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Thermal unit requirement of grape (*Vitis vinifera* L.) varieties under south western Punjab conditions

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ABSTRACT

Weather components have significant impact on the phenology of fruit plants. In order to study the effect of heat, photothermal and heliothermal units on phenology of grapes, an experiment was conducted during 2016 and 2017 on eleven grape varieties. The weather based indices were used for characterizing the thermal response to various phenophases of different grape varieties. Based on the thermal response the eleven varieties were classified into early, mid and late maturing categories. The fruit ripening was differed by 7-9 days for early, 4-8 days for mid and 1-3 days for late ripening groups. For early, mid and late maturing varieties the accumulated range of growing degree days was 1303-1530, 1617-1712 and 1912-1959 °C day, photothermal unit was 15971-19032, 20201-21484 and 24255-24923°C day. Likewise, minimum heliothermal unit was required by early ripening varieties *i.e.,* Himrod (9973 °C days) and Madeliene Anguvine (11235 °C days) but, maximum for long duration varieties like Black Muscat (15000 days) and Angur Early (14579 °C days). Maximum and minimum heat use efficiency was recorded by variety Perlette (1.57) and Black Muscat (0.96), respectively.

Key words: Growing degree days, photothermal unit, heliothermal unit, heat use efficiency, fruit yield and varieties.

Grape is an important commercial fruit crop predominantly grown under temperate and tropical regions of the world. Grape contributes nearly 16 per cent of the total global fruit production. The high nutritive value, excellent taste, multipurpose use and better monetary returns enhanced the popularity of grapes (Gowda *et al.,* 2008). Recently viticulture under hot climate has gained importance in different tropical regions of the world (Menora *et al.,* 2015). There are three distinct regions of grape cultivation in India *viz.*, temperate (Jammu and Kashmir and Himachal Pradesh), sub-tropical (Punjab, Haryana, Rajasthan and western Uttar Pradesh) and tropical (Andhra Pradesh, Maharashtra, Karnataka and Tamil Nadu). India is the second largest table grape producing country in the world. The total area in India under grapes cultivation was 1.39 lakh hectares with 29.20 lakh MT (Anonymous, 2018). In Punjab, during 2018-19 grapes was cultivated in an area of 290 ha and recorded 8289 MT annual production having 28584 kg ha^{-1} productivity (Anonymous, 2019). Grapes require long warm to hot dry summer and cool rainy winter (Khan *et al.,* 2011) having optimum growing-season temperature of 12ºC to 24ºC (Ramos *et al.*, 2013) and appropriate mesoclimatic characteristics (Van Leeuwen *et al.,* 2004) for the best berry growth and development. The pheno-physiological stages like bud burst, berry growth and development, berry size, time of maturity and ripening of grapes varieties have been reported to vary with change in site, location, topography and environment (Shiraishi *et al.,* 2010).

According to White *et al.* (2006) three major climatic factors affecting the grape production are the heat accumulation, risk of frost and the extreme heat. Variation in weather parameters determines the inter-annual variability of plant growth and yield. Various temperature based indices like growing degree days (GDD), photothermal units (PTU) and heliothermal units (HTU) can be successfully used for describing phenological behaviour and other growth parameters like leaf area development, biomass production, yield etc. (Neog and Chakravarty, 2005; Singh *et al.,* 2007).

Grapevines being one of the most responsive to its surrounding environment hence the temperature indices are the most common parameters used to assess the suitability of grapes to specific climates (Jones *et al.,* 2010). The concept of heat units has been applied to predict yield and physiological maturity of the crops by correlating the phenological development (Singh *et al.,* 2007). For attaining higher grapes yields, the knowledge of accurate period of different phenophases in existing environment and their

Table 1: Phenological stages and heat unit required for different varieties of grape

	Phenological stages attained after pruning (days)						Heat unit (°C day)					
	Bud Burst	Sprouting	Panicle	Anthesis	Fruit set	Fruit Ripening	Bud Burst	Sprouting	Panicle	Anthesis	Fruit set	Fruit Ripening
Himrod	24	31	41	66	72	120	63	88	152	354	421	1303
Perlette	36	39	44	67	75	130	111	130	172	369	470	1530
Cardinal	41	44	51	75	81	147	151	168	224	461	559	1920
Ruby Red	47	50	54	73	80	136	189	219	251	441	534	1668
Angur Early	39	46	53	73	80	146	130	182	242	444	544	1912
Banquiabyad	37	44	54	75	80	129	118	173	251	463	534	1510
Black Muscat	49	53	56	73	80	148	206	245	274	435	542	1959
Flame Seedless	38	44	49	71	81	138	128	168	211	417	560	1712
Beauty Seedless	43	46	49	68	77	128	162	186	206	378	499	1487
Madeliene Anguvine	33	36	47	71	78	127	98	111	195	417	503	1453
Punjab MACS Purple	40	43	50	71	81	134	137	166	215	416	551	1617

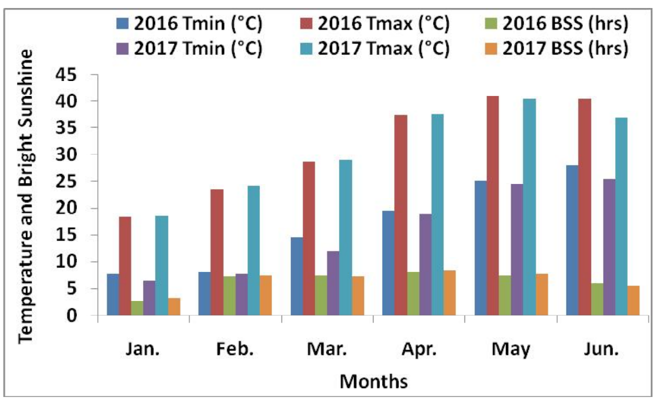

Fig. 1: Weather conditions during study period of 2016 and 2017 for grape orchards.

relation with yield determinants is vital (Saniya *et al.,* 2017). Duration of different phenophases is directly related to temperature that may be predicted using the sum of daily air temperature (Singh and Bhatia, 2012). Keeping the importance of weather parameters on phenology, a study was carried out to characterize the performance of different grape varieties grown under south-western region of Punjab in relation to climatic structure, phenology and their ripening.

MATERIALS AND METHODS

Location of the study

The experiment was carried out during 2016 and 2017 on eleven varieties of grapes in the orchard of Punjab Agricultural University (PAU) Regional Research Station (RRS), Bathinda, Punjab (latitude 30.58°N, longitude 74.18°E and altitude of 211m above mean sea level). The grapevines trained on 'bower' system at the spacing of 3 × 3 m in randomized block design with three replications were used as plant material.

The district of Bathinda lies in the extreme south–west part of Punjab. Annual normal rainfall is about 436 mm, 80 percent of which is received during the southwestern monsoon season. During May-June mercury often touches over 47.0°C and duststorms are a common feature in summer. However, in December and January, the minimum temperature sometimes reaches to sub zero temperature. The soil is mostly loamy sandy to sandy loam in texture and medium in available N (270 kg ha^{-1}), P (16 kg ha^{-1}) and high in available K content (220 kg ha^{-1}. In addition, the soil is slightly alkaline having pH between 8.41 to 8.65 with low in organic carbon content ranging from 0.31 to 0.37% (Yadav *et al.,* 2018).

Observation time and method

The number of days to attain various phenophases namely, bud burst, sprouting, panicle formation, anthesis, fruit set and fruit ripening were visually observed from randomly selected five grapevines after pruning (on 11th January each year).

Meteorological observations

Daily maximum temperature (Tmax), minimum temperature (Tmin) and duration of bright sunshine (BSS) were recorded at Agro-meteorological observatory installed at PAU, RRS, Bathinda (Fig. 1). The growing degree days (GDD), photothermal unit (PTU) heliothermal unit (HTU)

Table 2: Photo-thermal and helio-thermal required at various phenophases for different varieties of grape

	Photothermal unit (°C day)						Heliothermal unit (°C day)					
	Bud Burst	Sprouting	Panicle	Anthesis	Fruit set	Fruit Ripening	Bud Burst	Sprouting	Panicle	Anthesis	Fruit set	Fruit Ripening
Himrod	657	923	1624	3931	4736	15971	262	424	800	2300	2799	9973
Perlette	1173	1382	1847	4108	5326	19032	583	715	977	2407	3244	11749
Cardinal	1613	1806	2439	5226	6416	24365	823	940	1431	3125	3916	14602
Ruby Red	2047	2380	2741	4981	6112	20889	1147	1389	1623	2968	3739	13019
Angur Early	1382	1968	2639	5017	6231	24255	715	1082	1557	2984	3779	14579
Banquiabyad	1244	1861	2741	5244	6112	18762	628	989	1623	3174	3739	11698
Black Muscat	2238	2678	3002	4908	6210	24923	1277	1588	1759	2906	3819	15000
Flame Seedless	1361	1813	2287	4692	6430	21484	699	946	1329	2752	3917	13233
Beauty Seedless	1739	2014	2239	4218	5687	18451	880	1120	1294	2419	3425	11478
Madeliene Anguvine	1031	1173	2105	4692	5731	17989	496	583	1183	2752	3495	11235
Punjab MACS Purple	1460	1780	2333	4675	6321	20201	770	917	1349	2748	3846	12578

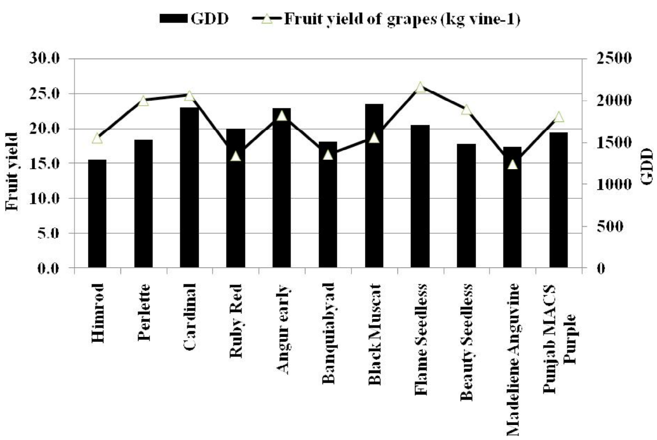

Fig. 2: Fruit yield (kg vines^{-1}) of grape for different varieties during 2016 and 2017.

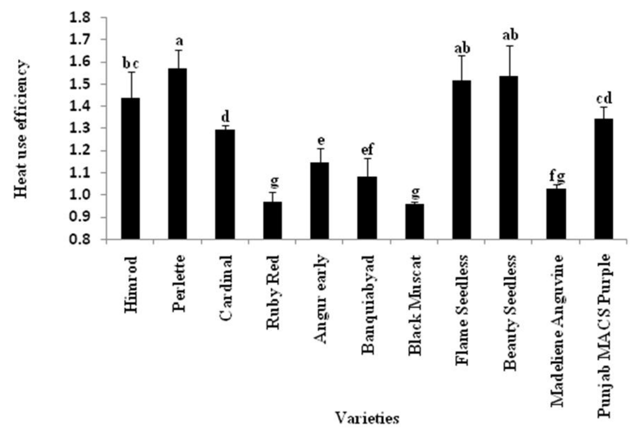

Fig. 3: Mean heat use efficiency of the grape varieties. The bars with similar letters are statistically at par with each other as per DMRT.

and heat use efficiency (HUE) for different phenophases of grapes were calculated using 10 °C base temperature (Tb) as per following formulas and accumulated from the date of pruning (i.e., 11th January) to date of occurrence.

$$GDD = \sum\left(\frac{T\max + T\min}{2}\right) - T_b$$

$$HTU = GDD \times Actual\ bright\ sunshine\ (hours)$$

$$PTU = GDD \times Day\ length$$

$$HUE = \frac{Yield\ (kg\ ha^{-1})}{\sum GDD\ (^{o}C\ day)}$$

RESULTS AND DISCUSSION

Phenology of grape varieties

Numbers of days required for commencement of different phenological events varied among varieties (Table 1). Results of two years pooled analysis depicted that number of days required by different varieties after pruning varied was 24 - 49 days for bud burst, 31 - 53 days for sprouting, 41-53 for panicle, 66-75 for anthesis, 72 - 81 days for fruit set and 120 - 148 days for fruit ripening. Kose (2014) also reported significant deviation in number of days from bud burst to blooming ranged from 47 to 65 days. Moreover, anthesis was earliest in Himrod followed by Perlette and Beauty Seedless. Fruit ripening was earliest in Himrod (120

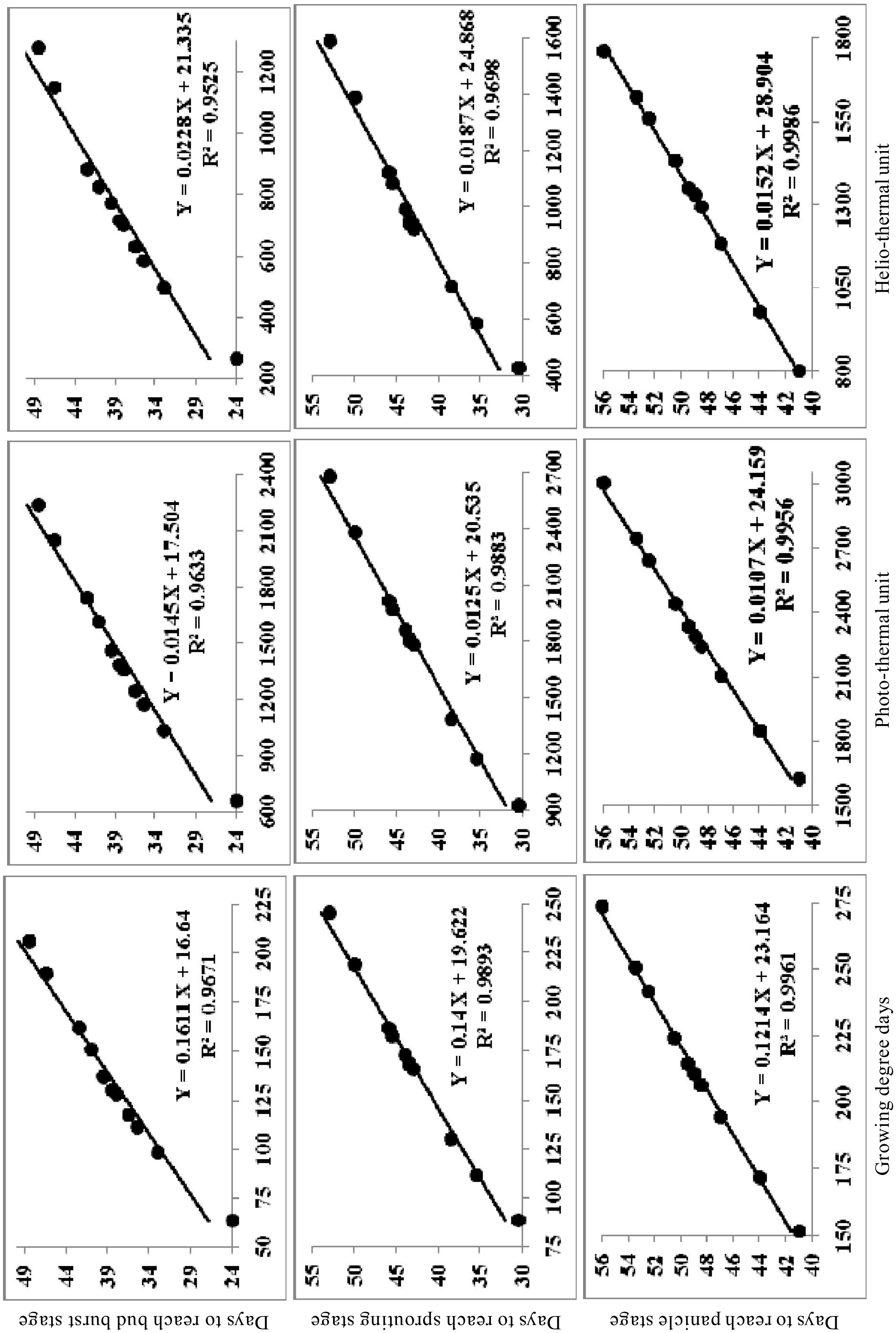

Fig. 4: Growing degree days, photothermal and heliothermal unite required for different vegetative growth stages of grapes

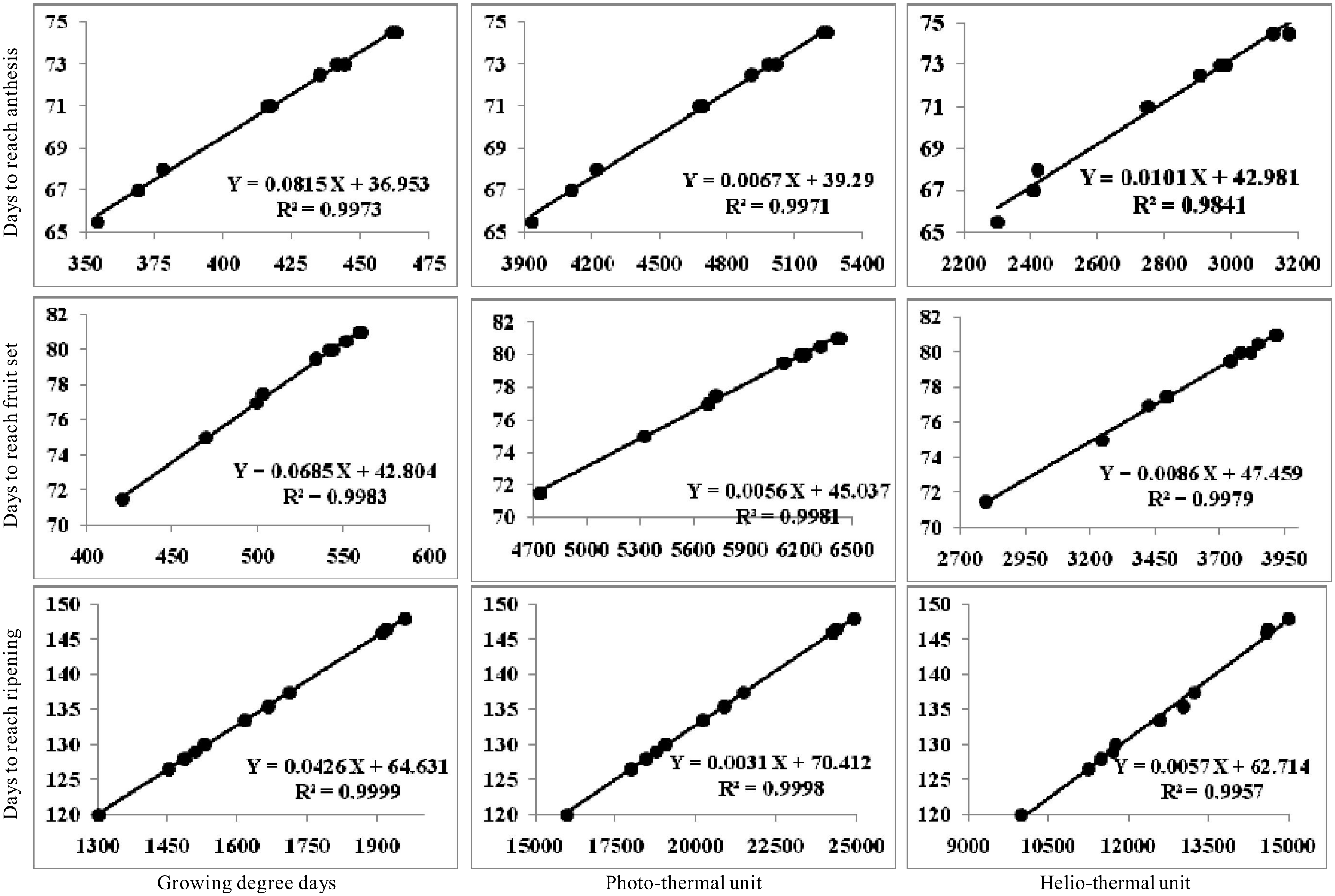

Fig. 5: Growing degree days, photothermal and heliothermal unit required for different reproductive growth stages of grapes

days), while, longest in Black Muscat (148 days) which identified as late maturing variety. Based on the maturation period, the grape varieties grouped into early maturing *i.e.* Himrod, Perlette, Banquiabyad, Beauty Seedless and Madeliene Anguvine (≤ 130 DAP), mid maturing *i.e.* Ruby Red, Flame Seedless and Punjab MACS Purple (131 - 140 DAP) and late maturing varieties *i.e.* Cardinal, Angur Early and Black Muscat (> 141 DAP). The fruit ripening was differed by 7 - 9 days, 4-8 days and 1-3 days within the early, mid and late ripening groups of the varieties, respectively. The variation in phenological stages may be due to varietal characteristics. Pommer *et al.* (2000) also reported deviations in the duration of early and very late varieties with 120 and 180 days, respectively. The rise in temperature due to climate change influence the vine phenology, time of harvesting increase, concentrations of grape sugar and alcohol content in wine (de Orduna, 2010).

Growing degree days requirement of grape varieties

The accumulated thermal unit requirement of grape to attain different phenophases varied among the varieties (Table 1 and 2). At anthesis stage, highest GDD of 463 °C day required by Banquiabyad was followed by Cardinal (461°C day) variety. Similarly, variety Himrod needed least GDD (354 °C day) followed by Perlette (369 °C day) and Beauty Seedless (378 °C day). But, to complete ripening, the accumulated GDD required in the range of 1303 - 1530 °C days for early maturing varieties, while, between 1617 - 1712 °C day for mid maturing and 1912 -1959 °C day for late maturing varieties of grapes. The accumulated GDD was linearly associated with vegetative as well as reproductive stages of grape varieties. Adak *et al.* (2017) also reported wide variations in thermal heat requirement in mango cv. Dashehari at different critical phenological stages. Unit change in heat unit could affect the days taken for bud burst, sprouting and panicle initiation @ 0.1611, 0.14 and 0.1214 days, respectively (Fig. 3) and anthesis, fruit set and ripening stages @ 0.0185, 0.685 and 0.0426 days, respectively (Fig. 4). Most of the grape varieties, which accumulated less growing degree days, resulted better yield response. Our results were in line with Makhija *et al.* (1984) who also reported that the early ripening varieties consume lesser GDD than the late ripening varieties. Similar results were also reported by Thakur *et al.* (2008) and Saniya *et al.* (2017).

Photothermal unit's requirement of grape varieties

The pooled analysis of two years data revealed that accumulated PTU was 657 – 2238 °C (at bud burst), 923-2678°C (at sprouting), 1624-3002°C (at panicle), 3931-5244°C (at anthesis), 4736-6430°C (at fruit setting) and 15971-24365°C (at ripening). Alternatively, accumulated PTU varied between 15971 - 19032 °C day, 20201 - 21484 °C day and 24255 - 24923°C day respectively for early, mid and late ripening group of the grape varieties (Table 2). The PTU requirements also varied with earliness or lateness of the variety in which early varieties required less PTU values than late varieties needed higher amount of PTU for ripening of the fruit (Table 2). Moreover, the value of PTU was found higher in early ripening varieties and successively reduced for mid and late ripening. Deviation in each unit of PTU may alter the commencing of bud burst, sprouting and panicle initiation stages @ 0.9633 0.9883 and 0.9956 days, while anthesis, fruit set and fruit ripening stages @ 0.09971, 0.9981 and 0.9998 days, respectively (Fig 4 and Fig 5). High significant linear relation ($p \leq 0.005$) between accumulated PTU and grape pheno-phases was again proved by high values of coefficient of determination (R^2 between 0.96 and 0.99 for vegetative stages, and $R^2 > 0.99$ for reproductive stages).

Heliothermal unit's requirement of grape varieties

Among weather parameters, duration of bright sunshine hours is considered as one of the important key factor for viticulture. Temperature and bright sunshine hours in terms of Heliothermal unit (HTU) has been adopted to evaluate the growing regions, selection of cultivars, phenological development and ripening characteristics of grape (Irimia *et al.,* 2013). For different grape varieties, HTU ranged from 262 - 1277 for bud burst that was in between 424 - 1588 and 800 -1678 for sprouting and panicle stage, respectively. Minimum HTU was required by early ripening varieties *i.e.,* Himrod (9973 °C days) followed by Madeliene Anguvine (11235 °C days). Contrarily, maximum HTU was needed for long duration variety like Black Muscat (15000 days) and Angur Early (14579 °C days). Number of days to reach different phenophases and accumulated HTU showed a significant linear regression for both vegetative as well as reproductive stages of the grape varieties (Fig. 4 and 5).

Fruit yield and heat use efficiency

Fruit yield of the grape varieties are presented in (Fig. 2). The long duration varieties Flame Seedless (26.0 kg/ vine) and Cardinal (24.8 kg/vine) indicated high yield followed by short duration varieties like Perlette (24.1 kg/ vine), Madeliene Anguvine (14.9 kg/vine). GDD showed linear relationship with fruit yield of grape. Vaidya *et al.*

(2019) also observed positive correlation between productivity and the minimum temperature in apple. The maximum HUE was significantly higher for Perlette (1.57) followed by Beauty Seedless (1.53) and Flame Seedless (1.52) whereas, least HUE was observed in Black Muscat (0.96) followed by Ruby Red (0.97) and Madeliene Anguvine (1.03).

CONCLUSION

Higher days of phenology with greater value of GDD, PTU and HTU were observed with the long duration varieties like Cardinal, Angur Early and Black Muscat, while minimum with short duration varieties like Himrod, Madeliene Anguvine, Beauty Seedless, Banquiabyad, Perlette etc. Accumulated GDD, PTU and HTU were linearly related with vegetative as well as reproductive stages of the grape varieties. As compared to short duration varieties, the long duration varieties were more efficient to utilize the heat units to produce the better fruit yield. The study confirmed the importance of various thermal units on growth, development and fruit yield of grape varieties. Findings of present study may be helpful in developing the yield prediction models of grape varieties based on thermal indices.

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