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Studies on Determination of Critical Growing Degree Days, Base Temperature (T_b) and Response of Temperature Variations on Flowering and Yield *per se* in Cowpea [*Vigna unguiculata* (L.) Walp.]

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Abstract

Growing degree days (GDD) or heat units accumulation is the major factor that affects the dry matter production in the plants. In the present investigation eleven genotypes were used to screen for temperature insensitivity through staggered plantings across the seasons in a year. Days to flowering initiation was recorded and base temperature (T_b) was determined using mean daily air temperature (MAT). GDD of individual genotypes was estimated using base temperatures of particular genotypes. It was observed that the GDD, days to flowering initiation and yield were exhibited high variation across the seasons, the flowering time from days to planting (FTDAP) registered significant negative correlation with GDD and MAT and positively correlated with yield. Whereas GDD is positively correlated with MAT and negatively correlated with yield. Here three genotypes namely, IC202926, IC198326 and IC257428 were identified as temperature insensitive genotypes as their performances were comparable across the seasons without much fluctuations.

Key words: Base temperature, Cowpea, Growing degree days.

Introduction

Crop adaptability to different environmental constraints is necessary in order to achieve the greater productivity. Among the different phenological events onset of flowering is most significant as it marks the transition from vegetative to reproductive phase. Researchers have found that air temperature is a dominant factor controlling crop development. To predict crop development with air temperature, growing degree days (GDD) or a similar linear unit system is widely used (Madariaga and Knott, 1951).

Considering the crop growth and air temperature, each crop/genotype has a particular base temperature. Physiologically, it is assumed that below a certain temperature level, crop growth and development will cease. However, it is difficult to determine the physiological base temperature.

However, in practice, the base temperature selected may vary among years or growing seasons. For example, Arnold (1959) reported that the base temperature value for corn was 6°C in 1954 and 4.3°C in 1955.

In most cases, the base temperature is determined statistically rather than physiologically. Many statistical methods to determine the base temperature have been reported (Yang *et al.,* 1995) anyway we are using least standard deviation in days method by Arnold (1959). Accordingly, prediction of time to flowering help select appropriate crop management practices such as optimum sowing and harvesting dates.

Simple linear regression models have been proposed to predict the effects of temperature on flowering behaviour (Keerthi, 2015). The effects of temperature have proved to be additive (Robberts and Summerfield, 1987). Attempts to model time to flowering have not been reported in cowpea. Cowpea [*Vigna unguiculata* (L.) Walp.] is a short day legume which shows considerable response for temperature, its phenological events differs with the temperature fluctuations across the seasons. The present study was carried out to assess the relative contributions of temperature on time to flowering variation among a set genotypes.

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Materials and Methods

Experimental material

The experimental material consisted of three stabilized lines of promising crosses (DC 15×DCS 47-1, C152×CP 206 and DC 15×SHUBRA) of F_6 generation. Five germplasm accessions which have early flowering nature IC97856, IC257428, IC202926, IC198326 and IC259064 and three checks (DC15, DC16 and DCS47-1).

Plant material and experimental design

Three stabilized crosses (DC15×DCS 47-1, C 152×CP 206, DC15×SHUBRA) of F_6 generation which are developed and maintained at University of Agricultural Sciences, Dharwad. Along with three checks (DC 15, DC 16 and DCS 47-1), five germplasms (IC97856, IC257428, IC202926, IC198326 and IC259064) which were early in flowering were used. The 11 genotypes were evaluated in 12 monthly intervals from March 2018 to February 2019 in 12 separate experiments laid-out in randomised block design with two replications at Botanical Garden, Department of Genetics and Plant Breeding, University of Agricultural Sciences, Dharwad. The seeds of each genotype were sown in two rows of 3 m length following a spacing of 45×15 cm.

Statistical analysis

Estimation of growing degree days (GDD)

Estimate of base temperature (T_b) is a prerequisite for estimation of GDD. T_b was calculated based on the method of least standard deviation (in GDD) (Yang *et al.,* 1995)

$$T_b = \frac{\sum T_t d_i \sum d_i - n\sum T_i d_i^2}{(\sum d_i)^2 - n\sum d_i^2}$$

Where,

T_i is mean diurnal temperature prevailed during planting date to time to flowering, d_i is days to flowering of i^{th} genotype and 'n' is number of planting dates. Replication-wise GDD between planting date to time to flowering were estimated and T_b for all the genotypes using the following equation (Yang *et al.,* 1995).

$$GDD\,(T_t) = \sum_{t=1}^{n} (T - T_b)$$

Prediction of flowering time of photoperiod sensitive genotypes

The linear model (thermal model) were used to predict flowering time, thermal model based on temperature alone: 1/f = a + bT, where, 1/f is the rate of progress or development in days, defined as the inverse of duration from sowing to flowering initiation (f) for each genotype averaged over two replications. T = mean temperature (°C) averaged over two replications. The coefficients, and b are genotype specific constants (Robberts and Summerfield, 1987). The constants of the thermal model were estimated through linear regression of T on 1/f of each genotype.

Critical minimum GDD

The graph of GDD on Y-axis and FTDOY on X-axis was drawn to estimate critical minimum GDD and photoperiod requirement for time to flowering (Robberts and Summerfield, 1987).

RESULTS AND DISCUSSION

Determination of base temperature (T_b) is a pre-requisite for a further calculation of growing degree days (GDD). T_b was calculated based on the method of least standard deviation (in GDD) (Yang *et al.,* 1995). Daily mean air temperature (MAT) of the respective months till flower initiation as well as days from planting to flower initiation (FTDAP) of the respective genotypes were used to calculate base temperature (T_b). Base temperature calculated for all the genotypes varied from 9.53°C to 12.09°C (Table 3).

Combined analysis of variance

Combined analysis of variance was performed to detect genetic differences among genotypes for temperature

Table 1: Combined analysis of variance of selected cowpea genotypes for flowering time in days after planting (FTDAP), mean air temperature (MAT), growing degree days (GDD) and yield.

		Pooled ANOVA			
Source of variation	df	FTDAP	MAT	GDD (°C day)	Yield
		Mean squares	Mean squares	Mean squares	Mean squares
Replication	1	25.47	4.61	4581.67	25.5
Planting dates (PD)	11	5.10**	1.08**	2936.81**	5.10**
Genotypes (G)	10	33.52**	106.82**	218254.39**	33.52**
PD × G	11	2.11	0.09	288.84	2.1

**: Significance at 1%; *: Significance at 5.

Table 2: Genotypical correlation of different indices.

	Genotypical correlation			
	Flowering	GDD	Mean air temperature	Yield
Flowering	1.00	-0.41**	-0.44**	0.38**
GDD		1.00	0.97**	-0.50**
Mean air temperature			1.00	-0.33**
Yield				1.00

**: Significance at 1%; *: Significance at 5.

induced sensitivity to flowering time (Table 1). The significant differences in planting dates for FTDAP, MAT, GDD and yield, indicates that the staggered date of plantings had significant variation in flowering days, air temperature, heat units accumulated for flowering initiation and also there is variation for yield at different planting dates. There is also significant differences of genotypes for FTDAP, MAT, GDD and yield, which means all the genotypes differed significantly for flowering days, air temperature, for heat units accumulation as well as for yield.

Flowering, GDD and base temperature (T_b)

The number of days required for the flower initiation varied across the season for individual genotypes. The flowering time from day of the planting (FTDAP) for DC 15 × DCS 47-1 varied from 48.50 days to 55 days, while for both C152 × CP206 and DC 15 × SHUBRA the FTDAP varied from 49 to 55 days. The germplasms, IC97856, IC257428, IC202926, IC198326 and IC259064 varied from 44 to 50, 44 to 48, 44 to 49, 43.50 to 48 and 44 to 48 days across all the season. Among the checks DC 15, DC 16 and DCS 47-1 registered 50 to 57, 47.5 to 57 and 48 to 56 days of variation across the season for flower initiation, respectively.

Among all the genotypes, the GDD required for flower initiation was varied for individual genotypes across the seasons. In F_6 crosses, DC 15 × DCS 47-1 had varied from 897.2 to 595.1°C day across the year. Similarly, C152 × CP206 and DC 15 × SHUBRA varied from 928.3 to 589.3°C day and 902.9 to 557°C day across the year, respectively. All the germplasms, IC97856, IC257428, IC202926, IC198326 and IC259064 varied from 770.9 to 417.3°C day, 861.3 to 573.6°C day, 818.7 to 484.7°C day, 821 to 515.7°C day and 798.5 to 432.5°C day across the year, respectively. In the checks DC 15 registered 916.5 to 555.2°C day of GDD. Whereas DC16 and DCS 47-1 registered 890.2 to 550.3°C day and 889.1 to 544.5°C day throughout the year, respectively.

Table 3: Flowering time from day of the planting (FTDAP), mean air temperature (MAT), base temperature (T_b) and growing degree days (GDD) required by cowpea genotypes for flower initiation.

Genotypes	Parameters	Flowering	GDD (°C day)	T_b (°C)
DC15	Mean	52.21	720.82	10.82
	SD	1.92	104.37	
	CV	3.69	14.48	
DC16	Mean	50.67	705.52	10.70
	SD	2.28	101.18	
	CV	4.50	14.34	
DCS47-1	Mean	50.79	692.10	11.03
	SD	1.97	105.45	
	CV	3.88	15.24	
DC15 × DCS47-1	Mean	50.71	725.44	10.39
	SD	1.81	103.16	
	CV	3.58	14.22	
C152 × CP206	Mean	51.08	739.33	10.17
	SD	1.73	108.14	
	CV	3.39	14.63	
DC15 × SHUBRA	Mean	51.50	683.90	11.38
	SD	2.00	111.87	
	CV	3.88	16.36	
IC97856	Mean	46.75	594.64	11.87
	SD	2.36	100.06	
	CV	5.05	16.83	
IC257428	Mean	46.21	699.09	9.53
	SD	1.83	96.73	
	CV	3.95	13.84	
IC202926	Mean	46.63	627.51	11.17
	SD	2.39	91.66	
	CV	5.14	14.61	
IC198326	Mean	45.17	660.57	10.04
	SD	1.27	93.31	
	CV	2.81	14.13	
IC259064	Mean	45.92	582.64	12.09
	SD	1.24	113.48	
	CV	2.70	19.48	

The overall mean of FTDAP and growing degree days (GDD) required by the cowpea genotypes for flower initiationdiffered for individual genotypes. The F_6 crosses, DC 15 × DCS 47-1 require 50.71 days and 725.44°C day for flowering initiation with its base temperature being 10.39°C. Similarly, C152 × CP206 and DC 15 × SHUBRA require 51.08 and 51.50 days with 739.33 and 683.90°C day for flowering initiation with their base temperatures 10.17 and 11.38°C, respectively. The germplasms, IC97856, IC257428, IC202926, IC198326 and IC259064 require 46.75, 46.21, 46.63, 45.17 and 45.92 days with their GDD of 594.64, 699.09, 627.51, 660.57 and 582.64°C day for flowering initiation with their base temperatures of 11.87, 9.53, 11.17, 10.04 and 12.09°C, respectively. Whereas, DC 15, DC 16 and DCS 47-1, registered 52.21, 50.67 and 50.79 days with 720.82, 705.52 and 692.10°C day for flowering initiation with base temperatures being 10.82, 10.70 and 11.03°C, respectively (Table 3).

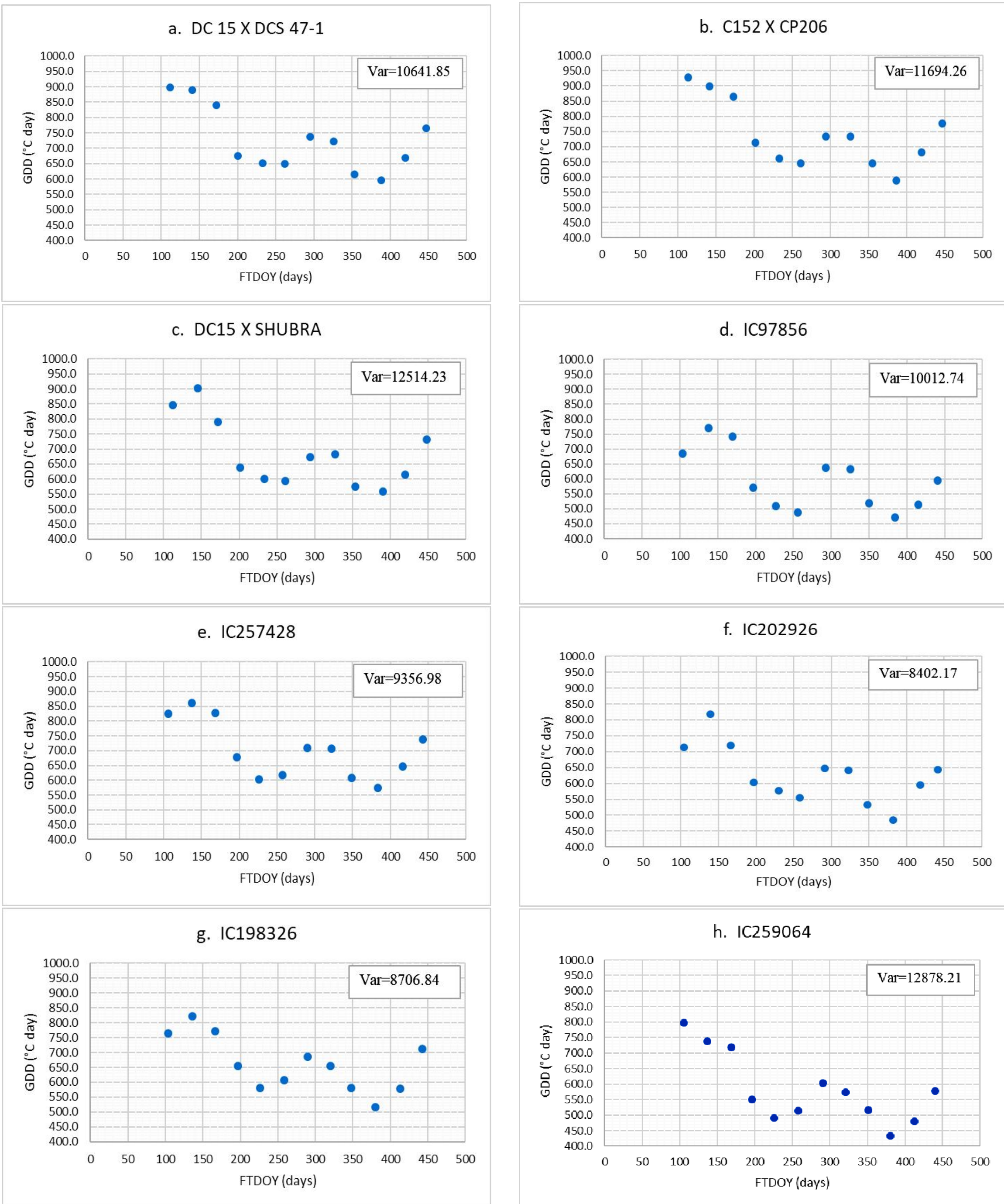

Fig 1: GDD (°C day) and calendar date of flowering initiation in cowpea genotypes sown in different dates.

Growing degree days (GDD) varied across the seasons, the genotypes which shown least variation of GDD across the seasons may be considered as insensitive one. IC202926 is the genotype with least variance of 8402.17 (Fig 1f) for GDD across the seasons, followed by IC198326, IC97856, IC257428 and IC259064 with variance value of 8706.84, 10012.74, 12878.21 and 12878.21 (Fig 1g, d, e and h). Genotypes like DC15×DCS47-1, C152×CP206 and DC15×Shubra exhibited higher variance (Fig 1a, b and c).

The genotypes which differed for time to flowering (FTDAP) and GDD for flower initiation across the seasons with respect to temperature were regarded as sensitive genotypes. In contrary, the genotypes where there performances were comparable across the seasons for flowering were regarded as insensitive genotypes (Keerthi., 2015). In the present study, three genotypes (IC202926, IC198326 and IC257428) were recognized, where their flowering days were comparable, they shown least variation for flowering across the season (Fig 2e, f, g). And the other genotypes (DC15×DCS47-1, C152×CP206, DC15×SHUBRA, IC97856, IC259064) shown higher variation (Fig 2a, b, c, d and h).

On an average, sensitive genotypes required higher T_b and average GDD for flowering than the insensitive genotypes (Keerthi., 2015). Among the three temperature insensitive genotypes recognized (IC257428, IC202926 and IC198326) had registered relatively lower T_b and average GDD of 9.53, 11.17 and 10.04°C of T_b and 573.6, 484.7 and 515.7°C day of GDD.

As expected temperature sensitive genotypes differed widely in flowering time as a function of temperature for flowering, whereas temperature insensitive genotypes maintained relatively constant number of flowering days irrespective of temperature, similar reports obtained by Keerthi (2015).

Flowering and yield

All the genotypes varied significantly for flowering as well as for yield across all the seasons. Flowering occurred earlier in the warm seasons and it took some additional days to flower in cool seasons (Hadley *et al.,* 1983). As the flowering differed, yield also varied. Yield was high in some of the months and it was low in some of the off seasons, genotypes with early flowering and high yielding are desirable. Here the 11 genotypes varied significantly for flowering and yield across the seasons. The genotype DC15 and DC16 took 51 and 50 days for flowering and recorded high yield of 35 and 36.7 grams per plant in the month of July. Whereas DCS47-1 registered 48 days of flowering and high yield of 37.6 grams per plant in the month of July. All these genotypes shown more yield fluctuation at different dates of plantings. Among the crosses, DC15 × DCS47-1 has registered 51 days for flowering and high yield of 39.4 grams per plant in the month of July, it also registered high yield (40.1 grams per plant) in the month of January with 52 days for flowering. Similarly, C152 × CP206 and DC15 × SHUBRA both took 51 days for flowering and registered their highest yield of 39.7 and 44.1 grams per plant, respectively in the month of July. They also registered high yield of 39.6 and 54.5 grams per plant, respectively in the month of January. All these exhibited maximum fluctuations for yield as well as for flowering.

The genotypes IC97856 and IC259064 exhibited higher yield of 45 and 42.5 grams per plant in the month of July with 45 days for flowering. Their yield was also high in the month of January (42.8 and 42.5 grams per plant) with 48 and 49 days for flowering, with all their yield fluctuated throughout the year. Whereas IC257428, IC202926 and IC198326 registered least variation for flowering and yield across the seasons. These genotypes took 44, 48 and 44 days for flowering, with yield of 37.2, 41.4 and 34.7 grams per plant in the month of July. Among all the genotypes these three registered least variance for flowering (1.48, 2.10 and 1.61 respectively) as well as for yield (32.15, 36.50 and 23.40) across the seasons (Fig 2e, f, g).

Critical minimum GDD and temperature requirement

The graph of GDD on Y-axis and FTDOY on the X-axis indicated requirement of critical minimum GDD for time to flowering (Fig 1). The critical minimum GDD required for flowering initiation by genotypes ranged from 417.3°C day (IC97856) to 595.1°C day (DC15 × DCS47-1) with an average of 506.2°C day. The minimum temperature required for flowering initiation ranged from 19.5 to 19.9°C with average minimum temperature of 19.7°C, on the other hand the optimum temperature required for flower initiation ranged from 24.3 to 25.2°C with average optimum temperature of 24.75°C (Table 4).

In the present study, the identified germplasms IC257428, IC202926 and IC198326 attained critical minimum GDD of 573.6, 484.7 and 515.7°C day in the month of December. This indicate that cooler months lead to the minimum heat units accumulation. Similar results were obtained by Keerthi (2015) where dolichos bean require 411°C day as critical minimum GDD for flowering. Similarly, in faba bean and pea critical minimum GDD of 833 and 770°C day are required for time to flowering (Iannuci *et al.,* 2008).

Correlation studies among different indices

Correlation studies had been carried to assess the genetic correlation between the parameters. The parameters (FTDAP, GDD, MAT and yield) were significantly correlated. The FTDAP is significantly and negatively correlated with GDD and MAT (-0.41** and -0.44** respectively) and positively correlated with yield (0.38**), which indicates that as temperature increases the days to flowering (FTDAP) decreases, flowering initiation occurs earlier in case of warm seasons (Hadley *et al.,* 1983) and late in case of cool seasons these additional cool days decreases the heat units accumulation (GDD), Whereas GDD is significantly and positively correlated with MAT (0.97**) and negatively correlated with yield (-0.50**), this indicates that as the GDD is increased by increase in temperature, but high temperature has deleterious effect on the yield (Table 2).

Prediction of time to flowering of cowpea genotypes

The timing of flowering and in particular the degree to which it is responsive to temperature as a key factor in the adaptation of species to different eco-geographical locations (Weller and Ortega, 2015) and cowpea is not exception to this. Hence, accurate prediction of time to flowering helps in making decisions on appropriate sowing and harvesting time to optimise productivity. The linear regression model described by Robberts and Summerfield (1987) are considered useful for predicting the rate of progress towards flowering. The regression constants (a and b) of all the genotypes helps us to predict the flowering time with respect to the average air temperature prevalent in that area, thereby helps us to plan the sowing and harvesting date. Regression of temperature on the rate of development in all the genotypes were significantly (P<0.01) correlated to mean air temperature, in this regard an attempt has been made to predict the flowering time in all genotypes using thermal

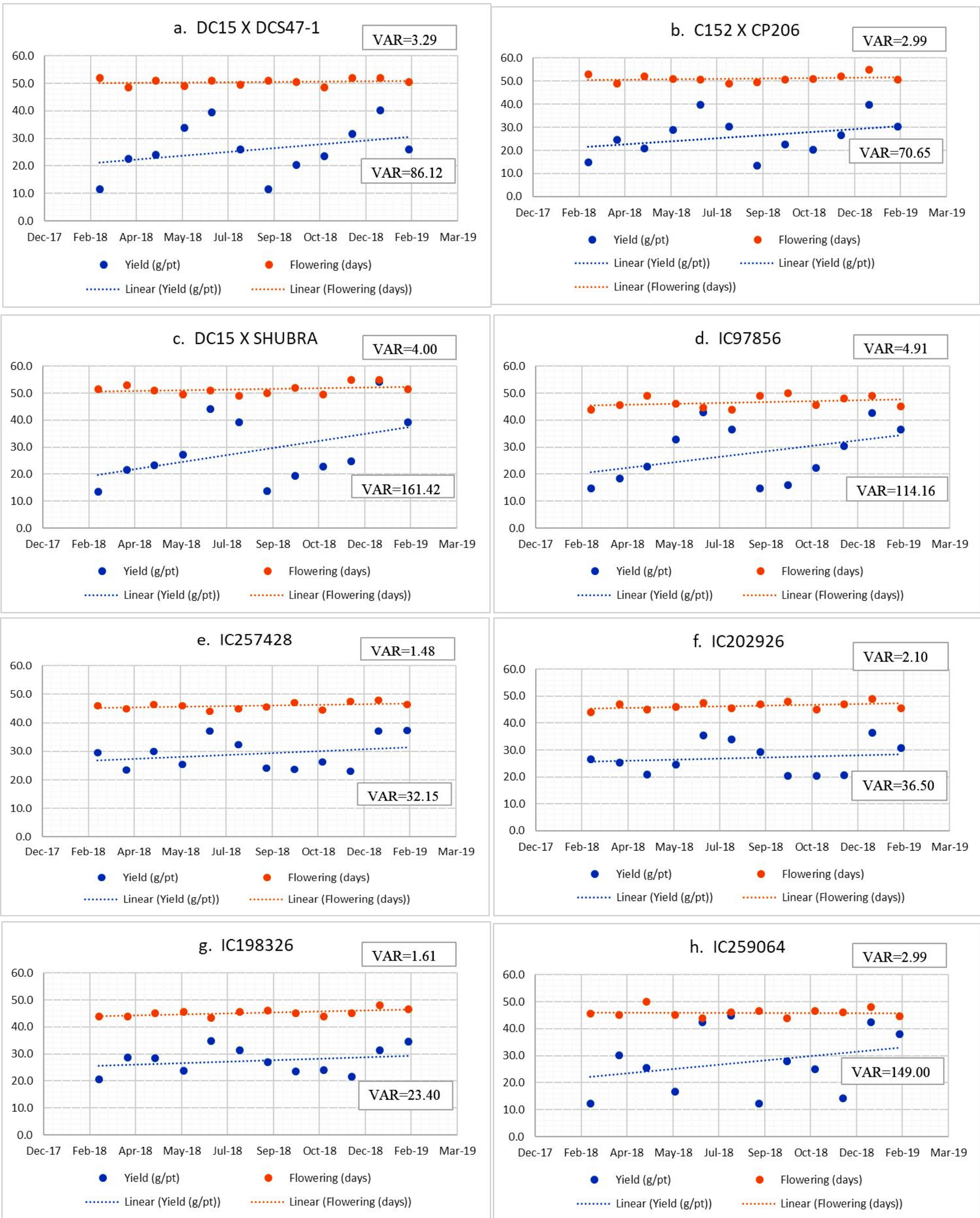

Fig 2: Days to flowering and yield recorded in cowpea genotypes sown in different dates.

Table 4: Critical minimum growing degree days (GDD), minimum and optimum temperature required for flowering and prediction of flowering through regression constants in cowpea genotypes.

Genotypes	Critical minimum	Temperature (°C)		Thermal model		
	GDD (°C day)	Minimum	Optimum	a	b	R^2
DC15	555.2	19.8	24.3	56.15**	-0.162	0.42
DC16	550.3	19.5	24.7	57.51**	-0.281	0.75
DCS47-1	544.5	19.9	24.4	55.48**	-0.192	0.47
DC15 × DCS47-1	595.1	19.9	25.1	54.94**	-0.173	0.46
C152 × CP206	589.3	19.9	24.8	55.22**	-0.170	0.48
DC15 × SHUBRA	557.8	19.7	24.6	55.74**	-0.174	0.38
IC97856	417.3	19.8	24.8	53.66**	-0.284	0.76
IC257428	573.6	19.5	24.7	50.92**	-0.193	0.57
IC202926	484.7	19.6	25.2	54.06**	-0.305	0.82
IC198326	515.7	19.6	24.4	47.50**	-0.096	0.30
IC259064	432.5	19.7	24.5	47.90**	-0.082	0.22

**: Significance at 1%; *: Significance at 5.

model. The genotypes like IC202926, IC97856, IC257428 and DC 16 were found highly significant (P<0.01) with $R^2 \geq 0.57$ (Table 4).

CONCLUSION

GDD is an empirical approach, used to predict the time of flowering by using the daily mean air temperature, it is possible to predict the combination of cultivar (GDD and T_b requirement) and sowing date that will produce the crop that is ready for harvest on a pre-determined day. It has been successfully used to choose grape cultivars for different end users in California (Hall, 2001). By applying this system to the vegetable type of cowpeas it is possible to continuously supply fresh pods to market by choosing cultivars with different GDD requirement from sowing to the date when pod quality is optimal and also sowing on different dates and regions with different thermal regimes.

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