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Short communication

Energy requirements for attainment of different phenological stages in broccoli inbreds

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ABSTRACT

The field experiment comprised of three broccoli inbreds was carried out to assess the requirement of thermal energy, helio-thermal units, photo-thermal units, relative temperature, disparity and thermal use efficiency for days to 50% head initiation, days to 50% head maturity and duration of head maturity at CCS Haryana Agricultural University, Hisar during winter seasons of 2013 and 2014. The results revealed that broccoli crop in general required 813.7, 168.1 and 981.8 (°C day h) thermal units, 5161.1, 705.4 and 5866.5 (°C day h) heilo-thermal units, 8600.7, 1713.9 and 10314.5 (°C day h) photo-thermal units and 4042.2, 1996.6 and 6038.8 (°C day h) relative temperature disparity for head initiation, duration of head maturity and head maturity. Minimum thermal use efficiency (14.3°C day h) was measured for days to 50% head maturity followed by days to 50% head initiation (17.30°C day h) and duration of head maturity (83.44°C day h). Genotypic differences also observed for requirement of thermal energy in attainment of different phenological traits in broccoli. Marketable curd yield expressed significant positive correlation with heat unit consumed in both years. The R^2 values of regression equation could explain the variation between 72-81% of the total variation in production of curd in broccoli.

Key words: Broccoli, heat unit, inbred, thermal use efficiency, thermal requirement.

Broccoli (*Brassica oleracea* L. var. *italica* Plenck), belongs to the family Cruciferae, closely resemble to cauliflower bears large flower head of green colour is generally used as a cooked vegetable. It needs 12-16°C for seed germination, 18-23°C for plant growth and 12-18°C for head development. A minimum of six hours of sunlight needed for its successful cultivation. Varieties roughly divided into early, mid, season and late season groups, respectively. Early maturing varieties are more sensitive to low temperature than the late maturing varieties. Long days and hot weather conditions during summer cause the broccoli to bolt. (Wang, 14) reported that the duration of a particular stage of growth were directly related to temperature, which could be predicted for a particular species by using sum of daily air temperature or cumulative thermal requirement, known as growing degree-days (GDD) or heat units (HU). Growing degree days are a measure of heat accumulation used to predict phenological development rates such as the date that a flower will open or a crop will reach maturity and further to explore the agro-climatic potential of a region (Pandey and Shekh, 10). Thus, air temperature based on agro-meteorological indices like growing degree-days, helio-thermal units, photo-thermal units and the thermal or heat use efficiency (Hundal *et al*., 6) were successfully used for describing phenological behaviour and growth parameters. Gouri *et al*. (5) found that the crop growth response largely influenced by crop microclimate environment, which varies from top of the canopy to the soil surface and affects crop development and yield. The environmental factors influencing growth are interception of photo-synthetically active radiation and temperature but light plays a key role in influencing crop production. The occurrence of different phenological events during the crop growth period in relation to temperature estimated by using accumulated heat units or growing degree-days. Thermal time is an independent variable to describe plant development (Dwyer and Stewart, 3), which used as a tool for characterizing thermal responses in different crops. Knowledge of accumulated growing degree-days can provide an estimate of harvest date as well as crop development stage (Bonhomme, 1). Hence, the present field experiment was conducted to study energy requirement for initiation of head and its maturity/marketable crud yield.

The experimental material consisted of three inbred broccoli lines, *viz*., GH-1, PH-1 and DPH-1. The experiment was conducted during winter seasons of 2013 and 2014 at Research Farm, Department of Vegetable Science, CCS HAU, Hisar situated 29°10'N; 75°46'E and 215 above sea level to study the thermal requirement for days to 50% head initiation, days to 50% head maturity and duration of head maturity. Seedlings of three inbred lines were transplanted on 20th October of 2013 and 2014 in

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randomized block design with four replications at spacing of 50 cm between rows and 50 cm between plants. All the agronomical practices were adopted to raise a healthy crop. The observations were taken on three phenological stages (traits), *viz*., days to 50% curd initiation (number of days taken from date of planting to dates when 50% plant shows head/curd initiation in each inbred), days to 50% curd maturity (number of days taken from date of planting to dates when days 50% plants show marketable head/ curd in each inbred) and duration of head maturity (number of days taken from 50% curd initiation to 50% head maturity) were recorded in both the years. The yield of marketable curd was also recorded (q/ ha) for each inbred used for correlation study with weather variables. The data pooled over the year 2013 and 2014 for statistical analysis. The daily agro-meteorological data recorded at CCS HAU, Hisar was used for the calculation of thermal requirement for days taken to 50% head initiation, days to 50% head maturity and duration of head maturity in broccoli. Different agro-meteorological indices like growing degree-days (GDD), helio-thermal units (HTU), photo-thermal units (PTU), relative temperature disparity (RTD) and thermal use efficiency (HUE) were calculated on daily basis and summations were made for different stages separately from sowing to 50% harvesting of heads.

Thermal units or growing degree days (GDD) were calculated by taking the average of daily maximum and minimum temperature and subtracting a base temperature, T_{base} (usually 5°C for winter season crops) as suggested by (Monteith, 9):

$$GDD = \frac{T_{max} + T_{min}}{2} - T_{base}$$

Similarly, helio-thermal units, photo-thermal units and relative temperature disparity were calculated using the following procedures:

HTU (°C day h) = GDD × Duration of bright sunshine hours (Rajput, 11)

PTU (°C day h) = GDD × Day length (h) (Major *et al*., 8)

$$RTD\ (°C\ day\ h) = \frac{(T_{max} - T_{min})}{T_{max}} \times 100 \quad \text{(Rajput, 11)}$$

The thermal use efficiency was calculated (kg/ ha per degree) to compare the relative performance of different genotypes with respect to utilization of heat by using the formula given below:

$$\text{Thermal use efficiency (TUE)} = \frac{\text{Head fresh wt. (kg /ha)}}{\text{GDD (°C day)}}$$

The correlation and predictive regression equation were also work out between thermal indices and curd yield of different inbred of broccoli.

Average thermal requirements of three inbred of broccoli for days to 50% head initiation (Table 1), days to 50% head maturity (Table 2) and duration of head maturity presented in (Table 3), respectively. Thermal units required to attain different stages varied with inbred lines. Among all the inbred lines, the maximum mean thermal units were needed by inbred GH-1 (819.2 day°C) followed by PH-1 (813.6 day°C) and DPH-1 (808.4 day°C) for reaching a stage of 50% head initiation (Table 1). The inbred DPH-1 used the lowest accumulated thermal units of 970.6 day°C for days to 50% head maturity, whereas, the inbred GH-1 required the highest amount of accumulated thermal units (992.5 day°C) followed by PH-1 (982.4 day°C) for this trait (Table 2). Similar trend were recorded for the duration of head maturity among all the inbreds. This might due to genotypic differences for consumption of thermal units to a trait attainment as Dhankhar and Singh (3) reported in okra.

Helio-thermal units (HTU) required for different stages presented as the inbred GH-1 utilized the highest amount of accumulated helio-thermal units for all the character studied *i.e*., days to 50% head initiation (5195.5 day°C h) (Table 1), days to 50% head maturity (5936.1°C day h) (Table 2) and duration of head maturity (740.6°C day) (Table 3). The lowest helio-thermal unit utilization value was observed in inbred DPH-1 for all three traits. All inbreds required less helio-thermal units for duration of head maturity followed by days to 50% head initiation and days to 50% head maturity. This might be due to the more number of days and growing degree-days taken by the respective traits to complete stage. The results

Table 1. Average requirement of agro-meteorological indices for different growth stages of broccoli inbreds.

Inbred	Days to 50% head initiation				
	GDD (°C day)	HTU (°C day h)	PTU (°C day h)	RTD (°C day h)	HUE
DPH-1	808.4	5129.3	8557.3	3946.0	19.59
PH-1	813.6	5158.5	8579.5	4042.8	18.15
GH-1	819.2	5195.5	8665.3	4137.9	14.18
Mean	813.7	5161.1	8600.7	4042.2	17.30
CD at 5%	4.95	8.14	5.75	9.31	2.73

Table 2. Average requirement of agro-meteorological indices for different growth stages of broccoli inbreds.

Inbred	Days to 50% head maturity				
	GDD (°C day)	HTU (°C day h)	PTU (°C day h)	RTD (°C day h)	HUE
DPH-1	970.6	5797.6	10214.9	5876.3	16.30
PH-1	982.4	5865.7	10287.1	6034.9	14.83
GH-1	992.5	5936.1	10441.5	6205.2	11.81
Mean	981.8	5866.5	10314.5	6038.8	14.31
CD at 5%	7.10	7.41	5.54	7.03	2.87

Table 3. Average requirement of agro-meteorological indices for different growth stages of broccoli inbreds.

Inbred	Duration of head maturity				
	GDD (°C day)	HTU (°C day h)	PTU (°C day h)	RTD (°C day h)	HUE
DPH-1	162.2	668.4	1657.6	1930.3	93.36
PH-1	168.9	707.2	1707.6	1992.1	86.26
GH-1	173.3	740.6	1776.2	2067.4	70.71
Mean	168.1	705.4	1713.9	1996.6	83.44
CD at 5%	4.22	7.65	8.79	8.27	6.23

are in line with the findings of Kumar *et al*. (7) in stover. The maximum their photo-thermal units were required by the inbred line GH-1 for attaining the stages of days to 50% head initiation (8665.3°C day h) (Table 1), duration of head maturity (1776.2°C day h) (Table 3) and days to 50% head maturity (10441.5°C day h) (Table 2). The minimum thermal units were accumulated by the inbred line DPH-1 for all the traits studied. The present results are in conformity with the results of Singh *et al*. (13) and Ram *et al*. (12) who observed that the photoperiodic and its interactions directly affect the phenological stages in wheat.

Relative temperature disparity value is dependent on maximum and minimum temperature during the different phenological stages of inbred lines. Among all the inbreds, maximum value of relative temperature disparity was utilized by inbred GH-1 for all the traits like days to 50% head initiation (4137.9°C day h) (Table 1), duration of head maturity (2067.4°C day h) (Table 3) and days to 50% head maturity (6205.2°C day h) (Table 2). The highest value of relative temperature disparity was used by the trait days to 50% head maturity (6038.8°C day h) (Table 2) followed by days to 50% head initiation (4042.2°C day h) (Table 1) and duration of head maturity (1996.6°C day h) (Table 3) to reach their stages. This might be due to the number of days taken by the respective traits to attain their stage in indices of white clover (Fyffe *et al*., 4; Kumar *et al*., 7).

Among these three inbreds, the maximum thermal use efficiency was used by inbred DPH-1 also followed by PH-1 and GH-1 for the all the traits. Minimum thermal use efficiency utilized by the trait days to 50% head maturity (14.31) (Table 2) followed by days to 50% head initiation (17.30) (Table 1) and duration of head maturity (83.44) (Table 3), respectively. The efficiency of thermal energy conversion for curd yield depends upon the genetic makeup of the genotype, time of head initiation and maturity of the inbred for its accomplishment of different stages. Dhankhar and Singh (2) also studied on thermal use efficiency in okra and observed genotypic differences for consumption of thermal units, respectively.

Regression model was developed for curd yield prediction in broccoli using curd yield of the inbreds for every year and pooled data along with accumulated thermal units by inbreds during the period of trial. Thermal units utilized by inbred for the 50% head maturity period were used for simple correlation and regression studies. The thermal units consumed for curd yield in each year expressed significant positive association values (0.88 and 0.77), with curd yield, whereas pooled data indicated 92 percent deviation in curd yield due to accumulated thermal use efficiency. The estimation of regression models (Table 4), which reveal that the model accounted for 81 and 72 percent of total variations as revealed by R^2 values in curd yield for first and second year, respectively, whereas, the pooled data showed 79 percent variability in curd yield due to the utilization of thermal unit.

There was genotypic difference for the requirement of thermal unit, helio-thermal unit, photo-thermal

Table 4. Regression equation for curd yield prediction in broccoli.

Year	Regression equation	R^2 value	SE	Correlation with curd yield
1st	Y = -354.83 + 0.482TU	81	0.05	0.88**
2nd	Y = -364.56 + 0.498TU	72	0.07	0.77**
Pooled	Y = -378.81 + 0.509TU	79	0.04	0.92**

unit, relative temperature disparity and thermal use efficiency for head initiation, head maturity and duration of head maturity. However, broccoli in common require 813.7 and 981.8 day°C h thermal units, 5161.1 and 5866.5 day°C h, helio-thermal units, 8600.7 and 10314.5 day°C h, photo-thermal units 4042.2 and 6038.8 day°C h, relative temperature disparity 17.3 and 14.3 thermal use efficiency for head initiation and head maturity, respectively. Curd production showed the evidence of positive relationship with thermal unit consumption. R^2 values of regression equation of pooled data could explain 79 percent variability of curd yield in broccoli under Hisar conditions. Thus, different agro-meteorological indices requirement and their efficient utilization by broccoli inbreds can be used to predict the performance of a crop to breed or introduce boccoli genotype in a particular region depending upon the thermal environment.

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