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Thermal requirement of pomegranate varieties growing in Maharashtra

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ABSTRACT

A field experiment was carried out to quantify growing degree days (GDD) requirement of 10 pomegranate varieties (*i.e.* Bhagwa, Ganesh, Mridula, Arkata, Jyoti, G-137, P-13, Kandhari, Bassein Seedless and Jalore Seedless) at ICAR-NRCP, Solapur, situated at 17° 10" north latitude, 74° 42" east longitude and 483.5 m above mean sea level. The water requirement through drip irrigation system at 90% efficiency for *Mrig bahar* (rainy season flowering) ranged from 5.7-13.0, 8.0-18.2, 9.2-20.8 and 10.3-23.4 l day^{-1} tree^{-1} for 2nd to 5th year pomegranate trees. The seasonal values of water applied to 2nd to 5th year pomegranate trees were estimated as 1259, 1763, 2015 and 2266 l bahar^{-1} tree^{-1}, respectively. Total GDD accumulations of all the varieties ranged from 2948 to 4105°D from defoliation to harvesting period. The growing degree days ranged from 947 to 1278°D at flowering stage and 2134 to 3306°D at fruiting stage. The lowest and highest GDD build up from defoliation to harvesting period were 2948°D for 'G-137' and 4105°D for 'Bhagawa', respectively. Photo-thermal index (PTI) at flowering and fruiting stages and heat use efficiency (HUE) of ten varieties ranged from 16.6 to 17.4°D/day, 16.5 to 18.3°D/day and 3.2 to 4.0 kgha^{-1} degree day^{-1}, respectively. The growing degree days (°D), photo-thermal index and heat use efficiency indices may be used to assess the crop performance with respect to suitability of the variety to a particular locality depending on the prevailing thermal environment.

Key words: Pomegranate, temperature, evapo-transpiration, growing degree days, photo-thermal index, heat use efficiency.

INTRODUCTION

The pomegranate (*Punica granatum* L.) is one of the oldest known edible fruits and is capable of growing under different agro-climatic conditions ranging from the tropical to temperate (Levin, 7; Jalikop, 6). Introduction of pomegranate in Deccan Plateau brought prosperity and improved livelihood of the growers that too from degraded lands. Pomegranate had been embedded in human history and utilization was associated to several ancient cultures as fruit, pharmaceutical and nutraceutical needs of population of various countries (Levin, 8). Major pomegranate growing countries include India, Iran, China, Israel, Spain, Egypt, Tunisia, Turkey, Japan, USA, Russia, Australia, South Africa and Saudi Arabia (Faria and Calhau, 3). At present pomegranate is grown on more than 0.180 million hectares area in India; of which, 0.087 million hectare area is in the state of Maharashtra alone. Hence, Maharashtra is considered to be the pomegranate basket of India, contributing about 70% of the total area and production. It is also cultivated at commercial scale in Karnataka, Gujarat, Telangana, Madhya Pradesh, Tamil Nadu, Rajasthan, Punjab, Himachal Pradesh and Haryana. Pomegranate is largely cultivated in marginal lands and *bahar* treatments are given for regulating flowering and fruiting.

Heat unit expressed in growing degree days (GDD) are frequently used to describe the timing of biological processes and assessment of yield potential of different crops. Temperature is one of the most important elements of the climate, which determines the potential productivity level of crops. GDD requirement has been used for characterizing the thermal response in pomegranate crop, assess the suitability of a region for production of a particular crop, estimate the growth stages of crops and estimate the heat stress on crops. It is also used to classify plants based on their flowering dates to estimate the harvest maturity and to predict the duration between two development stages (Bonhomme, 2). The growth and development of pomegranate are influenced by several parameters but temperature is most limiting factors (Singh and Bhatia, 13).

The aim of this work was to estimate the values of growing degree day (GDD) for ten pomegranate varieties in *Mrig bahar* for Solapur conditions of Maharashtra, India. The paper also presents the methodology used for determination of photo-thermal index (PTI), heat use efficiency (HUE) and predictive model (PM) in *Mrig bahar*.

MATERIALS AND METHODS

Ten pomegranate varieties, namely, Bhagwa, Ganesh, Mridula, Arkata, Jyoti, G-137, P-13, Kandhari, Bassein Seedless and Jalore Seedless grown at

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Kegaon Research Farm of ICAR-National Research Centre on Pomegranate (North latitude 17°10'', East longitude by 74°42''and 483.5 m above msl) were used during 2010, 2011, 2012 and 2013. The experimental plot was located on light texture soil. All the recommended cultivation practices were followed for each variety. Daily weather data were collected from Agro-Meteorology Observatory located in the same farm. The average weekly maximum, minimum temperature; maximum, minimum relative humidity; sunshine hours; wind speed; evaporation and total average rainfall were 32.7°C, 20.7°C, 78%, 45.8%, 6.9 h, 7.2 km h^{-1}, 7.2 mm and 614 mm in the *Mrig bahar* taking period from mid-May to mid-January (Fig. 1). Two important phenophases (*i.e.* fruit set and maturity) were visually observed by visiting the plants at one day interval for assessing the thermal unit's requirements.

The pomegranate evapotranspiration was calculated based on the actual atmospheric demand. It is important to know the values of reference crop evapotranspiration (ET_r) and crop coefficient (k_c) to estimate pomegranate evapotranspiration (ET_p) and eventually water requirement of pomegranate (WR). Hence, in this study k_c values were determined through shaded area approach and then used for estimation of pomegranate evapotranspiration (ET_p) after estimation of reference crop evapotranspiration (ET_r). ET_r and k_c values were estimated by climatological (Allen *et al.*, 1) and shaded area approaches (Williams and Ayars, 14). Once the values of pomegranate crop evapotranspiration are estimated, the values of the monthly shaded area for pomegranate trees of different ages as shown in Table 1, can be used to estimate the water requirement of pomegranate plantation irrigated by drip irrigation method.

The Penman-Monteith's method of estimation of ET_r that was considered for the reference crop evapotranspiration, the ET_r method which is considered as the most accurate and proposed by FAO, Irrigation and Drainage Paper -56 (Allen *et al.*, 1) was used for the determination of pomegranate evapotranspiration in mm. The reference crop evapotranspiration (ET_r) was calculated by the following equation:

$$ET_r = \frac{0.408\Delta\ (Rn - G) + \gamma\ \dfrac{(900)}{(T + 273)} * u_2 * (e_s - e_a)}{\Delta + \gamma * (1 + 0.34 * u_2)}$$

Where, ET_r = reference crop evapotranspiration (mm day^{-1}); G = soil heat flux density (MJ M^{-2} day^{-1}); R_n = net radiation (MJ M^{-2} day^{-1}); T = mean daily air temperature (°C); γ = Psychometric constant (kPa $°C^{-1}$); Δ = Slope of saturation vapor pressure function (kPa$°C^{-1}$); e_s = saturation vapor pressure at air temperature T (kPa); e_a = actual vapor pressure at dew point temperature (kPa); u_2 = average daily wind speed at 2 m height (m sec^{-1}).

The crop coefficient values were calculated using following equation, developed for deciduous fruit crops. (Williams and Ayars, 14).

$$k_c = 0.014 * x - 0.08$$

Where, k_c = Crop coefficient, x = Percentage of shaded area, (%)

The crop coefficient values were developed for phenological stages for ten pomegranate varieties defoliated in the month of mid-May (*Mrig bahar*). Very limited information about heat requirements of different pomegranate varieties is available in public domain. Growing Degree Days (GDD) in areas of crop phenology and development, is the concept of heat unit measured in terms of growing degree days (GDD, °D), has immensely improved description and prediction of phenological events compared to

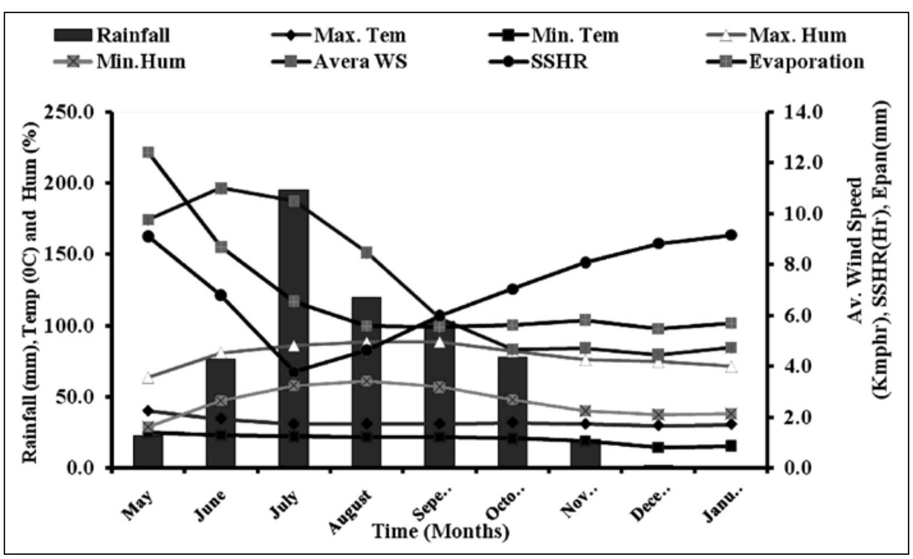

Fig. 1. Average weather during the pomegranate varieties growing period.

Table 1. Monthly shaded area (SA) and crop coefficient (k_c) values of 2nd to 5th year pomegranate trees in *Mrig bahar.*

Month	Tree age (year) 2nd		3rd		4th		5th	
	SA	k_c	SA	k_c	SA	k_c	SA	k_c
May	1.68	0.22	1.35	0.13	1.72	0.14	2.07	0.15
June	2.43	0.25	4.09	0.21	4.82	0.26	5.26	0.30
July	3.30	0.32	7.53	0.48	8.32	0.54	8.46	0.59
August	4.05	0.41	9.54	0.51	10.30	0.65	10.55	0.69
September	4.13	0.49	9.63	0.70	10.44	0.86	10.60	0.89
October	3.44	0.51	8.21	0.87	9.41	0.90	9.73	0.98
November	2.65	0.44	7.14	0.77	8.12	0.85	8.91	0.87
December	2.01	0.35	6.11	0.65	6.85	0.65	7.73	0.75
January	2.01	0.29	5.54	0.54	6.41	0.60	7.25	0.69

other approaches such as time of year or numbers of days (Russelle *et al*., 11). Growing degree days accumulated for attaining different phenological events were calculated as the sum of the differences between mean daily temperature at which bud development is activated with base temperature as 10°C (Olaniyi and Umezuruike, 10).

The canonical form for calculating GDD in ^{0}D is

$$GDD = \frac{T_{MAX} + T_{MIN}}{2} - T_{base}$$

Where, T_{MAX} = Maximum air temperature, (°C); T_{MIN} = Minimum air temperature, (°C); T_{base} = is the base temperature, (°C)

It is an expressed as degree days per growth day for flowering stage (from bud burst to fruit set) and fruiting stages (fruit set to maturity) were calculated as per the formula (Sastry and Chakravarty, 12).

$$PTI = \frac{GDD}{ND}$$

Where, ND = No. of days taken between two phenophases.

It is defined as the biomass accumulation during the given period per day, computed (kg ha^{-10} D^{-1}) for fruit yield to compare the relative performance of different varieties with respect to utilization of heat as:

$$HUE = \frac{FY\ (kgha^{-1})}{AGDD}$$

Where, FY = Fruit yield (kgha^{-1}); AGDD = Accumulates growing degree days, (°D)

Regression model was developed for fruit yield prediction. Linear regression model taking into account the aphasic development data pooled over different varieties in four *bahars* on the basis of growing degree days.

RESULTS AND DISCUSSION

The ET_r was maximum in the month of May and minimum in the month of December (Fig. 2). The shaded area increased from new leaf initial to maturity from 0.87 to 1.79 during second year (Table 1). During 3rd, 4th and 5th year, the shaded area increased from 1.35 to 9.63, 1.72 to 10.44 and 2.07 to 10.60 m^2, respectively, due to increase in number of leaves and fruit size. At harvest, the shaded area decreased from 9.63 to 5.54, 10.44 to 6.41 and 10.60 to 7.25 m^2 for 3rd, 4th and 5th year, respectively, due to leaf drop and harvesting of fruit. Lower k_c values represent slower plant growth and lower plant canopy cover, indicating lower ET_p. The water to be applied through drip irrigation system at 90% efficiency ranged from 5.7-13.0, 8.0-18.2, 9.2-20.8 and 10.3-23.4 l day^{-1} tree^{-1} for 2nd to 5th year pomegranate trees, respectively, due to the variation in reference crop evapotranspiration, crop coefficient and wetted area values (Gorantiwar *et al.*, 9). The total volume of water to be applied to pomegranate trees of two to five-year-old were estimated as 1259, 1763, 2015 and 2266 l *bahar*$^{-1}$ tree^{-1}, respectively in *Mrig bahar* (Table 2). In general, there was well distributed rainfall during July and August, hence, irrigation was not given for that period. The values given in the Tables 1 & 2 and Fig. 1 & 2 were used for irrigation scheduling of pomegranate through drip irrigation.

Average numbers of days taken to attain any phenological event from defoliation to harvesting varied in all the varieties in *Mrig bahar* (Fig. 3). The highest and lowest values were 255 days in Bhagwa and 170 days in G-137 from defoliation to harvesting. On an average the crop took 63 (CV = 1.06%) and 181 (CV = 0.50%) days to attain fruit set and physiological maturity in different varieties. For attaining the fruit set stage the variation was lowest in case of Bhagwa (CV = 1.06%) followed by Bassein Seedless (CV = 0.68%) and Kandhari (CV = 1.62%), whereas it was highest in case of Ganesh and Mridula (CV = 3.15%) followed

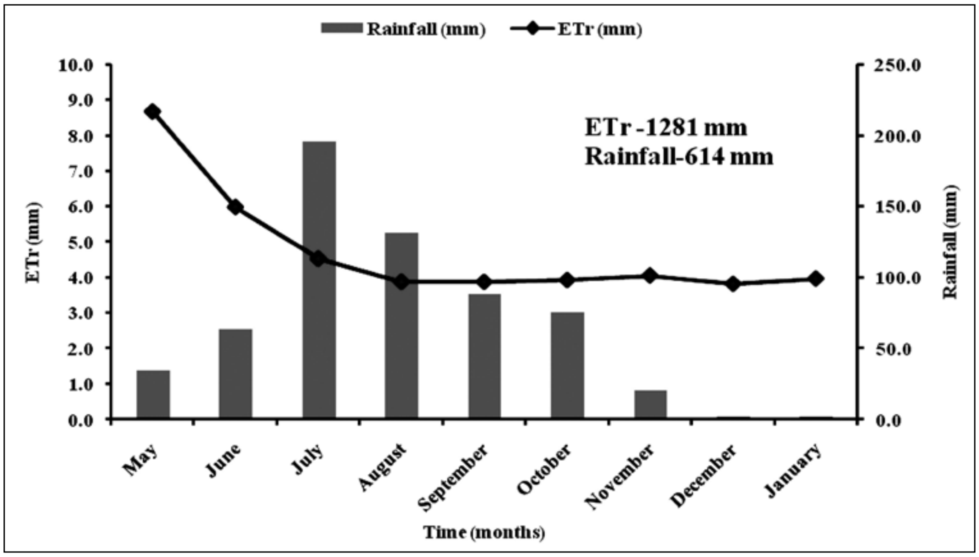

Fig. 2. Average monthly ET_r and rainfall values in mm for *Mrig bahar* during 2009 to 2013.

Table 2. Evapotranspiration (l day^{-1} $tree^{-1}$) for two to five year-old pomegranate trees.

Month	*Mrig bahar* (June-July flowering)			
	2nd	3rd	4th	5th
May	195	273	312	351
June	269	377	430	484
July	–	–	–	–
August	–	–	–	–
September	175	244	279	314
October	177	248	283	318
November	183	256	292	329
December	172	241	275	310
January	89	125	143	161
Total	1259	1763	2015	2266

by P-13 and Arkata (CV = 2.68%). This variation was at par among all the varieties for attaining the physiological maturity. During four years of study, Ganesh and Mridula took minimum days for fruit set and G-137 to mature as compared to other varieties in different *bahars*. It was observed that the variety Bhagwa, took 22 and 53 days more as compared to other varieties for fruit set and maturity. Bhagawa being the late maturing variety took more than 180 days from fruit set to maturity. Similar differences in duration across the phenlogical stages and varieties in pomegranate were reported by Ikinci *et al.* (5).

The GDD concept assumes that the amount of heat would be more or less same for a crop to reach a particular fruit set or maturity stage. The accumulated GDD to reach fruit set and physiological maturity stage varied in all the varieties across the four *Mrig bahars* (Fig. 3). This variation was observed highest in Arkata, Jyoti and P-13 varieties (CV = 2.2 to 2.5%), lowest in Bassein Seedless, Bhagwa and Jalore Seedless (CV = 0.7 to 1.3%) for fruit set. The variation in GDD for attaining maturity was lowest in Bhagwa, Ganesh, Jalore Seedles and Mridula with coefficient of variation ranging from 0.5 to 0.80 per cent followed by Arkata, G-137 and P-13 (CV = 1.5 to 1.9%). Remaining varieties required almost same numbers of GDD (CV = 1%). On an average, the crop took total 999, 1055, 1071 and 1131°D at fruit set and 2398, 2417, 2515 and 2422°D at maturity during 2nd, 3rd, 4th and 5th year, respectively. During four *Mrig bahars*, the lowest and highest GDD was observed in G-137 (2948°D) and Bhagwa (4105°D) varieties. This difference in GDD requirement across the varieties may be because of the fact that ripening or maturity time among cultivars is not derived from the differences in flowering dates but rather from the time required to ripening from anthesis. Ikinci *et al.* (10) also estimated the effective heat summation or growing degree days for three Turkish cultivars in the range of 2,874 to 3,652 GDD, which is in conformity of our finding.

The photo-thermal index gives an idea about the rate of development of the various phenological events with reference to heat units, which will eventually help in evaluating relative performance of different varieties. In four *bahars*, the PTI varied from 16.6 to 17.4°D/day during fruit set stage, while in reproductive growth stage (Fruit development stage) it ranged from 16.5 to 18.3°D/day in all varieties (Table 3). Like

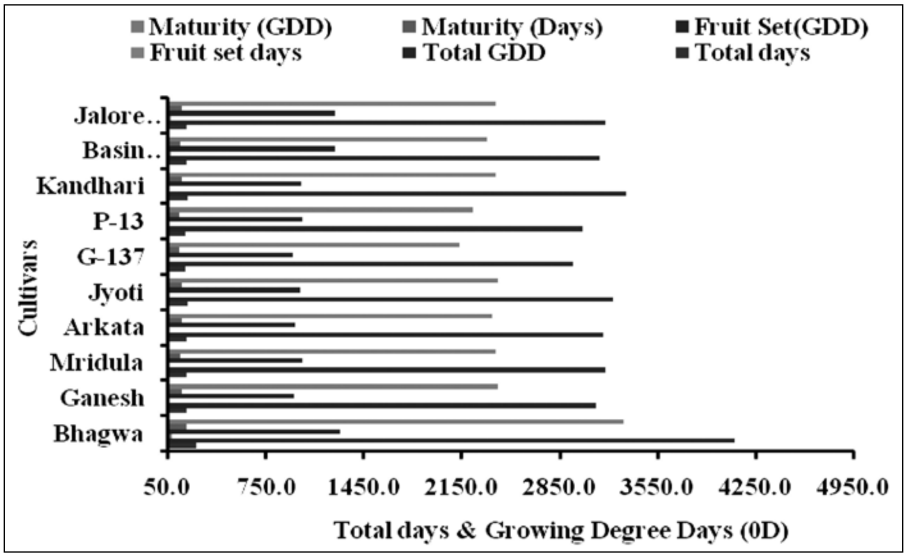

Fig. 3. Average monthly ET_r and rainfall values in mm for *Mrig bahar* during 2009 to 2013.

days and GDD the PTI during fruit set stage in all the varieties was more variable than at reproductive growth stage. During flowering period of all varieties, the PTI was maximum in 4th year (except in Bhagwa and Bassein Seedless, which required longer period for attaining the fruit set stage), which may be due to high day and night temperature at this stage during 4th year as compared to 3rd and 2nd. On an average, 16.9 °D/ day PTI was required to attain fruit set and physiological maturity in all varieties. The PTI at fruit setting stage was interestingly but significantly lower in case of Bhagwa as compared to Ganesh, Mridula, Jyoti, G-137, P-13, Kandhari, Bassein Seedless and Jalore Seedless. The PTI during maturity stage was significantly higher in Bhagwa as compared to other varieties. It was confirmed from the studies in many fruit crops that the heat requirements play important role in flower regulation, fruit set and fruit maturity (Ikinci *et al.*, 5).

Fruit yield of all the pomegranate varieties at different age is given in Table 4. The highest yield (21.15 t/ha) was observed in Bhagwa followed by Arkata (18.04 t/ha) in 5th year orchard. This may be because of combination of better plant canopy for realization of full yield potential and favourable weather conditions for growth and development. The mean yield of Bhagwa, Ganesh and Kandhari were at par and superior to other varieties. The yield was most variable in Bassein Seedless and Jalore Seedless and lowest in Arkata, Jalore Seedless and G-137. Several

Table 3. Photo-thermal index at flowering and reproductive stage of pomegranate varieties.

Variety	Fruit set (°D/day)					Maturity (°D/day)				
	2nd	3rd	4th	5th	Mean	2nd	3rd	4th	5th	Mean
Bhagwa	16.80	16.90	16.60	16.10	16.60	18.10	18.20	18.90	17.80	18.25
Ganesh	17.00	17.60	18.23	16.10	17.23	16.50	16.60	17.20	16.50	16.70
Mridula	17.00	17.30	18.53	16.10	17.23	16.40	16.60	17.10	16.40	16.63
Arkata	17.00	17.07	18.00	14.20	16.50	16.40	16.40	17.00	16.40	16.55
Jyoti	17.10	16.80	18.00	15.97	16.97	16.30	16.40	17.00	16.40	16.53
G-137	17.00	17.10	17.70	16.00	16.95	16.50	16.40	17.20	16.40	16.63
P-13	16.80	17.10	18.00	16.00	16.96	16.50	16.50	17.20	16.40	16.65
Kandhari	17.00	17.30	18.10	16.10	17.13	16.40	16.60	17.10	16.40	16.63
Bassein Seedless	16.80	16.90	18.00	16.10	16.95	16.33	16.60	17.20	16.50	16.66
Jalore seedless	16.80	16.90	18.00	16.10	16.95	16.40	16.60	17.10	16.40	16.63
CD (p = 0.05)	NS	NS	0.34	0.36	0.36	0.33	0.34	0.54	0.13	0.12

Table 4. Fruit yield and heat use efficiency of pomegranate varieties.

Variety	Yield (tonnes ha^{-1})					HUE (kg ha^{-1} $degree^{-1}$)				
	2nd	3rd	4th	5th	Mean	2nd	3rd	4th	5th	Mean
Bhagwa	9.57	10.91	11.84	21.17	13.37	2.30	2.70	2.60	5.20	3.20
Ganesh	9.71	7.59	14.59	18.36	12.56	3.20	2.30	4.90	5.60	4.00
Mridula	7.28	7.47	9.877	16.02	10.16	2.30	2.50	3.00	5.00	3.20
Arkata	8.32	7.62	11.99	18.84	11.69	2.60	2.40	3.50	5.70	3.55
Jyoti	10.75	8.72	9.33	16.15	11.24	3.20	2.70	2.90	5.00	3.45
G-137	7.82	6.42	11.84	13.55	09.91	2.60	2.30	3.80	4.40	3.28
P-13	7.50	8.01	14.43	16.20	11.54	2.40	2.80	4.50	5.50	3.80
Kandhari	7.04	8.68	14.28	20.89	12.72	2.20	2.50	3.90	6.30	3.73
Bassein seedless	8.00	7.84	9.72	15.30	10.22	2.50	2.50	3.10	4.50	3.15
Jalore seedless	6.67	8.32	11.65	15.55	10.55	2.00	2.60	3.30	4.70	3.15
CD (p = 0.05)	0.47	0.71	1.10	1.06	1.21	0.19	0.18	0.29	0.47	0.38

other researchers, while working with pomegranate reported the variable yield potentialities of different pomegranate varieties due to combined impact of climate, age, horticultural practices and genetic vigour (Jalikop, 6; Holland *et al*., 4).

The heat use efficiency among different varieties and *bahars* varied from 2.0 to 6.3 kg ha^{-1} degree day^{-1} (Table 4). The values of heat use efficiency were slightly higher in 4th and 5th year as compared to 2nd and 3rd, which indicate that the plant canopy is in ideal shape to harvest maximum thermal energy to produce optimum yield. The significantly higher HUE were found in Ganesh (4.0 kg ha^{-1} $degree^{-1}$), P-13 (3.80 $kgha^{-1}$ $degree^{-1}$) and Kandhari (3.73 kg ha^{-1} $degree^{-1}$) as compared to other varieties suggesting better utilization of thermal energy to produce higher yield per degree. This index can be used to asses yield at relative term, it may be inferred that growing degree day, pheno-thermal index and heat use efficiency indices may be used to assess the crop performance with respect to suitability of the variety to a particular locality depending on the thermal environment. A linear regression model for yield prediction was developed; taking into account the aphasic development data pooled over different varieties in four cropping *bahars* on the basis of thermal unit requirement was developed as under.

$Y = 0.00367\ AGDD + 6.06\ (R^2 = 0.98)$

Where, Y is the number of days predicted AGDD the accumulated growing degree days for particular phenophases. This model indicated that accumulated thermal units account for nearly 98 per cent variation of occurrence/ onset of different phenophases in pomegranate. Similar work on developing agro-climatic models for apple (Singh and Bhatia, 13) has been reported under agro-climatic conditions of Punjab and Kullu valley of Himachal Pradesh.

Total water requirement through drip irrigation and total heat requirement of ten popular pomegranate varieties of India were estimated for *Mrig bahar* crop. The total volume of water to be applied to pomegranate trees were estimated as 1259, 1763, 2015 and 2266 *bahar*$^{-1}$ for 2nd to 5th year pomegranate tree in *Mrig bahar.* The varieties G-137 and Bhagwa consumed the lowest and highest GDD for attaining physiological maturity in different *bahars*. But Arkata and Bhagwa had the lowest and highest GDD for fruit set. The photo-thermal index (PTI) in all the varieties and *bahars* varied from 16.6 to 17.4 and 16.5 to 18.3°D/day at flowering and reproductive stages, respectively. The regression model indicated that accumulated thermal units account for nearly 98 per cent variation of the incidence / commencement of different phenophases in pomegranate varieties. GDD can be used to assess the suitability of a region for production of a particular crop. It can also be used to classify plants based on their flowering dates to estimate the harvest maturity and to predict the duration between two development stages.

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