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Impact of climatic variations in horticulture sector, Kinnaur, Himachal Pradesh, India

HARISH BHARTI, ADITI PANATU, PRIYANKA SHARMA, S. S. RANDHAWA,

SATPAL DHIMAN and R. S. RANA*

State Centre on Climate Change O/o H.P. Council for Science, Technology & Environment

(HIMCOSTE) Vigyan Bhawan, Bemloe Shimla, H.P., India

**Centre for Geo-informatics, Research and Training, CSK Himachal Pradesh Agriculture University*

Palampur, Himachal Pradesh, India

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e mail : harishbharti733@gmail.com

सार – हिमालय क्षेत्र में बदलती जलवायु परिस्थितियों के संबंध में जलवायु परिवर्तन का हिमाचल प्रदेश की बागवानी फसलों पर प्रभाव पड़ता है। अध्ययन का उद्देश्य यह निर्धारित करना था कि हिमाचल प्रदेश के किन्नौर जिले में बागवानी फसलों में इन अंतरों की क्यान आव्रती रहती है क्योंकि हिमाचल प्रदेश में बागवानी उद्योग को इस जिले से बहुत लाभ होता है। 1990 से 2020 तक दीर्घकालिक तापमान (अधिकतम, न्यूनतम और दैनिक) और वर्षा डेटा का विश्लेषण विभिन्न फेनोलॉजिकल चरणों (फूल आने से पहले, फूल आने और फल लगने) के लिए किया गया था। निष्कर्षों से पता चलता है कि फूल आने की अवस्था के दौरान औसत अधिकतम और दैनिक तापमान में क्रमशः 0.027 °C और 0.042 °C की दर से उल्लेखनीय वृद्धि पाई गई। हालाँकि, अन्य फेनोलॉजिकल चरणों की विविधताओं में कोई सराहनीय परिवर्तन नहीं हुए। फसल उपज के रुझान विश्लेषण के तहत, पिछले 20 वर्षों में नाशपाती और बादाम की उत्पादकता में उल्लेखनीय रूप से गिरावट आई है, जो क्रमशः -0.029 टन/हेक्टेयर/वर्ष और -0.016 टन/हेक्टेयर/वर्ष है, जबकि अखरोट की उत्पादकता 0.008 टन/हेक्टेयर/वर्ष वृद्धि हुई है। फसल और जलवायु परिवर्तन के रुझान विश्लेषण के अलावा जलवायु और फसल के बीच संबंध या प्रभाव की भी जांच की गई। परिणामों से पता चलता है कि तीन फेनोलॉजिकल चरणों में से, सेब और खुबानी पर फूल आने से पहले के चरण में (54.4%) अत्यधिक प्रभाव पड़ा, इसके बाद खुबानी पर यानी फूल आने के दौरान 72.6% और अंगूर पर (53.2%) फल लगने के चरण के दौरान अत्यधिक प्रभाव पड़ा। वर्तमान स्थिति में, जलवायु में उतार-चढ़ाव का सेब, अखरोट और अंगूर पर अनुकूल प्रभाव पड़ा है जबकि खुबानी, प्लम, नाशपाती और बादाम पर नकारात्मक प्रभाव पड़ा है।

ABSTRACT. Climate change has an impact on the horticulture crops of Himachal Pradesh in relation to the varying climatic conditions in the Himalayan Region. The purpose of the study was to determine how frequently these differences in horticultural crops occur in the Kinnaur district of Himachal Pradesh since the horticulture industry in Himachal Pradesh greatly benefits from this district. Long-term temperature (maximum, minimum, and diurnal) and rainfall data from 1990 to 2020 were analyzed for different phenological stages (pre-flowering, flowering, and fruit setting). The findings revealed that the average maximum and diurnal temperatures were found to have increased significantly, at the rate by 0.027 °C and 0.042 °C, respectively, during the flowering stages. However, there were no appreciable changes in the variations for other phenological stages. Under trend analysis of crop yield, the productivity of Pear and Almond notably fell over the past 20 years, at -0.029 t/ha/year and -0.016 t/ha/year, respectively, whereas Walnut productivity climbed at 0.008 t/ha/year. The relationship or impact between the climate and the crop was also examined in addition to the trend analysis for crop and climatic variables. The results showed that among the three phenological stages, Apple and Apricot were highly impacted (54.4%) during pre-flowering stage, followed by Apricot, *i.e.*, 72.6% during flowering, and Grapes (53.2%) during the fruit setting stage. In the current situation, climate fluctuations had a favorable effect on Apples, Walnuts and Grapes while having a negative effect on Apricots, Plums, Pears and Almonds.

Key words – Climate change, Phenological stages, Temperature, Trend analysis and correlation.

1. Introduction

Horticulture is the primary agricultural sector, characterized by the size of growth and commercialization, which plays a key role in promoting global food, economic and nutritional stability. Over the two-year period 2021-22, it exported fresh product worth Rs.11,412.50 crore (US$ 1,527.60 million), of which fruits and vegetables were worth Rs.5,593 crore (US$ 750.7 million) and Rs. 5,745.54 crore (US$767.01 million), respectively (IBEF, 2023).

Climate change, manifestations in the horticulture sector across two parameters, *viz*., erratic precipitation (rain and snowfall) and unknown temperature rises that have an unforeseeable effect on fruit crop productivity. Climate change has harmed food security and terrestrial ecosystems, as well as led to desertification and land degradation in many areas by increasing the frequency and intensity of extreme events (IPCC, 2019). India is the world's third-largest emitter of greenhouse gases (GHGs), after China and the US. India is also very vulnerable to climate change, notably due to the melting of the Himalayan glaciers and changes to the monsoon. The consequent human activities are responsible for an increase in the so-called "greenhouse gases" (GHGs), which include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and chlorofluorocarbons (CFCs) (Gora *et al*., 2019). In 2013, India produced 2.8 gigatons of CO_2e, far less than the United States (6.2 gigatons of CO_2e) or China (11 gigatons of CO_2e), but per capita emissions remain significantly lower (WRI, 2018). The country has pledged a 33-35% reduction in the "emissions intensity" of its economy by 2030, compared to 2005 levels (Carbon Brief, 2022). India released 20.54 billion tons of carbon dioxide equivalent (CO_2e) between 2005 and 2013, a yearly increase of 5.57%. Emissions per capita are also increasing at a rate of 4.07 percent per year.

Temperature can have a direct impact in the fruit development stages. Likewise, increased respiration, altered photosynthesis, and partitioning of photosynthates into useful portions would all result from a change in temperature. Additionally, it could affect phenology, reducing crop duration, flowering and fruiting days, and fruit maturity, ripening, and senescence times (Malhotra, 2017). The loss in soil moisture and rise in evapotranspiration that comes with a warmer climate may cause severe agricultural water-stress situations,which could affect horticultural crops (India Water Portal, 2023).

1.1. *Himachal Pradesh and climate*

Himachal Pradesh is a mountainous state in the northernmost part of India, situated in the western Himalayas. The state has a complex geological structure that dissects its topography into extreme altitudinal ranges from 350 m to 6,975 m above mean sea level. Himachal Pradesh is an important Himalayan state which offers an enabling environment with favorable micro-climatic conditions for the cultivation of a wide range of horticultural crops such as apples, plums, peaches, bananas, mangoes, pineapples, citrus fruits, walnuts, and more. Himachal Pradesh is known as the India's fruit bowl, with the horticulture sector accounting for about 38% of the state's GDP (agricultural and allied services contributed to 10% of the state's GDP in 2015-16) and providing a variety of farm and off-farm employment possibilities (MoSPI, 2016). Lot of efforts were made to study the impact of climate change on fruit crop like the instrumental function of anomalous climatic conditions during the stages of flowering and fruit growth that caused Apple productivity to decline was evaluated using five-year fruit production and meteorological data (Jindal *et al*., 2001). Other factors that are unfavorable to fruit crop productivity include delectable variety monoculture, weaker orchard management requirements, and others, according to the report. Meanwhile, Crepinsek and Bogataj (2004) investigated the effect of increasing temperature (per degree) on faster occurrence of leaf and fruit ripening by 2 days in Apple and plum crops. The Apple production has been reduced as a result of an increase in average temperature, prolonged summer drought spells, a delayed start to winter, and a drop in snowfall. Furthermore, the chill units, which are essential to Apple's growth, have been declining (Rai *et al*., 2015).

The effects of climate change are visible in every sector and area of the world, and they can also be observed visually at the local level. This study was conducted for a district in Himachal Pradesh, a small but important area of the state. This is due to the district's significant contribution to the state's horticulture industry. Therefore, it is crucial to investigate how the local climate affects fruit crops (whether it is positive or negative). The study's primary goals were to look at trends in local temperature and rainfall patterns, fruit productivity and the relationship between phenological stages and climate factors which ultimately impacting the productivity. Phenological stages were designated as the preferred and pertinent indicator for measuring plant response to climate change (Chmielewski and Rötzer, 2001). On the other hand, the climatic conditions vary according to the fruit crop type and the phenological phases of pre-flowering, flowering, fruit setting and development.

2. Study area and methodology

2.1. *Study area*

Kinnaur district constitutes the southern part of the Trans Himalayan Zone. It lies between 31° 05' 55"and 32° 5' 20" North latitude and 77° 45' 0" and 79° 10' 50" East longitude. The district is bounded by Lahaul & Spiti in the north, Kullu district in the north-west, Shimla district in the west and in the southwest, state of Uttarakhand in the south while Tibet (China) makes its eastern boundary (Fig. 1). Reckong Peo, the present headquarters of the district, is situated at an elevation of 2,290 meters, and the total area of the district is 6,401 sq kms. It ranks 3rd in terms of area and 11th in terms of population among the districts of the state (District Census Handbook Kinnaur, 2011).

2.2. *Methodology*

The mean minimum, maximum, diurnal temperature, and rainfall data for Kinnaur district were collected from the India Meteorological Department (IMD), Shimla, covering a period of 31 years (1990-2020). Datasets were further categorized for different phenological stages, *i.e.*, pre-flowering (November to February), flowering (March to April), and fruit setting (May to August). Apple, Plum, Apricot, Pear, Almond, Walnut, and Grape's acreage, and production data were collected from the Directorate of Horticulture, Himachal Pradesh, covering the period of 2001 to 2020.

2.3. *Trend analysis*

The Mann Kendall Test (Mann, 1945; Kendall, 1975), a generally accepted statistical test for trend analysis in climatologic and hydrologic time series, was used to analyses seasonal patterns in climatic variables such as minimum, maximum, and diurnal temperatures, as well as rainfall (quantity and days) (Pohlert, 2018). This statistical test has two advantages: first, since it is a non-parametric test, it does not require normally distributed master data. Second, the test has a low sensitivity to abrupt data breaks and time series that are not homogeneous. As a consequence, data gaps are filled by assigning a common value that is less than the master data set's smallest measure value. The Mann Kendall Test works on the basic null hypothesis Ho of no trend, *i.e*., data is independent with a random order that is tested against the alternative hypothesis H_1.

The test follows a time series of n data points with *Ti* and *Tj* as two subsets of data where $i = 1, 2, 3, n\text{-}1$ and $j = i+1, i+2, i+3, \ldots, n$.

Each data point in an ordered time series is compared to the next data point, and if the next data point has a higher value, the statistic S is incremented by 1, while if the next data point has a lower value, S is decremented by 1. The final value of S, *i.e.*, the Mann Kendall S statistic, is calculated by the net results of all iterations.

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sign}(Tj - Ti)$$

$$\operatorname{sign}(Tj - Ti) = \begin{cases} 1 \text{ if } Tj - Ti > 0 \\ 0 \text{ if } Tj - Ti = 0 \\ -1 \text{ if } Tj - Ti < 0 \end{cases}$$

where *Tj* and *Ti* are the annual values in years *j* and *i*, $j>i$, respectively

A positive (negative) value of S indicates an upward (downward) trend.

Sen's Slope, which basically computes the linear rate of change and intercept, measures the magnitude of the pattern. After evaluating a range of linear slopes, the Sen's Slope is determined as the median of all linear slopes, resulting in the magnitude of the observed seasonal pattern. The *P*-value* is another statistic correlated with the Mann Kendall test. The greater the weight of evidence against the null hypothesis of no pattern, the lower the *P*-value (below 0.05). The statistical Mann Kendall test is performed on software XL-STAT, 2020 for this analysis. For the time span 1990-2020, the null hypothesis is checked at a 95% confidence level for minimum, maximum and diurnal temperate, as well as rainfall (quantity and days). Annual productivity patterns for Apple, Apricot, Plum, Pear, Almond, Walnut and Grapes crops were also analyzed.

* The *P* value is defined as the probability under the assumption of no effect or no difference (null hypothesis), of obtaining a result equal to or more extreme than what was observed. The *P* stands for probability and measures how likely it is that any observed difference between groups is due to chance (Dahiru, 2008).

(* $P<.05$, represent moderate significant *P* value, ** $P<.01$, represent high significant value *P* and *** $P<.001$, represent highly significant *P* value)

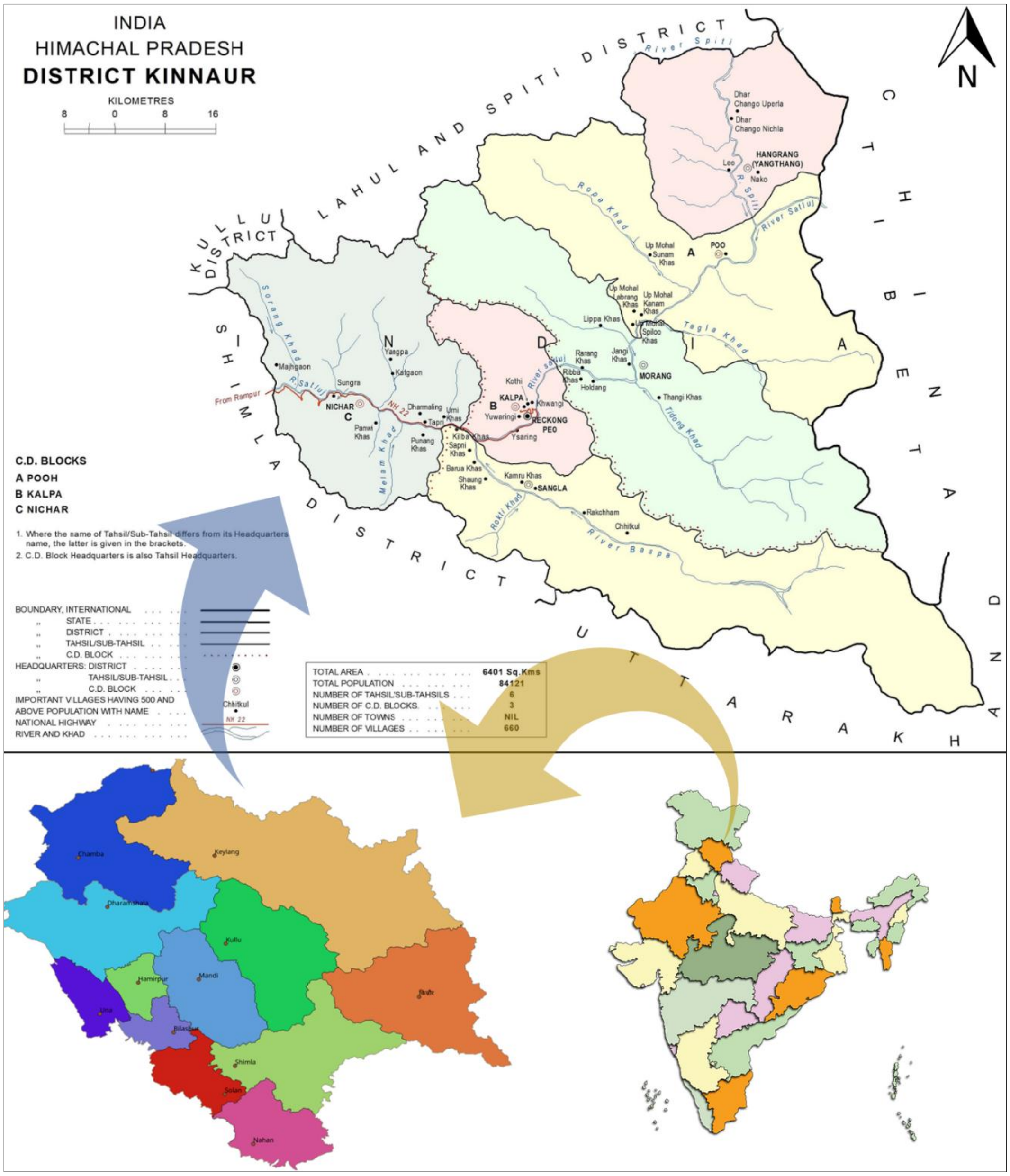


Fig. 1. Administrative map of Kinnaur district of Himachal Pradesh

2.4. *Standardized anomaly index*

SAI is a widely used index for regional climate change studies that is determined by subtracting the long-term mean value of temperature and rainfall data sets from individual values and dividing by their standard deviation (Koudahe *et al*., 2017).

2.5. *Multivariate linear regression model*

The linear multivariate regression statistical measure is chosen to assess the climate-crop yield relationship. A dependent variable is driven by multiple independent variables in a multivariate linear regression model and thus multiple coefficients are calculated. Pearson's correlation coefficient was used to determine the strength of the relationship between climatic variables and crop productivity in this analysis. A correlation coefficient of -1 indicates a perfectly negative linear relationship between the two variables; a correlation of 0 indicates no linear relationship between the two variables (but probably a non-linear relationship); and a correlation coefficient of 1 indicates a perfectly positive linear relationship between the two variables. Correlation

TABLE 1

Mann-Kendall Test Results-Climatic Trends for pre-flowering, flowering and fruit setting stage (1990-2020)

Climatic Variables	Mean	Sen's slope	P-value
Pre-Flowering (November-February)			
Av. Max Temperature	0.003	0.027	0.304
Av. Min. Temperature	-0.026	-0.015	0.321
Diurnal Temperature	0.023	0.042	0.058
Total Rainfall	0.012	-0.019	0.416
Flowering (March-April)			
Av. Max. Temperature	**0.072**	**0.052**	**0.002*** **
Av. Min. Temperature	0.016	0.022	0.269
Diurnal Temperature	**0.063**	**0.044**	**0.004*** **
Total Rainfall	-0.030	-0.003	0.805
Fruit- Setting (May-August)			
Av. Max. Temperature	-0.007	0.029	0.155
Av. Min. Temperature	-0.024	0.022	0.339
Diurnal Temperature	0.021	0.018	0.436
Total Rainfall	0.032	-0.010	0.272

coefficient values can never be less than -1 or greater than 1. The regression analysis verified the effect of anomalies in the studied climatic parameters on crop productivity, as demonstrated by the following linear model:

$$\Delta P = \text{constant} + (\alpha \times \Delta T_{min}) + (\beta \times \Delta T_{max}) + (\gamma \times \Delta T\text{dt}) + (\delta \times \Delta R) + (\varepsilon \times \Delta \text{Rd})$$

where, ΔP is the observed change in the productivity due to minimum, maximum, diurnal temperature, and rainfall in the respective phenological stages of the fruit crops. Coefficients α, β, γ and δ are the coefficients of minimum, maximum, diurnal temperature and rainfall, respectively. ΔT_{min}, ΔT_{max}, Tdt, ΔR and ΔRd are the observed changes in minimum, maximum, diurnal temperature, rainfall and rainy days respectively for the cropping seasons during the study period.

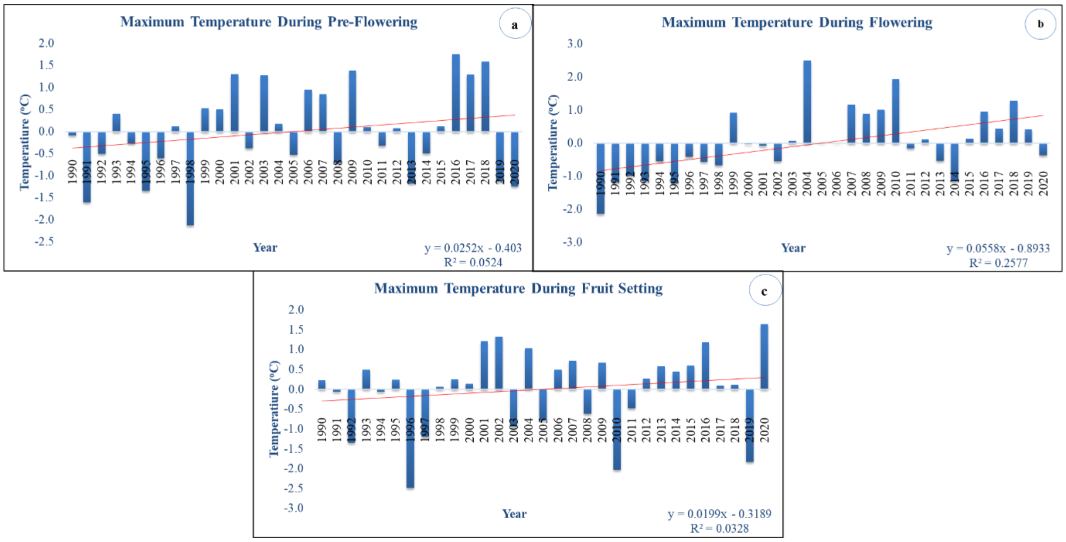
3. Results and discussion

3.1. *Current climate trends*

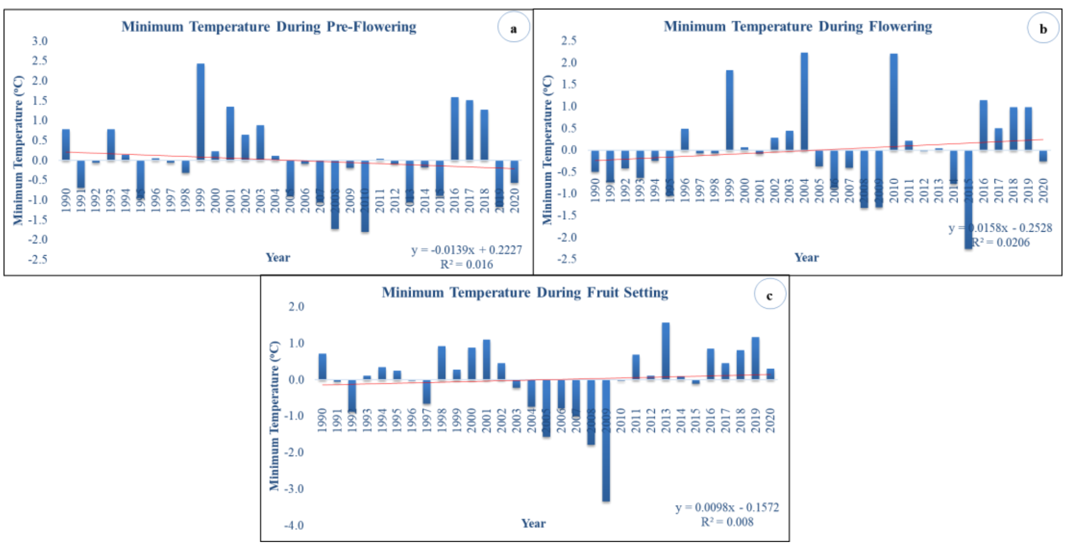
To capture the nerve of climatic changes in the district, temperature (min, max, diurnal) and rainfall (quantity and days) are considered as explanatory indicators. Based on the statistical analysis of the Mann-Kendall trend test, the variations in climatic variables were observed in the pre-flowering season, flowering season and fruit-setting season. Table 1 exhibits the results of the Mann-Kendall test at a 95% confidence level for minimum, maximum, diurnal temperature, and rainfall for the time period of 1990-2020.

According to the analysis**, the average maximum temperature and diurnal temperature during the pre-flowering stage were increased at a rate of 0.027 °C per year and 0.042 °C per year, respectively. In contrast, the minimum temperature and annual rainfall decline by -0.015°C per year and -0.019mm per year, respectively (Table 1). All the fluctuations due to the climatic variables were non-significant. In the flowering stage, *i.e*., March and April, the average maximum temperature and diurnal temperature increased highly significantly at the rate of 0.052 °C per year and 0.044 °C per year, respectively. Similar observations were also observed for Kullu district, which indicate a significant increase in average maximum temperature during the flowering stage (Vaidya *et al*., 2019). An increasing trend for the minimum temperature

** Diurnal temperature range (DTR), as defined by the difference between the maximum and minimum temperatures within 1 day, is an important meteorological indicator associated with climate change (David *et al*., 1997)



Figs. 2 (a-c). Standardized Anomaly Index (SAI) for Average Maximum Temperature during pre-flowering, flowering, and fruit setting stages (1990-2020), District Kinnaur, HP

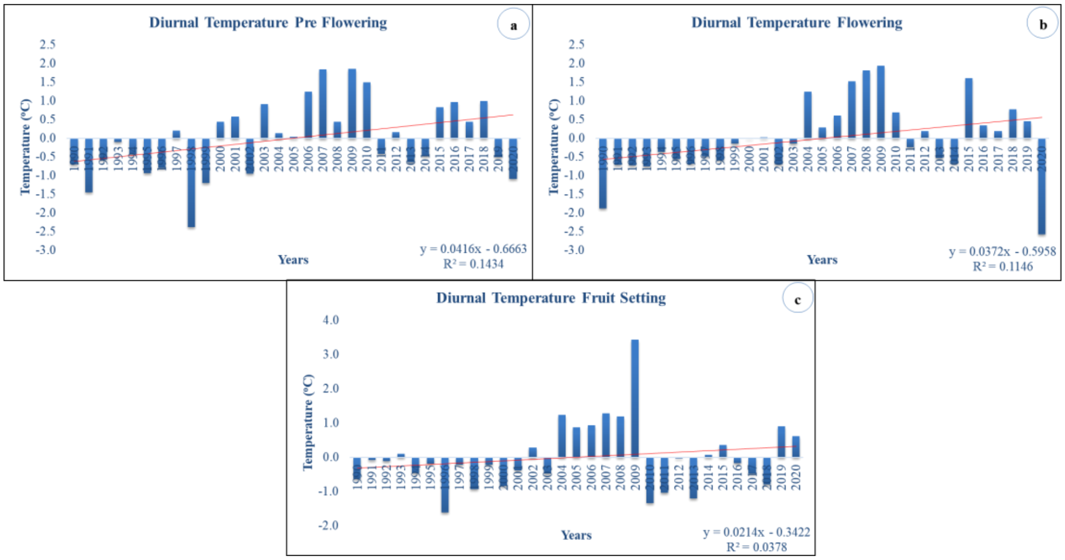


Figs. 3 (a-c). Standardized Anomaly Index (SAI) for Mean Minimum Temperature during pre-flowering, flowering and fruit setting stages (1990-2020), District Kinnaur, HP

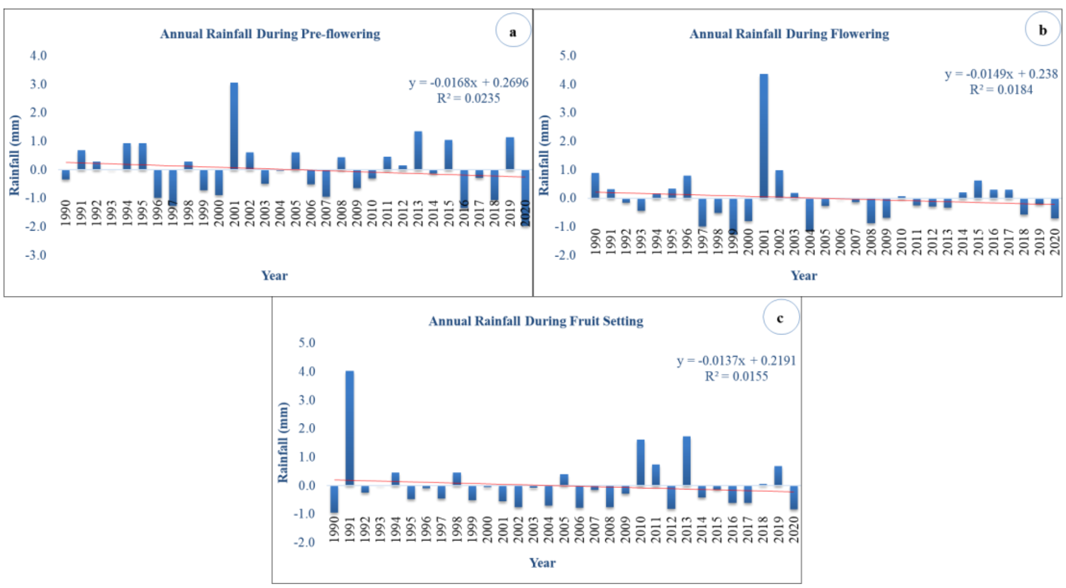
was also observed, although it was non-significant. Whereas the total rainfall during this phenological stage declined at -0.003 mm per year which was non-significant. Similarly, for the fruit setting stage, the average maximum, minimum, and diurnal temperature increased while the total rainfall declined non-significantly (Table 1).

According to the findings revealed by Standardized Anomaly Index (SAI) analysis, the average maximum temperature during the pre-flowering, flowering and fruit setting stages showed an increasing trend. In all three phenological stages, the recent years represented the warming years along with the long-term average, *i.e.*, 1990-2020, which ultimately contributed to the increasing trend as shown in Figs. 2(a-c) and Table 1.

The average minimum temperature during the pre-flowering stage showed a slight decrease in the trend as exhibited by Fig. 3(a). At this phenological stage, the effect of warming years was more pronounced as compared to the later ones. In contrast, a reverse trend was observed for the flowering stage, *i.e.*, a slight increase was seen over the long-term average. Similar observations



Figs. 4(a-c). Standardized Anomaly Index (SAI) for Mean Diurnal Temperature during pre-flowering, flowering and fruit setting stages (1990-2020), District Kinnaur, HP



Figs. 5 (a-c). Standardized Anomaly Index (SAI) for Mean Annual Rainfall during pre-flowering, flowering and fruit setting stages (1990-2020), District Kinnaur, HP

were also perceived for the fruit setting stage. This phenological stage produced an undulating result, with the initial years (1990-2002) representing continuous warming years, then continuous cooling years until 2010, and then later ones with warming years, as shown in Fig. 3(c).

The diurnal temperature is another temperature variable, and trend analysis was done for it as well. The SAI revealed that the diurnal temperature showed an increasing trend for all phenological stages, *i.e.*, pre-flowering, flowering, and fruit setting stages. The effect of warming years was much more pronounced along the long-term average (1990-2020) for all stages, as shown in Figs.4(a-c). Apart from the important temperature variable, the other climatic variable considered for the trend analysis is annual rainfall. The trend analysis revealed a decreasing trend, showing a slight decline along the long-term average for all three phenological stages. In general, the trendline is stuck with the average line, showing a marginal visible change in the trend as shown in Figs. 5(a-c).

Figs. 6 (a&b). Variations in Annual Acreage, Production and Productivity of Apple in District Kinnaur, HP (2001-2020)

TABLE 2

Mann-Kendall Test Results - Crop Yields of Fruit Crops (2001-2020)

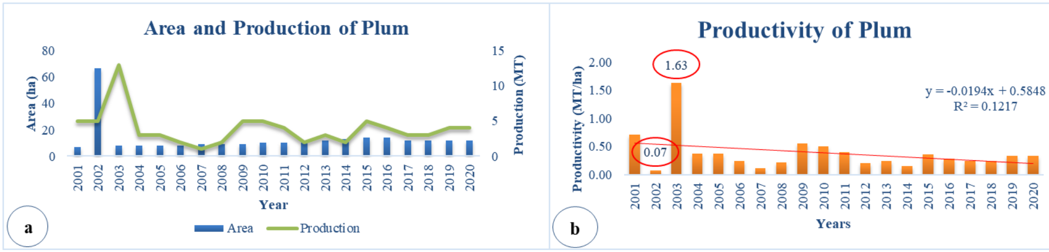
Fruits Productivity	Mean	Sen's slope	*P*-value	Kendall's tau
Apple	5.190	0.074	0.008	0.439
Apricot	1.024	-0.020	0.629	-0.088
Plum	0.363	-0.002	0.751	-0.054
Pear	0.483	**-0.029**	**0.010****	-0.427
Almond	0.202	**-0.016**	**0.000*****	-0.567
Walnut	0.248	**0.008**	**0.036***	0.352
Grapes	3.086	0.014	0.726	0.059

3.2. *Acreage, production, and productivity assessment of major horticulture crops*

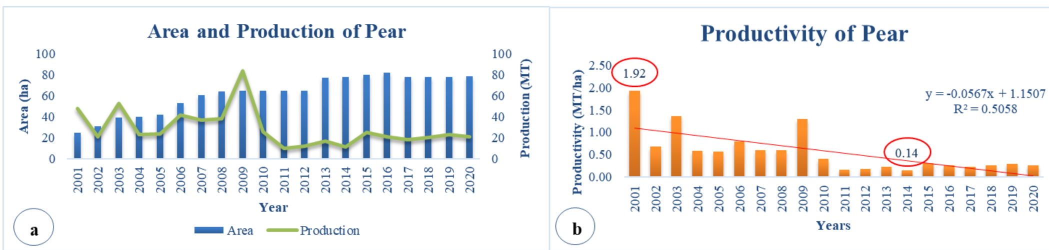
In Himachal Pradesh, Apples were known to be cultivated at altitudes between 1200-1500meters in the early 1980s (National Horticulture Borad. Apple, 2012). Orchards have shifted to 1500-2500 meters in the 2000s. More recently Apples are now being cultivated at more than 3500 meters elevation in the Himachal Pradesh, owing to warming of the surface temperature since the 1980s (Kothawale and Kumar, 2005). Apple trees in the Himalayan range, experiences 1,000-1,500 hours of chilling (the number of hours during which the temperature remains at or below 7 °C during the winter season). In Kalpa, the temperature during the growing season is around 20-23 °C. For optimum growth, Apple plant need 100-125 cm of annual rainfall. In Kalpa, significant precipitation and fog around the time of fruit maturity led to poor fruit quality with uneven coloration and fungal spots on its surface (District Agriculture Plan Kinnaur, Himachal Pradesh, 2009). Apple output in Kinnaur is anticipated to expand at a rate of 9.68% annually based on the yields of typical farmers, those of progressive farmers, and the present area under diverse fruit crops. The other significant fruits of the region include Walnuts and other stone fruits like Apricots, Plums, Peaches, *etc*. The production of these fruits shall increase at the rate of 15.20 per cent per annum. Like this, it is anticipated that output of other temperate fruits will increase from 213 MT to 324 MT, representing a growth rate of 4.34% annually (District Agriculture Plan Kinnaur, Himachal Pradesh, 2009).

For the acreage, production, and productivity assessments, 7 major horticulture crops were covered, *viz*., Apple, Plum, Pear, Apricot, Almond, Walnut, and Grapes. A trend analysis for 20 years, *i.e*., 2001-2020, was done and the analysis revealed the following results:

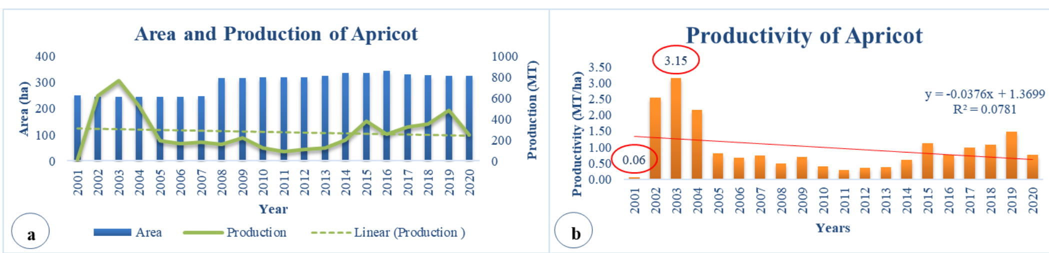
As per the figures released by the Ministry of Agriculture & Farmer Welfare, GoI, the total area under Apple crop was 1,14,000.65 ha as per first advance estimate of 2021-22 (Department of Agriculture & Farmer Welfare, 2022). Despite just making up 9% of the state's territory, Kinnaur contributes more than 15% of the state's Apple crop (District Agriculture Plan Kinnaur, Himachal Pradesh, 2009). As shown in Figs. 6 (a&b), the area under Apple cultivation expanded from 6604 ha in 2001 to 10911 ha in 2020 and production climbed from 18,808 MT to 73,330 MT (2001-2020). Between 2001 and 2020, Apple's productivity climbed from 2.85 to 6.72 MT/ha, although no statistically significant changes in



Figs. 7 (a&b). Variations in Annual Acreage, Production and Productivity of Plum in District Kinnaur, HP (2001-2020)



Figs. 8 (a&b). Variations in Annual Acreage, Production and Productivity of Pear in District Kinnaur, HP (2001-2020)

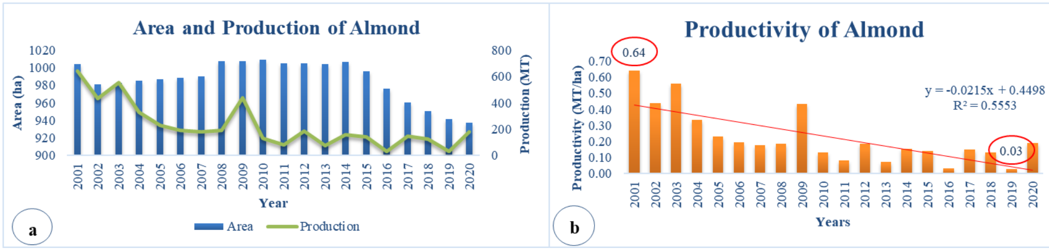


Figs. 9(a&b). Variations in Annual Acreage, Production and Productivity of Apricot in District Kinnaur, HP (2001-2020)

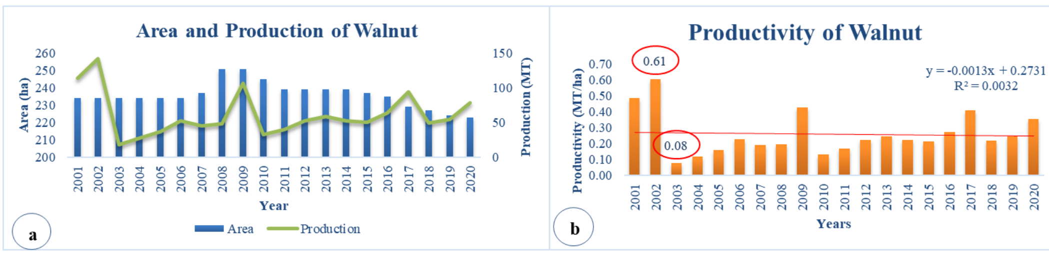
productivity were observed (Table 2), with a minimum productivity of 2.85 MT/ha in 2001 and a maximum of 6.74 MT/ha in 2015. Kalpa's Apple production has been steadily rising every year. According to evidence collected from the fields, the improved production may be attributable to the introduction of hybrid variety, low chilling cultivars, high density plantations, and a change in the land use pattern from agriculture to fruit crops. Despite several difficulties in the apple farming industry, such as disease, insect, and pest incidences, higher productivity is directly attributed to technological advancements and widespread usage of insecticides and pesticides.

In 2001, the Plum crop covered 7 ha,but in 2002, it increased to 67 ha which was the highest among all years, and following that, the area gradually increased. Aminimum production of 1 MT was observed in the year 2007 and a maximum of 13 MT was produced in the year 2003, illustrating an erratic trend in production shown in Fig. 7(a). The productivity showed a decreasing trend for 20 years of long-term data, with a minimum of 0.07 MT/ha for 2002 and a maximum of 1.63 MT/ha for 2003 [Fig. 7(b) and Table 2]. There are only a few plum growers because people are starting to switch from plum to other fruit crops (mostly apple). Due to its short shelf life compared to apples, is also a major problem during marketing, production has decreased for a second major reason. Additionally, 46% of plumgrowers experience significant hardship as a result of their ignorance of scientific production procedures (Arora, 2004).

Another major fruit crop in the Kinnaur district is Pear. Pear showed a gradual increase in acreage between 2001 and 2020. The production of Pear showed a decreasing trend, whereas the highest production of Pear was (84 MT) in 2009, which afterwards decreased to 0.27 MT in 2020, as shown inFig. 8(a). The productivity of Pear showed decreasing trend (Table 2). The highest productivity was observed in 2001 (1.92 MT/ha) and the lowest in 2014 (0.14 MT/ha), but in 2020 it remained at 0.27 MT/ha as shown in Fig. 8(b).



Figs. 10 (a&b). Variations in Annual Acreage, Production and Productivity of Almond in District Kinnaur, HP (2001-2020)



Figs. 11 (a&b). Variations in Annual Acreage, Production and Productivity of Walnut in District Kinnaur, HP (2001-2020)

Figs. 12 (a&b). Variations in Annual Acreage, Production and Productivity of Grapes in District Kinnaur, HP (2001-2020)

In the Kinnaur district, Apricots are a major temperate fruit crop. According to trend analysis, the acreage was constant from 2001 to 2007, but from 2008 to 2020, it increased at almost the same rate [Fig. 9(a)]. The total area of Apricots increased from 251 ha to 336 ha over the past 20 years (2001-2020). The Apricot production dropped from 623 MT to 249 MT, from 2002 to 2020,(Table 2) whereas, the lowest production observed forthe year 2001, *i.e.*, 14 MT,[Fig. 9(a)]. The productivity of Apricot was recorded at its lowest in 2001 *i.e.*, 0.06 MT/ha and its highest in 2003 *i.e.*, 3.15 MT/ha; however, in general the apricot following the decreasing trend and in year 2020 and the productivity was 0.77 MT/ha [Fig. 9(b)].

For Almond, the acreage and production showed decreasing trend. The maximum acreage for Almond was in 2009 (1009 ha) and the lowest was in 2020 (937 ha). Following 2002, the amount of acreage increased gradually until 2010, when it reached a maximum of 1009 ha, and then after a certain increase it decreased to 937 ha in 2020[Fig. 10(a)]. Almond production showed a significant decrease over time, from 645 MT to 179 MT in 2001 and 2020, respectively. In 2001 and 2020, the productivity of Almond substantially declined, averaging 0.64 MT/ha and 0.19 MT/ha, respectively.The highest productivity was seen in 2001 (0.64MT/ha) and lowest in 2019 (0.03 MT/ha), as seen in Fig. 10(b) and Table 2. Summer fruits, including Cherries, Apples, Plums, Peaches, and Apricots suffer significant damage from periodic hailstorms and windstorms (Choudhary *et al*., 2015).

Walnut is one of the major dry fruits in the Kinnaur district. Trend analysis revealed that the acreage and production of Walnut crop decreased slightly from the year 2001 to 2020. The production trend showed anirregular trend, as exhibited in Fig. 11(a). Similarly, the productivity of crops showed a marginal change in trend. The highest productivity was seen in the year 2002 (0.61MT/ha) and the lowest in 2003, *i.e.*, 0.08 MT/ha [Fig. 11(b)].

TABLE 3

Multivariate Linear Regression Analysis-Crop Yields and Climatic Parameters, (2001-2020) for Pre-Flowering, Flowering and Fruit Setting Stages of temperate fruit crops of Kinnaur, Himachal Pradesh

S No.	Crops	Variable / Statistics	Pre-Flowering						Flowering						Fruit Setting					
			Min *T*	Max *T*	DT	RF	R^2	% Change	Min *T*	Max *T*	DT	RF	R^2	% Change	Min *T*	Max *T*	DT	RF	R^2	% Change
1	Apple	Coefficient	-0.375	-0.512	-0.027	-0.429	0.544	**54.4**	0.181	-0.032	-0.029	-0.577	0.443	**44.3**	-0.277	0.012	-0.158	0.258	0.106	10.6
		P-value	0.052	0.011	0.456	0.03			0.222	0.446	0.452	0.004			0.119	0.48	0.252	0.136		
2	Plum	Coefficient	0.186	0.056	0.226	-0.013	0.193	19.3	0.168	0.089	0.033	-0.032	0.052	5.2	-0.351	0.019	-0.131	0.261	0.128	12.8
		P-value	0.217	0.407	0.169	0.479			0.239	0.354	0.444	0.448			0.065	0.469	0.291	1.34		
3	Pear	Coefficient	0.409	0.125	0.426	0.063	0.400	40	0.255	-0.071	0.26	0.325	0.371	37.1	0.089	-0.338	0.443	-0.248	0.195	19.5
		P-value	0.037	0.3	0.03	0.396			0.139	0.384	0.134	0.081			0.354	0.072	0.028	0.145		
4	Apricot	Coefficient	-0.181	-0.197	-0.065	-0.637	54.4	**54.4**	0.147	0.072	0.05	-0.829	0.726	**72.6**	-0.175	-0.203	0.175	0.036	0.079	7.9
		P-value	0.223	0.202	0.392	0.001			0.269	0.381	0.417	0.001			0.23	0.196	0.231	0.44		
5	Almond	Coefficient	0.109	0.167	-0.034	0.034	0.314	31.4	-0.095	-0.213	-0.094	0.198	0.200	20	0.198	-0.225	0.274	-0.413	0.188	18.8
		P-value	0.324	0.241	0.444	0.443			0.345	0.184	0.347	0.201			0.201	0.17	0.121	0.035		
6	Walnut	Coefficient	-0.033	0.17	-0.22	0.154	0.156	15.6	-0.311	-0.283	-0.157	0.315	0.198	19.8	0.503	0.155	0.176	-0.256	0.382	**38.2**
		P-value	0.445	0.236	0.176	0.258			0.091	0.113	0.255	0.088			0.012	0.258	0.229	0.138		
7	Grapes	Coefficient	0.162	-0.118	0.326	-0.249	0.207	20.7	0.116	-0.221	0.259	-0.186	0.136	13.6	0.098	-0.48	0.669	-0.069	0.532	**53.2**
		P-value	0.148	0.31	0.081	0.145			0.131	0.174	0.135	0.217			0.34	0.016	0.001	0.386		

Abbreviations used: Min T: Minimum Temperature, Max T: Maximum Temperature, DT: Diurnal Temperature, RF: Rainfall

Apart from the temperate fruit crops, Grapes are one of the important fruit crops of Kinnaur district. The acreage and production of Grapes showed an increasing trend. As the acreage from 2001 to 2007 did not show much variation, but after 2007 has increased to 28 ha which is a visible change and maintained the level till 2020 [Fig. 12(a)]. The productivity of the Grapes showed a marginal increase from 2001 to 2020 and the highest productivity was observed in the year 2009 and the lowest in 2012 [Fig. 12(b)].

Furthermore, when examining the productivity patterns for the horticultural crops in more detail, the Mann-Kendall Test was also done for all the crops at a 95% confidence interval. The analysis revealed that the productivity of Pear and Almond decreased significantly at -0.029 t/ha/year and -0.016 t/ha/year, whereas, Walnut increased at the rate of 0.008t/ha/year in the last 20 years. In the Kullu district, the productivity of Apple, Walnut and Almond showed similar results (Vaidya *et al.*, 2019). While, the other crops like Apple, Apricot, Plum, and Grapes did not show any significant variation (Table 2).

Trend data in tandem with the outcomes of Mann Kendall Test results hint toward a shift in focus from Apple crops to other stone crops and a consistent decline in dry fruit, solely in terms of productivity. Several research studies have found consistent trends supporting the significance of climate change in affecting the yield of Apple and other temperate crops in Himachal Pradesh. While Singh (2003) discussed the role of changing weather patterns in determining the success of the Apple crop in Himachal Pradesh, such as reduced annual snowfall and fluctuating temperatures during the flowering period, Gautam *et al*., (2004) uncovered the factors of reduced natural pollinating agents, inadequate winter chilling, frequent spring frosts and hail, and droughts as reasons for poor fruit segregation. Therefore, at this stage, it becomes imperative to get a better insight into the factors leading to this supposed transition, with a specific focus on the role of climate change-led variations in individual crop productivity.

3.3. *Climate-fruit crop juxtaposition*

There are several factors that play a critical role in impacting the crops productivity which can be broadly categorized as abiotic and biotic restrictions. These issues become more pronounced as a result of climate change brought on by global warming (Liliane and Charles, 2020). The soil parameters (soil components, pH, physicochemical and biological qualities), as well as climatic stresses (drought, cold, flood, heat stress, *etc*.), are examples of abiotic restrictions. On the other side, biotic factors consist of beneficial species (pollinators, decomposers, and natural enemies), pests (weeds, vertebrate pests, pathogens), and anthropogenic evolution.Abiotic stressors have a negative impact on a plant's development and productivity as well as cause several morphological, physiological, biochemical, and molecular alterations (Liliane and Charles, 2020). Some of the most significant effects of climate change that have a detrimental effect on crop yields are variations in yearly rainfall, average temperature, the worldwide increase in atmospheric CO_2 and variations in sea levels (Raza *et al*., 2019). To determine how much each factor affects the phenological stage and ultimately the yield, only two variables-temperature (maximum, minimum, and diurnal) and rainfall-were assessed in this study.

A correlation study was carried out to ascertain the association between climatic variables throughout phenological phases and the production of temperate fruit crops. This analysis was done to study the impact of temperature and rainfall in the phenological stages of fruit crops hence affecting the productivity of crops. The analysis highlighted the total percentage of impact on crops by the considered variables only. Multivariate linear regression analysis revealed that during the pre-flowering, flowering, fruit setting, and development stages, highly significant correlations between climate variability and production were found, with an emphasis on the productivity of Apple, Plum, Pear, Apricot, Almond, Walnut, and Grapes (Table 3). The overall impact of climatic variables on the productivity of Apple was 54.4% for the pre-flowering stage. Whereas, the highest impact of these variables was 54.4% on Apricot, followed by Pear (40%), Almond (31.4%), Grapes (20.7%), Plum (19.3%) and Walnut which was least impacted (15.6%). While for the flowering stage, Apricot was impacted the most *i.e*., 72.6% (*highest*) by climatic variables followed by Apple (44.3%), Pear (37.1%), and Walnut (19.8%). However, the other crops during this stage were the least impacted. Whereas, for fruit setting stage, the highest impact of climatic variables was observed for Grapes (53.2%) followed byWalnut (38.2%), Pear, Almond, Plum, Apple and Apricot was least impacted (Table 3). The above impact mentioned in terms of percentage is only due to temperature and rainfall variables. However, there are other factors which are also responsible for impacting the crop productivitywere not considered.

In a nutshell, among the three phenological stages, the most highly impacted crop was Apricot because this crop showed a strong negative correlation with annual rainfall with a highly significant *P* value. This means that as the annual rainfall showed a decreasing trend, very little rainfall was received during these phenological stages, which were crucial for flowering stage development. Hence, the production of apricot declined in Kinnaur district, and this impact in terms of percentage was 54.4% (pre-flowering) and 72.6% (flowering). The increased maximum temperature during the pre-flowering stage was negatively correlated, which supported the flowering development of Apple crops. A strong negative correlation with rainfall, which showed a declining trend, also supports the good flowering, therefore increasing the crop yield of Apples in the district. According to research by Warrington *et al*., (1999), Apple fruit growth is often strongly responsive to temperature early in the season (Tromp, 1977; Ford, 1979), but less responsive later during the fruit development period. Furthermore, the fruit setting stage of Grapes showed a strong positive correlation with diurnal temperature (which increased). This slight increase in the diurnal temperature helps the fruit setting stage which ultimately boost the crop yield of Grapes and the total impact of this variable on these stages was 53.2%.

4. Conclusion

Findings revealed that the average maximum and diurnal temperatures during flowering stages showed a significant increase, *i.e*., 0.027 °C per year and 0.042 °C per year, respectively. However, the variations for other phenological stages did not show any significant variations. Trend analysis for the crop yield revealed that the productivity of Pear and Almond decreased significantly at -0.029 t/ha/year and -0.016 t/ha/year, whereas the productivity of Walnut increased at 0.008 t/ha/year in the last 20 years. Additionally, the district's crop yields of Grapes and Apples climbed while those of Plums and Apricots declined, but the overall trends for all four crops were not supported by significant values. Alongside, the climate and crop relationship revealed that among three phenological stages, the most highly impacted fruit crop during pre-flowering, flowering, and fruit setting stages was Apple (54.4%), Apricot (72.6%), and Grapes (53.2%), respectively.

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