Thermal Time Utilization of Plum in Semi Arid Region of Gangetic Plain

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Abstract: Plum prefers temperate climate thus a major crop of hills however, it has been found growing from higher hills in Srinagar to Jaipur in Rajasthan and areas around Delhi. It requires less chilling hours and can tolerate frost and high summers both, that is why it can be cultivated in both low temperatures to 0°C and up, highest up to 47°C in summers. Among the major Japanese cultivar the Kala Amritsari, Satluj Purple and Titron are planted at HAU farm in 2001 on which the present study was done during 2013-14. The overall growth was observed better in Kala Amritsari followed by Satluj purple and Titron which is a late maturing variety. The thermal time required by Kala Amritsari and Satluj Purple was at par but the Titron required more thermal indices. The heat use efficiency was observed highest for Kala Amritsari and lowest for Titron whereas the photothermal index was highest in Titron followed by Kala Amritsari and Satluj Purple. The thermal units explained the 94 per cent variation in fruit yield of Kala Amritsari, 87 per cent variation in Satluj Purple and 83 percent variation in fruit yield of Titron cultivar.

Keywords: Plum, Phenophases, GDD, HTU, PTU, HYTU, HUE

1. Introduction

Plum is native to China, although it became a commercial fruit of Japan and America. It is known as Japanese plum (*Prunus salicina* Lindell) due to its cultivation in Japan from where cultivars spread to other places. At present, plum is cultivated in all temperate climate countries of the world. It has been found growing from higher hills in Srinagar to Jaipur in Rajasthan and areas around Delhi in semi arid region of Gangetic plain of India. It requires less chilling hours and can tolerate frost and high summers both, that is why it can be cultivated in both low temperatures to 0°C and up, highest up to 47°C in summers. It may also be planted as a filler fruit plant in orchards due to low chilling requirement and less juvenile period. Plums are highly productive due to profuse flowering, high fruit set and early ripening habit of cultivars recommended for plains. The major cultivars of plum grown in plain area of Haryana and Punjab state are Kala Amritsari which is a self-fruitful high yielding local cultivar and is most preferred cultivar of plains. Its fruits are of medium size, round oblate depressed at both ends which ripen in second half of May. The cultivar Satluj Purple is a self-unfruitful cultivar and requires pollinizer for good fruit

set. Tree is medium in vigor with upright habit of growth. It is an early ripening low yielding cultivar. Titron is a self-fruitful cultivar but its yield increases if Alucha Early Round is used as a pollinizer. Titron trees are smaller than Kala Amritsari.

The plum tree remains in dormancy during December and January and bud beak takes place from first week of February after completing the chilling requirements under Haryana conditions. Prevailing weather conditions during the whole crop growing season have direct bearing upon the phenological events of the crop which ultimately affect the crop yield. The duration of each growth phase is a result of crop response to external environmental factors. Temperature is one of the important elements of the climate which determines directly the potential productivity level. Thermal time effect has been described as the independent variable to delineate plant growth and development (Dwyer and Stewart, 1986). Temperature based agrometeorological indices like GDD, HTU, PTU and HYTU are based on the concept that real time to attain the phenological stages is linearly related to temperature in the range between base temperature and the optimum temperature (Monteith, 1981). This concept is widely used for growth, phenological development and yield of different crops (Rajput *et al.,* 1987; Shanker *et al.,* 1996;

Swan *et al.,* 1989). Such works have been done elsewhere (Rao *et al.,* 1999) it has not hitherto been reported from semi arid region of Haryana especially on fruit crops. Hence, the present investigation was carried out to assess the response of phenology and fruit yield of plum cultivars growing degree days and heat unit utilization under semi arid conditions.

2. Materials and Methods

Field experiment was conducted during 2013 and 2014 at experimental orchard of the Chaudhary Charan Singh Haryana Agricultural University Hisar (29.10°N, 75.46°E and 215 m amsl) to assess the heat unit utilization for different phenophases 13 years old three genotypes of plum planted at spacing of 6x6 meters. The spacing under reference accommodate 277 plants/ha. Pomologists have given different names to the various developmental growth stages of plum fruits tree. Out of these we have observed only six important phenophases of plum (Plate 1) which were recorded on marked four branches of five trees of each genotype by visiting the selected tree at two days interval. The meteorological data was collected from the Agromet Observatory situated in the research farm (Fig 1). Following agrometeorological indices and heat use efficiencies were calculated on daily basis and accumulated from bud burst to maturity/harvesting taking 10° C as base temperature. The dormant period was supposed to be over when the accumulated chilling hours started decreasing.

1. Growing degree days (GDD) = (Tmax +Tmin)/2- 10° C
2. Photothermal unit (PTU) = GDD * Day Length
3. Heliothermal unit(HTU) = GDD * Sunshine Hours
4. Hydrothermal unit (HYTU) = GDD * RH

Under the semi arid conditions on an average accumulation of heat units started from January 22 in 2013 and from January 20 in 2014 when the accumulation of chilling hours started decreasing. The energy use efficiencies were computed ((kg ha^{-1} per degree) to compare the relative performance of different cultivars with respect to utilization of heat unit using the following formulae:

1. Heat use efficiency (HUE) = Fruit yield (kg ha^{-1})/GDD ° C day.
2. Photothermal use efficiency (PTUE) = Fruit yield (kg ha^{-1})/PTU ° C day.
3. Heliothermal use efficiency (HTUE) = Fruit yield (kgha^{-1})/HTU ° C day.
4. Hydrothermal use efficiency (HYTUE) = Fruit yield (kg ha^{-1})/HYTU ° C day

Phenothermal index (PTI) for each phenophases was calculated as per following formula (Sastry and Chakravarty, 1982). PTI = (GDD)/No. of days taken between two phenophases. Predictive regression relation models were also worked out between thermal indices and yield of different genotypes.

Dormant

Bud burst

White bud

Full bloom

Petal fall

Maturity

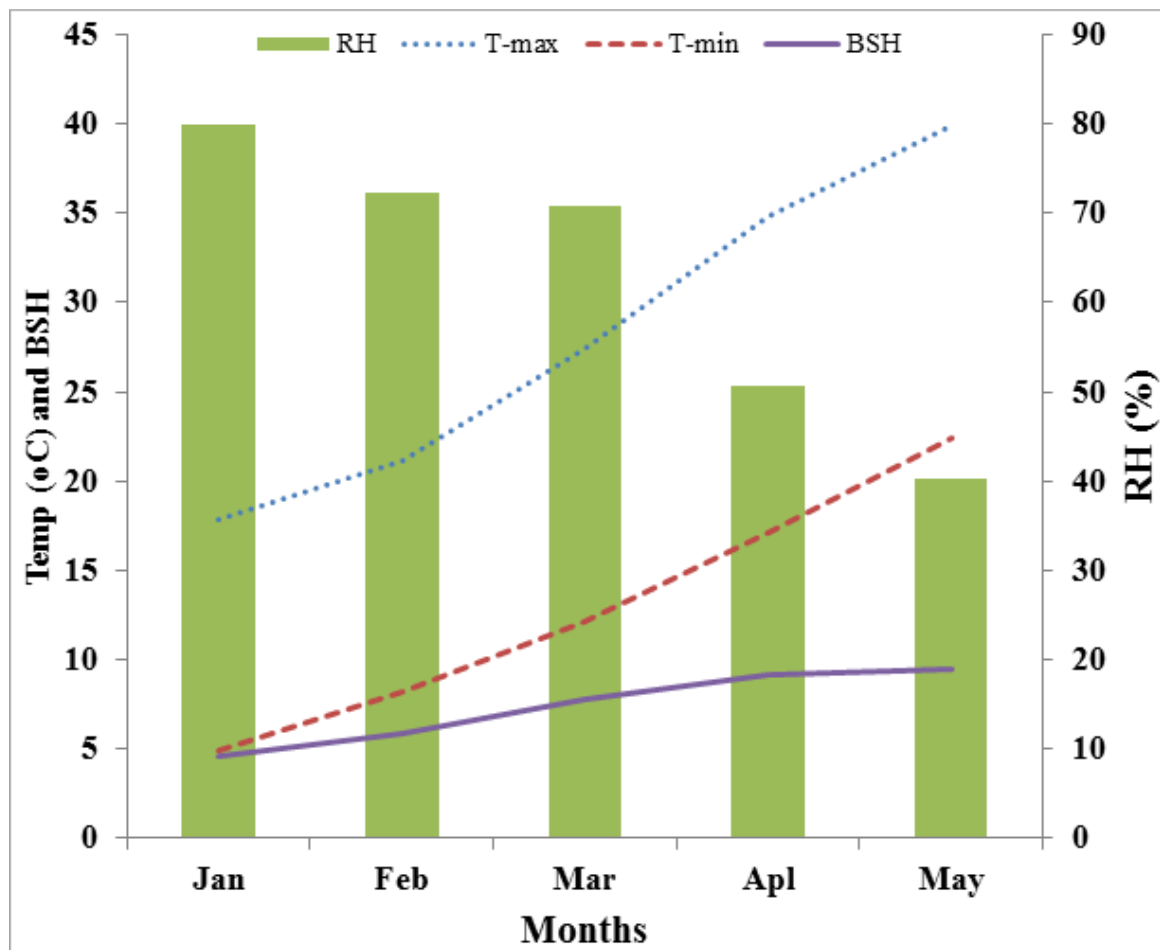*Plate 1. Important phenophases recorded in Plum at Hisar.*

Fig. 1. *Weather during the crop growth period (average of two years).*

BHS: Bright sun shine hours
RH: Relative humidity
T-max: Maximum Temperature
T-min: Minimum temperature

3. Results and Discussion

3.1. Thermal Indices

Bud burst of all the three cultivars took place on first February during 2013 and on January 30 during 2014. Days taken to complete growth stages from dormant to bud burst, from bud burst to white-bud and from white-bud to full-bloom were lowest in Kala Amritsari followed by Satluj Purple and Titron. Similar trend was observed in photothermal units (PTU), heliothermal units (HTU) and hydrothermal unit (HYTU).

Kala Amritsari required absolute value of 35 GDD, 186 PTU, 375 HTU and 2876 HYTU to attain bud burst after completion of dormancy (Table 1); 35 GDD, 155 PTU, 380 HTU and 2857 HYTU from bud burst to attain white bud; 48 GDD, 284 PTU, 534 PTU and 3837 HYTU from white bud to full bloom; 41 GDD, 266 PTU, 470 HTU and 3438 HYTU from full bloom to petal fall and 805 GDD, 6971 PTU, 10144 HTU & 45487 HYTU Table 2). Satluj Purple required 48 GDD, 234 PTU, 519 HTU and 3953 HYTU to attain bud burst after completion of dormancy; 35 GDD, 190 PTU, 386 HTU and 2910 HYTU from bud burst to white bud; 46 GDD, 279 PTU, 512 PTU and 3613 HYTU from white bud to full bloom; 41 GDD, 283 PTU, 463 HTU and 3262 HYTU from full bloom to petal fall and 816 GDD, 7065 PTU, 10292 HTU & 45839 HYTU from petal fall to attain the maturity stage. The Titron which is a late maturing cultivar of plum required 56 GDD, 268 PTU, 606 HTU and 4645 HYTU to attain bud burst after completion of dormancy; 37 GDD, 225 PTU, 412 HTU and 3010 HYTU from bud burst to white bud; 50 GDD, 279 PTU, 564 PTU and 4082 HYTU from white bud to full bloom; 45 GDD, 363 PTU, 513 HTU and 3345 HYTU from full bloom to petal fall and 957 GDD, 8433 PTU, 12234 HTU & 50793 HYTU from petal fall to maturity (Table 1).

The mean of two years of thermal indices by Kala Amritsari from break of dormancy to attain physiological maturity were 965 GDD, 7863 PTU, 11904 HTU and 58897 HYTU by Satluj purple 986 GDD, 8051 PTU, 12172 HTU and 59578 HYTU and by Titron 1146 GDD, 9570 PTU, 14332 HTU and 65876 HYTU (Table 2). The growth period

during 2014 was almost one week longer as compared to 2013 which might be due to the cloud weather and more rains received from fruit set to maturity during 2014. Days taken to attain different phenophases by Kala Amritsari and Satluj purple were almost at par but Titron has taken 3- 12 days more for attaining different growth stages in plum (Table 3).

Table 1. Thermal units used for attaining different Phenophases of different genotypes of plum.

Gynotypes	GDD	PTU	HTU	HYTU
Kala Amritsari				
Bud burst	35.2	186.0	375.0	2876.1
White bud	35.0	155.3	380.1	2857.3
Full bloom	48.1	283.6	534.2	3837.6
Fruit set	41.3	266.3	470.3	3438.5
Maturity	805.7	6971.9	10144.7	45887.8
Satluj Purple				
Bud burst	48.5	234.3	519.4	3953.4
White bud	35.4	190.3	385.5	2910.7
Full bloom	45.8	278.8	511.8	3612.5
Fruit set	40.5	283.0	462.8	3262.2
Maturity	815.8	7065.0	10292.9	45839.2
Titron				
Bud burst	56.6	268.3	606.6	4645.5
White bud	37.6	225.7	412.6	3010.1
Full bloom	50.1	279.6	564.5	4082.3
Fruit set	44.5	363.4	513.0	3344.9
Maturity	957.0	8433.2	12234.9	50793.3

Table 2. Agrometeorological indices (degree days) to attain different phenophases in plum genoypes.

	2013				2014				Mean			
	GDD	PTU	HTU	HYTU	GDD	PTU	HTU	HYTU	GDD	PTU	HTU	HYTU
Kala Amritsari												
Bud burst	26.4	172.3	282.7	1909.5	43.9	199.8	467.3	3842.7	35.2	186.0	375.0	2876.1
White bud	62.4	317.3	673.7	4733.0	78.0	365.3	836.5	6733.7	70.2	341.3	755.1	5733.4
Full bloom	88.8	489.6	956.4	6642.5	121.9	565.1	1303.7	10576.4	105.3	527.3	1130.1	8609.5
Fruit set	152.7	845.7	1687.6	11965.1	166.4	936.8	1831.6	14053.9	159.6	891.2	1759.6	13009.5
Maturity	965.8	7797.7	11886.9	57446.5	964.8	7928.6	11921.6	60348.1	965.3	7863.2	11904.3	58897.3
Satluj Purple												
Bud burst	39.6	234.6	425.5	2871.1	57.5	234.1	613.4	5035.6	48.5	234.3	519.4	3953.4
White bud	75.2	423.9	813.4	5680.4	92.6	425.3	996.4	8047.7	83.9	424.6	904.9	6864.1
Full bloom	128.1	702.4	1404.4	9944.9	131.2	704.3	1428.9	11008.3	129.6	703.4	1416.6	10476.6
Fruit set	173.9	1036.1	1927.3	13423.7	166.4	936.8	1831.6	14053.9	170.2	986.4	1879.5	13738.8
Maturity	1007.1	8174.2	12423.1	58807.9	964.8	7928.6	11921.6	60348.1	985.9	8051.4	12172.3	59578.0
Titron												
Bud burst	48.4	261.8	521.0	3649.9	64.7	274.7	692.1	5641.0	56.6	268.3	606.6	4645.5
White bud	85.6	494.1	930.0	6439.0	102.7	493.8	1108.3	8872.1	94.1	494.0	1019.1	7655.5
Full bloom	143.3	776.9	1580.1	11231.3	145.1	770.3	1587.2	12244.3	144.2	773.6	1583.6	11737.8
Fruit set	192.0	1233.5	2141.9	14563.3	185.4	1040.6	2051.5	15602.3	188.7	1137.0	2096.7	15082.8
Maturity	1164.0	9741.8	14552.0	63579.6	1127.4	9398.6	14111.2	68172.6	1145.7	9570.2	14331.6	65876.1

Table 3. Days taken to attain different phenophases of plum genotypes.

Phenophases	Kala Amritsari		Satluj Purple		Titron	
	2013	2014	2013	2014	2013	2014
Bud burst	11	11	13	15	14	16
Pink bud	17	18	21	22	24	26
Full bloom	29	32	32	33	34	36
Petal fall	36	40	39	40	42	44
Maturity	98	104	104	110	110	117

3.2. Phenothermal Index (PTI)

Phenothermal index steadily increased from bud burst stage to maturity in all the cultivars. It was highest from petal fall to maturity stage which is the longest stage and during this period (March - April) the accumulation of heat units were higher. The value of the PTI was lowest in Satluj Purple followed by Kala Amritsari and Titron for different phenophases. On an average the PTI was 2.9, 3.9, 4.0, 4.3, and 9.2 for bud burst, white bud, full bloom, petal fall and physiological maturity, respectively in Satluj Purple. The corresponding values of PTI for Kala Amritsari were 3.2, 4.0,

3.9, 4.2, and 9.6, and for Titron it were 3.8, 3.8, 4.1, 4.4 and 10.1 for bud burst, white bud, full bloom, petal fall and

physiological maturity, respectively (Table 4).

Table 4. Photothermal index (PTI) during various phenological stages of plum genotypes.

Cultivar	Bud burst	White bud	Full Bloom	Petal fall	Maturity
Kala Amritsari	3.2	4.0	3.9	4.2	9.6
Satluj Purple	2.9	3.9	4.0	4.3	9.2
Titron	3.8	3.8	4.1	4.4	10.1

3.3. Thermal Use Efficiency

The efficiency of thermal, Heliothermal, photothermal and hydrothermal energy conversion for yield and dry matter depend upon genetic factors of crop and time of breaking of bud, after, the completion of the rest period. Thermal use efficiency was highest for the cultivar which required lower amount of thermal units for producing higher grain and biological yields. In plum the highest use efficiency (21.5 kg ha^{-1}/GDD day) was observed in cultivar of Kala Amritsari followed by Satluj Purple (18.3 kg ha^{-1}/GDD day) and the lowest heat use efficiency (13.7 kg ha^{-1}/GDD day) was

observed in Titron (Table 5). The utilization efficiency for other indices also followed similar trend. On an average the thermal use efficiency in Kala Amritsari was 12.4 kg ha^{-1}/GDD day with 28 per cent of coefficient of variation. In Satluj purple it was 10.7 kg ha^{-1}/GDD day with 33 per cent of coefficient of variation and in Titron the average heat unit use efficiency was observed 8.7 kg ha^{-1}/GDD day per cent with 37 per cent of coefficient of variation. Similar trend was observed for other three thermal use efficiencies in both the cultivars.

Table 5. Thermal use efficiencies of three genotypes of plum at Hisar conditions.

Cultivars	HUE kg ha^{-1}/ degree day	HTUE kg ha^{-1}/ degree day	PTUE kg ha^{-1}/ degree day	HYTUE kg ha^{-1}/ degree day
Kala Amritsari	21.5	2.6	1.7	0.4
Satluj Purple	18.3	2.2	1.5	0.3
Titron	13.7	1.6	1.1	0.2

3.4. Predictive Model

Regression models were developed for fruit yield prediction using thermal units consumed during this period. Strong and linear regression relationship was observed between fruit yield (FY) and Heat Units (HU). This prediction model holds good for all the other three thermal units (PTU, HTU and HYTU). The required equation for forecast of fruit yield is as under:

(1) For Kala Amritsari:

$$FY = 4341 \ HU - 203.6 \ (R^2 = 0.94)$$

(2) For Satluj Purple:

$$FY = 0.3122 \ HU - 152.8 \ (R^2 = 0.88)$$

(3) For Titron:

$$FY = 4833 \ HU - 420.6 \ (R^2 = 0.84)$$

(4) For Pooled data:

$$FY = -0.186 \ HU + 377.7 \ (R^2 = 0.71)$$

The Kala Amritsari and Satluj purple showed higher thermal use efficiencies and also showed a better relation in comparison with Titron and the pooled model.

Thermal indices explained 94 percent variation in fruit yield of Kala Amritsari, 87 per cent variation in Satluj purple and 83 percent variation in Titron. Similar works on developing agroclimatic models based on temperature, photoperiod and day length for mustard (Hundal et al., 2003)

for wheat (Hundal et al., 1970) have been reported under Punjab conditions and for apple fruit (Mohan Singh and H.S Bhatia, 2011) under mid hill region of Himachal Pradesh.

4. Conclusions

The thermal indices were calculated for three important cultivars of plum taking 10° C as base temperature. The plum cultivar Kala Amritsari required 70 GDD, Satluj purple 84 GDD and Titron 94 GDD to attain the first important phenophases (white bud) after bud break. Thermal indices explained more than 71 to 94 per cent variation in fruit yield of plum. In term of plant growth, plant girth, annual extension, fruit set and other physical parameters the performance of Kala Amritsari was observed better followed by Satluj Purple. Both these cultivar were observed precocious and fruiting was recorded in the third year after plantation. They are showing better utilization of heat units and hence, suitable for diversification in plum cultivation under changing and prevailing climatic conditions of Gigantic plain in general and semi arid region of Haryana in particular.

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