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Chilling Hours and Growing Degree Days of Himalayan Wild Pomegranate

Divya Mehta[1, *], Tara Gupta[1], Rakesh Kumar Gupta[2], Sanjeev Thakur[1], Jai Pal Sharma[1], Parminder Kaur Baweja[3], Parul Sharma[4]

[1]Department of Tree Improvement and Genetic Resources, Dr Yashwant Singh Parmar University of Horticulture and Forestry Nauni, Solan, India

[2]Department of Basic Science, Dr Yashwant Singh Parmar University of Horticulture and Forestry Nauni, Solan, India

[3]Directorate of Extension Education, Dr Yashwant Singh Parmar University of Horticulture and Forestry Nauni, Solan, India

[4]Department of Biotechnology, Dr Yashwant Singh Parmar University of Horticulture and Forestry Nauni, Solan, India

Email address:

divya.mehta1726@gmail.com (Divya Mehta)

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Abstract: The purpose of the present experiment was to determine chilling hours and growing degree hours of *Punica granatum* L. in four sites *viz*., Narag, Jonaji, Waknaghat and Nauni, in Himachal Pradesh, India. More variation exists between sites as compared to the within sites for most of the duration of phenophases. Chilling hour and GDH for vegetative bud were lower as compared to reproductive bud. Chilling hours and growing degree hours for vegetative bud ranged from 779.0 (Nauni) to 921.9 hours (Jonaji) and 914.5 (Jonaji) to 1067.9°C (Narag), respectively. However, for reproductive bud, chilling hours and growing degree hours fluctuated from 836.0 (Narag) to 1155.1 hours (Jonaji) and 1220.0 (Jonaji) to 2164.3°C (Narag), respectively. Narag with warmer microclimate had lower chilling requirement and higher value for growing degree hours than the Jonaji with cooler microclimate, suggesting adaption of the genotypes to the given climatic conditions. GDH was significantly correlated with the leaf area (0.64) and fruit weight (0.69) of the wild pomegranate. The findings of this study have important implications for optimizing the cultivation and management of Punica granatum L. in varying climatic conditions. Understanding the differential chilling and growing degree hour requirements between vegetative and reproductive buds, as well as the influence of microclimate on these parameters, can guide the selection of suitable genotypes for specific locations.

Keywords: *Punica Granatum*, Chilling Hours, Growing Degree Days, Leaf Area, Fruit Weight

1. Introduction

Pomegranate is a fruit crop consumed worldwide owing of its health benefits. The species is native to Central Asia, however, cultivated throughout the globe in different micro-climate regions. Wild population of tree crops carries significant genetic variation, which is the key to success of any tree improvement program. Mid-altitude regions of North Indian states are habitat of Wild populations of the pomegranate. In North India, the fruit of wild pomegranate is called Daru. Wild pomegranate fruits are sourer in taste and people don't prefer to consume their ripe arils as in the case of cultivated pomegranate arils. However, its dried arils (*anardana*) are used massively for culinary purposes. *Anardana* is the main value-added product of wild pomegranate and it provides livelihood to local people. The market price of *anardana* varies from 300 to 400 ₹ per kilogram, depending on the grade of the aril which is decided by its colour [13]. Other than dried arils, the rind of the fruit fetched half of the *anardana* market price.

Wild pomegranate is a deciduous fruit tree species found in temperate as well as sub-tropical climatic conditions. Phenology is a complex character and it is significantly influenced by microclimatic conditions such as air temperature and precipitation [11]. During winter the species enters into a dormancy stage, the start of which is characterized by the shedding of all leaves. After the start of dormancy, the tree begins to accumulate chilling hours until the chilling requirement of the buds is fulfilled, which is characterized by the bursting of vegetative or reproductive buds [4]. One chilling hour (CH) is equal to one hour in less than 7.2°C air temperature [1]. Once the required chilling hours are accumulated by the tree, it starts to accumulate heat to enter the next phenophases [4] *i.e.* leafing (in case of vegetative buds) or flowering (in case of reproductive buds). Elloumi *et al.* reported early flowering at warmers locations [5]. The total heat accumulated by the tree during this process is called Growing Degree Hours (GDH). One GDH (°C) is one hour in temperature 1°C above the base temperature [5].

Chilling and heat requirements of wild pomegranate will help in anticipation of phenological stages. This information can be utilized in breeding programs, canopy management, pest management etc. Many studies are carried out on determination of chilling hours and growing degree hours of cultivated pomegranate, however, there is a lack of such research in wild pomegranate populations in the Western Himalayan region. Therefore, the present study was carried out to determine phenology and thermal requirement of wild pomegranate.

2. Materials and Methods

2.1. Study Sites

The study was conducted in the four selected sites *viz*., Narag, Jonaji, Waknaghat and Nauni, in Himachal Pradesh, India. Selected sites had distinct topographic features (Figure 1). The altitude of the sites ranged from 1209 (Nauni) to 1483 m a.m.s.l. (Waknaghat). Except for Nauni, all sites had moderately steep slopes. The aspect of the sites varied from North to South facing.

2.2. Observations Recorded

Within each site three pomegranate genotypes were selected and five branches of every genotype were tagged to study phenophases. Vegetative and reproductive phenophases of selected genotypes were recorded weekly during 2020-2021. The phenophases are described in Figure 2. Leaf size, proportion of hermaphrodite flowers and fruit weight for selected genotypes was also observed. Weather data from December, 2020 to December, 2021 was acquired [6]. The mean daily air temperature and rainfall varied from 18.85 (Jonaji) to 19.63°C (Narag) and 2.88 to 3.16 mm/day, respectively, during the study period.

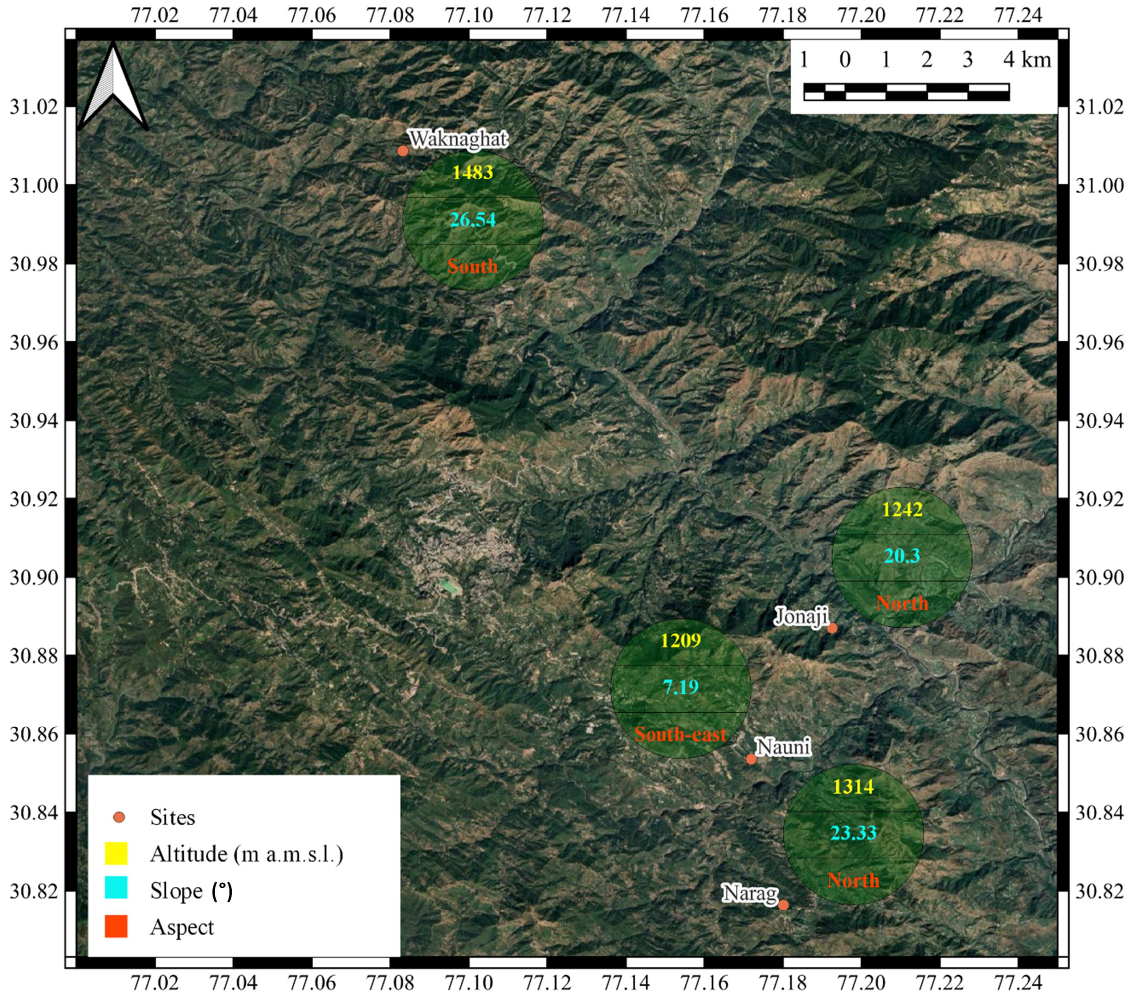

Figure 1. *Topography of the study sites.*

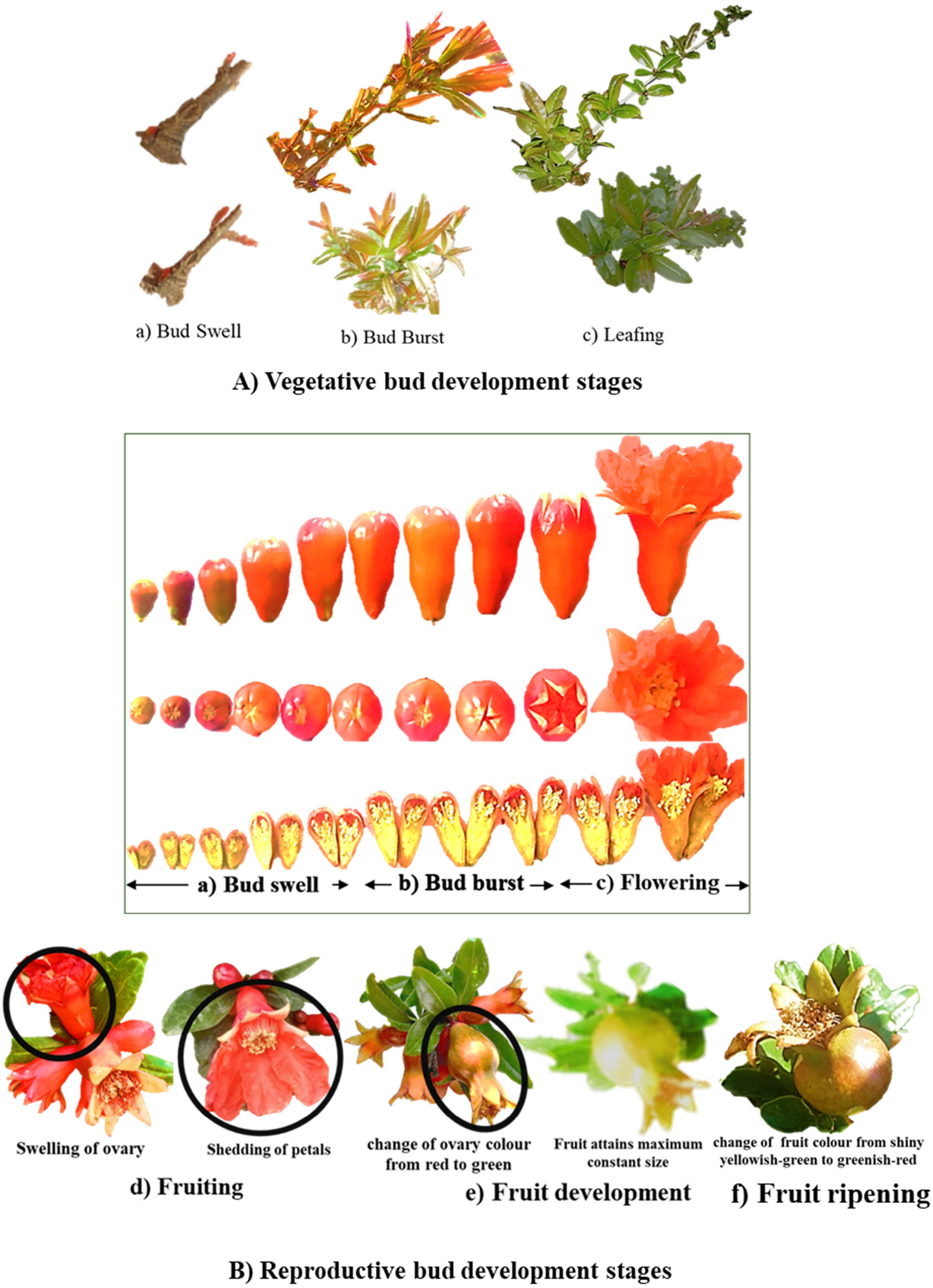

Figure 2. *Description of phenophases of wild pomegranate.*

2.3. Statistical Analysis

ANOVA was performed for phenological data to check the effect of sites on the duration of different phenophases [15].

Hourly temperature data were used to calculate chilling hours (CH) and growing degree hours (GDH). One chilling hour (CH) is equal to one hour in less than 7.2°C air temperature [9]. Accumulated CH (hr) was calculated by summing up all chilling hours during the dormancy period of the genotypes.

$$CH(hours) = \sum\left(if\ T_h \begin{matrix} <7.2°C, & CH = 1\ hour \\ >7.2°C, & CH = 0\ hour \end{matrix}\right), \quad (1)$$

where, $T_h = temperature\ at\ 'h'\ hour$

A GDH (°C) is one hour in temperature 1°C above the base temperature. Base temperature is the minimum air temperature at which the tree growth starts. In the present study 10°C base temperature was used for pomegranate genotypes [8]. Accumulated GDH was calculated from bud bursting to leaf formation stage (in case of vegetative bud) or to flowering stage (in case of reproductive bud).

$$GDH\ (°C) = \sum \left(if\ T_h \begin{array}{c} <10.0°C,\ GDH = 0\ °C \\ 10.0°C\ to\ 25.0°C,\ GDH = T_h - 10°C \\ >25.0°C,\ GDH = 15°C \end{array} \right), \quad (2)$$

where, $T_h = temperature\ at\ 'h'\ hour$

Correlation and regression analysis for the was performed using MS excel 2019 to determine relation between thermal requirements and morphological traits of the wild pomegranate.

3. Results and Analysis

3.1. Phenological Studies

Vegetative and reproductive bud stages of wild pomegranate was recorded and had been presented in Table 1 and Figure 3. More variation exists between sites as compared to the within sites for the most of the phenophases. Phenological studies illustrated that the durations of vegetative bud swelling, vegetative bud bursting, leaf formation and leaf fall at different sites ranged from early February to late February, mid-February to mid-March, early March to mid-June and mid-October to late December, respectively. The longest duration (12.1 days) of vegetative bud swelling was noticed for Narag and the shortest (7.9 days) for Jonaji. The mean temperature during the phase was lowest (13.4°C) in the Jonaji site as compared to the other sites, suggesting early fulfillment of the chilling hours, which was required to enter the next stage *i.e.* bud burst. On the other side, Narag was warmer (15.2°C) than the other sites during the phase, increasing the duration of the stage. Cizmovic et al. [2] and Dhiman *et al.* [3] reported a difference of seven days between sites for vegetative bud swell which is similar to the findings of the present study.

The longest period (14.5 days) of vegetative bud burst was recorded for the Narag site, while the Nauni site showed the shortest duration (11.2 days). During the phase Jonaji had the lowest mean temperature followed by Nauni (16.0°C). Bud bursting is a function of cooler thermal conditions. Higher duration (12.8 to 17.8 days) for vegetative bud burst of wild pomegranate in diverse sites were reported by Dhiman *et al.* [3]. Maximum number of days (97.5 days) for leafing was detected in the Waknaghat site and the minimum (87.3 days) was recorded in the Nauni location. Leafing duration was more controlled by size of the tree crown rather than the temperature during the phase. Genotypes at Narag and Waknaghat sites were larger than the genotypes at Nauni and Jonaji site. More the branches of the trees more will be the number of leaves and these leaves will take time to reach its maximum size. Dhiman *et al*. [3] also presented comparable results for leafing duration (100.1 to 106.0 days) of wild pomegranate genotypes. Cizmovic *et al.* [2] observed a non-significant difference among sites for leafing duration. Maximum number of days (39.20 days) for leaf fall was observed in the Nauni site and the minimum (28.47 days) was observed in the Waknaghat site. The results owed to low temperature (12.2°C) and low rainfall (10.0 mm) in Waknaghat site during the phase, which accelerated the leaf fall to enter dormant stage. Similar results were documented by Dhiman *et al.* [3] for leaf fall duration (30.8 to 35.3 days) of wild pomegranate. Leaf fall in pomegranate has been linked to the strong wind during November and December, which accelerated the leaf shedding process [2].

The duration of reproductive bud swelling, reproductive bud bursting, flowering, fruiting, fruit development and fruit ripening at different locations ranged from mid-March to late April, early April to early May, mid-April to mid-June, mid-May to late June, early June to early September and mid-August to mid-October, respectively. Maximum number of days (19.1 days) for reproductive bud swell was observed in the Nauni and Jonaji demonstrated minimum number of days (14.5 days). Jonaji had the lowest (19.2°C) mean temperature during the phase as compared to other sites. Dhiman *et al.* [3] studied duration of reproductive bud swell (19.6 to 24.6 days) for wild pomegranate in the different locations and found almost similar results. The largest number of days (14.0 days) for reproductive bud burst was recorded for Narag site and Waknaghat showed the smallest number of days (7.9 days). During the phase the Waknaghat site was cooler (21.4°C) as compared to the other site, accelerating the bud burst process. The reproductive bud burst results of present study were slightly higher than the study conducted by Dhiman *et al.* (6.95 to 8.56 days) in the year 2017 [3]. Narag showed the maximum number of days (31.7 days) for flowering and the minimum number of days for flowering (27.1 days) was observed for Nauni site. Flowering was function of crown size, smaller the size rapid will be the flowering. Dhiman *et al.* (2017) presented the greater duration for flowering (42.3 to 45.8 days) in the wild pomegranate as compared to the present study. The duration of flowering reported by Cizmovic *et al.* [2] in cultivated pomegranate ranged from 40.0 to 69.0 days. Smallest number of days for fruiting (13.5 days) was observed for the Nauni site, whereas Waknaghat exhibited the largest number of days (21.9 days) for fruiting. Nauni had highest mean temperature (27.4°C) and total rainfall (47.2 mm) during the phase, which may have quickened the fruiting phase. Shortest fruit development duration (78.4 days) was observed for Waknaghat site and Nauni site demonstrated longest fruit development period (83.5 days). The mean temperature (26.5°C) of Waknaghat site during the phase was more than the other sites. Fruit development duration (133.4 to 138.8 days) reported by Dhiman *et al.* [3] and Medina *et al*., [11] was higher for the wild pomegranate genotypes. Shortest fruit ripening duration (18 days) was recorded for Waknaghat, whereas Nauni site demonstrated the longest fruit ripening period (35.0 days). Warmer the temperature rapid will be the ripening process. The mean temperature (26.9°C) of Waknaghat site during the phase was higher than the other sites. Dhiman *et al.* [3] documented the smaller range (23.8 to 26.8 days) for fruit ripening days in the wild pomegranate genotypes. Variations in the reproductive bud phenophases were due to internal and external factors *i.e.* biorhythms, temperature and rainfall. Vegetative bud development was shorter in warmer sites than the other sites. Similar results were found by Cizmovic *et al.* [2], in which lower temperatures slowed down the phenophases for cultivated pomegranate varieties.

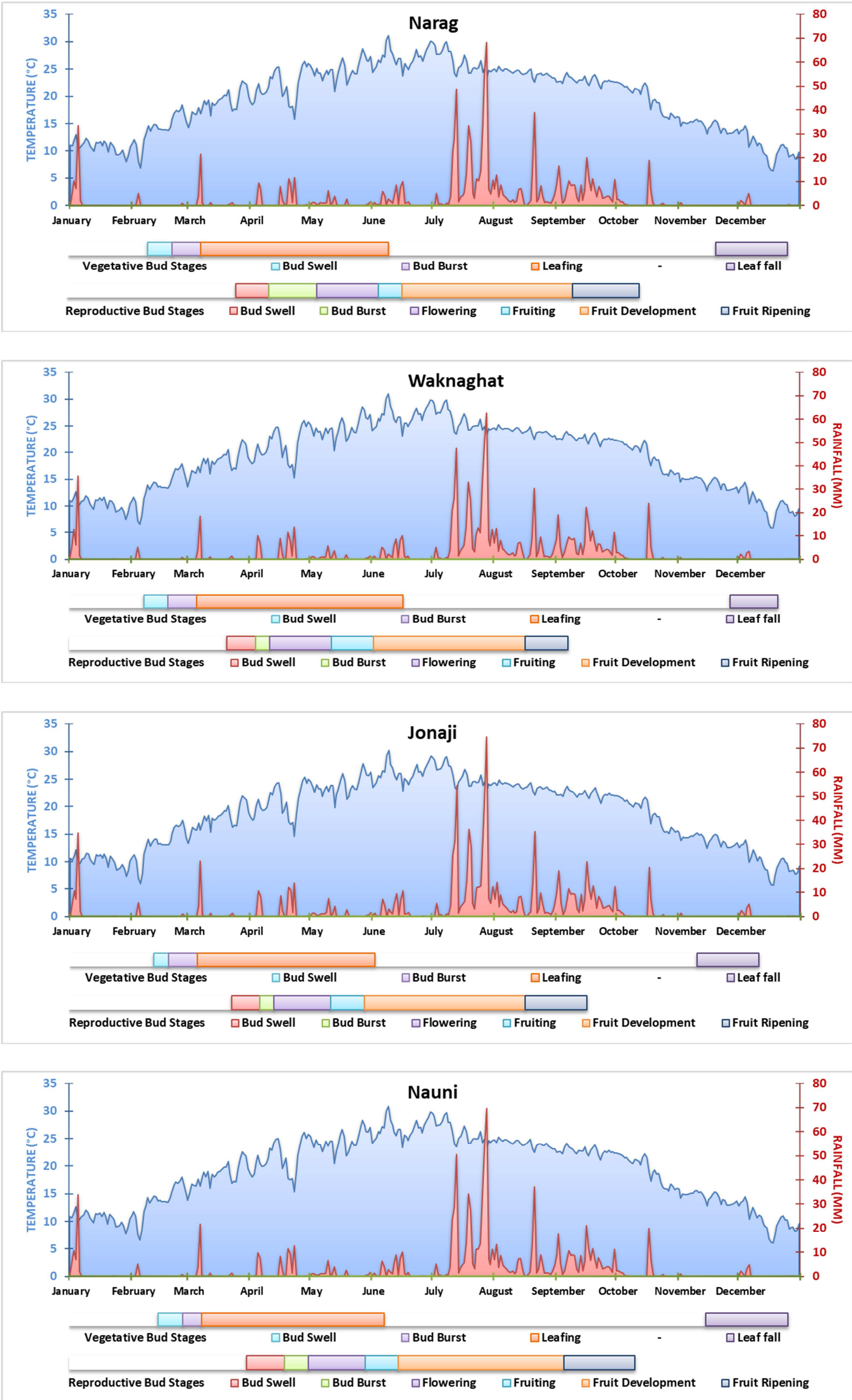

Figure 3. *Phenophases and meteorological parameters in selected sites.*

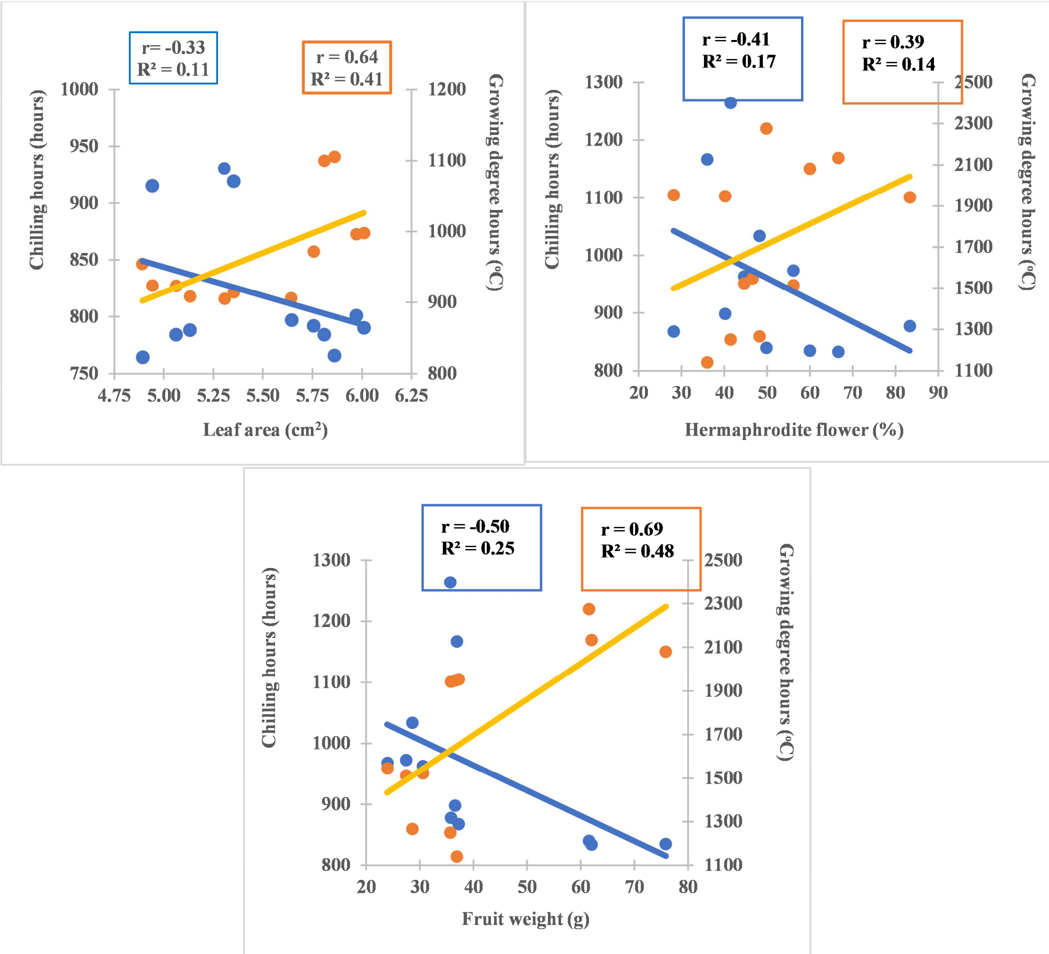

Figure 4. *Relation between thermal requirement indices and morphological traits of wild pomegranate.*

3.2. Thermal Requirements

Thermal requirement of the wild pomegranate population had been presented in and there were significant variations between and within sites for the thermal characters (Table 2). For vegetative bud chilling hours and growing degree hours ranged from 779.0 (Nauni) to 921.9 hours (Jonaji) and 914.5 (Jonaji) to 1067.9°C (Narag), respectively. However, for reproductive bud, chilling hours and growing degree hours fluctuated from 836.0 (Narag) to 1155.1 hours (Jonaji) and 1220.0 (Jonaji) to 2164.3°C (Narag), respectively. Chilling hour and GDH for vegetative bud were lower as compared to reproductive bud. Researcher reported that chilling hours of cultivated pomegranate varied from 100 to 900 hours [14, 17]. Previous studies reported higher range (4092 to 9000°C) of GDH for pomegranate cultivars in comparison to the results of present study [14, 17, 7]. Chilling requirement of the wild pomegranate was slightly higher as compared to the documented chilling requirement (100 to 900 hours) of pomegranate cultivars [14, 17]. High value for chilling hours was observe for Jonaji site denoting that population was adapted to cooler climate of the site and Narag with low chilling requirement was adapted to warmer climate. Recent studies [10, 16] for fruit trees, suggested higher GDH in warmer areas and lower GDH in cooler areas. Similar results were found in the present investigation, where, Narag (warmer microclimate) had higher value for growing degree hours than the Jonaji (cooler microclimate).

Table 1. *Duration (days) of vegetative and reproductive phenophases in wild pomegranate.*

Sites	Genotypes	Vegetative				Reproductive					
		VBS	VBB	L	LF	RBS	RBB	F	FI	FD	FR
Narag (S_1)	G_1	12.6	14.0	99.4	42	16.8	15.4	36.4	12.6	84	30.8
	G_2	7.0	14.0	91.0	37.8	15.4	15.4	28	18.2	82.6	35.0
	G_3	9.8	15.4	86.8	36.4	18.2	11.2	30.8	14.0	82.6	33.6
	Mean	9.8	14.5	92.4	38.7	16.8	14.0	31.7	14.9	83.1	33.1
Wakna- ghat (S_2)	G_1	8.4	14.0	102	29.4	16.8	8.4	29.4	19.6	77.0	19.6
	G_2	9.8	14.0	93.8	29.4	15.4	7.0	28	19.6	79.8	22.4
	G_3	11.2	12.6	96.6	26.6	15.4	8.4	32.2	26.6	78.4	11.2
	Mean	9.8	13.5	97.5	28.5	15.9	7.9	29.9	21.9	78.4	17.7

Sites	Genotypes	Vegetative				Reproductive					
		VBS	VBB	L	LF	RBS	RBB	F	FI	FD	FR
Jonaji (S_3)	G_1	8.4	14.0	91.0	30.8	14.0	8.4	29.4	19.6	82.6	32.2
	G_2	8.4	11.2	93.8	43.4	15.4	8.4	28.0	14.0	78.4	33.6
	G_3	7.0	16.8	93.8	23.8	14.0	9.8	28.0	12.6	77.0	36.4
	Mean	7.9	14.0	92.9	32.7	14.5	8.87	28.5	15.4	79.3	34.1
Nauni (S_4)	G_1	14.0	9.8	81.2	43.4	22.4	7.0	28.0	16.8	79.8	36.4
	G_2	8.4	14.0	86.8	35.0	19.6	9.8	25.2	14.0	85.4	33.6
	G_3	14.0	9.8	93.8	39.2	15.4	16.8	28.0	9.8	85.4	35.0
	Mean	12.1	11.2	87.3	39.2	19.1	11.2	27.1	13.5	83.5	35.0
$CD_{0.05}$ (between sites)		2.1	2.2	5.8	6.4	2.5	3.6	2.9	4.5	2.8	5.3
$CD_{0.05}$ (within sites)		3.6	3.8	NS	NS	NS	NS	NS	NS	NS	NS
*VBS= vegetative bud swell		LF= leaf fall				F=flowering			FD=fruit development		
VBB= vegetative bud burst		RBS= reproductive bud swell				FI= fruiting initiation			FR=fruit ripening		
L= leafing		RBB= reproductive bud burst									

Table 2. *Thermal requirement and morphological traits of wild pomegranate genotypes.*

Sites	Genotypes	Vegetative		Reproductive		Leaf area	Bisexual Flower (%)	Fruit weight
		CH (hours)	GDH (^{o}C)	CH (hours)	GDH (^{o}C)			
Narag (S_1)	G_1	790.2	998.2	840.0	2276.8	6.0	49.8	61.5
	G_2	784.4	1100.0	835.1	2081.8	5.8	60.0	75.9
	G_3	766.1	1105.4	832.9	2134.5	5.9	66.7	62.0
	Mean	780.2	1067.9	836.0	2164.3	5.9	58.8	66.4
Wakna-ghat (S_2)	G_1	801.0	996.4	877.4	1943.5	6.0	83.3	35.7
	G_2	797.0	906.1	898.5	1948.2	5.6	40.2	36.5
	G_3	791.9	972.1	867.8	1953.8	5.8	28.2	37.2
	Mean	796.6	958.2	881.2	1948.5	5.8	50.6	36.5
Jonaji (S_3)	G_1	919.6	914.6	1166.7	1141.2	5.4	36.0	36.9
	G_2	915.6	923.8	1034.1	1267.6	4.9	48.3	28.6
	G_3	930.5	905.2	1264.5	1251.6	5.3	41.4	35.6
	Mean	921.9	914.5	1155.1	1220.1	5.2	41.9	33.7
Nauni (S_4)	G_1	764.5	954.3	963.1	1523.8	4.9	44.6	30.6
	G_2	788.2	908.4	967.5	1547.4	5.1	46.6	23.9
	G_3	784.2	923.5	973.6	1513.9	5.1	56.1	27.5
	Mean	779.0	928.7	968.1	1528.4	5.0	49.1	27.3
$CD_{0.05}$ (between sites)		0.7	0.6	0.8	0.7	0.3	0.6	7.8
$CD_{0.05}$ (within sites)		1.3	1.1	1.4	1.3	NS	1.1	NS
* CH= chilling hours; GDH= growing degree hours								

3.3. Correlation and Regression Analysis

Morphological traits and chilling hours were negatively correlated, however morphological traits showed positively correlation with GDH (Figure 4). Highest positive correlation coefficient (0.69) and R-squared (0.48) value was demonstrated by GDH and fruit weight, however fruit weight had negative correlation (-0.50) with the chilling hours. Leaf area was positively correlated with the GDH (0.64) with a R-squared value of 0.41. Similar results were found by Moral *et al.* [12, 18], in which growth characters were positively correlated with GDH and negatively correlated with chilling hours.

4. Conclusions

The following conclusions were obtained from the present study:

(1) More variation exists between sites as compared to the within sites for most of the duration of phenophases.
(2) Chilling hour and GDH for vegetative bud were lower as compared to reproductive bud.
(3) Narag with warmer microclimate had lower chilling requirement and higher value for growing degree hours than the Jonaji with cooler microclimate, suggesting adaption of the genotypes to the given climatic conditions.
(4) GDH was significantly correlated with the fruit weight of the wild pomegranate.

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Conflicts of Interest

The authors declare that they have no conflicts of interest.

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