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Heat Accumulation and Crop Phenology in Different Varieties of Grape (*Vitis* sps.)

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Abstract The present investigation entitled studies on heat accumulation and crop phenology in different varieties of grape (*Vitis* sps.) was carried out during October 2013–April 2014. The aim of this experiment was to study the number and pattern of the heat units (HUs) accumulation at various phenological stages in different groups of sixteen grape varieties. Wide variations were recorded in the heat units accumulation from stage to stage and variety to variety. The varieties Anab-e-Shahi (1864.3 GDD), Italia (1714.3 GDD), Bangalore Blue (1634.4 GDD) and Concord (1634.4 GDD) accumulated significantly highest number of UDs, while the varieties Pusa Navrang (815.7 GDD) and Shiraz (836.6 GDD) accumulated significantly least number of HUs from pruning to maturity. Among different groups, the wine varieties manifested all the phenological events early. Correspondingly, the mean HUs accumulation in wine varieties was significantly least at all stages. On the other hand, all the phenological events occurred lately in table varieties and correspondingly, the mean HUs accumulation was also significantly high at all stages. Different phenological stages also differed significantly for HUs requirement. The mean HUs requirement was maximum for fruitset to maturity stage (676.4 GDD) while, the panicle emergence to anthesis stage (88.2 GDD) had the minimum requirement of heat units. This experiment emphasized the importance of heat units as a non-destructive and accurate index of crop maturity.

Keywords Heat Units (HUs), Growing Degree Days (GDD), Crop phenology, Phenological progression, Grape varieties.

Introduction

Crop phenology involves the study of phenological progression from one phase to the next of a given plant species. Each phenological phase is completed when a genetically defined threshold of temperature summation is achieved. This total heat so required is expressed in threshold of temperature summation is achieved. This total heat so required is expressed in

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Table 1. Phenological stages-heat units accumulated in sixteen grape varieties evaluated. *Figures in the parentheses denote heat units required for transition from one phase to the next.

	Heat units (GDDs) accumulated from pruning stage				
	50% Budbreak	50% panicle appearance	50% Anthesis	50% Fruitset	50% Maturity
Table/raisin varieties					
T_1: Thompson Seedless	103.20 (190.6)*	293.80 (159.0)	452.90 (199.6)	652.50 (385.4)	1037.90
T_2: A 17/3	88.20 (273.0)	361.25 (72.7)	434.00 (249.0)	683.05 (554.8)	1237.90
T_3: Flame Seedless	48.50 (281.3)	329.85 (69.4)	399.30 (155.8)	555.10 (682.8)	1237.90
T_4: Kishmish Chorni	66.70 (263.1)	329.85 (80.3)	410.20 (242.3)	652.50 (377.3)	1029.85
Mean	76.65 (252.0)	328.7 (95.4)	424.1 (211.6)	635.7 (425.1)	1135.88
Table Varieties					
T_5: Anab-e-Shahi	293.85 (143.0)	436.85 (116.0)	552.90 (230.1)	783.05 (1081.2)	1864.30
T_6: Italia	163.70 (288.3)	452.00 (109.9)	561.95 (190.5)	752.50 (961.8)	1714.30
r	245.45 (91.4)	336.85 (116.0)	452.90 (219.6)	672.50 (861.8)	1534.30
T_8: Rizamat	87.20 (187.4)	274.65 (122.2)	396.85 (275.6)	672.50 (865.4)	1537.90
Mean	197.5 (177.9)	375.0 (116.0)	491.15 (228.9)	(720.1) (942.5)	1662.7
Juice varieties					
T_9: Pusa Navrang	73.10 (84.3)	157.30 (172.5)	329.85 (164.4)	494.25 (321.4)	815.70
T_{10}: Bangalore Blue	225.45 (79.3)	304.75 (125.1)	429.85 (184.9)	614.80 (1049.5)	1664.30
T_{11}: Rubi Red	245.45 (68.8)	314.30 (94.5)	408.85 (243.6)	652.50 (781.5)	1434.3
T_{12}: Concord	273.85 (40.4)	314.30 (115.5)	429.85 (184.9)	614.80 (1049.5)	1664.3
Mean	204.46 (68.2)	272.66 (126.9)	399.6 (194.4)	594.0 (800.4)	1394.65
Wine varieties					
T_{13}: Shiraz	57.55 (155.2)	212.75 (131.2)	344.00 (178.5)	522.50 (314.1)	836.65
T_{14}: Zinfandel	83.20 (210.6)	293.85 !10.1)	404.00 (221.1)	625.10 (554.7)	1179.85
T_{15}: Chenin Blanc	75.15 (169.5)	244.65 (107.6)	352.30 (170.2)	522.50 (507.3)	1029.85
T_{16}: Cabernet Sauvignon	83.20 (210.6)	293.85 (108.4)	402.30 (222.8)	625.10 (512.8)	1137.90
Mean	74.77 (186.4)	261.27 (114.3)	375.65 (198.1)	573.8 (472.2)	1046.06
SEm	3.11	3.95	0.47	4.9	1.53
CD @ 5%	9.4	11.92	1.43	14.99	4.64

terms of heat units (HUs) or growing-degree-days (GDD). The concept of degree-days or heat units is now widely accepted as a means to relate plant growth, development, and maturity to temperature Sthapit et al. [1]. Accurate prediction of crop maturity and harvest dates is important in view of avoiding field losses (both qualitative and quantitative), optimum utilization of resources and retaining shelf life potential. Now maturity indices are available for almost all the crops. The heat units - based crop maturity models will further increase precision of these predictions. Based on the weather forecast, predictions can be made well in advance which will help farmers prepare for harvesting, storage and marketing. *Vitis vinifera* is a phenologically distinct crop, and the most important developmental stages consist of budburst, bloom set, veraison and harvest Jones [2]. The time required for grapes to reach ripening from full bloom is specific to varieties, and this varies from 1600 to 3500 degree days. However, information regarding HUs summation from pruning to berry ripening is lacking in grapes. Hence, the present investigation was taken up to study, thoroughly, the number and pattern of HUs accumulation in relation to crop phenology in different varieties of grape.

Materials and Methods

The experiment heat accumulation and crop phenology in different varieties of grape (*Vitis* sps.) was conducted at Grape Research Station, Dr YSR Horti-

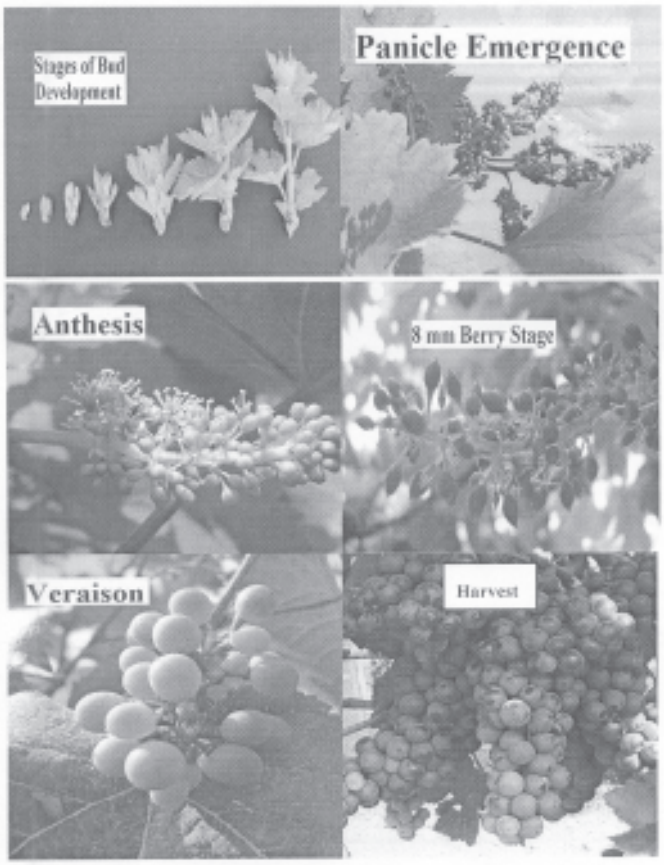

Fig. 1. Phenological stages in grape.

cultural University (presently SKL TSHU)Rajendranagar, Hyderabad during September 2013 to April 2014. The grape cultivars selected for the experimentation were nine years old, grown on own roots, planted at 10´ × 6´ spacing and trained on bower system of training. The backward pruning was done on 9th April, 2013 and forward pruning on 8th November, 2013. The varieties include table and raising varieties viz., Thompson seedless, A17/3, Flame seedless, Kishmish Chorni, table varieties viz., Anab-e-Shahi, Italia, Madhu Angur, Rizamat. Juice varieties viz., Pusa Navrang, Bangalore Blue, Rubi Red, Concord and IV. Wine varieties viz., Shiraz, Zinfandal, Chenin Blanc and Caberner Sauvignon. The minimum, maximum and mean temperature during winter (November, 2013 to January, 2014) spring (February, 2014) and summer (March to April, 2014) were 6°C, 30°C, 20°C; 14°C, 28°C, 22°C; and 19°C, 38°C, 29°C respectively. The average RH from pruning till harvesting was 80 and 40% the during the night and day respectively. Identifying phenological stages: I. Budbreak was identified by taking the bud emergence as the standard indicator for all the varieties (Fig. 1). In some vines, budbreak was earlier compared to other canes. In such a case, ten fruitful canes on different parts of the vine selected at random in the pre-woolly bud stage and when, on an average, fifty per cent of the buds reach bunch emergence 2. Fifty per cent panicle emergence was recognized by conical shape of emerging bud and its resemblance to a miniature bunch. 3. Fifty per

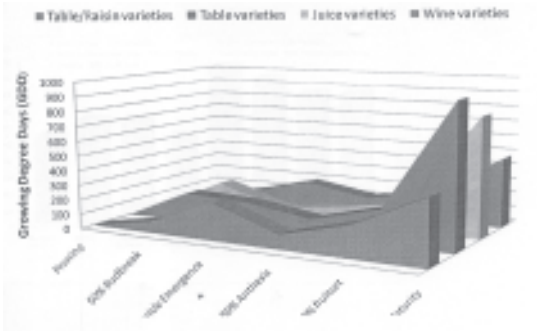

Fig. 2. Pattern of phenological progression – heat units requirement in different varieties of grapes.

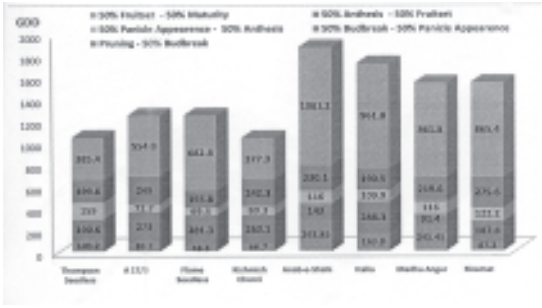

Fig. 3. Pattern of phenological progression-heat units requirement in table and table/raisin varieties of grapes.

cent anthesis was identified when fifty per cent or above number of the panicles achieved blooming. 4. Fifty per cent fruitset stage was determined when the per cent of panicles on a few random shoots showed fruitset of 50% or above. 5. Fifty percent maturity stage was identified when all bunches on shoots showed fifty per cent or more ripening or when more than fifty per cent of bunches on the shoots showed complete ripening. In case of colored varieties, the ripeness was indicated by the change in color, while in case of white varieties, the ripeness was identified by measuring the TSS of berries using a refractometer. Heat units were calculated by using the formula:

$$HU/GDD=\sum \{[(T_{max} + T_{min})/2]-Tb\}$$

Where, HU=Heat Units; GDD=Growing Degree Days; T_{max} and T_{min} =Maximum and Minimum Temperatures of the day respectively; T_b=Base Temperature below which plant growth is arrested. The base temperature for grape is taken as 10°C.

Results and Discussion

Phenological stages – heat unit accumulation

Among different groups, the wine varieties manifested all the phenological events early (Table 1). Correspondingly, the mean HUs accumulation in wine varieties were significantly less at all stages viz., 50% budbreak (74.7 GDD), 50% panicle appearance (261.27 GDD), 50% anthesis 375.65 GDD), 50% fruitset (573.8 GDD), and 50% maturity (1046.06 GDD). On the other hand, all the phenological enents occurred lately in table varieties. Correspondingly, the mean HUs accumulation were significantly high at different stages viz., 50% panicle appearance (375.0 GDD), 50% anthesis (491.15 GDD), 50% fruitset (720.1 GDD) and 50% maturity (1662.7 GDD). The above results clearly indicate that, the early maturing varieties accumulated lesser HUs compared to the late maturing varieties.

1. Heat units accumulated till 50% bidbreak (Table 1) were minimum and budbreak was earliest in wine (74.77 GDD) and table/raisin (76.65 GDD) varieties, while, late in juice (204.46 GDD) and Table (197.5 GDD) varieties. The seeded table variety, Anab-e-Shahi accumulated significantly maximum number of HUs (293.85 GDD) and hence took significantly long time to reach 50% budbreak. The seedless table/raisin variety, Flame seedless accumulated significantly less number of HUs (48.5 GDDs) among all the sixteen varieties.

2. Heat units accumulated till 50% panicle emergence (Table 1) indicated that, the wine varieties (261.27 GDDs) showed earlier emergence of panicle when compared to juice (272.66 GDDs), table/raisin (328.7 GDDs) and table (375.0 GDD) varieties. The

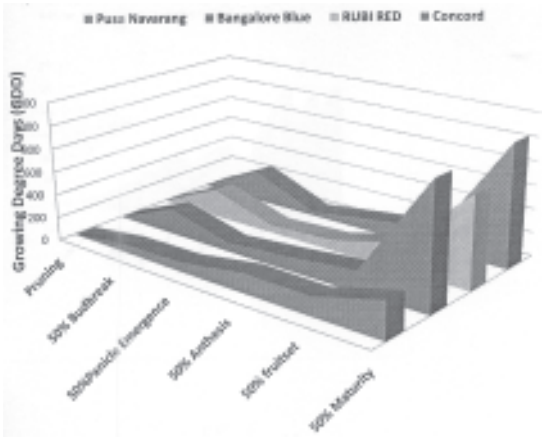

Fig 4. Pattern of phenological progression - heat units requirement in juice varieties of grape.

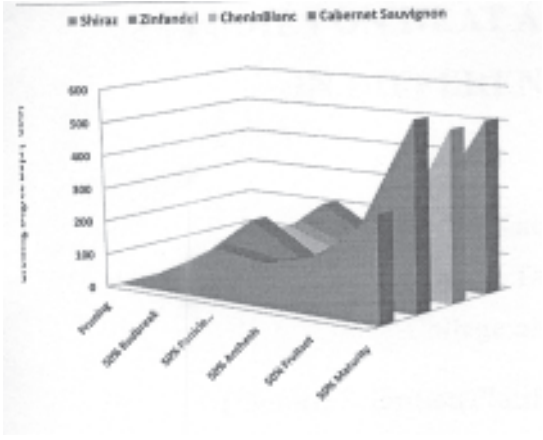

Fig. 5. Pattern of phenological progression - heat units requirement in wine grapes.

juice variety, Pusa Navrang (157.3 GDDs) accumulated significantly least number of HUs and was earliest to show panicle emergence compared to the remaining sixteen varieties. The juice variety, Pusa Navrang (157.3 GDDs) accumulated significantly least number of HUs and was earliest to show panicle emergence compared to the remaining sixteen varieties. The table varieties Italia (452.0 GDDs) followed by Anab-e-Shahi (436.85 GDDs) took maximum number of days for emergence of panicle and were significantly different from remaining sixteen varieties.

3. Heat units accumulated till 50% anthesis revealed that, table group required the maximum number of HUs to reach 50% anthesis from pruning (491.15 GDDs) compared to table/raisin (424.1 GDD), juice (399.7 GDDs) and wine (375.65 GDDs) varieties (Table 1). The juice variety, Pusa Navrang (329.85 GDDs) was significantly earliest of the juice group, as well as the sixteen varieties evaluated. The table variety, Italia (561.95 GDDs) consumed significantly highest number of HUs from pruning to 50% anthesis within the table group, as well as the sixteen varieties evaluated. Both these varieties were significantly different from the remaining sixteen varieties as well as within their groups. Italia (561.95 GDDs), Anab-e-Shahi (552.9 GDDs) followed by Thompson seedless (452.9 GDDs) and Madhu Angur (452.9 GDDs) were the late blooming varieties in the table/raisin group, as well as all the sixteen varieties. The table/raisin varieties Italia and Anab-e-Shahi were found to be at par, while the remaining varieties significantly differed.

4. Heat units accumulated till 50% fruitset indicated that, the table carieties (720.1 GDDs) accumulated maximum HUs compared to table/raisin (635.7 GDD), juice (594.08 GDDs) and wine varieties (573.8 GDDs) (Table 1). Pusa Navrang (494.25 GDDs) was the earliest of the juice varieties as well as all the sixteen varieties to achieve 50% fruitset. The remaining juice varieties, Bangalore Blue (614.8 GDDs), Concord (614.8 GDDs) and Rubi Red (652.5 GDDs) showed delayed fruitset. The table varieties, Abab-e-Shahi (783.05 GDDs) and Italia (752.5 GDDs) required the maximum number of heat units to reach 50% fruitset and showed late fruitset among the table, as well as the sixteen varieties.

5. Heat units accunulated till 50% maturity revealed that the HUs accumulated were least in case of wine varieties (1046.06 GDDs) and highest in case of table varieties (1662.7 GDDs) (Table 1). The juice variety Pusa Navrang (815.7 GDDs) was the earliest of all the sixteen varieties followeed by the wine variety Shiraz (836.65 GDDs) to reach 50% maturity. These

results were in conformity with the heat unit requirements of early varieties stated by Thakur et al. [3]. Both these varieties showed significantly lower heat unit requirements compared to remaining sixteen varieties. The highest number of HUs required to reach 50% maturity was recorded by the table varieties Anab-e-Shahi (1864.3 GDDs), Italia (1714.3 GDDs), followed by the juice varieties Bangalore Blue (1664.3 GDDs),and Concord (1664.3 GDDs). All these varieties were found to be significantly higher compared to the remaining varieties. Flame seedless, the earliest variety to show budbreak (at 48.5 GDDs) showed maturity at (1237.9 GDDs). This indicates that the earliness of budbreak need not always correspond with early onset of maturity. This was also observed by Shellie [4] in the cultivar Zinfandel.

Pattern of phenological progression– heat units requirement

Wide variations were recorded in the HUs requirement for transition from one stage tothe next, and from variety to variety (Fig. 2). The average HUs requirement was maximum during the last phase, i.e., fruitset to maturity (676.4 GDD) followed by anthesis to fruitset (312 GDD). The panicle emergence to anthesis required minimum HUs (88.2 GDD) followed by pruning to budbreak (140. 3 GDD). Santibáñez et al. [5] observed that in the earlier phase of the life cycle, differences among cultivars are rather small. As it moves forward in the cycle, differences start to express clearly, and degree-days required for accomplishing latter phenological phases, increase more in later cultivars than in the earlier. Further, different varieties also showed wide variations in HUs requirement for phenological progression. For transition from fruit set to maturity, table varieties required maximum HUs (942.5 GDD), followed by juice varieties (800.48 GDD), whereas, table/raisin (425.1 GDD) and wine varieties (472.2 GDD) required minimum HUs. Similarly, for transition from 50% panicle appearence to 50% anthesis, the varieties required minimum number of HUs. Van Leeuwen et al. [6] made a similar observation that differences among varieties are smaller for the temperature sums for flowering, compared to other phenological stages.

Table/raisin varieties

Among the table and table/raisin group (Fig. 3). Flame seedless (48.5 GDD) took the shortest time while Anab-e-Shahi (293.85 GDD) took a significantly long time to reach fifty per cent budbreak compared to the remaining varieties. The varieties requiring highest and least number of HUs from pruning to 50% budbreak belonged to the table/raisin group, indicating significant variation within the group. Similarly, the differences were more conspicuous during the last phase i.e., fruit set to maturity. The variety Kishmish Chorni (377.39 GDD) required minimum HUs while, Anab-e-Shahi (1081.25 GDD) and Italia (961.8 GDD) required maximum HUs for transition from fruitset to maturity. The data on cumulative HUs at maturity indicated that, Kishmish Chorni (1029.85 GDD) and Thompson seedless (1037.9 GDD) were the earliest, recording significantly least number of heat units while, Anab-e-Shahi (1864.3 GDD) and Italia (1714.3 GDD) were late varieties requiring the significantly highest HUs. Flame seedless, the variety which was earliest to show fifty per cent budbreak at 48.5 GDD, reached fifty per cent maturity at 1237.9 GDD (cumulative). The onset of maturity did not always correspond with earliness of budbreak. This was also observed by Shellie [4] in the cultivar Zinfandel.

Juice varieties

In the juice group, variations were prominent mainly during two phases viz., 1. pruning– bud break, and 2. Fruitset- maturity) (Fig. 4). The variety Pusa Navrang (73.1 GDD) was the earliest to show budbreak compared to other varieties Concord (273.85 GDD) Rubi Red (245.45 GDD) and Bangalore Blue (225.45 GDD). However, Pusa Navrang required marginally higher number of HUs for transition from bidbreak - panicl emergenc (84.2 GDD) and panicle emergence – anthesis (172.55 GDD) compared to other juice varieties. Again, during the last phase, i.e. fruitset to maturity, Pusa Navarang required least number of HUs (321.45 GDD) while Bangalore Blue (1049.5 GDD) and Concord (1049.5 GDD) required maximum number of HUs. Among juice varieties, Pusa Navrang exhibited a different pattern of HUs requirement for phenological progression.

Wine varieties

In the wine group (Fig. 5), Shiraz (57.55 GDD) was the earliest to break bud while Cabernet Sauvignon (83.2 GDD) and Zinfandel (83.2 GDD) were the last. This finding was supported by Shellie [4]. Similarly, Shiraz (135.2 GDD) required minimum HUs, while Cabernet Sauvignon (210.65 GDD) and Zinfandel (210.65 GDD) required maximum HUs for transition from budburst to panicle emergence. The differences in HUs requirement were more conspicuous during the last phase, i.e., fruitset to maturity. During this phase, Shiraz required minimum HUs (314.15 GDD), while maximum HUs were required by Zinfandel (554.75 GDD), Cabernet Sauvignon (512.8 GDD) and Chenin Blanc (507.3 GDD). Heat unit models provide a relatively simple means for monitoring the physiological development of crops and adjusting cultural practices to correspond to the favorableness of the growing season. These models can serve as an aid in making timely decisions. The heat units - based crop maturity models will be a promising criterion for predicting physiological maturity and harvest in grapes.

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