)
Independent	Temperature Change	Perceived increase (Likert scale)
Independent	Rainfall Variability	Irregular rainfall index
Independent	Water Scarcity	Irrigation shortage score
Mediating	Pest Incidence	Frequency of pest attacks
Moderating	Adaptation Practices	Adaptation index

The empirical relationship is estimated using multiple linear regression:

$$Cp_i = \beta_0 + \beta_1 TEMP_i + \beta_2 RAIN_i + \beta_3 WATER_i + \beta_4 PEST_i + \beta_5 ADAPT_i + \epsilon_i$$

where CP = citrus productivity; TEMP = temperature change; RAIN = rainfall variability; WATER = water scarcity; PEST = pest incidence; ADAPT = adaptation practices; and ε = the stochastic error term.

Results

Descriptive Statistics

Table 1. Descriptive Statistics of Key Variables

Variable	Mean	Std. Deviation	Minimum	Maximum
Citrus Yield (tons/acre)	4.12	0.76	2	5
Temperature Increase Perception	3.95	0.81	2	5
Rainfall Variability	4.08	0.73	2	5
Pest & Disease Incidence	3.88	0.85	1	5
Adaptation Practices Score	3.67	0.92	1	5

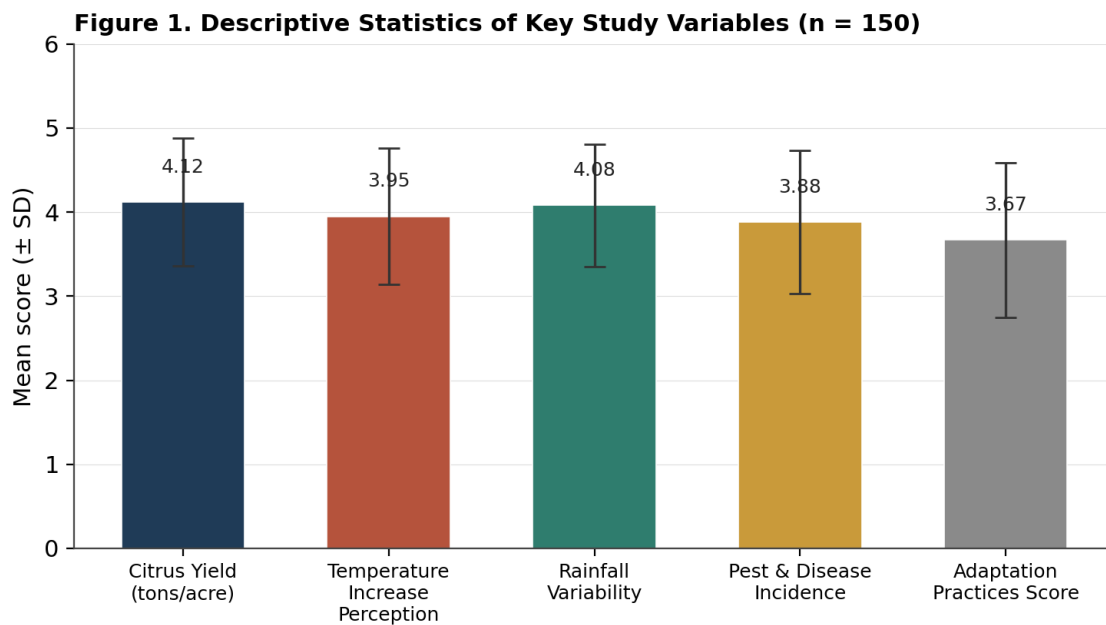


Figure 1. Mean scores ($\pm$ SD) for citrus yield, climatic-stressor perceptions, pest/disease incidence, and adaptation-practice adoption among sampled growers (n = 150).

Reliability Analysis

Table 2. Reliability Analysis (Cronbach's Alpha)

Construct	Number of Items	Cronbach's Alpha
Climate Change Perception	6	0.83
Adaptation Practices	5	0.81
Production Constraints	4	0.79
Overall Scale Reliability	15	0.84

Note: Alpha > 0.70 indicates acceptable to strong internal consistency.

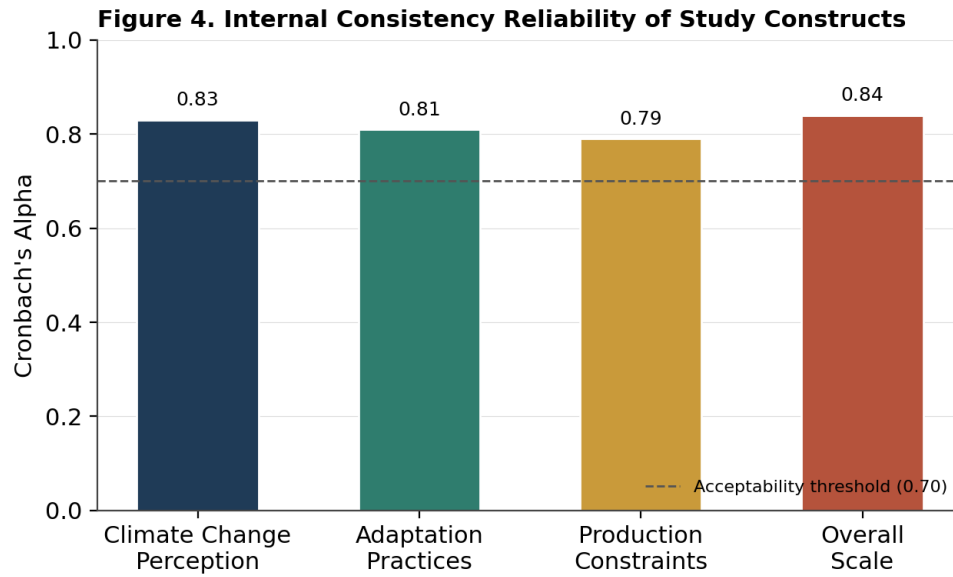


Figure 4. Internal consistency (Cronbach's alpha) of the climate-perception, adaptation, and production-constraint constructs, relative to the conventional 0.70 acceptability threshold.

Correlation Analysis

Table 3. Correlation Matrix

Variables	Yield	Temperature	Rainfall	Water Scarcity	Adaptation
Citrus Yield	1				
Temperature	-0.55**	1			
Rainfall Variability	-0.47**	0.52**	1		
Water Scarcity	-0.51**	0.48**	0.44**	1	
Adaptation Practices	0.49**	-0.21*	-0.19*	-0.26**	1

** $p < 0.01$, * $p < 0.05$

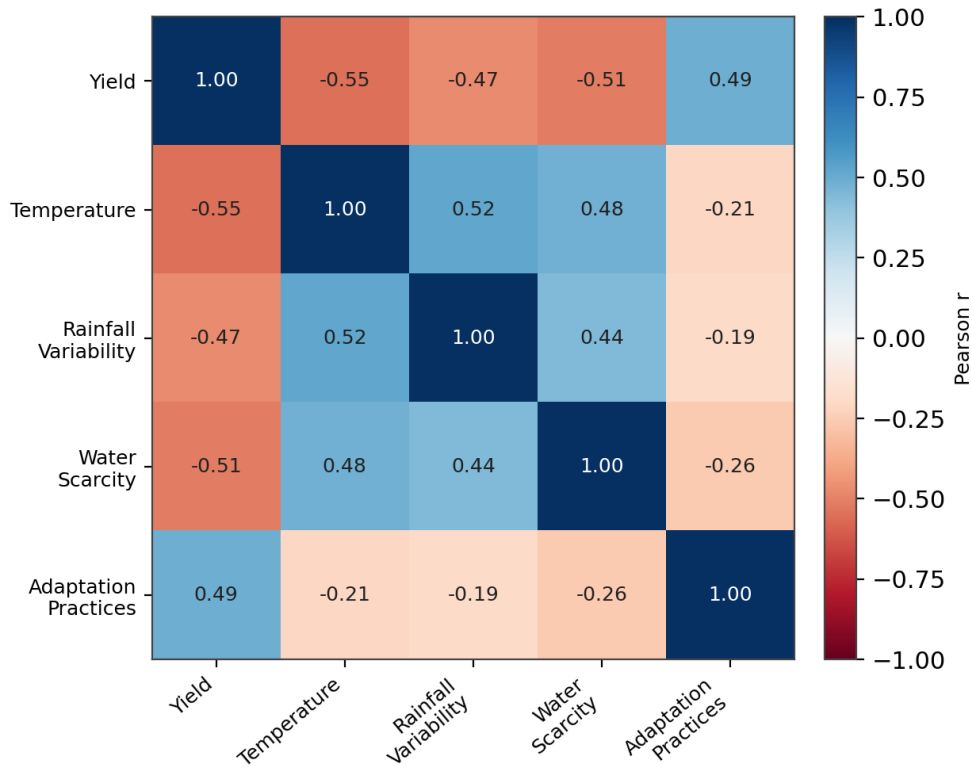
Figure 2. Correlation Matrix Heat Map of Study Variables

Figure 2. Correlation matrix heat map of citrus yield, climatic stressors, and adaptation practices. Darker red indicates a stronger negative correlation; darker blue indicates a stronger positive correlation.

Regression Results

Table 4. Model Summary (Multiple Regression)

Model	R	R ²	Adjusted R ²	Std. Error of Estimate
1	0.787	0.619	0.608	1.32

Note: Climate and adaptation variables jointly explain 61.9% of the variance in citrus productivity.

Table 5. ANOVA Results

Source	Sum of Squares	df	Mean Square	F	Sig.
Regression	412.55	4	103.14	58.71	0.000
Residual	253.81	145	1.75		
Total	666.36	149			

Note: The overall model is statistically significant ($p < 0.001$).

Table 6. Regression Coefficients

Variable	B	Std. Error	Beta (β)	t-value	Sig.
Constant	12.41	0.88	–	14.09	0.000
Temperature Increase	-0.72	0.22	-0.41	-3.25	0.001
Rainfall Variability	-0.53	0.19	-0.29	-2.71	0.007
Water Scarcity	-0.61	0.20	-0.36	-3.02	0.003
Adaptation Practices	0.78	0.19	0.44	4.11	0.000

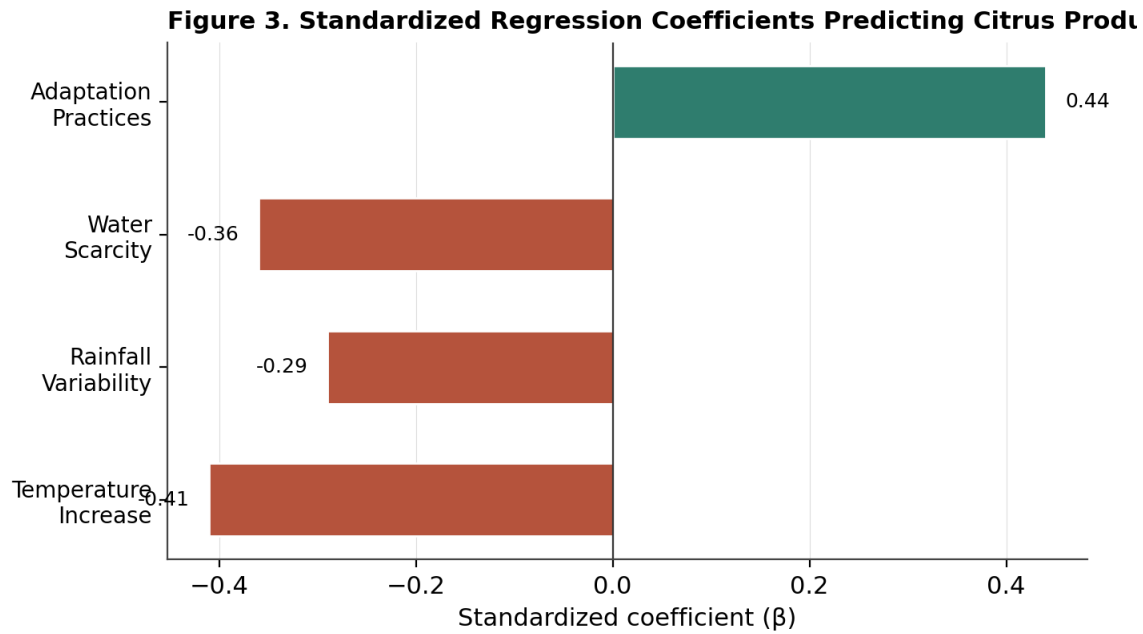


Figure 3. Standardized regression coefficients (β) for predictors of citrus productivity. Bars extending left indicate a negative association with yield; the bar extending right (Adaptation Practices) indicates a positive association.

Hypothesis Testing

Hypothesis	Statement	Result	Interpretation
H1	Climate change (temperature rise) significantly affects citrus production.	Supported (p < 0.01)	Temperature rise exerts the strongest negative influence on yield among the climatic predictors tested.
H2	Rainfall variability negatively affects citrus productivity.	Supported (p < 0.05)	Irregular rainfall disrupts flowering and fruit-set stages.
H3	Water scarcity reduces citrus production.	Supported (p < 0.01)	Irrigation shortages significantly lower orchard productivity.
H4	Adoption of climate-smart adaptation practices improves citrus yield.	Supported (p < 0.01)	Adoption of improved practices partially offsets climatic stress.

Taken together, the regression and hypothesis-testing results confirm that climatic stressors — temperature rise in particular — are the dominant drivers of declining citrus productivity in the sampled districts, while adaptation practices provide a statistically significant, though only partial, offsetting effect.

Discussion

The quantitative results are in line with the explanations that are provided qualitatively by farmers. This chapter will provide interpretations for the regression results in relation to the climate, biological, and market factors discussed by the participants and described in the regional literature.

Climate Change Trends in the Study Area

Climate change trends have been observed in the region in recent years, where there has been a rise in temperatures, shorter winters, unpredictable rainfall, dry spells, and an increased occurrence of heat waves. Since citrus plants depend on cool weather during the flowering phase, warm winters interrupt this process. Increasing temperature leads to increased rates of evapotranspiration in an already arid area.

Effect of Temperature Increase on Stress

The citrus trees need sufficient periods of cold weather for proper flowering to take place; however, warm weather affects this stage of development and causes uneven flowering, leading to uneven fruiting. High temperature during spring increases the rate of metabolism and reduces the period of fruit development resulting in low-quality fruits with less juice. High temperatures during summer cause sunburn and blemished peels, affecting the market value of the fruit. The heat stress has negative impacts on the process of photosynthesis and respiration causing the reduction in carbohydrate production and thus weakens the tree and decreases its yield potential. This has been demonstrated at the level of orchards in the citrus belt of Punjab (Nawaz et al., 2019). Even though the growers practiced traditional methods in the orchards, they still faced low yields due to climatic stress.

Rainfall Variability and Water Scarcity

Access to water is a basic requirement in the production of citrus, and climatic change has affected both the frequency and amount of rainfall, leading to an unpredictable rainfall pattern characterized by long periods of drought followed by heavy rains. In addition, the depletion of underground water sources has resulted in citrus production being very reliant on irrigation in order to produce fruit. Heavy rains and flooding may damage the root system and lead to anaerobic soil conditions, while erratic rainfall leads to soil erosion and high salinity in irrigated lands in Punjab – this has reduced the effectiveness of flood irrigation.

Pests and Diseases

Climatic changes have also been affecting pest pressures and the incidence of diseases in citrus groves. Increased temperature and humidity levels result in favorable conditions for increased pest reproductive cycles, while diseases such as citrus canker and Huanglongbing have reportedly increased in occurrence. Fruit flies, which are known to increase in population at warm weather conditions, pose a challenge in citrus production and have led to increased use of chemicals for control – this affects not only the cost of production but also meets the food safety requirements.

Effects of Pests and Diseases

Moreover, changes in weather affect pests and diseases in citrus plantations as higher temperature and humidity facilitate pest reproduction. Diseases, such as citrus canker and Huanglongbing (also known as citrus greening), have been identified as increasing problems in the citrus industry. In addition, higher temperatures speed up the fruit fly's breeding cycle, which requires increased use of chemical pesticides to protect fruits from damage. Pest pressure, thus, becomes an essential mediation channel for climatic stress influencing crop yield and its quality.

Smog and Environmental Pollution

The problem of air quality can be considered another region-specific stressor for citrus plantations in the Punjab region as smog limits the solar radiation used in photosynthesis process. The result is that fruit skin gets darker and there is uneven ripening along with lower level of sugar content (Goheer et al., 2025). Given that fruit appearance determines its marketability in export markets, smog-induced quality problems have immediate commercial consequences for exporters.

Decline, Reduced Product Quality and Post-Harvest Losses

Increased fluctuations in temperature levels and water scarcity were found to affect fruit size, lower juice concentration and lead to peeling problems, thus resulting in shorter fruit shelf life. Furthermore, greater variations in temperature levels during fruit storage and harvesting have been linked to higher rates of post-harvest spoilage, thereby decreasing the share of harvested produce meeting export quality standards and ultimately impacting growers' income levels.

Economic Impact on Farmers and National Exports

Economic impacts of the observed negative effects on productivity and product quality are not limited to the farms themselves but may extend further. With declining yields and growing production costs due to the increase in the cost of such inputs as irrigation and pest control, as well as rejection of exportable products due to the lack of quality, income levels of growers may decrease, with lower export sales impacting foreign currency earnings and Pakistan's competitiveness in the international citrus market, in which case price, quality and relations impact the export performance (Hayat et al., 2024). Indeed, in line with the findings obtained through descriptive analysis, profitability decline leads farmers to switch from citrus cultivation to other crops.

Vulnerabilities Related to Varieties and Technological Deficit

Pakistan's citrus production largely depends on conventional kinnow varieties which are susceptible to heat, drought, and diseases and, due to lack of domestic investments in citrus breeding, Pakistan suffers from the scarcity of more resilient rootstocks and cultivars. Such variety limitations contribute to the exposure caused by climatic stressors and create a structural barrier that cannot be overcome by adaptation alone.

Farm-level Adaptation Strategies to Increase Resilience to Climatic Stressors in Citrus Production

The large, positive value of adaptation practices ($\beta = 0.44$, $p < 0.01$) shows that climate-resilient adaptations are effective tools to reduce climatic stress in agriculture, even if they do not solve it completely, in agreement with findings about other Pakistani cash crops where adaptation-adopting farms have significantly higher productivity compared to those that do not adopt any (Khan et al., 2022). The key practices highlighted by this research and confirmed by the literature on climate-smart agriculture (FAO, 2022; Abebaw, 2025) include: drip and precision irrigation to reduce water waste; mulching and canopy management to mitigate moisture stress and cool microclimate temperatures; IPM using biological and cultural pest control methods; soil health management; weather forecasting services; and development.

Table 7. Climate-Smart Adaptation Practices, Mechanisms, and Supporting Evidence

Practice	Primary Climatic Stressor Addressed	Mechanism	Supporting Evidence
Drip / precision irrigation	Water scarcity, rainfall variability	Improves water-use efficiency; reduces dependence on erratic rainfall	FAO (2022); Baocheng et al. (2024)
Mulching & canopy management	Temperature rise, water scarcity	Moderates root-zone microclimate; reduces evapotranspiration losses	FAO (2022); this study ($\beta = 0.44$, $p < 0.01$, composite adaptation index)
Integrated pest management (IPM)	Pest & disease incidence	Reduces chemical reliance; targets climate-driven pest cycles	FAO (2022); Sajid (2026)
Localised weather-forecasting access	Temperature rise, rainfall variability	Enables timely operational decisions (irrigation, spraying, harvest)	Mustafa & Alotaibi (2024); Saddique et al. (2022)
Collective/group-based adaptation	General adaptive capacity	Pools resources and knowledge among smallholders	Jabbar et al. (2023)
Heat-/drought-tolerant rootstocks and cultivars	Temperature rise, water scarcity	Reduces varietal vulnerability to climatic stress	This study (Section 5.8); industry commentary on kinnow varietal ageing

Policy Recommendations

- Increase public spending on research and development in horticulture, especially breeding programs for heat-resistant and drought-resistant varieties of citrus fruits.
- Provide subsidies and credit facilities to adopt modern irrigation systems such as drip irrigation and micro-irrigation systems.
- Improve agricultural extension services for farmers' knowledge about adaptation measures.
- Conduct investment for setting up cold chain and cold storage facilities to minimize losses after harvest and keep the export-grade standard.
- Provide weather-based crop insurance facilities for safeguarding farmers from any risks of climate change impacts on crops and income.

- Curb the problem of poor air quality due to crop residue burning, which is causing smog to spoil the quality of fruits grown in citrus areas.
- Establish collaboration between different stakeholders including government, research organizations, exporters, and farmer organizations.

Conclusion

There are significant impacts of climate change on the citrus industry of Pakistan, which make it a serious threat for the future. Increased temperatures, rainfalls, water shortages, increased pest pressure, and seasonally occurring smog pollution are all affecting the quantity of produce, its quality, and the competitiveness of the sector, where increasing temperature seems to be a dominant factor causing reduced productivity. The conventional way of cultivating citrus crops in Pakistan has failed to keep up with the changes in the climatic situation, but there is a clear, positive correlation between adaptation activities and productivity levels, showing that adaptation is possible. Increasing farmers' adaptability, developing and adopting climate-resilient varieties and technologies, and improving the water management and air pollution policies are crucial for the sustainable development of the citrus sector in Pakistan.

Limitations and Further Research Directions

There are some limitations of the present study that must be kept in mind while interpreting the results of this research. First of all, since this research study is designed using a cross-section framework and only covers a single season (2025), it does not help draw causal and long-term relationships between climate and productivity issues. Second, climate-related variables (i.e. temperature, rainfall, and water scarcity) have been measured through farmer perceptions and not meteorological instrumentation, which can give rise to possible biases in perception or recall. The future research needs to validate such perceptions with climatic records from meteorological stations or satellites. Third, the sample size of 150 growers used in this research study is enough to run the regression analysis but is geographically concentrated in the main citrus belt of Punjab.

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