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Thermal indices: Impact on phenology and seed yield of spring-summer greengram [*Vigna radiata* (L.) Wilczek] under different dates of sowing

Shrabani Basu, Pramiti K Chakraborty, R Nath and PK Chakraborty

Abstract
Temperature, one of the prime weather factors significantly influences crop growth processes. The thermal indices like growing degree day (GDD), Helio-thermal unit (HTU) are useful to predict the onset of different phenophases, growth behavior and yield. Greengram, being short duration and photo-thermo sensitive, is influenced by prevailing thermal regime. To assess the crop phenology and yield behavior under existing thermal regime, a two year field experiment was conducted during the spring-summer seasons in 2011 and 2012 at District Seed Farm, Bidhan Chandra Krishi Viswavidyalaya, Kalyani, West Bengal, India in split-plot design with three replications. Four dates of sowing (15th February, 25th February, 7th March, 17th March) had been placed as main plot treatment and five varieties (IPM-2-3, *Samrat*, Pant Mung-5, *Sonali* and *Meha*) as sub-plot treatment. Observations started from sowing and continued upto pod maturity with coverage of branch initiation, bud emergence, 100% flower emergence and pod emergence stages. Calculations on cumulative GDD, HTU and their impact on seed yield suggested that maximum cumulative GDD was noted under D_3 sowing in both the year during sowing to germination (107.6 and 112.7 day °C in 2011 and 2012 respectively). The cumulative GDD requirement at pod maturity under D_2, D_3 and D_4 sowing was higher in second year than first year. There is a gradual increase of cumulative HTU from vegetative to reproductive stage irrespective of dates of sowing. The cumulative HTU at pod maturity stage recorded higher in 2012 as compared to 2011. The variation in duration of phenophases caused by the variation of thermal regime. Both GDD and HTU for all the phenophases positively and significantly affected the seed yield in the first year whereas in second year, the impact was negative but insignificant in bud and pod emergence stages.

Keywords: Greengram, Growing degree day, Helio-thermal unit, Phenophase, Thermal indices

Introduction
Crop physiological process dependent on integrated atmospheric parameters (Ko *et al.*, 2010) [6], in which temperature is an important weather parameter that affects plant growth, development and yield. Temperature plays a significant role in physiological, chemical and biological processes of plants. For quantifying the thermal relation of crops, thermal units approach is widely used (Ramteke *et al.*, 1996) [9]. The occurrence of different phenological events during a growing season of crop and the effect of temperature on plant growth can be explained using accrued heat units (Sunil and Sarma, 2005) [10]. Influence of temperature on phenology and yield of crop plants can be studied under field conditions through accumulated heat unit system (Bishnoi *et al*., 1995) [2]. The heat units or thermal indices *viz.* growing degree day (GDD), Helio-thermal unit (HTU) are useful to predict the onset of different phenophases, crop growth behavior and ultimately the yield. A degree day or a heat unit is the departure from the mean daily temperature above the minimum threshold temperature (Basu *et al.*, 2012) [1]. Requirement of cumulative GDD is regulated by the ambient temperature as well as change in physiological stage of crop regulated by hormonal activities (Nath *et al.*, 1999) [8].

Greengram is one of the most important pulse crops grown during the spring-summer season; in the Gangetic plains of Eastern India, it is preferably grown during January to March. Being short duration and sensitive to photo-thermal regimes, the variation of temperature during its growth period may affect its yield achievement. With a successful study on these thermal indices may provide the information on the crop phenology and approximate date of crop harvest. The implication of heat unit as an input in crop growth studies *i.e.* the impact of temperature and bright sunshine hour on crop phenology and yield particularly in green gram sown under different sowing times has not been well documented. In view of this context, the present experiment has been framed with the objective to address this lacuna.

Materials and Methods

Experimental site

The experiment was framed during spring-summer season of 2011 and 2012 at the District Seed Farm, Bidhan Chandra Krishi Viswavidyalaya, Kalyani, Nadia, West Bengal (22°56' N latitude, 88°32' E longitude, 9.75 m above MSL). The experimental site falls under sub-tropical humid climate with short and mild winter. The average annual rainfall is 1457 mm, 85% of which is received during June to September and the mean monthly temperature ranges between 10 °C-37 °C.

Experimental soil

The experimental soil comes under the order of Entisol in the USDA modern taxonomical classification. The soil was sandy loam in texture with almost neutral pH (7.1). The soil had a good drainage capacity. The soil contains 0.053% total N, 19.72 kg/ha available P_2O_5 and 218.96 kg/ha available K_2O.

Experimental Design

The Split-plot statistical design had been followed in the experiment along with three replications. In this experiment, the four dates of sowing (15th February, 25th February, 7th and 17th March) were allocated to the main plots as main plot treatment and five varieties (IPM-2-3, *Samrat*, Pant Mung-5, *Sonali* and *Meha*) varieties to the sub-plots as sub-plot treatment. The size of each plot has been considered as 5×6=30 m^2.

Agronomic packages

The time and need based standard agronomic management practices have been followed to raise the plants in field condition properly, including seed inoculation with *Rhizobium* culture and the recommended fertilizer dose of 20:40:40 kg N-P_2O_5-K_2O ha^{-1} as basal. The source of nitrogen, phosphorus and potassium were urea, single super phosphate (SSP) and muriate of potash (MOP) respectively. The seed rate of 30 kg ha^{-1} had been adopted with a spacing of 25cm (inter row) ×10cm (intra row) during spring-summer.

Observations

Observations on different phenophases had been started from branch initiation, bud emergence, 100% flowering, pod emergence and also included with sowing, germination and pod maturity stages. The matured pods after harvesting had been sun dried in the threshing floor. Seeds are separated from pods and weighed to calculate the seed yield data, initially per plot-wise and then converted to kilogram per hectare basis.
The thermal indices had been calculated based on the collected data and using the following formula:

A. Growing Degree Day (GDD)

The growing degree days per day was calculated in accordance with the following formula:

$$GDD\ (\text{day °C}) = [(T_{max} + T_{min}) / 2 - T_b]$$

Where,
T_{max} = Maximum temperature
T_{min} = Minimum temperature
T_b = Base temperature (Kiran and Bains, 2007) [5]
(for greengram, 10 °C was considered as base temperature)

B. Heliothermal unit (HTU)

Helio thermal unit (day ^{0}C hour) was measured in accordance with the following formula:

$$HTU = [(T - T_b).\ N]$$

(Nath *et al.*, 1999) [8]
Where,
T = Mean temperature of a day
T_b = Base temperature below which the crop cannot thrive (10 °C for mungbean)
N = Total bright sunshine hour of that day

Statistical analysis

The data collected in two experimental years were analyzed statistically by applying the analysis of variance techniques laid down by Gomez and Gomez (1984). Pearson's correlation coefficients were computed to find out the relationship between important biological and environmental components. The relationship between environmental and biological parameters was analyzed by SPSS 7.5 software, (SPSS 7.5 copyright, 1997 by SPSS Inc., USA Base 7.5 Application guide).

Results and Discussion

Thermal indices

Growing degree days (GDD)

During sowing to germination, the cumulative GDD requirement ranged from 79.3 to 107.6 day °C in the first year and in the second year, it was in the range of 85.2 to 112.7 day °C. Maximum thermal time was noted under D_3 sowing in both the year (Table 1). In the first year, a declined trend of the cumulative GDD requirement with the delay in sowing had been observed from branch initiation upto pod maturity stages, but no such trend was observed in the second year. During germination to branch initiation phenophase, the cumulative GDD requirement under different dates of sowing varies from 595.6 to 832.2 day °C whereas it ranges from 740.5 to 846.7 day °C in the second year. The range of cumulative GDD requirement of greengram crop to attain the phenophases *viz.* bud emergence, 100 % flowering and pod emergence are 1239.4 to 1724.8, 1378.8 to 1832.3 and 1543.3 to 1987 day °C respectively in the first year and for second experimental year the thermal regime ranges from 1509.8 to 1678, 1670.6 to 1863.5 and 1775.5 to 1986.3 day °C respectively under four dates of sowing. The cumulative GDD requirement by the second year crop to reach the pod maturity stage had been recorded higher as compared to the first year crop for D_2, D_3 and D_4 sown crop. This may be due to the gradual increase of maximum and minimum temperature in the later phases of the crop growing season in two experimental years (Fig. 1).

Helio-thermal unit (HTU)

The cumulative HTU requirement for spring-summer greengram crop varies under different phenophases, dates of sowing and two experimental years. There was a gradual increase of HTU requirement by the crop as it approaches towards the pod development and maturity stage irrespective of dates of sowing and year of experiment. Meena *et al.*, (2013) observed that the heat use efficiency went on increasing from vegetative growth to pod filling stage. During sowing to germination, the D_1 sown crop recorded the lowest HTU (624.5 day °C hr.) and D_4 sown crop was recorded the highest cumulative HTU (958.7 day °C hr.) in the first year.

The similar trend had been observed when the crop reaches at pod maturity stage (11176.3 and 11301.9 day °C hr. in D_1 and D_4 sowing respectively). In the second year, there was no such trend had been noted in these two phenophases (Table 2). For branch initiation, bud emergence and 100 % flowering, the cumulative HTU requirement by the greengram crop was decreased with the delay in sowing in the first year. Although, there was no definite trend had been recorded in the second year crop, except the bud and pod emergence stages (cumulative HTU declined with the late sowing). For the onset of pod maturity, the D_2 sown crop recorded maximum value of cumulative HTU while D_1 sowing recorded the minimum in the second year (12464.7 and 11743.0 day °C hr. in D_2 and D_1 sowing respectively). This variation appeared due to the temperature as well as bright sun-shine hour variation in two different experimental years (Fig.2)

Duration of phenophases and yield assessment

The prevailing maximum and minimum temperature and thus the thermal regime have the influence on the onset and duration of phenophases. Onset of different phenophases is initiated when a specific temperature regime is available (Chakraborty *et al.*, 1994) [3]. In the two experimental years, there was variation in duration of some phenophases under different dates of sowing had been recorded. In the first year, the D_1 sown crop took 4 days to germinate while it was 5 days in the second year and it may be due to the high maximum or minimum temperature prevailing during the initial growth. (Table 3). The reverse situation was occurred during germination to branch initiation stage under D_1 sown crop, where the second year crop was one day earlier than first year crop to reach this phenophase. The sudden increase of prevailing temperature profile may be the reason behind this (Fig.1). For other dates of sowing, the duration was also varied in two different years. Out of other phenophases, from branch initiation upto pod emergence stage, no remarkable variation in duration was observed in between two experimental years under all dates of sowing, except D_4 sowing (the second year crop was 2 days earlier in bud emergence to 100% flowering than first year crop). The similar maximum temperature regime may be the probable reason no definite variation in duration of phenophases from branch initiation upto pod emergence stage for D_1, D_2, D_3 and D_4, besides, the slight variation in bud emergence to 100% flowering in D_4 sown crop and this may be due to increased maximum and minimum temperature prevailing during this stage under D4 in the second year (maximum and minimum temperature were 33.4, 22.5 and 38.4, 26.0 °C respectively for first and second year respectively). The variation of total crop duration for D_1, D_2 and D_4 sown crop may be explained through the variation of thermal regime.

The impact of GDD and HTU of different phases on the seed yield differed in two experimental year (Table 4). In the first year, GDD and HTU at different phases had a positive and significant correlation with the seed yield of the crop. However, in the second year, the seed yield was negatively correlated with the GDD as well as HTU (bud and pod emergence stages), but the correlation remained insignificant. The GDD and HTU during branch initiation, 100% flowering and pod maturity were positively correlated with the seed yield, but the correlation was also found to be insignificant.

Conclusion

From the above findings, it can be noted that the thermal indices (GDD and HTU) have a significant influence over the crop phenology. The combined impact of temperature as well as bright sunshine hour over the crop growth and development can be studied with these parameters. The greengram seed yield has positive and negative correlation with GDD and HTU and this may be caused due to the combined influence of prevailing temperature and bright sunshine hour during the crop growing period. Henceforth, in broader aspect, it can be suggested to use the thermal indices for modeling to study the growth behavior of greengram crop under the changing scenario of climate.

Table 1: Cumulative GDD requirement by greengram crop during different phenophases under different dates of sowing

Dates of sowing	Sowing-Germination		Branch initiation		Bud Emergence		100 % flowering		Pod Emergence		Pod Maturity	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
D_1	79.3	85.2	832.2	766	1724.8	1676.4	1832.3	1756.7	1987	1942.2	2106.6	2042.5
D_2	81.8	95.7	684.3	846.7	1426.5	1678	1534	1863.5	1688.7	1986.3	1912.7	2187.4
D_3	107.6	112.7	671.2	740.5	1342.3	1553.8	1497	1676.6	1636.4	1837.4	1911.8	2034.4
D_4	106.5	102.2	595.6	744.6	1239.4	1509.8	1378.8	1670.6	1543.3	1775.5	1871.3	2042.7

Table 2: Cumulative HTU requirement by greengram crop during different phenophases under different dates of sowing

Dates of sowing	Sowing-Germination		Branch initiation		Bud Emergence		100 % flowering		Pod Emergence		Pod Maturity	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
D_1	624.5	613.7	6951.1	6668.8	8110.8	8532.8	9049.4	9070.4	10398.4	10749.7	11176.3	11743.0
D_2	807.9	911.9	5909.4	7307.1	7069.1	7844.7	8007.7	9524.0	9356.7	10742.8	11187.5	12464.7
D_3	856.6	976.4	5565.6	6092.3	6504.2	7771.6	7853.2	8990.4	8844.4	10372.9	11194.5	12247.0
D_4	958.7	732.5	4999.2	6163.5	6348.2	7382.3	7339.4	8764.8	8778.6	9770.6	11301.9	12128.1

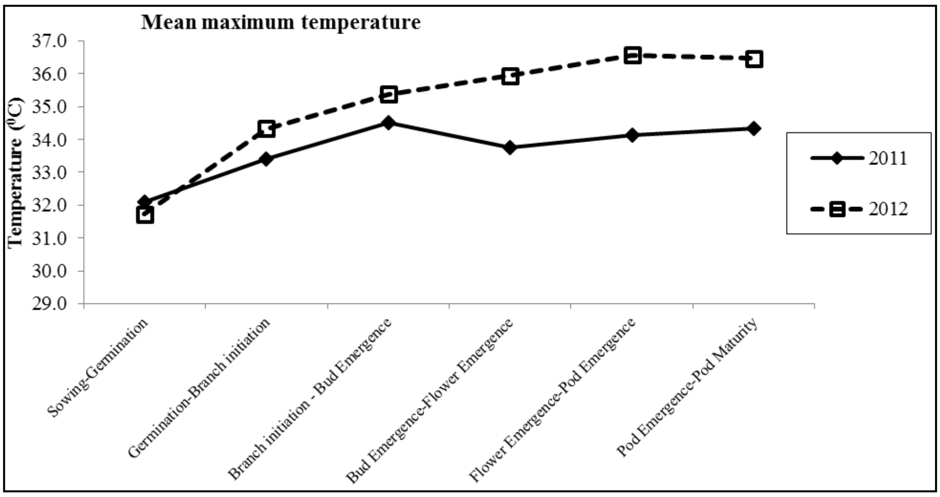
Table 3: Duration of different phenophases of greengram under different dates of sowing

Dates of sowing	Sowing-Germination		Germination-Branch initiation		Branch initiation - Bud Emergence		Bud Emergence-100% flowering		100% flowering-Pod Emergence		Pod Emergence-Pod Maturity		Total duration	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
D_1	4	5	26	25	6	6	5	5	7	6	23	23	**71**	**70**
D_2	5	5	23	25	6	6	6	6	5	5	21	21	**66**	**68**
D_3	5	5	24	24	6	6	6	6	5	6	19	18	**65**	**65**
D_4	4	4	26	25	6	6	7	5	5	5	17	17	**65**	**62**

Table 4: Impact of GDD and HTU under different phenophases on seed yield of greengram crop

Growth phases	GDD (day°C) Seed yield (kg ha^{-1})		HTU (day°C hr) Seed yield (kg ha^{-1})	
	(2011)	**(2012)**	**(2011)**	**(2012)**
Branch Initiation	0.680**	0.346	0.698**	0.227
Bud Emergence	0.636**	- 0.149	0.648**	-0.236
100 % flowering	0.604**	0.234	0.666**	0.219
Pod Emergence	0.570**	- 0.0005	0.621**	-0.004
Pod Maturity	0.878**	0.375	0.864**	0.417

Note: ** Significant at 1% level, * Significant at 5% level.



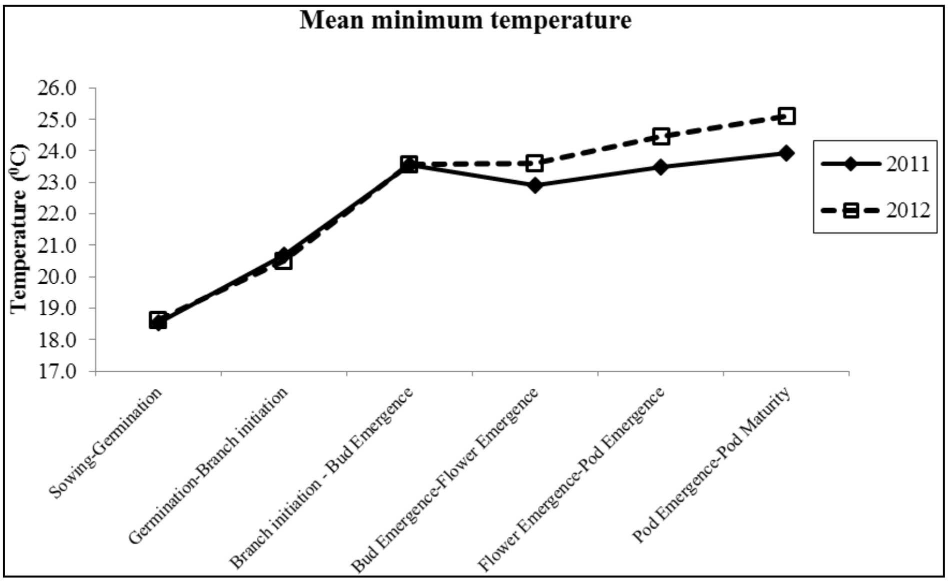


Fig 1: Changes of mean maximum and minimum temperature (°C) in different phenophases in two experimental years (pooled over dates of sowing).

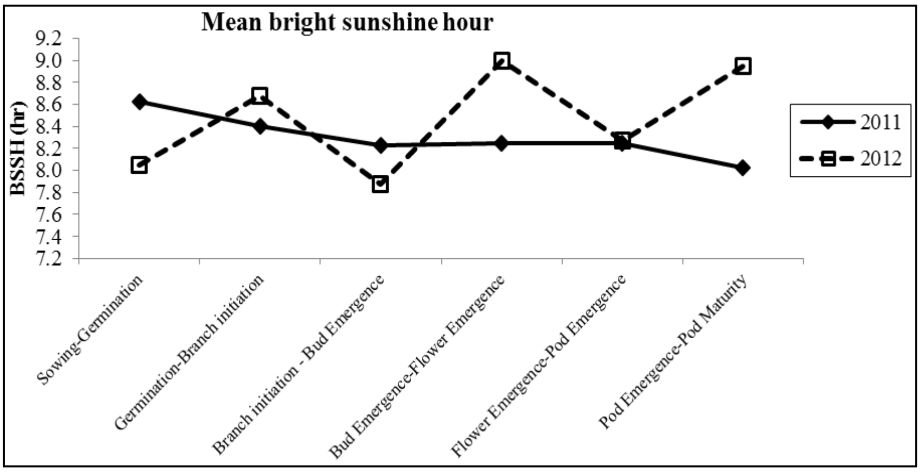


Fig 2: Changes of mean bright sunshine hour (hr.) in different phenophases in two experimental years (pooled over dates of sowing).

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