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Research Article

Elevated Temperature-Driven Changes in Phenological Development and Horticultural Traits of Guava (*Psidium guajava* L.) in Punjab

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ABSTRACT

Climate change-driven increase in temperature affects the growth and development of crops. Guava is a tropical fruit which is highly susceptible to an increase in temperatures. So an experiment was conducted to evaluate the impact of elevated temperature regimes on phenology and fruit production quality of three guava cultivars viz., V_1-Shweta, V_2-Allahabad Safeda and V_3-Punjab Pink. The guava cultivars were grown in the open conditions as well as in a temperature gradient tunnel (TGT) and a mean temperature increase of ~1.91-2.73ºC from the open to the closed end of the TGT was recorded. The phenological stages of guava cultivars were significantly advanced under high temperatures. The days from bud appearance to fruit ripening were advanced by 13 to 32, 18 to 41 and 10 to 32 days in cultivars V_1, V_2 and V_3, respectively. Subsequently, the fruit's physical traits, i.e. size and weight, were negatively affected However, the titratable acidic content of guava fruits was positively correlated with elevated temperature. The yield-related attributes, i.e. fruit yield and fruit yield efficiency, showed a decreased (34.1-95.9%) trend in all three cultivars. Similarly, the percent fruit scaring and leaf burning were maximum at higher temperatures. The TSS of Allahabad Safeda fruits showed an increase of 0.29% with a temperature rise of 1.91°C (TGT-1) and hence reflects a divergent pattern. It may be concluded that the rise in temperature in the future will adversely affect the phenological and horticultural performance of guava, though the response will be cultivar-specific depending upon the extent of temperature increase. This differential response of guava cultivars will help the growers and/or scientists in formulating adaptive strategies to counter this climatic challenge.

Key words: Elevated temperature regimes, Guava, Phenology, TGT, TSS, Yield efficiency

Introduction

Guava (*Psidium guajava* L.) commonly known as the '*Apple of Tropics*' is the fourth most cultivated fruit crop in India after mango, banana, and citrus (FAO, 2021). Guava is a hardy crop that is widely grown all across the country, extending from the sea level to 1300m above the mean sea level (Dinesh and Vasugi, 2010). The cultivated area of guava extends from 25°N to 30°S humid tropical (Fischer and Melgarejo, 2021). Guava fruit is cultivated in the tropical as well as in the sub-tropical (Nimisha *et al.,* 2013) parts of the world due to : (i) its adaptability to a wider range of climates and soil types (Pommer and Murakami, 2009) and (ii) reasonably limited amount of asset investment on inputs (Sanda *et al.,* 2011). The successful cultivation of guava requires an annual rainfall of 1000-2000 mm, with a temperature range of 23-28°C (Anonymous, 2022).

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Guava is considered a very hardy tree due to its tolerance to numerous stress situations like drought, flooding, and alkalinity (Parthasarathy *et al.,* 2021). Although this fruit crop is widely adapted to varied soil conditions (Arévalo-Marín *et al.,* 2021), it is more sensitive to weather variations, particularly fluctuating atmospheric temperatures (Hirpo and Gebeyehu, 2019). Temperature fluctuations shift the occurrence of phenological events thereby affecting its different developmental phases (Malhotra, 2017). The prevailing temperature conditions are the chief driving factor for phenological/developmental events such as budding, leaves, and flowering (Laxman *et al.,* 2010). The higher temperatures speed up the plant developmental process (Datta, 2013; Badeck *et al.,* 2004) and induce an earlier time switch to the next phenological stages (Malyshev, 2020). Under North-Indian conditions, an extended winter period results in delayed sprouting of vegetative buds (Yadav and Yadav, 2008; Panda *et al.,* 2022), which ultimately leads to delayed flowering, fruit setting and fruit maturity (Singh and Kushwaha, 2005). Similarly, extreme winters result in pre-harvest fruit drop of the winter-seasoned guava crop as well as higher anthocyanin accumulation in leaves (Hao *et al.,* 2009). At mid-latitudes, with ever-increasing late winter and early spring, the cyclic timing of spring events starts earlier (Chmielewski and Rotzer, 2001; Thakur *et al.,* 2008).

According to NOAA (National Oceanic and Atmospheric Administration), the temperature of the earth has risen by an average of 0.08ºC per decade since 1880 (Anonymous, 2023). So there is a need to set up a phenological station network across India (Kushwaha and Singh, 2008) as crop phenology is largely temperature-dependent and is considered a bio-indicator of climate change. The seasonal appearance and timing of plant life cycle events (Moza and Bhatnagar, 2005), are easily observable and the responsive determinants of global warming (Sparks and Menzel, 2002; Badeck *et al.,* 2004). Even a minor change in climate conditions causes a phenological shift in tree species (NBRI, 2009). Global warming has a greater impact on flowering as the shoot meristem is delicate to temperature changes and severe fluctuation will cause a halt in peak reaction (Moriondo and Bindi, 2007). Flowering is delayed by a fall in temperatures (Yadav and Yadav, 2008). The phenology of crops or the study of the timing of chronic biological events, the causes of their timing about abiotic forces, and the interrelation amongst phases of the different species (Lieth, 1974) need to be investigated for quantitative and qualitative analysis.

In literature, several investigations have been done to ascertain the effect of different temperature regimes on major fruits such as apple, mango, and litchi, however, little information is available in the case of guava. With this objective, a systemic study was conducted to investigate the influence of prevailing and differential temperature regimes on phonological development and horticultural traits of the guava plant. Three cultivars of guava were kept in a Temperature Gradient Tunnel (TGT) and so were exposed to elevated temperature conditions to critically evaluate their growth and behavioural response and compare them with plants kept in open conditions.

Materials and Methods

Experimental site description

The experiment was conducted at Research Farm, Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana. The site is situated at 30°54′N latitude, 75°48′ E longitude and at an elevation of 247 m above mean sea level. It receives an annual rainfall of 750 mm and 75-80% of it is received during July-September with a few rain showers during the winter season (Prabhjyot-Kaur *et al.,* 2016). The soil of the experimental site was found to be sandy loam textured with a neutral pH value of 8.2, electrical conductivity ranging from 0.12-0.18 ds/m, and organic carbon ranging from 0.02-0.18%. Weekly data of meteorological parameters (maximum temperature, minimum temperature, and rainfall) for 2019 were collected from the Agro-meteorological Observatory of the Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana. The average maximum temperature recorded was 28.96°C with extremes of 42.74°C and the minimum temperature was 17.80°C with extremes of less than 5.70°C.

Temperature Gradient Tunnel (TGT)

The experiment was conducted during the crop years 2019 within a Temperature Gradient Tunnel (TGT) which is made up of galvanized iron pipes and covered with polythene sheets having a dimension of 30 m in length, 5 m in breadth, and 3 m in height (Fig. 1). The cooling pads at the backside wherein water is sprinkled with the pump produce a cool draft and the two exhaust fans suck in the cool air draft from the backside of TGT, thereby producing a gentle gradient of the temperature. The meteorological data within and outside the TGT was monitored with a set of temperature and relative humidity sensors installed within and one set outside the TGT. The data was sensed by the data logger (Delta-T devices make) at a five-minute interval and logged at half an hour intervals.

Experimental description

The experiment was carried out in Randomized Complete Block Design (RCBD) with three treatments of elevated temperature regimes (+1.91°C, +2.45°C, and +2.73°C), whereas the fourth treatment of open-field conditions outside TGT served as full control. A total of thirty-six plants of three cultivars, i.e., "Shweta", "Allahabad Safeda" and "Punjab Pink" (replicated thrice) planted in cemented pots (24-inch size) were placed within the TGT, while twelve plants having a similar genotypic constitution were placed outside TGT.

The experiment was planned to investigate the phenological and horticultural traits of guava cultivars planted inside TGT and outside the TGT, during their active growth phase. i.e., April to November during year 2019. The phenological data was recorded from the four tagged shoots of each plant. The monitoring of experimental trees and recording of observations was done daily in case of critical phenophases. The phenological transformations i.e., in terms of the time of commencement and duration of their occurrence from flower bud emergences to fruit maturity, were recorded and additional phenological alterations happened under different temperature regimes. The

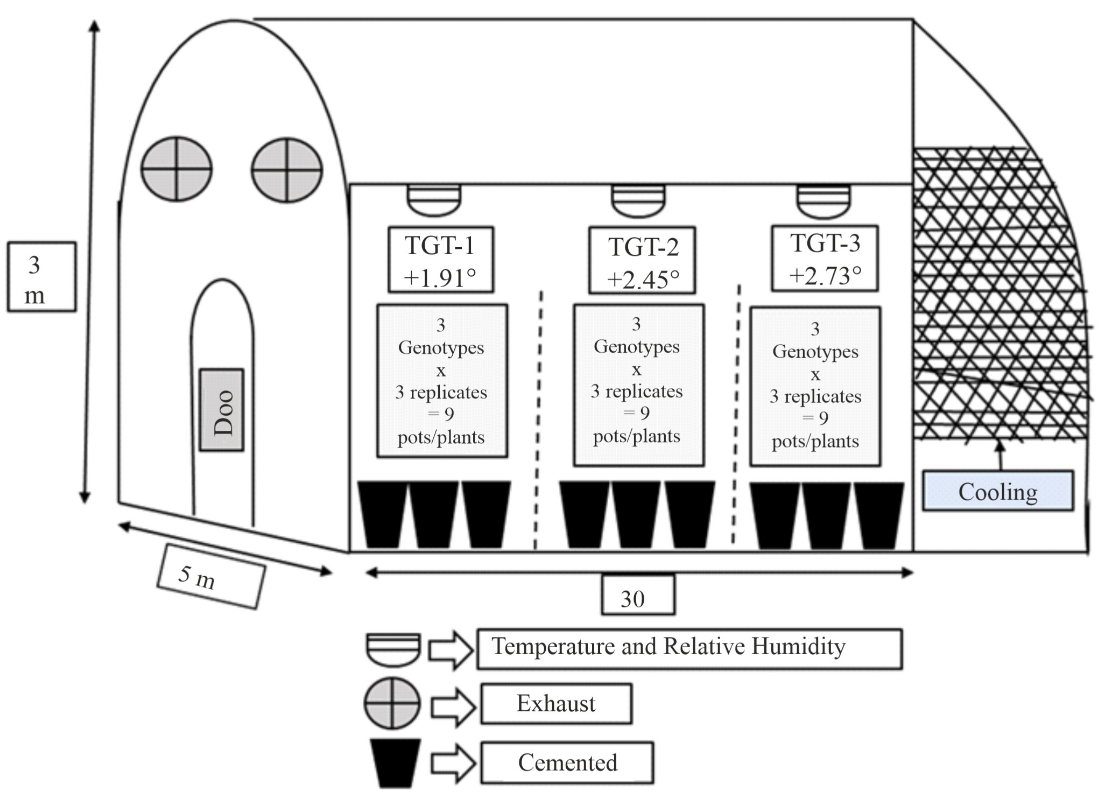

Fig. 1. Diagrammatic representation of the Temperature Gradient Tunnel (TGT)

tree canopy volume (CV) was calculated (Eq.1) by using the formula given by Roose *et al.* (1986) as given below :

$$CV = \frac{4}{6\pi} hr^2 \qquad \ldots(1)$$

where, h = height of tree (m) r = (Sum of East-West and North-South direction (m)/4.

The yield efficiency (kg/cm^2) was calculated (Eq. 2) by the method described by Westwood (1993) as given below :

$$\text{Yield efficiency} = \frac{\text{Yield (kg)}}{\text{Tree tunk cross sectional area (TCSA)}} \qquad \ldots(2)$$

where Yield = Yield (kg) of the tree
Trunk cross-sectional area (TCSA) = πr^2

r = Radius (cm) of the tree

The sampling was done from the whole plant for recording the horticultural traits. The physio-chemical characteristics were recorded as per standard procedures. The total soluble content (TSS) of fruits was estimated using a digital hand refractometer in terms of degree Brix.

Titratable Acidity (%) was measured by titration of fruit juice with standardized N/10 Sodium Hydroxide (NaOH) solution, using phenolphthalein dye (two drops). However, ascorbic acid content (Vitamin C) was determined using 2, 6-dichlorophenol indophenols dye (DCPIP) visual titration method (AOAC, 2000).

The statistical analyses of the data were performed using the R studio (R Core Team, 2013). R packages "*lme4*" and "*lmerTest*" were used in the ANOVA analyses. The Pearson correlation coefficient (r) was used to analyze the degree and magnitude of correlation of the increased temperature with the horticultural performance of guava. It was computed (Eq. 3) as given below :

$$r = \frac{COV_{xy}}{\sigma_x^2 + \sigma_y^2} \qquad \ldots(3)$$

where COV_{xy} = covariance between trait x and trait y,

σ_x^2 = variance of trait x, σ_y^2 = variance of trait y.

The package "ggcorrplot2" was used for the correlation analysis. The principal component analysis (PCA) was used to analyze the main factors and calculated using "factoextra" and "FactoMineR" packages from R studio.

Results

The gradients of temperature were achieved in the longitudinal direction of the tunnel and the gradients showed a linear increase of 1.91-2.73°C from the open to the closed end. The weekly progress of minimum and maximum temperature during the crop growing period is shown in Fig. 2. The average temperature gradient was 1.91°C (TGT-1), 2.45°C (TGT-2) and 2.73°C (TGT-3) as compared to the ambient environment. The increase in temperature under the TGT tunnel induced various changes in the floral, and fruit characteristics, and that further affected yield and fruit quality of different guava cultivars. The results are presented as follows:

Effect of elevated temperature regimes on phenological stages of guava cultivar

The phenological calendar of guava cultivars Shweta, Allahabad Safeda, and Punjab Pink inside TGT and open normal conditions are presented in Table 1. The vegetative bud appearance first commenced in Allahabad Safeda under TGT-3 on the 18th of February. Similarly, the duration of different phenological stages was reduced linearly with an elevated temperature in all three cultivars of guava with a maximum reduction of 42 days (from bud appearance to fruit ripening) in Allahabad Safeda with a temperature increment of 2.73°C. Whereas, the phenological changes in Shweta and Punjab Pink were somewhat similar with a maximum reduction of approximately 32 days under a TGT-3 environment (2.73°C). The transition period from bud appearance to fruit setting in Allahabad Safeda was 57 days under TGT-3 as against 80 days in an open environment. Thus, the length of this interval is the main driver of the advancement of fruit maturity of Allahabad Safeda. The advancement in fruit maturity of Shweta and Punjab pink might be due to the length of a transition period of fruit development (75%) to fruit ripening. The length of the interval between different phenological shifts decreased at varying intensities with a non-significant trend between different phenological shifts of this

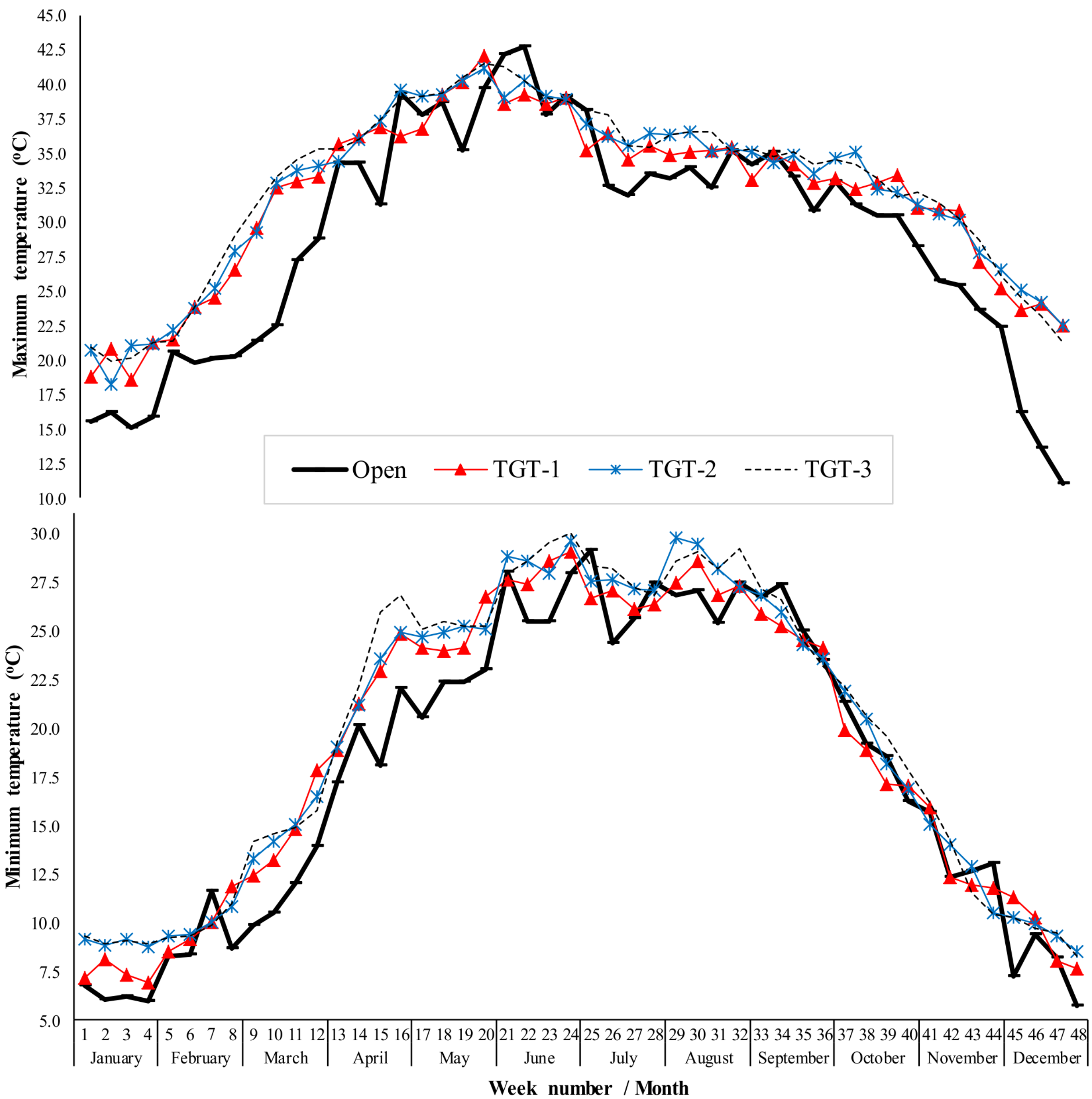

Fig. 2. Comparison of the weekly progress of daily ambient (Open) and TGT maximum and minimum temperature (ºC) during the guava crop growing phase

cultivar. This differential response of cultivars suggests that guava breeders might be able to harness these differences to help adapt to the high-temperature stress challenge posed by climate change.

Effect of elevated temperature regimes on growth attributes of guava cultivars

Elevated temperatures brought about significant differences in the plant height of guava plants across the different regimes (Fig. 3A). The plant height of the guava cultivar was significantly higher under open conditions. The plant height of the Shweta cultivar increased up to 6.2% at 1.91°C, and then decreased by 2.6 and 6.2% with an increase in mean elevated temperature by 2.45 and 2.73°C. However, the plant height of Allahabad Safeda and Punjab Pink was significantly reduced by 9.0 to 12.8% and 5.8 to 13.0%, respectively at elevated temperature levels. Similarly, canopy volume was reduced under

Table 1. Dates of onset of different phenological phase, their duration in terms of days for rainy season crop of three guava cultivars under open field (OEC) and elevated temperature (TGT) conditions

Phenological	Shweta				Allahabad Safeda				Punjab Pink			
stages	OEC	TGT-1	TGT-2	TGT-3	OEC	TGT-1	TGT-2	TGT-3	OEC	TGT-1	TGT-2	TGT-3
Bud appearance	26 February -	21 February -	20 February -	19 February -	26 February -	23 February -	20 February -	18 February -	27 February -	25 February -	24 February -	22 February -
Bud swelling	3 March (6)	26 February (5)	25 February (5)	24 February (5)	3 March (6)	28 February (6)	24 February (5)	23 February (5)	4 March (5)	3 March (5)	2 March (5)	26 February (5)
Appearance of floral buds	11 April (38)	1 April (35)	1 April (34)	29 March (33)	12 April (40)	5 April (36)	30 March (34)	27 March (32)	16 April (43)	14 April (43)	12 April (40)	8 April (40)
Flower buds visible	19 April (7)	8 April (8)	7 April (7)	5 April (7)	21 April (10)	14 April (9)	9 April (9)	8 April (8)	24 April (8)	21 April (7)	19 April (7)	14 April (6)
Flower opening (50%)	4 May (15)	21 April (14)	20 April (13)	17 April (12)	6 May (16)	25 April (11)	19 April (10)	15 April (5)	10 May (16)	6 May (14)	2 May (13)	26 April (11)
Fruit setting	14 May (11)	30 April (9)	28 April (8)	24 April (8)	15 May (10)	3 May (8)	26 April (7)	21 April (6)	22 May (12)	17 May (11)	10 May (10)	5 May (9)
Fruit development (75%)	18 July (65)	22 June (53)	19 June (51)	12 June (48)	16 July (61)	26 June (53)	15 June (49)	9 June (48)	22 July (60)	12 July (55)	9 July (49)	22 June (48)
Fruit colour change	30 July (12)	11 July (19)	5 July (16)	24 June (11)	30 July (15)	9 July (15)	28 June (14)	20 June (12)	4 August (13)	24 July (12)	20 July (11)	2 July (10)
Fruit ripening	14 August (13)	22 July (11)	15 July (12)	5 July (10)	12 August (13)	22 July (13)	11 July (13)	1 July (11)	14 August (10)	4 August (10)	29 July (9)	9 July (7)
Total days*	167	154	147	135	169	151	141	128	168	158	145	136

† Parenthesis figures indicate the number of days to achieve the stage

*Total days required from bud appearance to fruit ripening

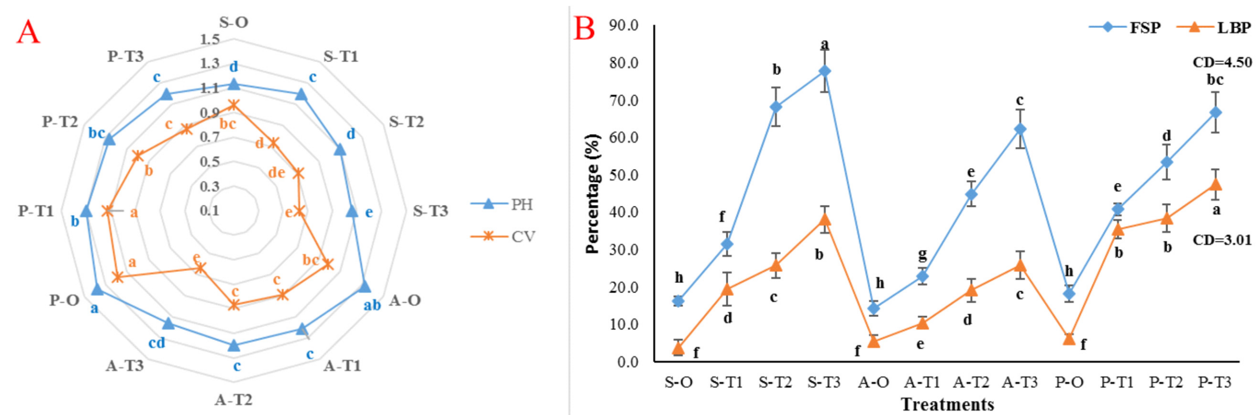

Fig. 3. A) Plant height (PH), tree canopy volume (CV) characteristics and B) Fruit scaring (FSP) and leaf burning (LBP) of three guava cultivars under open field (O) and elevated temperature (T1, T2 and T3) conditions. S= Shweta, AS= Allahabad Safeda, PP= Punjab Pink

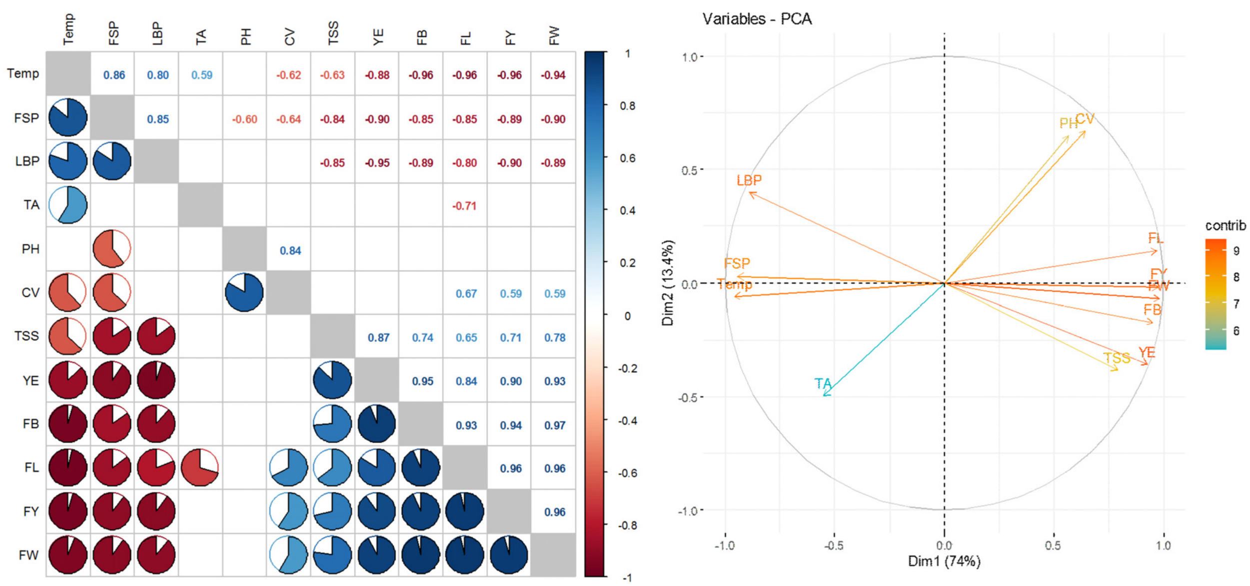

Fig. 4. A) Correlation analysis B) PCA analysis of horticultural performance of guava cultivars at elevated temperature conditions inside the TGT.

Temp= temperature, FSP= fruit scaring percentage, LBP= leaf burning percentage, TA= titratable acidity, PH= plant height, CV= canopy volume, TSS= total soluble solids, YE= yield efficiency, FB= fruit breadth, FL= fruit length, FY= fruit yield, FW= fruit weight

elevated conditions (ranging from 5.0 to 34.7%) as compared to ambient conditions (Fig. 3A). Inside the temperature gradient tunnel, a non-significant correlation of the temperature regimes with plant height of guava but a negative correlation between with canopy volume ($r= -0.62, p<0.01$) was observed (Fig 4A). In general, the leaf burning (LBP) and fruit scaring percentages (FSP) of the three cultivars increased with an increase in temperature. The variability in fruit scaring and leaf burning under TGT environments was 1.9 to 4.8 and 1.9 to 10.3 times, more pronounced as compared to open conditions (Fig. 2B). The fruit scaring of the Shweta cultivar was more pronounced (varied from 31.3 to 77.8%), whereas the leaf burning was more pronounced in Punjab pink (varied from 35.3 to 47.3%). The correlation between elevated temperature and FSP and LBP was highly significant, with a correlation coefficient (r) of 0.86 ($p<0.01$) with FSP and 0.80 ($p<0.01$) with LBP.

Effect of elevated temperature regimes on horticultural performance of guava cultivar

The results of the study indicated that the floral number, fruit retention, and fruiting density of the cultivar in elevated temperature treatments was 31.7 to 64.2%, 5.1-64.6%, and 15.1 to 85.7% respectively, lower than that under ambient temperature treatment (Table 2). The variability in floral characteristics under TGT was more pronounced as compared to open conditions. Maximum reduction of flower number (64.2%), fruit retention (64.6%), and fruiting density (85.7%) were under TGT-3 environment (i.e. 2.73°C). Elevated temperature conditions exhibited a significant negative effect on the fruit's physical attributes. The rise in temperature inside the TGT caused a significant reduction in the fruit weight (FW) of the studied cultivar. Under the TGT-III environment, the fruit weight reduction of 29.1, 18.6, and 22.5% for Shweta, Allahabad Safeda, and Punjab Pink, respectively. This could be attributed to a decrease in fruit length (Shweta =22.2%, Allahabad Safeda =16.1%, Punjab Pink =17.7%).) and fruit breadth (Shweta =19.0%, Allahabad Safeda =16.1%, Punjab Pink =16.9%). In general, the TSS percentage of guava fruits was significantly lower under elevated conditions than in ambient conditions. However, guava cv. Allahabad Safeda fruits yielded an increase in TSS by 0.29 % under the TGT-I environment (+1.91°C). The elevated temperature conditions stimulated an increase in the titratable acidity of guava fruits by 16.1-17.9% in cv. Shweta, 1.7-5.0% in Allahabad Safeda and 1.8-14.3% in Punjab Pink as compared to ambient temperature (Table 3).

The correlation analysis revealed the highest negative correlation of -0.96 ($p<0.01$) between temperature vs. fruit breadth (FB) and fruit length (FL). Similarly, the correlation coefficient between temperature and FW reached -0.94 ($p<0.01$). While, the correlation between temp

Table 2. Floral, fruiting and yield related traits of three guava cultivars under open field (OEC) and elevated temperature (TGT) conditions

Cultivar	Temperature conditions	Flower numbers	RP* (%)	Fruit Retention (%)	RP* (%)	Fruit Yield (kg/ tree)	RP* (%)	Fruiting density	RP* (%)	Yield Efficiency (kg/ m^3)	RP* (%)
Shweta	OEC	95.6 ± 4.93 ^{b}	0	52.51±12.61^{bc}	0	2.01±0.27 ^{b}	0	19.34 ± 1.23 ^{a}	0	2.08 ± 0.19 ^{a}	0
	TGT-I	65.3±6.03 ^{cd}	31.70	48.61 ± 2.41^{c}	7.43	0.87±0.15 ^{d}	56.71	15.27 ± 3.39 ^{abc}	21.04	1.25 ± 0.30^{bc}	39.90
	TGT-II	65.0±7.55 ^{cd}	32.01	46.16 ± 15.92	12.10	0.56±0.14 ^{ef}	72.13	9.89 ± 1.62 ^{cde}	48.86	0.75 ± 0.14^{cde}	63.94
	TGT-III	62.0 ± 5.20 ^{d}	35.15	32.5 ± 4.33^{de}	38.11	0.17± 0.03 ^{gh}	91.54	4.72 ± 0.46^{ef}	75.59	0.27 ± 0.04 ^{e}	87.01
Allahabad Safeda	OEC	114.6±7.37 ^{a}	0	48.78 ± 2.11^{c}	0	1.93± 0.08 ^{b}	0	19.42±1.91 ^{a}	0	1.98 ± 0.21 ^{a}	0
	TGT-I	74.7 ± 7.68 ^{c}	34.82	46.27 ± 3.80	5.13	1.27± 0.02 ^{c}	34.19	16.49 ± 0.27^{ab}	15.08	1.43 ± 0.09^{ab}	27.77
	TGT-II	72.7±7.02 ^{cd}	36.57	48.04 ± 4.46	12.32	0.78± 0.06 ^{de}	59.59	11.89 ± 2.16 ^{bcd}	38.77	0.96± 0.19^{bcd}	51.51
	TGT-III	71.3±2.08 ^{cd}	37.79	31.98 ±3.01 ^{de}	34.44	0.36± 0.05 ^{fg}	81.34	6.11 ± 0.52^{def}	68.54	0.41 ± 0.05^{de}	79.29
Punjab Pink	OEC	123.6±7.37 ^{a}	0	73.72 ± 7.86 ^{a}	0	2.47± 0.26 ^{a}	0	13.97 ± 2.10 ^{abc}	0	1.45 ± 1.26^{ab}	0
	TGT-I	50.0 ± 6.56 ^{e}	59.55	56.42± 10.62^{bc}	23.47	0.63± 0.17 ^{e}	74.49	7.30 ± 1.40 ^{def}	47.74	0.55 ± 0.13 ^{de}	62.07
	TGT-II	48.0 ± 5.20 ^{e}	61.17	46.14±17.00 ^{cd}	37.41	0.34 ± 0.10 ^{fg}	86.23	5.26 ± 1.58 ^{ef}	62.34	0.36 ± 0.14 ^{de}	75.17
	TGT-III	44.3±13.01 ^{e}	64.16	26.11 ± 6.74^{e}	64.59	0.10± 0.05 ^{h}	95.95	2.00 ± 0.10 ^{f}	85.68	0.10 ± 0.04 ^{e}	93.10
CD (≤0.05)		12.54		11.02		0.41		6.03		0.69	

*RP= Reduction percentage

Table 3. Fruit physio-chemical characteristics in three guava cultivars under open field and elevated temperature conditions

Cultivar	Temperature conditions	Fruit Weight (g)	RP* (%)	Fruit Length (cm)	RP* (%)	Fruit Breadth (cm)	RP* (%)	TSS	RP*/EP** (%)	Acidity (%)	EP** (%)**
Shweta	OEC	107.52 ± 2.82 ^{a}	0	6.00 ± 0.10^{ab}	0	6.05 ± 0.05 ^{a}	0	10.00 ± 0.1^{ab}	0	0.56 ± 0.02^{cd}	0
	TGT-I	90.70 ± 1.02 ^{cd}	15.64	5.08 ± 0.08 ^{de}	15.33	5.35 ± 0.15 ^{c}	11.57	9.76 ± 0.15^{bcd}	2.40	0.66 ± 0.01 ^{a}	17.86
	TGT-II	88.26 ± 0.83 ^{de}	17.91	5.03 ± 0.06 ^{de}	16.17	5.26 ± 0.08 ^{cd}	13.06	9.66 ± 0.15^{cde}	3.40	0.66 ± 0.01 ^{a}	17.86
	TGT-III	76.19 ± 4.93^{h}	29.14	4.66 ± 0.21 ^{f}	22.23	4.90 ± 0.10^{gh}	19.01	9.13 ± 0.23 ^{g}	8.70	0.65 ± 0.03 ^{a}	16.07
Allahabad Safeda	OEC	101.93 ± 1.69 ^{b}	0	5.91 ± 0.08 ^{b}	0	5.98 ± 0.03 ^{a}	0	10.20 ± 0.1 ^{a}	0	0.60 ± 0.03^{abcd}	0
	TGT-I	93.05 ± 4.58 ^{c}	8.71	5.28 ± 0.13 ^{c}	10.66	5.28 ± 0.13 ^{cd}	11.71	10.23 ± 0.15 ^{a}	0.29*	0.63 ± 0.05^{ab}	5.00
	TGT-II	89.64 ± 1.39^{cde}	12.06	5.16 ± 0.03 ^{cd}	12.69	5.21 ± 0.06 ^{de}	12.88	9.90 ± 0.1^{bc}	2.50	0.63 ± 0.04 ^{a}	5.00
	TGT-III	82.97 ± 1.27^{fg}	18.60	4.96 ± 0.06 ^{e}	16.08	5.02 ± 0.03^{fg}	16.06	9.43 ± 0.06^{ef}	7.55	0.61 ± 0.03^{abcd}	1.67
Punjab Pink	OEC	104.36 ± 0.81^{ab}	0	6.11 ± 0.03 ^{a}	0	5.80 ± 0.05 ^{b}	0	9.73 ± 0.21^{bcd}	0	0.56 ± 0.02 ^{d}	0
	TGT-I	86.62 ± 2.55^{def}	17.00	5.10 ± 0.10 ^{de}	16.53	5.10 ± 0.05^{ef}	12.07	9.56 ± 0.21 ^{de}	1.75	0.64 ± 0.03 ^{a}	14.29
	TGT-II	86.19 ± 2.87^{ef}	17.41	5.08 ± 0.08 ^{de}	16.86	5.08 ± 0.08^{ef}	12.41	9.53 ± 0.06 ^{de}	2.06	0.62 ± 0.02^{abc}	10.71
	TGT-III	80.89 ± 0.87 ^{g}	22.49	5.03 ± 0.06 ^{de}	17.66	4.82 ± 0.06 ^{h}	16.90	9.23 ± 0.25^{fg}	5.14	0.57 ± 0.06^{bcd}	1.79
CD (≤0.05)		4.28		0.20		0.23		0.25		0.07	

*RP= Reduction percentage, **EP= Elevated percentage, TSS= Total soluble solids

and TSS is somewhat weaker (r= -0.63, p<0.01) which might be due to the large extent of variation for traits in the studied cultivars. The analysis revealed that fruit yield (kg/ha) was reduced by 91.5% (Shweta), 81.4% (Allahabad Safeda), and 96.0% (Punjab Pink) with an increase in mean elevated temperature (of 1.91, 2.45, and 2.73°C) from the ambient condition. Amongst the cultivars, the fruit yield was reduced to the maximum in the cv. Punjab Pink (74.5 to 96.0%) and minimum in cv. Allahabad Safeda (34.2 to 81.4%). Similarly, minimal fruit yield efficiency reduction was observed in Allahabad Safeda as compared to Shweta and Punjab Pink. As compared to ambient temperature, the fruit yield and yield efficiency were significantly reduced by 34.2 to 96.0% and 27.8 to 93.1%, respectively. The highest correlation coefficient of -0.96 (p<0.01) was observed for Temp vs. fruit yield (FY), while between temperature and yield efficiency (YE) is somewhat lesser (r = -0.88, p<0.01) as compared to FY.

Similarly, to correlation analysis, the PCA depicts that the increase in temperature has a very strong relationship with FSP, LBP, and TA, while it has a negative association with fruit physical traits (i.e., FW, FL, FB), TSS, and yield efficiency (YE). The first two components of PCA i.e., PC1 and PC2 have an eigenvalue of more than 1 and their contributions were 74 and 13.4%, respectively (Fig. 4B). The cumulative contribution reached 87.4%, thereby indicating that these two components already contained most of the information regarding the horticultural performance of different guava cultivars under the elevated temperature regimes. PC1 was strongly correlated with Temp, FSP, LBP, FY, FW, FL, FB, and TSS. Whereas PC2 was associated with PH, CV, and TA. Therefore, based on this field evidence, warming during the growing season and fruit development period leads to the overall deterioration in the appearance of leaf and fruit skin and thus, has a significant negative effect on the commercial acceptability of guava fruits.

Discussion

One of the most perceptible effects of climate change is the increase in temperature (Anonymous, 2023). The phenological development of plants is highly susceptible to this increase in temperature

(Kushwaha and Singh, 2008). Guava is a very hardy fruit plant which is acclimatized to a wide range of environmental conditions. However, its phenological development and growth attributes are also affected by the rise in temperature. Guava is an important fruit crop of Punjab state and so a study was conducted by exposing the guava cultivars to elevated temperature conditions created within a TGT (30 m length x 5 m w x 5 m height) by exhaust fans sucking the cool draft of air from the front end which is produced with water getting sprinkled on cooling pads at the back end. The data on phenological development, growth and horticultural traits of three guava cultivars (Shweta, Allahabad Safeda and Punjab Pink) were recorded and analysed.

Plant height is an index of the growth and development of tree crops. One of the easily observed effects of high-temperature stress is growth retardation due to the alteration in cellular processes i.e. cell division and cell elongation, which significantly affect the leaf size, morphology and leaf weight (Dinesh and Reddy, 2012). The optimum temperature range for optimal growth of most of the tropical fruits was about 24-30°C (Rajan, 2012). In the present study, the height growth rate was suppressed under elevated temperature regimes and, as a result, plant height and canopy volume of the guava cultivar were reduced under elevated temperature regimes. The plant height of Allahabad Safeda and Punjab Pink was significantly reduced by 9.02-12.78% and 5.80-13.04%, respectively at elevated temperature levels. In the case of cv Shweta, the plant height increased up to 6.20% at an elevated temperature of 1.91°C from ambient, but a further increase in temperature by 2.45 and 2.73°C from ambient decreased the plant height by 2.65 and 6.19%, respectively. Consequently, the canopy volume was reduced under elevated conditions by 5.04 to 34.69% as compared to ambient conditions. Similar results on increase in plant height under elevated temperature environments were reported in different fruit crops such as apple (Zavala *et al.,* 2004), grapevine (Tombesi *et al.,* 2022), olive (Elloumi *et al.,* 2020) and peach (Mohamed *et al.,* 2004).

The rise in temperature both delays and advances the phenological stages of fruit trees and results in deviations in vegetative and reproductive growth phases (Panda *et al.,* 2021). The climatic variables i.e., temperature (Thakur *et al.,* 2008) and rainfall (Ragusa-Netto and Silva, 2007) are assumed to be the main elements affecting the phenology of tree crops. The phenological stages of the guava cultivars were advanced with the warming effect of temperature inside the TGT environment. In the guava cultivars Shweta, Allahabad Safeda and Punjab Pink the days from bud appearance to fruit ripening was advanced by 13 to 32, 18-41 and 10-32 days, respectively. These results are in concurrence with results reported in fruit plants, i.e., in grapevine (Reis *et al.,* 2020; Cameron *et al.,* 2022), guava (Brar *et al.,* 2021), cherry (Chmielewski *et al.,* 2001), and apple (Zavala *et al.,* 2004). Makhmale *et al.* (2016) observed that the effect of climate change on the phenology of mango is the deciding factor for the habitat and distribution of different cultivars. Similarly, Rajan (2012) also reported that temperature has a great effect on the growth cycle of mangoes in almost all mango-growing areas. Chmielewski *et al.* (2001) highlighted the effect of the timing of phenophases of fruit trees on their yield in terms of absolute economic return and pointed out that it gets disturbed due to the associated effects of climate change. Under North-west Indian conditions, the rise in temperature during February-March severely affects the flowering and fruiting in 'Kinnow' mandarin (Dalal and Kumar, 2018). The high temperature is not favourable for fruit and shoot growth of apples after full bloom (Calderón-Zavala *et al.,* 2004).

In literature, direct and indirect effects of environmental factors on horticultural traits of fruit crops such as abscission rate which compromises the yield of fruit crops (Khefif *et al.,* 2020) have been reported. In the present study, with an increase in temperature by +2.73°C (TGT-3) from ambient the fruit yield in cv. Punjab Pink was reduced by ~ 95.96%, in cv Shweta by 91.54% and in cv. Allahabad Safeda by 81.35%. Khefif *et al.* (2020) observed that a rapid change from low to high temperature favours the fruit abscission of citrus fruits since the tree starts accumulating carbon in its tissues. The abrupt increase in heat stress in plants hurts the uptake of nutrients and it ultimately leads to a decrease in both plant growth as well as fruit productivity. These results have been studied for different fruit crops such as mango (Rajan, 2012), grapevine (Reis *et al.,* 2020), guava (Brar *et al.,* 2021), and cherry (Chmielewski *et al.,* 2001). Dalal and Kumar, (2018) reported that the high temperature prevailing at the time of blooming in Kinnow mandarin resulted in lesser fruit-setting. Warming during the spring season results in inadequate chill unit accumulation of apple plants which greatly influences the fruit setting and ultimately the fruit yield (Nautiyal *et al.,* 2020).

The TSS / total acidity ratio is a physiological parameter that can influence the quality of guava fruit. In the present study, increased temperature regimes seemed to decrease hurt the accumulation of total soluble solids but simultaneously increased the titratable acidic content of fruits. Previous studies in citrus fruits have shown reduced TSS contents of fruits under high-temperature treatment (Susanto *et al.,* 1990; Moon *et al.,* 2015; Kim *et al.,* 2021). Further, the advancement of phenophases, makes it possible to affect the growth and production of flower buds and fruit development. Thus, higher temperatures accelerate fruit development of horticultural crops, leading to earlier maturity, smaller fruit size and poor quality of fruits. Overall, the rise in temperature if it occurs at the projected magnitude in future, will hurt fruit production (Medda *et al.,* 2022). The daily variations in temperature and humidity can cause citrus fruit peel to crack or crease which deteriorates the fruit quality and production (Khadivi-Khub, 2015; Juan and Jiezhong, 2017). In warmer regions, temperatures exceeding the optimal threshold during flower bud differentiation can lead to a reduction in fruit quality (Saygi, 2020). Hence rise in temperature from normal/optimum from bud initiation to harvest promotes the advancement of phenological phases and consequently is thought to negatively affect fruit characteristics, quality and production.

Conclusions

Climate change is expected to have a detrimental impact on agriculture. In the present study, the phenological behaviour and horticultural performance of three cultivars of guava were critically evaluated under three elevated temperature regimes ((+1.91ºC, +2.45ºC and +2.73ºC) within a TGT. The results revealed a significant advancement in the flowering and fruiting of guava which subsequently affected the horticultural traits of guava fruit. A negative relationship between the total soluble content of fruits and high temperature inside the TGT was recorded. However, the acidic content of fruits has a positive correlation with temperature. So further screening of guava cultivars may help in identifying some of the genetically diverse guava cultivars which may be able to cope with high-temperature stresses.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability Statement

The datasets generated for this study are available to the corresponding author upon reasonable request.

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