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Impact of accumulated growing degree days (GDD) on phenology of apple (*Malus domestica* Borkh) in Kullu district of Himachal Pradesh

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Abstract

The present investigation was undertaken to study the location based weather variations on phenology of apple (*Malus domestica* Borkh) cultivars in Kullu district of Himachal Pradesh during 2015 and 2016. The studies were conducted at four locations with different altitudinal gradients, viz. Bajaura (1090 m A.M.S.L.), Seobagh (1189 m A.M.S.L.), Naggar (1880 m A.M.S.L.) and Arsu (2080 m A.M.S.L.) on three commercial apple varieties viz. Red Delicious, Royal Delicious and Golden Delicious. The number of days required to complete various phenological stages increased with the increase in altitude of localities studied. Minimum numbers of days for silver tip stage (54.22 days with 349.22 GDD), green tip stage (71.67 days with 484.00 GDD), pink bud stage (86.94 days with 662.54 GDD), full bloom stage (93.89 days with 749.67 GDD) and for petal fall stage (99.00 days with 807.48 GDD) were recorded at Bajaura location, followed by Seobagh, Naggar and Arsu. Significantly maximum numbers of days for silver tip stage (64.06 days with 220.82 GDD), green tip stage (81.72 days with 328.02 GDD), pink bud stage (97.00 days with 462.10 GDD), full bloom stage (103.39 days with 704.06 GDD) and for petal fall stage (109.22 days with 589.78 GDD) were at Arsu location, which was followed by Naggar. Among different cultivars, Red Delicious cultivar took minimum number of days for silver tip stage (56.58 days and 264.93 GDD), green tip stage (74.92 days with 387.44 GDD), pink bud stage (89.00 days with 526.85 GDD), full bloom stage (95.71 days with 598.33 GDD) and for petal fall stage (101.58 days with 662.14 GDD), followed by Royal Delicious and Golden Delicious.

Keywords: Apple, golden delicious, red delicious, royal delicious, flowering, GDD, location

Introduction

Apple (*Malus domestica* Borkh) is the major fruit crop of Himachal Pradesh occupying about 49 per cent of the total area under fruits and 72 per cent of total area under temperate fruits, contributing about 85 per cent of total fruit production in the state (Anonymous, 2015) [1]. Climatic conditions viz., temperature and water availability are important factors controlling active growth of the crop and therefore, affect the final production. Climate not only limits for growth of a crop but also influence the productivity and the quality of the produce. Climate change has many facts including changes in long term trends in temperature and rainfall regimes as well as year to year variability. The decreased productivity of apple orchards in the recent years due to change in climatic conditions has become a serious concern of the growers in Himachal Pradesh. Due to the erratic weather conditions, some parts of state dominated by apple are now falling low in terms of being commercially productive (Vedwan, 2006) [9]. Extending and fully integrating the knowledge of climate and weather can optimize agricultural production with maximum use of weather resources and minimal damage to environment.

The temperature is an important weather parameters regulating the growth and development of crops planted. The temperature requirement for completion of various developmental stages is measured in terms of growing degree days. Growing degree days (GDD) are the number of temperature degrees above a certain threshold base temperature within consecutive 24 hr period (Kanzaria *et al.*, 2015) [6]. The base temperature for apple has been found as 4 °C (Singh and Bhatia, 2012) [8]. The growing degree days can be used for prediction of various development stages of plants. It varies with altitude of the areas and among different crops and their varieties.

Therefore, the present study was conducted to know the relationship of accumulated growing degree days and phenology of apple in different altitudinal gradients with different varieties in Kullu district of Himachal Pradesh.

Materials and Methods

The study was conducted in Kullu district of Himachal Pradesh at four locations, viz. Bajaura (1090 m a.m.s.l.), Seobagh (1189 m a.m.s.l.), Naggar (1880 m a.m.s.l.) and Arsu (2080 m a.m.s.l.) and on three commercial apple cultivars namely; Royal Delicious, Red Delicious and Golden Delicious during 2015 and 2016. The apple trees of about 15-20 years old were selected for the study. The experiment was laid out in randomized block design (factorial) with three replications. Utmost care was taken while selecting the healthy and optimum productive trees of the uniform size, shape and age. Detailed phenological observations were made during two growing seasons (2015 and 2016) in a frequency depending on the stage, from two to three times per week. To record the duration of every phenological stage, four random shoots were selected in all directions of the canopy at each site. In order to account for variability within a shoot, all the branches in the selected shoot were evaluated and average observation was recorded. The data on maximum and minimum temperature for the study period were procured from Regional Horticultural Research Station, Bajaura for Bajaura and Seobagh locations and from IARI regional station at Katrain for Nagar location. Whereas, for Arsu location the weather data were downloaded from the internet manually. The beginning of the year i.e. 1st January was used as an approximation of the beginning of the development across the study area. The consequent number of calendar days to attain each phenological stage was calculated. The first clearly identifiable stage in apple (silver tip) was used as a biofix for the onset of growth with GDD accumulated starting January 1. Accumulated growing degree days (GDD) was computed by mean daily temperature degree above base temperature. The formula applied for calculation of GDD was $(T_{\max} + T_{\min})/2 - T_{\text{base}}$. The base temperature of 4°C as reported by Singh and Bhatia (2012) [8] for apple was used for calculation of GDD. The data on calendar days and GDD required to complete various developmental stages at different locations were analyzed by RBD (factorial). The data for 2015 and 2016 were pooled before analyzing the same. Developmental periods and accumulated degree days at different locations and in different cultivars were compared by using critical difference (CD) at 5% level of significance.

Results and Discussion

The number of calendar days required and GDD accumulated to complete various phenological stages in apple varied among different varieties and locations in Kullu district of Himachal Pradesh. Temperature played important role in occurrence of various development stages.

1. Silver tip stage

The results of study revealed that number of days required for silver tip stage was maximum at Arsu (64.06), which was significantly highest as compared to all other locations, followed by Naggar (60.94), Seobagh (57.67) and Bajaura (54.22) (Table 1). Among different cultivars, Golden Delicious cultivar (61.92) took maximum number of days for silver tip stage followed by Royal Delicious (59.17) and Red Delicious (56.58). The interactions of locations and cultivars

revealed maximum number of days for silver tip stage in Golden Delicious cultivar (66.33) at Arsu and the minimum in Red Delicious cultivar (51.67) at Bajaura. Maximum accumulated degree days required for silver tip stage in apple cultivars were recorded in Bajaura (349.92), followed by Seobagh (309.34), Naggar (243.69) and Arsu (220.82). Among different cultivars, Golden Delicious accumulated highest degree days (296.75) for silver tip stage, followed by Royal Delicious (281.14) and Red Delicious (264.93).

The variation in number of days and GDD required for silver tip stage amongst different cultivars can be explained by the fact that the amount of chilling hours required and the threshold temperature to break dormancy vary between the cultivars, wherein, cultivars with a low chilling requirement, tend to have a bud-break at lower temperatures (Jackson 2003; Wertheim and Schmidt 2005) [5, 10]. Similarly, in locations with lower altitudes (e.g. Bajaura) the higher temperature resulted in earlier accumulation of heat units leading to an earlier occurrence of silver tip stage in comparison to other altitudinal gradients. The results are in conformity with the findings of Jackson (2003) [5] and Landsberg (1979) [7] which state that the rate of growth after bud break is determined by prevailing temperatures, so that lower temperatures slow down the rate of development, while higher temperatures lead to a more rapid development.

2. Green tip stage

Significant differences were observed in number of calendar days required for green tip stage at different locations and cultivars (Table 2). The pooled data of 2015 and 2016 also revealed the maximum number of days required for green tip stage at Arsu (81.72), which was significantly highest than all other locations, followed by Naggar (78.50), Seobagh (75.89) and Bajaura (71.67). Among different cultivars significantly highest number of days was recorded in Golden Delicious cultivar (79.04), followed by Royal Delicious (76.88) and Red Delicious (74.92). The interaction effect showed maximum number of days required for this stage in Golden Delicious cultivar (84.17) at Arsu and the minimum number in Red Delicious cultivar (69.67) at Bajaura. Similarly, significant differences were observed in accumulated degree days required for green tip stage at different locations and cultivars. The maximum number of accumulated degree days was recorded at Bajaura (484.00), followed by Seobagh (461.71), Naggar (342.60) and minimum in Arsu (328.02). Among different cultivars significantly highest accumulated degree days were recorded in Golden Delicious cultivar (422.18), followed by Royal Delicious (402.63) and Red Delicious (387.44). In interaction of cultivars and locations, the maximum accumulated degree days were recorded in Golden Delicious cultivar (499.12) at Bajaura and the minimum in Red Delicious cultivar (308.40) at Arsu. In this stage, the high temperature resulted in higher accumulation of GDD leading to an earlier occurrence of green tip stage in locations with lower altitudes as compared to other altitudinal gradients. Donnelly *et al.* (2004) [3] have also attributed the significant role of air temperature in influencing the seasonal timing of spring phenophases related to foliage and flowering of various plant species.

Table 1: Effect of location-wise weather variations on calendar days and accumulated degree days for silver tip stage in different cultivars of apple in Kullu district of HP

Location \ Cultivar	Number of days required for silver tip stage				Accumulated GDD				
	Red Delicious	Royal Delicious	Golden Delicious	Mean	Red Delicious	Royal Delicious	Golden Delicious	Mean	
Bajaura (1090m amsl)	51.67	54.33	56.67	54.22	328.82	351.15	369.80	349.92	
Seobagh (1189 m amsl)	54.83	57.67	60.50	57.67	287.90	310.08	330.03	309.34	
Naggar (1880m amsl)	58.33	60.33	64.17	60.94	232.43	241.71	256.92	243.69	
Arsu (2080 m amsl)	61.50	64.33	66.33	64.06	210.56	221.64	230.27	220.82	
Mean	56.58	59.17	61.92		264.93	281.14	296.75		
C.D. (0.05)									
Location	0.46				Location	2.81			
Cultivar	0.40				Cultivar	2.44			
Cultivar X Location	NS				Cultivar X Location	4.87			

Table 2: Effect of location-wise weather variations on calendar days and accumulated degree days for green tip stage in different cultivars of apple in Kullu district of HP

Location \ Cultivar	Number of days required for green tip stage				Accumulated GDD				
	Red delicious	Royal delicious	Golden delicious	Mean	Red delicious	Royal delicious	Golden delicious	Mean	
Bajaura (1200 m amsl)	69.67	71.67	73.67	71.67	469.22	483.65	499.12	484.00	
Seobagh (1400 m amsl)	74.17	75.83	77.67	75.89	446.43	460.70	478.01	461.71	
Naggar (1800 m amsl)	76.17	78.67	80.67	78.50	325.70	343.54	358.55	342.60	
Arsu (2000 m amsl)	79.67	81.33	84.17	81.72	308.40	322.62	353.04	328.02	
Mean	74.92	76.88	79.04		387.44	402.63	422.18		
C.D. (0.05)									
Location	0.31				Location	3.41			
Cultivar	0.27				Cultivar	2.95			
Cultivar X Location	0.54				Cultivar X Location	5.91			

3. Pink bud

In pink bud stage also maximum days for this stage to occur was recorded in Arsu (97.00), followed by Naggar (92.50), Seobagh (90.28) and Bajaura (86.94) (Table 3). Among cultivars, pink bud stage in Golden Delicious took maximum number of days (94.46) followed by Royal Delicious (91.58) and Red Delicious (89.00). Similarly significant differences were also observed accumulation of heat units required for pink bud stage in different locations and cultivars. Among locations, significantly highest accumulated degree days for pink bud stage in apple cultivars was recorded in Bajaura

(662.54), which was followed by Seobagh (625.78), Naggar (474.26) and Arsu (462.10). Golden Delicious accumulated maximum degree days (585.29) for pink bud stage as compared to Royal Delicious (556.37) and Red Delicious (526.85). In interaction studies maximum accumulated degree days were recorded in Golden Delicious cultivar (707.98) at Bajaura and the minimum in Red Delicious cultivar (440.65) at Arsu. As for other stages, temperature played important role in occurrence of pink bud stage in different apple cultivars and locations.

Table 3: Effect of location-wise weather variations on calendar days and accumulated degree days for pink bud stage in different cultivars of apple in Kullu district of HP

Location \ Cultivar	Number of days required for pink bud stage				Accumulated GDD				
	Red Delicious	Royal Delicious	Golden Delicious	Mean	Red Delicious	Royal Delicious	Golden Delicious	Mean	
Bajaura (1200 m amsl)	83.33	87.33	90.17	86.94	609.62	670.03	707.98	662.54	
Seobagh (1400 m amsl)	88.00	90.33	92.50	90.28	600.15	626.58	650.60	625.78	
Naggar (1800 m amsl)	90.33	91.33	95.83	92.50	456.99	464.82	500.96	474.26	
Arsu (2000 m amsl)	94.33	97.33	99.33	97.00	440.65	464.05	481.61	462.10	
Mean	89.00	91.58	94.46		526.85	556.37	585.29		
C.D. (0.05)									
Location	0.39				Location	4.71			
Cultivar	0.34				Cultivar	4.08			
Cultivar X Location	0.68				Cultivar X Location	8.16			

The higher temperature resulted in higher and early accumulation of heat units and thereby advancing the pink bud stage. The Bajaura location was at lower altitude (1090 m amsl) and was the warmest as compare to other locations. So at this location apple cultivars took minimum days for pink bud stage and accumulated higher number of heat units. Wolfe *et al.* (2005) [11] have also reported that higher temperatures (1 °C rise) during the late growing season promoted earlier leafing and flowering initiation in apple crop. Hanke *et al.* (2007) [4] stated that alteration in exogenous factors such as chilling temperature during the winter season resulted in the variations in the flower buds formation.

4. Full bloom stage

The number of days required for full bloom stage also varied among different locations and cultivars (Table 4). The full bloom in different apple cultivars took 103.39 average number of days at Arsu which was significantly highest than all other locations. The average number of days required for full bloom in Naggar, Seobagh and Bajaura was 98.83, 96.78 and 93.89, respectively. Among different cultivars, significantly maximum number of days for full bloom stage was recorded in Golden Delicious cultivar (100.88) followed by Royal Delicious (98.08) and Red Delicious (95.71). The interactions of locations with apple cultivars resulted in

highest number of days for full bloom stage in Golden Delicious cultivar (105.83) at Arsu and the lowest in Red Delicious cultivar (91.17) at Bajaura. The accumulated degree days required for full bloom stage also varied among locations and cultivars. The apple cultivars accumulated 749.67 average number of degree days for full bloom at Bajaura which was significantly highest than all other locations. The average number of accumulated degree days for full bloom in Seobagh, Naggar and Arsu was 704.06, 529.80 and 522.20, respectively. Among different cultivars, significantly maximum accumulated degree days required for full bloom stage were recorded in Golden Delicious cultivar (655.42) followed by Royal Delicious (625.55) and Red

Delicious (598.33). While comparing apple cultivars at different locations highest accumulated degree days for full bloom stage were recorded in Golden Delicious cultivar (779.33) at Bajaura and the lowest in Red Delicious cultivar (493.19) at Arsu. In present studies, the locations with higher average temperatures resulted in early flowering in different apple cultivars as compared to localities with lower average temperatures. These results are in line with the study of Chmielewski *et al.* (2004) [2] who studied response of the beginning of apple tree blossom to the annual deviations in air temperature in Germany and reported that increased mean temperature and decreased photoperiod caused a shortening of developmental phases of crops with effects on crop yields.

Table 4: Effect of location-wise weather variations on calendar days and accumulated degree days for full bloom stage in different cultivars of apple in Kullu district of HP

Cultivar Location	Number of days required for full bloom stage				Accumulated GDD				
	Red Delicious	Royal Delicious	Golden Delicious	Mean	Red Delicious	Royal Delicious	Golden Delicious	Mean	
Bajaura (1200 m amsl)	91.17	93.83	96.67	93.89	719.30	750.38	779.33	749.67	
Seobagh (1400 m amsl)	94.33	96.83	99.17	96.78	670.53	705.55	736.11	704.06	
Naggar (1800 m amsl)	96.83	97.83	101.83	98.83	510.29	520.10	559.00	529.80	
Arsu (2000 m amsl)	100.50	103.83	105.83	103.39	493.19	526.17	547.23	522.20	
Mean	95.71	98.08	100.88		598.33	625.55	655.42		
C.D. (0.05)									
Location	0.41				Location	4.59			
Cultivar	0.35				Cultivar	3.97			
Cultivar X Location	0.71				Cultivar X Location	7.95			

5. Petal fall stage

The petal fall stage in apple also showed significant variations in different locations and apple cultivars (Table-5). The pooled data of 2015 and 2016 revealed maximum average number of days for petal fall stage in apple cultivars at Arsu (109.22), followed by Naggar (106.44), Seobagh (102.61) and Bajaura (99.00). Among different cultivars, significantly highest number of days for petal fall stage was recorded in Golden Delicious cultivar (107.21), followed by Royal Delicious (104.17) and Red Delicious (101.58). In interactions of different apple cultivars with locations, maximum number of days required for petal fall stage was recorded in Golden Delicious cultivar (111.50) at Arsu and the minimum in Red Delicious cultivar (96.50) at Bajaura. The data also revealed significant differences in number of GDD required for petal fall stage in different locations and cultivars. Maximum mean accumulated degree days required for petal fall stage in apple cultivars were recorded in Seobagh (816.03), followed by Bajaura (807.48), Naggar (610.42) and Arsu (589.78). Among different cultivars, significantly highest accumulated degree days for petal fall stage were recorded in Golden Delicious cultivar (747.92),

followed by Royal Delicious (707.72) and Red Delicious (662.14). The interaction of locations with apple cultivars revealed highest accumulated degree days in Golden Delicious cultivar (879.65) at Seobagh and the minimum accumulated degree days in Red Delicious cultivar (557.08) at Arsu.

As for other phenological stages, the warmer locations resulted in early petal fall/ fruit set in different apple cultivars. The results are in conformity with findings of other workers (Landsberg, 1979, Jackson, 2003, Wolfe *et al.* 2005) [7, 5, 11] who verified the role of temperature in apple phenology. The variations among different apple cultivars may be attributed to their varied chilling requirements and sensitivity to temperature. The altitude played an important role in completion of various phonological stages of apple. For example, the location Arsu was at higher altitude (2080 m a.m.s.l.) as compared to other locations. The phenological phases at this location were delayed due to lower temperature regime. The apple trees also accumulated lower heat units at higher altitudes as compared to the locations at lower altitudes. Similar results were also obtained by Kanzaria *et al.* (2015) [6] in mango.

Table 5: Effect of location-wise weather variations on calendar days and accumulated degree days for petal fall stage in different cultivars of apple in Kullu district of HP

Cultivar Location	Number of days required for petal fall stage				Accumulated GDD				
	Red Delicious	Royal Delicious	Golden Delicious	Mean	Red Delicious	Royal Delicious	Golden Delicious	Mean	
Bajaura (1200 m amsl)	96.50	98.83	101.67	99.00	776.53	804.95	840.97	807.48	
Seobagh (1400 m amsl)	99.33	102.50	106.00	102.61	737.20	831.23	879.65	816.03	
Naggar (1800 m amsl)	103.83	105.83	109.67	106.44	577.77	601.71	651.78	610.42	
Arsu (2000 m amsl)	106.67	109.50	111.50	109.22	557.08	592.98	619.28	589.78	
Mean	101.58	104.17	107.21		662.14	707.72	747.92		
C.D. (0.05)									
Location	0.45				Location	5.82			
Cultivar	0.39				Cultivar	5.04			
Cultivar X Location	0.78				Cultivar X Location	10.08			

Conclusion

From the present study, it can be concluded that different growth stages in apple phenology such as silver tip stage, green tip stage, pink bud stage, full bloom stage and petal fall were observed earliest at Bajaura location where the apple crop experienced higher average temperature. The apple trees accumulated higher number of GDDs in locations at lower altitudes as compared to those at higher altitude. Red Delicious variety required minimum calendar days and GDD to reach maturity as compared to Royal Delicious and Golden Delicious. GDD accumulation had direct influence on the duration of different phenological stages of apple which varied in locations with different altitudinal gradients and among apple varieties.

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