



# An assessment of changes and variability of climate impact on cotton production yield over Southern Punjab, Pakistan

Iqra Shahzadi<sup>1,2</sup> · Nausheen Mazhar<sup>1</sup>  · Sohail Abbas<sup>1,2</sup>

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## Abstract

As the country's primary cash crop and the source of cattle feed, fiber, and oil, cotton is regarded as Pakistan's economic backbone, contributing 0.8% of the national gross domestic product (GDP) and 4.1% of the agricultural value-added amount. South Punjab, Pakistan has remained a significant cotton belt of the country, however, in recent years, the region has witnessed a significant decline in annual cotton production. Cotton production in this region is threatened by several issues-including a decline in area under cultivation, increasing temperature and decreasing rainfall patterns, whitefly and other pest attacks due to changing climate. The objective of this study is to explore the possible impact of climatic variables on the decrease of cotton production in South Punjab, Pakistan over the years 2004 through 2020. Pearson correlation coefficients were used to analyze the correlation between climatic factors and cotton crop yield in the study area. The analysis indicated a weak positive effect of rainfall on cotton production during the flowering and picking stages in the Jhang district, as well as during the vegetative stage in the Vehari and Pakpattan districts. During the picking stage and germination stage in Rahim Yar Khan, minimum temperature has a significantly weak negative effect on cotton production respectively. This study aims to provide a framework for policy, incorporating certain valuable cotton varieties, suitable for the climate of the study area, that will help increase the country's GDP by increasing cotton crop production in this region.

**Keywords** Climate change · Cotton · Variability · Kharif crop · Growth stages

## 1 Introduction

According to global statistics, 232 countries produced cotton in the entire world during the year 2021 (Adam & Hameed, 2022). With the cultivation of 34.5 million hectares, cotton lint production increased from about 22.5 million tonnes (Mt) in 2019 (Voora et al., 2023). The top ten countries that produce cotton in the world are India, China, the United States, Pakistan, Brazil, Australia, Uzbekistan, Turkey, Turkmenistan,

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✉ Nausheen Mazhar  
nausheen.mazhar@lcwu.edu.pk

<sup>1</sup> Department of Geography, Lahore College for Women University, Lahore, Pakistan

<sup>2</sup> Department of Geography, Climate Research Institute (CRI), Konkuk University, Seoul, Korea

and Burkina Faso. According to a survey, global cotton purchases totaled US\$49.9 billion in the 2017–2018 period, and thus cotton is one of the most important crops (Ahmad & Hasanuzzaman, 2020). It is known as “white gold” in some countries because it generates the bulk of revenue (Ahmad & Hasanuzzaman, 2020). It is the world’s most common natural fiber, supporting one of the world’s largest textile industries with an annual economic effect of at least \$600 billion (Ahmad & Hasanuzzaman, 2020). More than 30% of the 8.8 million tonnes of raw cotton produced globally in 2017 or USD 13.5 billion was exported (Voora et al., 2020).

Cotton growth and yield are facing fluctuations and decline at a global level as a result of changing climatic conditions. The temperature rises, droughts, salinity, and greenhouse gas emissions worsen the situation for cotton production. By the end of the twenty-first century, atmospheric greenhouse gas concentrations of carbon dioxide might rise from their present levels of 380 parts per million to 500–970 parts per million resulting in a 1 to 5.5 °C global temperature increase (Hebbar et al., 2013). This increase in global temperature indirectly is leading to a shift in the sowing time and the boll opening time of cotton crops. Furthermore, several studies have shown that GHG-induced global warming can affect pest metabolism, increasing the pest population (Ahmad & Hasanuzzaman, 2020; Karl et al., 2009). Cotton production declines in South East Asian and African countries, that are warmer due to threats related to heat stress. Due to rising carbon dioxide, climate change may significantly reduce cotton production in Argentina, Bolivia, Egypt, Iraq, and Syria. In India, the effects of climate change will reduce cotton production in the north. Central and southern India has no change in production.

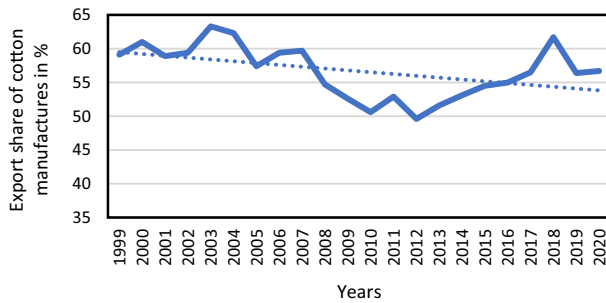
In Pakistan cotton was planted on 2527 thousand hectares in 2019–20, however, an increase of 6.5% over the previous year’s area (2,373 thousand hectares) was witnessed (GoP, 2020). Pakistan ranks fourth after China, India, and the USA, in global cotton production (Chaudhry et al., 2009). Punjab and Sindh provinces are the main cultivators of cotton in the country (Anwar et al., 2009). Pakistan’s agricultural sector is the most important element of the country’s economy and accounts for nearly 23.4% of the country’s GDP (Usman, 2016). According to GoP (2020), Cotton (*Gossypium hirsutum L.*) is one of the most significant cash crops in Pakistan and is recognized as the country’s economic backbone. Cotton provides raw material to the domestic cotton sector, which includes 430 textile mills, 1050 ginning units, and 350 oil expelling units, which provide 84% of the total oilseed, that is produced in Pakistan (USDA, 2020). The value of Pakistan’s cotton crop exports to the rest of the world increased from 2003 to 2008 then began to decline until 2018 when the overall value of Pakistan’s cotton exports was US\$3498.997 million (GoP, 2018; Khalid et al., 2021).

Pakistan has always been a great exporter of raw cotton and cotton-manufactured goods. Over the years the production of cotton-manufactured goods has been going through various ups and downs, as is visible in Fig. 1.

Data source: Economic Survey Report, 2019.

In the years 2001, 2005, 2009, 2012, and 2019 the production declined substantially which led to the decline of the share of this sector in the GDP but in 2000, 2003, 2007, 2011, and 2018, we witnessed a slight increase with 61, 63.3, 59.7, 52.9 and 61.7% share. The trendline is showing a slightly decreasing trend in 2019 and onward. Since the climatic conditions in south Punjab are ideal for the growth of the cotton crop, the government must focus on this sector of the economy and try to use some pre-emptive measures so that maximum advantage can be taken from these lands in the future.

In terms of global climate change and extreme weather, Pakistan is ranked 12th in the world (Ahmad & Hasanuzzaman, 2020; Karl et al., 2009). Pakistan’s agricultural- sector



**Fig. 1** Export share of cotton manufacturers in Pakistan

is struggling and will continue to suffer as a result of climate change (Abbas, 2020). Pakistan fell short of its target of 10.671 million bales of cotton in 2016–17. Pest infestations, a sluggish marketing system, and a marked decrease in area under cotton, all led to reduced productivity (Ashraf et al., 2018). During the years 2013–2014, cotton production decreased as a result of the lesser area under cotton cultivation, which was a situation that arose because of lower cotton rates nationally and internationally over the last two years. This situation discouraged growers from putting more land under cotton crops and shifted the area to maize and rice crops in some districts of Punjab, owing to better market returns (GoP, 2014). During the year 2019, the cotton crop's overall performance in Pakistan was below expectations due to unfavorable weather and related pest infestations along with the lack of water availability required in important stages of plant development (GoP, 2020).

During 2017–2018, the total area under cotton cultivation was 2,700,000 ha, which decreased to 2,373,000 ha in 2018–2019. Cotton production decreased from 11,946,000 bales in 2017–2018 to 9,861,000 bales in 2018–2019, and per hectare, yields shifted from 753 kg in 2017–2018 to 707 kg in 2018–2019 (GoP, 2018). Studies have shown that less rainfall, a 0.5-degree rise in temperature across the country in the last three decades, and changes in the frequency and severity of droughts and floods in Pakistan could have a significant effect on crop production (Imran et al., 2018). According to Abbas (2020) the flowering and boll-forming phases, the cotton crop reacts to changing environmental conditions. Pakistan's annual temperature hits its highest point during the flowering and boll-forming stages. Furthermore, as the environment changes, pathogens and insect pests become more prevalent.

Cotton crop production is highly dependent on several factors. Maximum and minimum temperatures, as well as rainfall, are major factors that affect cotton crop production. According to the study by Raza and Ahmad (2015), Precipitation and monthly temperature relate to variables of climate change. Fiber length is a standard dimension along the length of a thread by the quantity of more than 50% of the load in a sample. The extent of fiber in which 25% of the fibers by weight are lengthy and 75% less than the length gained (Abbas & Ahmad, 2018). At different phases of development, the temperature has a different influence on plants. As a result of the plant's phenological properties, the overall cotton production cycle is split into four stages. The first stage, termed germination, takes a greater temperature, which is why seeding occurs in May. A temperate temperature and a small amount of humidity are needed for the vegetative phase, which involves the development of a stem and the spreading out of leaves. On the other hand, high temperatures and humidity lead to pest infestation and leaf shedding.

**Table 1** Calendar of phenological stages of cotton crop Source: (GoP, 2016)

Stages	Germination	Vegetative	Flowering and fruit production	Picking
Months	April-May	June-July	August-September	October

The most important months for a successful agricultural harvest fall within this stage, which includes the months of June and July. The third stage, flowering and fruit production, takes place in August and September and calls for a moderate amount of rainfall as well as temperatures. Cotton plants are more vulnerable to pest infestation at this time, and any increase in warmth or rainfall will result in increased insect invasion, as well as flower and boll loss. Picking is the fourth stage, and the lint formation process continues throughout this time. The greater temperature has a significant impact on lint quality. As a result, during this stage, the crop typically requires a moderate temperature range of 27–30 °C, and thus, higher temperature exposure to cotton crops typically causes shorter thread length, which has an impact on productivity and quality. The most frequent times for this stage to occur are in October and November (Raza & Ahmad, 2015). The phenological stages of the cotton crop are depicted in Table 1 below.

Maund is a local unit equal to approximately 37.32 kg. According to a review of the empirical literature conducted by Abbas and Ahmad (2018); Anwar et al. (2009); Bakhsh et al. (2005) and Imran et al. (2018), it is evident that no study has been conducted to investigate the effects of climate change on cotton production, especially in Southern Punjab, Pakistan. These studies have examined various aspects of cotton crop cultivation in the southern Punjab regions including land availability, irrigation practices, seed selection, fiber quality, and production costs. However, these studies have not adequately emphasized the impacts and relationships between climate change and cotton production. This research fills that gap by looking at the area, production, and yield of cotton in Southern Punjab Pakistan over time. According to the data sets (2004–2020) of the Southern Punjab districts, the selected districts for the current study are those with a percentage change greater than 40%, in production and area under cotton. The main aim of the study is to identify the factors impacting the decline of cotton production in those selected districts of southern Punjab, where the production of cotton has remained very high in the past but now has decreased substantially. The research objective of this study is to investigate the effects of climate on cotton production in Southern Punjab's cotton cultivation zone for the period between 2004 and 2020. The study also recommends a suitable policy framework to manage climate change impacts on the cotton crop.

## 2 Materials and methods

### Characterization of the Study Area.

The Punjab province can be placed around 27° and 34° north latitude and 69° to 75° east longitude. Punjab is Pakistan's most populated province and is situated in the semi-arid lowlands zone. South Punjab is also called the cotton belt, as most of its districts have been famous for cotton production. Cotton is primarily grown in the districts of Bahawalpur, Bahawalnagar, Multan, D.G. Khan, Khanewal, Rahim Yar Khan, Rajanpur, Lodhran, and Muzzafargarh in Punjab, and the districts of Nawabshah, Sanghar, Nosheroferoz, and Ghotki in Sindh (Ahmad & Hasanuzzaman, 2020). These regions,

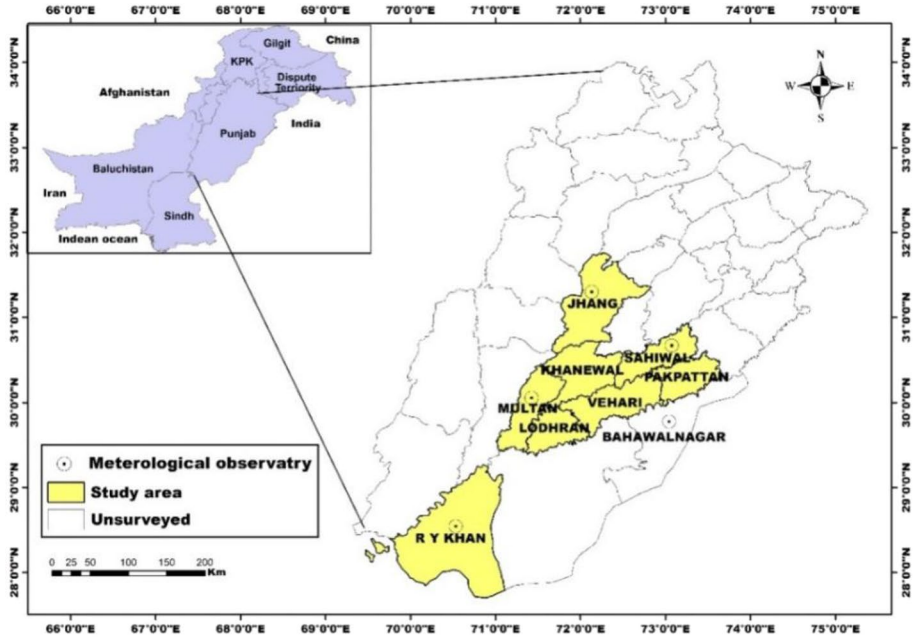


Fig. 2 Locational map of the study area

which are highly known for producing cotton, have around 50 years’ worth of historical evidence of pesticide use. Selected districts of South Punjab, with a percentage change greater than 40%, in production and area under cultivation are Khanewal, Lodhran, Multan, Sahiwal, Rahim Yar Khan, Vehari, Pakpattan, and Jhang. Initially, the study was planned for the entire South Punjab, including some districts that had no data sets due to the absence of an observatory. Later selected districts were included in the study, i.e. Lodhran, Khanewal, Vehari, and Pakpattan, for which this study used meteorological data from nearby districts, such as Multan’s data for Lodhran, Sahiwal’s data for Khanewal, and Bahawalnagar’s data for Vehari and Pakpattan as suggested by metrological experts. As a result, this study couldn’t investigate the relevant minute variations related to climate’s impact on cotton production, in exact locations. Figure 2. depicts the study area map, with shaded districts indicating the selected districts.

Table 2 provides comprehensive information regarding the geographical coordinates and area for each of the eight study area districts. Districts that are not surveyed are not shaded. Also, points on the map show the location of meteorological observatories, which provided data for this study. The three main seasons in Punjab are hot weather (April to June) when temperatures can reach 110 °F, and the rainy season (July to September). The sub-mountain area receives 96 cm of annual rainfall on average, whereas the plains receive 46 cm (October to March). Low temperatures of 40 °F are experienced. Figure 3A shows the rainfall variations for the years 2004–2020 in the districts of southern Punjab Pakistan and depicts that the low precipitation stations can be very easily identified, for example, the low precipitation 19.5–21.2 mm is located in Multan, and Lodhran districts. If we move toward the Northern Punjab, the mean annual precipitation increases so much that Jhang is experiencing 33.1–34.8 mm of rainfall annually Fig. 3A.

**Table 2** Geographical characteristics of the study area

Districts	Latitude	Longitude	Area km <sup>2</sup>
Jhang	31.278069	72.331675	8809
Multan	30.157458	71.524917	3721
Sahiwal	30.6682	73.111356	3201
Khanewal	30.286417	71.932025	4349
Lodhran	29.686853	71.667336	1790
Vehari	30.044156	72.344069	4364
Pakpattan	30.357289	73.382658	2728
Rahim yar khan	28.421156	70.298875	4141

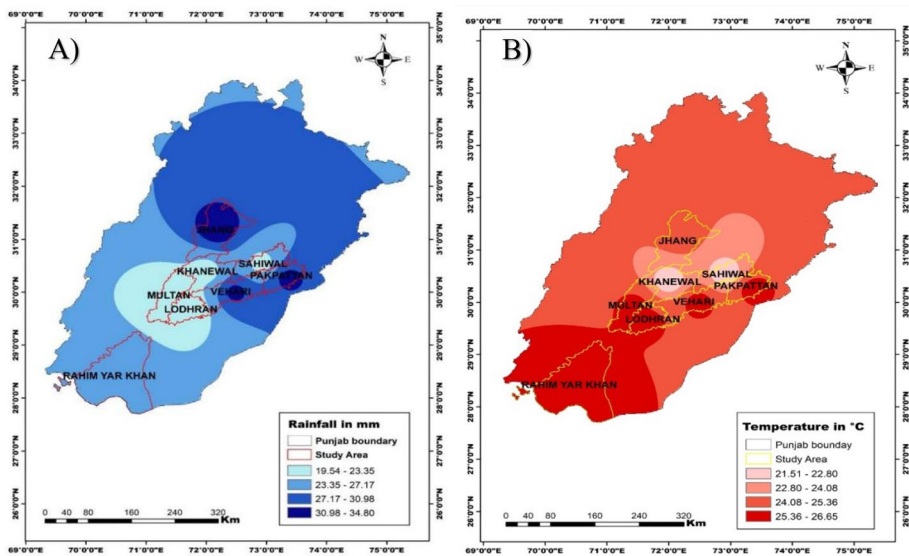
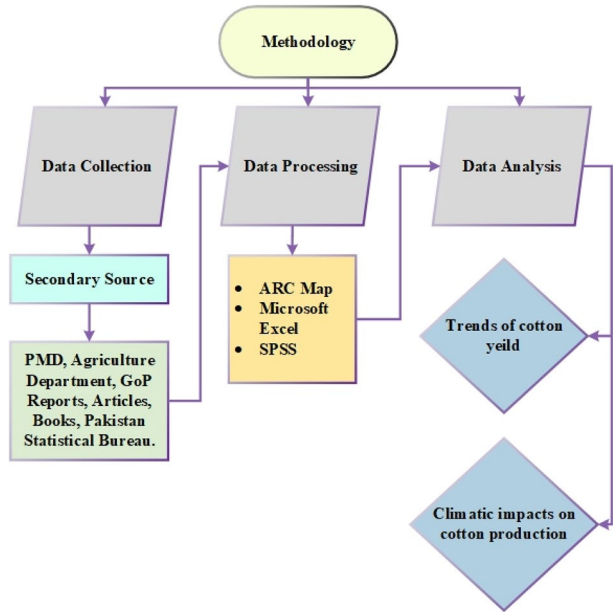
**Fig. 3** Climatology of southern Punjab **A** Annual rainfall **B** Annual Mean Temperature

Figure 3B. is showing the average temperature variations for the years 2004–2020 in the districts of southern Punjab. In Fig. 3B. minimum temperature stations can be very easily identified, for example, the minimum temperature 21.5–22.0 °C cluster is in Sahiwal and Khanewal districts. If we move towards southern Punjab, the mean annual temperature increases so much that Rahim Yar Khan is experiencing 26.0–26.6 °C mean maximum temperature annually. The research that proceeds is quantitative because it emphasizes the quantification of data collection and analysis. The variables for this research, which cover the years 2004 to 2020, are taken from a variety of national data sources (secondary source). The Agriculture Department and the Federal Bureau of Statistics, Government of Pakistan (GoP, 2020), provided data on cotton production in 000 bales, average yield in Mnds<sup>1</sup>/acre, and area under cultivation in 000 acres, whereas the Pakistan Meteorological

<sup>1</sup> 1 Maund is equal to approximately 37.32 kg.

Fig. 4 Methodological Flowchart

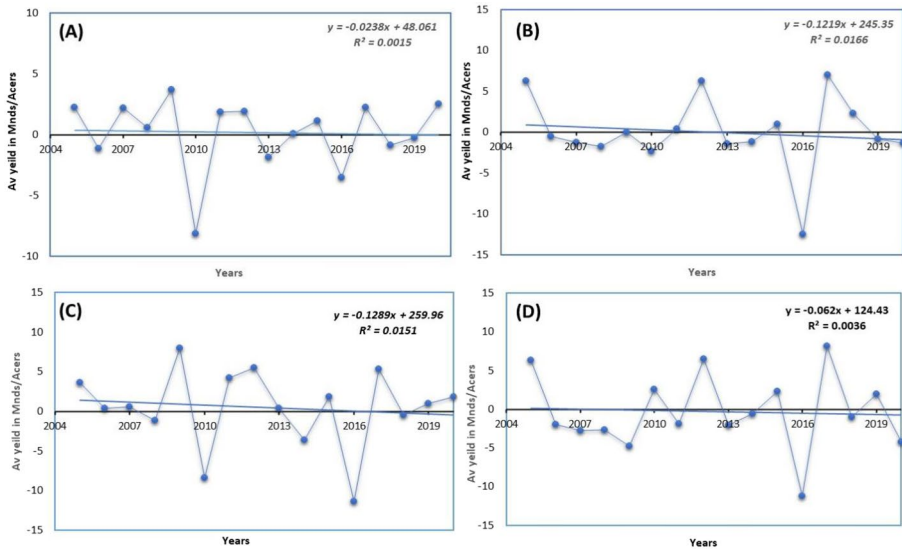


Department (PMD) provided meteorological data on mean monthly rainfall, humidity, and mean monthly minimum and mean monthly maximum temperatures. The information about the export rate of cotton manufacturers in Pakistan was collected from the Pakistan Economic Survey Report (GoP, 2020).

To examine the correlation assessment between climatic elements and cotton crop production, data were analyzed by normalizing values of temperature and precipitation. The study of Abbas (2020); and Abbas et al. (2020) used the Pearson Correlation Coefficient method to check the climatic impact on rice production in the Punjab province, Pakistan. Also, the study by Li et al. (2021) used the Pearson Correlation Coefficient method to check the effects of crop management and climate change on cotton phenology in China’s primary cotton-growing regions. Therefore, the Pearson Correlation Coefficient was applied in the current study to check the correlative assessment between climatic elements and cotton crop production in Southern Punjab Pakistan. The cotton yield was taken as the dependent variable, while climatic elements are taken as independent variables. The formula of the Pearson Correlation Coefficient technique is given in the Eq. (1)

$$\nabla = \frac{\Sigma(\xi_j - \bar{x})(\dagger_j - \bar{y})}{\sqrt{\Sigma(\xi_j - \bar{x})^2 \Sigma(\dagger_j - \bar{y})^2}} \tag{1}$$

Where,  $\nabla$ = Pearson Coefficient,  $\xi_j$ = value of the x variable,  $\bar{x}$ = average of the x variable’s values,  $\dagger_j$ = value of the y variable, and  $\bar{y}$ =variable of the y variable’s values. For achieving the objectives of the study, Pearson Correlation Coefficient in SPSS, Microsoft Excel, and Mapping of Rainfall Interpolation and temperature Interpolation in ARC Map were performed. Through this analysis and graphs, results were drawn. The results were supportive of the hypothesis and objective of the study. Figure 4. provides the steps that were followed in this research. The linear regression was used to eastimate the linear



**Fig. 5** Changes and variability of the annual yield of cotton over various regions of Punjab, Pakistan **A** Jhang, **B** Multan **C** Sahiwal **D** Khanewal

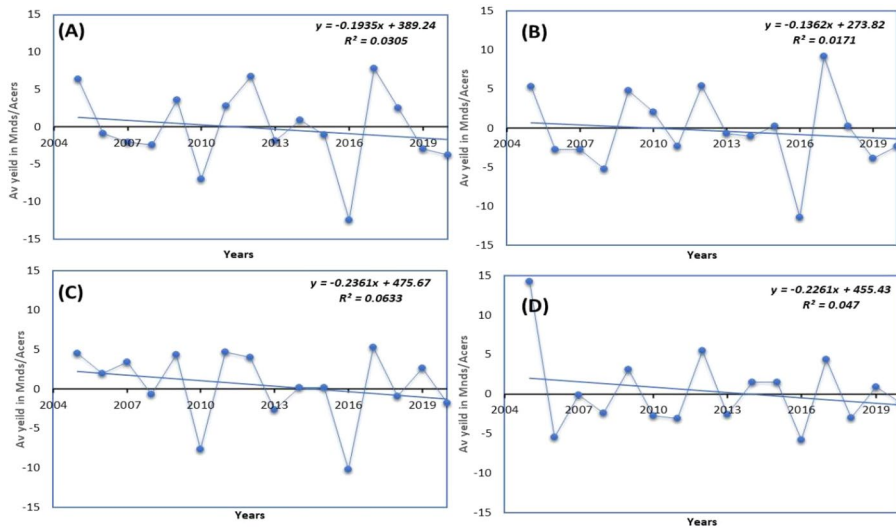
equation. It indicates how much smooth relationship was found between dependent and independent variable. Comparatively, such relationship also showed the negative and positive effects of the dependent variable with respect to independent variable by getting the assumed value in equation.

### 3 Results and discussion

#### 3.1 Inter-annual variability and trends of cotton yield

The Punjab province's climate differs from district to district. Cotton yields in each of the eight districts fluctuated dramatically from year to year. Climate variability demonstrates the temporal variation in cotton yield. Figure 5 A-D showed the relationship between independent variables (years on the x-axis) and dependent variables (yield on the y-axis) over different regions of the Punjab. Such linear relationship consistently reveal a downward decreasing trend of cotton yields for eight districts, particularly after 2009. While similar effects of climate was found in Fig. 6A and D. The results revealed the decreasing trends of  $-8.11$  in 2010,  $-1.84$  in 2013,  $-3.53$  in 2016, and  $-0.85$  in 2018. In Multan district, there was a decrease of yield  $-1.78$  in 2008,  $-2.3$  in 2010, and  $-12.45$  in 2016. On the same way, cotton yield found decreases of  $-4.77$  in 2009 over the Lodhran district,  $-0.54$  in 2014,  $-11.23$  in 2016, and  $-4.26$  in 2020. In Sahiwal district, the decline of cotton yield was found  $-1.1$  in 2008,  $-8.4$  in 2010,  $-3.57$  in 2014, and  $-11.41$  in 2016. Khanewal district recorded declines of  $-2.43$  in 2008,  $-7.01$  in 2010, a decrease of  $6.75$  in 2012, a substantial  $-12.41$  in 2016, and  $-3.70$  in 2020. In Vehari District, cotton yield reductions were  $-2.73$  in 2006,  $-5.19$  in 2008, a significant  $-11.40$  in 2016, and  $-3.87$  in 2019. Likewise, Pakpattan District experienced declines of  $-0.68$  in 2008,  $-7.64$  in 2010,  $-2.64$  in 2013, and  $-10.19$  in





**Fig. 6** Changes and variability of the annual yield of cotton over various regions of Punjab **A** Lodhran **B** Vehari **C** Pakpattan **D** Rahim Yar Khan

2016. Lastly, Rahim Yar Khan saw decreases of  $-5.45$  in cotton yield in 2006,  $-3.05$  in 2011, and a notable  $-5.82$  in 2016, amounting to a decline of  $\text{Mnds}^{-1}$  acre in yield.

Within the Jhang area, a one-unit decrease in the dependent variable results in a 2.38% decrease in cotton output and a  $r^2$  value of 0.0015 (Fig. 5a). Moving on to the Multan District, a one-unit drop in the dependent variable is associated with a significant 12.19% decline in cotton output, as demonstrated by a  $r^2$  value of 0.0166 (Fig. 5b). A one-unit decrease in the dependent variable is related with a substantial 12.89% decrease in cotton production in the Sahiwal District, as confirmed by a  $r^2$  value of 0.0151 (Fig. 5c). In the Khanewal District, a one-unit decline in the dependent variable results in a 6.2% decrease in cotton output and a  $r^2$  value of 0. In the Khanewal District, a one-unit decline in the dependent variable results in a 6.2% decrease in cotton output and a  $r^2$  value of 0.0036 (Fig. 5d). A unit decrease in the dependent variable is associated with a stunning 19.35% drop in cotton output in the Lodhran District, as evidenced by a  $r^2$  value of 0.0305 (Fig. 6a).

Transitioning to the Vehari District, a decrement of one unit in the dependent variable results in a noteworthy 13.62% decrease in cotton yield, with an  $r^2$  value of 0.0171 (Fig. 6b). Progressing to the Pakpattan District, a unit decrease in the dependent variable corresponds to a substantial 23.61% reduction in cotton yield, as supported by an  $r^2$  value of 0.0633 (Fig. 6c). Finally, in the Rahim Yar Khan District, a decrement of one unit in the dependent variable leads to a substantial 22.61% decrease in cotton yield, accompanied by an  $r^2$  value of 0.047 (Fig. 6d). Pakpattan revealed a lot of diversity. While cotton yields in the Jhang district have been gradually declining since 2014, cotton yields in Multan Khanewal, Lodhran, Vehari, Rahim Yar Khan, and Sahiwal districts have been declining since 2012. Cotton yields have been steadily declining over the last fourteen years, from 2008 to 2020.

**Table 3** Pearson Correlation Coefficient table of South Punjab districts

Months	Variables	Jhang	Multan	Sahiwal	Khanewal	Lodhran	Vehari	Pakpattan	Rahim Yar Khan
April	Rainfall	-0.164	-0.111	0.165	0.274	-0.009	-0.137	0.29	0.065
	Maximum Temperature	-0.382	-0.027	0.242	0.332	0.136	0.132	-0.389	-0.169
	Minimum Temperature	-0.43	-0.049	0.253	0.34	0.175	-0.063	-0.285	-0.106
May	Rainfall	-0.167	-0.056	-0.026	0.127	-0.185	-0.271	0.039	0.275
	Maximum Temperature	-0.413	-0.296	0.261	0.334	-0.253	-0.081	-0.385	-0.468
	Minimum Temperature	-0.314	-0.379	0.254	0.336	-0.307	-0.269	-0.437	-0.558*
June	Rainfall	-0.332	0.117	-0.16	-0.124	0.26	0.145	-0.088	-0.214
	Maximum Temperature	-0.033	-0.132	-0.026	-0.048	-0.238	-0.118	0.12	-0.149
	Minimum Temperature	0.1	-0.323	-0.313	-0.291	-0.375	-0.092	-0.01	-0.147
July	Rainfall	0.336	0.305	0.382	0.408	0.343	0.5*	0.509*	0.401
	Maximum Temperature	-0.033	-0.2	-0.099	-0.168	-0.432	-0.421	-0.393	-0.035
	Minimum Temperature	0.012	-0.301	-0.222	-0.093	-0.439	-0.382	-0.324	-0.027
August	Rainfall	-0.367	-0.284	-0.2	-0.224	0.086	-0.321	-0.275	-0.09
	Maximum Temperature	0.477	0	0.099	0.224	-0.312	0.145	0.018	0.028
	Minimum Temperature	0.409	0.207	0.279	0.374	-0.134	0.428	0.249	-0.245
September	Rainfall	0.542*	0.31	0.239	0.244	0.3	0.035	0.518*	0.019
	Maximum Temperature	-0.297	-0.205	-0.167	-0.468	-0.247	-0.14	-0.312	-0.163
	Minimum Temperature	-0.039	-0.316	-0.093	-0.099	-0.246	-0.006	-0.041	0.284
October	Rainfall	-0.571*	-0.082	-0.142	-0.084	0.11	0.194	0.369	-0.036
	Maximum Temperature	-0.109	-0.1	-0.234	-0.448	-0.123	-0.332	-0.178	0.26
	Minimum Temperature	0.568*	-0.13	-0.378	-0.201	0.01	-0.196	-0.33	-0.163

### 3.2 Correlation coefficients and impacts on cotton production

This research is based on district statistics from 2004 to 2020. The Pearson coefficients are shown in Table 3. Results shows the significant and insignificant results for correlating climatic variables with cotton crop production in the south Punjab Pakistan districts. Cotton is ideally sown between April and June, and harvested between October and December. According to Table 3, rainfall has a significant impact in October with a highly negative correlation of  $-0.571$ , since October is the ball ripening stage, where rain can harm the cotton ball.

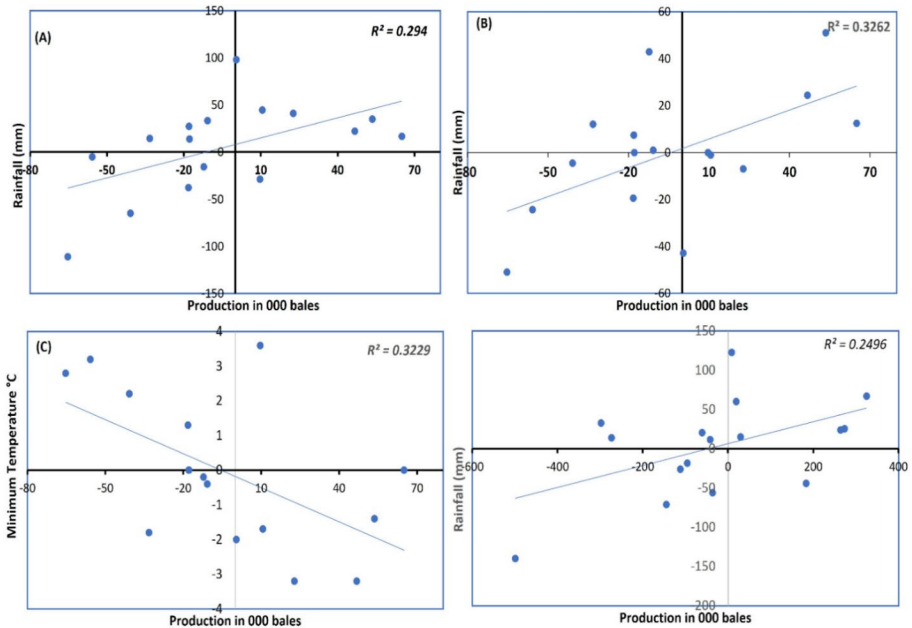
According to Table 3, rainfall has a significant impact in October with a highly negative correlation of  $-0.571^*$ , since October is the ball ripening stage, where rain can harm the cotton ball, thus low rain is beneficial for this stage of cotton growth, and minimum temperature has a significant impact with a highly positive correlation of  $0.568^*$  in the same month in the Jhang district. Rainfall in July had a significant impact in the Vehari district, with a highly positive correlation of  $0.5^*$ . In the Pakpattan district, rainfall had a significant impact in July with a highly positive correlation of  $0.509^*$ , and it also had a significant impact in September with a highly positive correlation of  $0.518^*$ . In the Rahim Yar Khan district, the minimum temperature in May had a significant impact, with a highly negative correlation of  $-0.558^*$ . However as shown in Table 3 Multan, Sahiwal, Khanewal, and Lodhran, there was no correlation between climatic variables and cotton crop productivity.

As a result, the Pearson Correlation coefficient model demonstrates the relationship between the climatic and agricultural variables. Each climatic variable has a negative and positive correlation to cotton crop productivity in South Punjab districts. As a result, this study may conclude that rainfall and minimum temperature cause a significant change in cotton crop production of Jhang, Rahim Yar Khan, Vehari, and Pakpattan because of the significant correlation value which is less than the acceptable limit of 0.01 with high positive and negative correlation.

The results of the Pearson Correlation coefficient prove that the districts Multan, Sahiwal, Khanewal, and Lodhran show insignificant results for all three climatic variables on cotton crop production. However, the other four districts show significant results for all three climatic variables on cotton crop production. Significant change occurs in Jhang, Rahim Yar Khan, Vehari, and Pakpattan due to variations in rainfall and minimum temperature. Minimum temperature causes a significant change in Rahim Yar Khan and Jhang. Pakpattan, Jhang, and Vehari cause a significant change in production by rainfall. Pearson Correlation coefficient analysis helped in achieving the objective of this study and showed the correlative assessment between climatic variables and the production of cotton in the area under study.

### 3.3 Effect of climate on growth phases of cotton production

Cotton is a climate-sensitive crop that is very reliant on the climate. Cotton growth is influenced by climate factors such as rainfall and temperature. Each climate element has a different impact on each growth phase. Only those scatter plots whose coefficient values are significant at the 0.01 level are shown here, as a result, only the results of districts with significant values are discussed in this study. Significant values with asterisk signs are shown in September and October in Jhang district, May in Rahimyar Khan, July in Vehari, and July and September in Pakpattan district, according to Table 3. In the Jhang district, rainfall has a weak positive effect

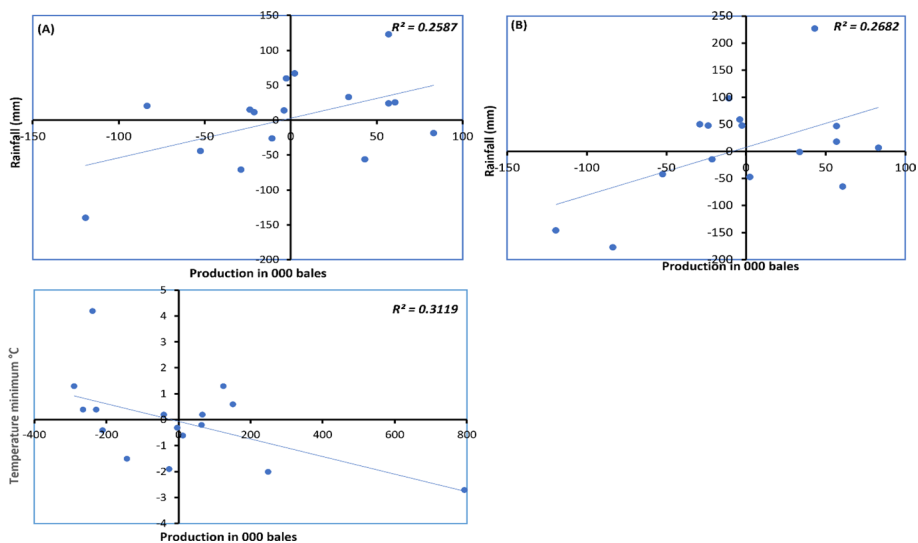


**Fig. 7** Effect of climate on cotton production during various crop growth stages **A** effect of rainfall on cotton production during the flowering stage **B** effect of rainfall on cotton production during the picking stage **C** effect of minimum temperature on cotton production during the picking stage **D** effect of rainfall on cotton production during the vegetative stage

on cotton production during the flowering and picking stages. In September 2013, less rainfall was reported at  $-111$  mm and had an  $r^2$  value of 0.294 Fig. 7A, while in October 2013, less rainfall was recorded at  $-51$  mm. It seems to have an  $r^2$  value of 0.3262 Fig. 7B. Additionally, in the Jhang district,

The minimum temperature has a significant although weakly negative impact on cotton production during the picking stage. In October 2007, the minimum temperature was  $-3.2$  °C. It seems to have an  $r^2$  value of 0.3229 Fig. 7C. Rainfall has a weak positive relationship with cotton production during the vegetative stage in the Vehari district. In July 2010, a total of  $-44$  mm of rain was recorded. It seems to have an  $r^2$  value of 0.2496, Fig. 7D. Rainfall has a weak positive relationship with cotton production during the vegetative stage in the Pakpattan district. In July 2016, a total of  $-140$  mm of rain was recorded. It has an  $r^2$  value of 0.2587 Fig. 8A. Also, Rainfall has a weak positive relationship with cotton production during the flowering stage in the Pakpattan district. In September 2017, there was a decrease in rainfall, with a total of  $-177$  m, with an  $r^2$  value of 0.2682 Fig. 8B. The minimum temperature has a weak negative relationship with cotton production during the germination stage in the Rahimyar Khan area.

The minimum temperature recorded in May 2005 was  $-2.7$  °C. It has an  $r^2$  value of 0.3119, Fig. 8C.



**Fig. 8** Effect of climate on cotton production during various crop growth stages **A** effect of rainfall on cotton production during the vegetative stage **B** effect of rainfall on cotton production during the flowering stage **C** effect of minimum temperature on cotton production during the germinating stage

## 4 Discussion

The present study was conducted to observe the impact of climate change on cotton production in various districts of Southern Punjab Pakistan over the period 2004–2020. Cotton growth depends on the phenological stages which play a crucial role in determining the plant's development, yield potential, and overall productivity. Temperature affects crop physiological growth processes, which in turn affects how long the phenological phases last and, as a result, how much cotton will ultimately be produced biologically and economically (Ahmad et al., 2017). The estimated results of the Pearson Correlation Coefficient model have documented the negative and positive impacts of temperature and rainfall on cotton production over the districts of south Punjab. On the monthly investigation, results showed that during the picking stage in Jhang district, rainfall has a strongly negative impact on cotton crops.

As depicted in Fig. 3A, it is evident that the districts of Jhang and Vehari experience a higher amount of rainfall. To correctly use the cotton boll, which makes it easier to select the cotton and strengthens the cotton fiber, irrigation water should be restricted during the picking stage (Sarwar & Iqbal, 2020). The current study also found that during the picking stage in the Jhang district minimum temperature has a strongly positive correlation with cotton production. During the vegetative stage in the Vehari district rainfall showed a significant impact with a positive correlation. The results obtained from the current study indicate a significant positive correlation between rainfall during the stages of vegetation, flowering, and fruit production in the Pakpattan district. The third stage, known as flowering and fruit formation (FFF), takes place in the months of August and September and requires moderate temperatures and little precipitation. At this point, cotton plants are more vulnerable to pest attack; hence, any rise in temperature or amount of precipitation will result in a greater invasion of pests, as well as bloom and boll shedding (Raza & Ahmad, 2015).

The study of Raza and Ahmad (2015) also revealed that increased temperatures throughout the vegetative period (June to July) are harmful to cotton. This study examines the relationship between minimum temperature and cotton crop during the germination stage in Rahim Yar Khan district, revealing a strong inverse correlation. Ambient temperature is crucial during the germination phase since temperatures below 5 °C can kill seedlings, while temperatures below 10 °C can result in abnormal root development or radicle abortion during the incubation phase (Rehman & Farooq, 2019). There was no discernible relationship found between climate variables and cotton crop productivity in the districts of Multan, Sahiwal, Khanewal, and Lodhran.

The line graphs depicting cotton yields from 2004 to 2020 exhibit a consistent downward trajectory across all eight districts, with a more pronounced decline observed after 2012. Furthermore, scatterplots were employed to examine the relationships between minimum temperature, rainfall, and cotton crop production. In Jhang, Rahim Yar Khan, Vehari, and Pakpattan districts, the results demonstrated a weak positive correlation. This study aims to elucidate the progressive decline in cotton production across eight districts of Punjab, namely Jhang, Multan, Sahiwal, Lodhran, Khanewal, Pakpattan, Vehari, and Rahim Yar Khan, by analyzing the association between cotton production and three climatic variables: rainfall, minimum temperature, and maximum temperature. The investigation highlights the diminishing trends between cotton production and the aforementioned climate variables, providing insights into the changing dynamics of cotton cultivation in these districts over the study period.

## 5 Conclusion and recommendations

Cotton, Pakistan's main cash crop, is thought to be the backbone of the country's economic growth. This crop contributes significantly to the foreign exchange market. In this study, some important factors were taken into account to see how they affected cotton productivity. These critical factors were rainfall and minimum and maximum temperatures. This study presents the possible correlated assessment between climatic and cotton crop productivity over various districts of Southern Punjab Pakistan. The cotton varieties that are grown in southern Punjab are MNH-786a, S 12, FH 629, MVH 518, VS-13, Tarzan-1, FH-113, CIM-448a, FH-87, FH-657, MNH-516, IR 3701, B 820, FDH-170b, FH-628b, FDH-170b, CIM-496c, Neelam-121c, CIM-465c, CRSM-38d, NIBGE-2d, NIBGE-1e, NIAB-846e, IR-1524, VH-305, NIAB-78, B-821, NIAB-26, FH-113, AGC 999, CIM 109, TS-103, CYTO-177, BH 118, AA 703, AC 134, MM 58, B 803, FVH 49, 149-F, TSR-2375, NIAB 846, FH Lalazar, CIM 240, CIM 1100 (Arshad et al., 2021). The statistical analysis Pearson Correlation Coefficient model has been used. The estimated results of the Pearson Correlation Coefficient model have revealed that in Sahiwal, Multan, Lodhran, and Khanewal there is an insignificant relationship between variables of climate i.e.; rainfall and minimum-maximum temperature with cotton production. However, in Jhang Pakpattan and Vehari, significant relationship was witnessed due to rainfall in September October, and July; in Jhang and Rahim Yar Khan significant relationship was witnessed due to the Minimum temperature in October and May.

While Jhang and Rahim yar khan had a highly negative correlation between climatic and agricultural variables. Line graphs of cotton yields for the years 2004 to 2020 have been showing a steadily declining trend in all eight districts, especially after 2012. Scatterplots present relationships between minimum temperature, rainfall, and production

of the cotton crop. Results were weakly positive in Jhang, Rahim yar khan, Vehari, and Pakpattan. This study explains the gradually decreasing trends between the production of cotton and three variables of climate i.e., rainfall, temperature minimum and maximum in eight districts of Punjab i.e., Jhang, Multan, Sahiwal, Lodhran, Khanewal, Pakpattan, Vehari, and Rhim Yar Khan. Farmers will benefit from this research because they will be able to easily identify the cause of cotton crop decline in their districts, whether it is due to rainfall or temperature, and will be able to take appropriate actions to improve production.

This study calls on Pakistan to address its most serious agricultural problems, particularly cotton production because its poor performance affects the largest value chain of the textile sectors. Here are some of the policy recommendations that will prove beneficial for future cotton crop production: The government should prioritize introducing recent agricultural technology and make it accessible, since it will ensure an increase in crop productivity and be, in the long run, cost-effective. Farmers should be taught the most cutting-edge production techniques in the world, and they should be supported by quality breeds, seeds, unique plant types, advanced equipment, trade data, and information. Sindh-1, Abadgrar-901, and other fibers can be used wisely to turn fibers into yarn when soft and fine counts are desired by the spinner, while Tarzen-1 may be the first choice when high-strength yarns are required, such as for sewing threads, according to the study by (Khatri et al., 2018).

Additionally, Sattari, which had the highest whiteness index value, would be a strong candidate for use in the production of fabrics that need to have bright and light colors, as well as other materials. CIM-443, CIM-448, B-557, BH-36, BH-118, CIM-473, FH-87, FH-634, FH-901, FH-631 S, Karishma, MNH-93, 17. MNH-552, NIBGE-1, and NIAB-78 varieties should be sown for stronger fiber. Similar conclusions were made in the study of Asif et al. (2008); Zhang et al. (2005), which evaluated the field effectiveness of commercial cotton cultivators in the US. Thus, these varieties should first be tested in Pakistan before being used to produce stronger fiber. As the example of Kholliyev and Boltayeva (2020) study, it was recommended that the districts that face a declining trend in cotton production due to rainfall should sow Bukhara-6, Bukhara-102, and Bukhara-8 varieties of cotton, for example in district Jhang, Vehari and Pakpattan where rain has significant impact on cotton production.

VH-144, CIM-496, MNH-552, FH-1000, NIAB-111, -362- T-362 (GL), and Cedex LRA-5166 S are the cotton varieties that are heat tolerant, therefore this study suggests that these varieties should be sown in the districts that are affected by high temperature, for example in district Jhang and Rahim Yar Khan where significant impact of temperature on the cotton crop is suggested. One of the limitations of this study is that the human perspective is not explored, in this research. The study was purely based on secondary data sets. As a result of this research, it is suggested that future studies should conduct surveys with farmers in these areas to determine why farmers' preferences have changed, and why they grow other crops instead of cotton.

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**Author contribution** Methodology, Formal analysis and investigation, Writing—original draft preparation: IS; Conceptualization, review and editing, Supervision, Resources: NM Review and editing: SA.

**Data Availability** The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

## Declarations

**Conflict of interest** The authors certify that they have no affiliations with or involvement in any organization or entity with any financial, or non-financial in the subject matter or materials discussed in this manuscript.

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