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Regression Model Based on Thermal Indices and Heat Use Efficiency for Estimation of Pigeonpea (*Cajanus cajan* (L.) Millsp.) Seed Yield

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

A field experiment was conducted on experimental farm of Dept. of Agricultural Meteorology, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani, Maharasthra, India during the during *kharif* season 2015 under rainfed condition to find the relationship of pheno thermal and heat use efficiency indices with yield. The field experiment was laid out in factorial randomized bock design with five sowing dates (i.e. 25th, 26th, 27th, 28th and 29th SMW) and three varieties (*viz.,* BDN-711, BSMR-736 and BSMR-853) with three replications. The sowing dates significantly influenced on the phenology, growth, development and yield attributes. The dry spell experienced during sowing to emergence period in first sowing date (25th SMW sowing) and thereafter no rainfall condition during remaining period of sowings *viz.*, 26th, 27th, 28th and 29th SMW, therefore, emergence and final plant count was observed lowest in 25th SMW (30 and 29 %) and highest in 27th SMW sowing (92 %). Hence, significantly highest dry matter plant^{-1}, no. of pods plant^{-1}, seed weight and seed yield plant^{-1}

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was observed in 25th SMW sowing; seed yield (417.7 kg ha^{-1}), seed yield heat use efficiency (0.20 kg ha^{-1} ^{0}C day^{-1}) was recorded highest in 27th SMW sowing and lowest in 25th SMW sowing. Significantly highest no. of pods plant^{-1}, seed weight and seed yield plant^{-1}, seed yield heat use efficiency, pheno thermal index was observed in BDN-711 variety and significantly lowest in BSMR-853 variety. The significantly highest total dry matter plant^{-1} was observed in BSMR-853 and lowest in BDN-711 variety. Significantly highest GDD, HTU and PTU required for completion of different phenophases were recorded in BSMR-736 variety and significantly lowest in BDN-711 variety. Weather indices *viz.*, GDD, HTU, PTU, PTI showed non-significant correlation at all the phenophases with seed yield of pigeonpea. The yield prediction model based on thermal indices and seed yield heat use efficiency at floral bud initiation to 50 % flowering and at 50 % flowering to 50 % pod formation phenophases was found useful in assessing the crop yield one and half to one month in advance.

Keywords: GDD; HTU; PTU; PTI; SMW; multiple regression model; pigeon pea.

1. INTRODUCTION

Pigeonpea (*Cajanus cajan* (L.) Millsp.) is well adapted to arid and semi-arid climates of the tropical and sub-tropical regions of the world [1]. Pigeonpea has traditionally been a kharif season crop grown as rainfed on marginal lands and mostly as a mixed crop during late June or early July. Recently, under changed climatic condition and cropping pattern, under rainfed farming, pigeonpea crop area is increased, because it is a leguminous crop that has been cultivated for human consumption and many other uses in many parts of the world. It contains high level of proteins and important amino acids such a methionine, lysine and tryptophan.

However, during recent years in India as well as in Maharashtra state, reduction of crop productivity, quality of crop produce and share of agriculture in GDP, because of abiotic stresses are prominently noted in rainfed and dryland farming, due to changed Indian climatic condition [2,3]. Pigeonpea is a long duration, deep rooted, very heat tolerant and most drought tolerant legume crop. It is a crop of slow growth rate at initial stage and resistant to early drought of monsoon season [4]. Hence, it's area and production has been increased from 3726 thousand hectors and 3076 thousand metric tonnes in 2007-08 to 4450 thousand hectors and 3315 thousand metric tonnes in 2018-19 respectively, but the reduction of productivity was found from 826 in 2007-08 to 729 kg /ha in 2018-19 in India [5]. The similar observations at regional level for Marathwada were reported by Dhokar, et al. [6].

In such areas of uncertainty, intra and inter annual variability in weather causes substantial fluctuations in pigeon pea productivity. Photoperiod and temperature are two main environmental factors determining the flowering time in pigeonpea. Influence of temperature on phenology and yield of crop plants can be studied under field conditions through accumulated heat unit system because plants have a definite temperature requirement before they attain certain phenological stage [7]. Therefore, any possible understanding of weather-seed yield relationship may help to determine the best time to apply specific agronomic practices in order to maximize yield. Sowing at the optimum time gives higher yields due to suitable weather conditions that prevail at all the growth stages. Under monsoon climatic condition, in rainfed farming, early sown crop may accumulate excessive dry matter resulting in reduced pod development, while late sown crop may have less biomass accumulation and consequently reduced yields. Delayed sowings beyond the optimum period result in low grain yields of pigeon pea [8]. Production potential for a given crop is often strongly related to crop phenology which is largely sensitive to temperature variations. The term most often used to quantify temperature effects on phenological development has been the degree day or heat unit [9].

The success or failure of dry land rainfed crops depends mostly on the pattern of monsoon rains, and duration of each growth phase determines the accumulation and partitioning of dry matter in different organs [10] as well as crop response to environmental and external factors. Reaumur was the first to suggest in 1735 that the duration of particular stages of growth was directly related to temperature and this duration for particular species could be predicted using the sum of daily air temperature [11]. Keeping these factors in mind, the present experiment was conducted to study the effect of sowing time and genotypes on phenothermal and heat use efficiency (HUE) indices and to estimate of seed yield of pigeon pea by regression model. The results of the study can be used to assess the crop performance in assessing the suitability of the variety to a particular locality depending on the thermal environment and will be useful input in crop modelling of pigeon pea.

Thus, findings of the experiments may be useful to pigeon pea growers as well as agricultural policy makers, because this paper may give clear idea about relationship in between weather parameters, thermal indices and crop growth stages as well as seed yield. It may also useful to assess seed yield forecast before one to one and half month before harvesting.

2. MATERIALS AND METHODS

A field experiment was conducted on experimental farm of Dept. of Agricultural Meteorology, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani, Maharasthra, India. Its geographical coordinates are: longitude 76^0 47' East, latitude 19^0 16' North and its altitude is 409 m above mean sea level. Parbhani district falls under Central Maharashtra Plateau Agroclimatic Zone (MH-7) in Maharashtra. The district receives a mean annual rainfall of 916.0 mm, out of which 86 % is received during south west monsoon, 9-10 % in North East monsoon and 4-5 % in remaining season.

A sowing date experiment carried out to assess pheno thermal indices during *kharif* season of 2015 under rainfed condition in factorial randomized bock design with five sowing dates (i.e. 25^{th}, 26^{th}, 27^{th}, 28^{th} and 29^{th} SMW) and three varieties (*viz.,* BDN-711, BSMR-736 and BSMR-853) with three replications.

Five plants from each plot were selected randomly and tagged for taking observations at each phenophase. Whenever, more than 3 plants out of the tagged 5 plants of each plot of the treatment attained a particular growth stage, the date was considered as the one for attainment of that stage. The phenophase stages identified by Nihalani [12] were adopted. Based on visual observations, different phenological stages viz., emergence to branching (P_1), branching to floral bud initiation (P_2**),** floral Bud Initiation to 50 % flowering **(**P_3), 50 % flowering to 50 % pod formation (P_4), 50 % pod formation to maturity (P_5). Daily weather data were collected from Agrometeorological observatory of the Department of Agricultural Meteorology, VNMV, Parbhani, which is located at aside of the experimental plot. Which was averaged on standard meteorological week (SMW) and presented in Table 1.

The thermal indices *viz.,* growing degree days (GDD), helio thermal unit (HTU), photo thermal unit (PTU) and phenothermal index (PTI) at different phenophases, heat use efficiency (HUE) at maturity (harvest) were computed by using the daily meteorological data and converted phenophasewise. The accumulated GDD (°C day) was worked out for different phenophases by considering the base temperature of 10.0 °C Rajbongshi et al., [4] by the following formula-

$$\text{Accumulated GDD} = \sum_{ds}^{dh} [(T_{max} + T_{min}) / 2] - Tb \quad (1)$$

The sum of HTU (°C day hrs) for each phenophase was worked out by following equation which was given by Nagamani *et al.* [13]. Here, the actual bright sunshine hours (BSS) were recorded by Campbell's Stocks sunshine recorder installed in agrometeorological observatory which is located aside of the experimental plot.

$$\text{Accumulated HTU} = \text{GDD x BSS} \quad (2)$$

PTU (°C day growth day^{-1}) was computed by using following formula. This was proposed by Gudadhe *et al*. [14]. Day length was estimated by calculating the sun rise and sun set [15].

$$\text{PTU} = \text{GDD x Day length} \quad (3)$$

PTI (°C day hrs) was computed to compare the relative performance of pigeon pea under various treatments and it is expressed as degree days per growth days for vegetative stage of the crop were calculated by using following formula [4].

$$PTI\ (°C\ day) = \frac{Accumulated\ GDD\ for\ attain\ the\ physiological\ stage\ (°C)}{No.of\ days\ taken\ between\ two\ phenophases} \quad (4)$$

HUE is defined as the biomass accumulated during the given period per degree and it was also computed to compare the relative performance of Pigeon pea varieties under various treatments using the formula [4].

$$\text{HUE } (kg\ h^{-1}\ ℃\ day^{-1}) = \frac{\text{seed or total dry matter yield } (kg\ ha^{-1})}{\text{Accumulated GDD } (℃\ day^{-1})} \quad (5)$$

Entire collected data was taken for analysis of statistical differences among sowing dates and varieties, and their interaction on seed yield was tested by using SAS (ver. 9.3, SAS, Inc., Cary, NC) computer package program. The mean values were evaluating and analysis of variance was performed by the 'F' (variance ratio) test. The means were compared using the critical difference (CD) test at 5% significance level. The statistical measurements of coefficient of determination (R^2) of the equations was determined to show the proportion of the variation in the dependent variable that is predictable form the independent variable, and descriptive analysis was done with the new Microsoft Excel (Windows v. 10.0) to indicate the degree of association between two variables (i.e. dependent and independent variable).

Simple correlation and regression between weather indices i.e. GDD, HTU, PTU and PTI with yield at different phenophases of pigeon pea was estimated. Yield of all the plants from each net plot was considered as seed yield. For forecasting the yield, most commonly used model are based on following type of multiple regression equation.

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \ldots\ldots\ \beta_i X_i \quad (6)$$

Whereas, Y and Xi are yield (dependent parameter) and weather parameters (independent parameters) respectively. β_0= Constants and β_i= Regression coefficient.

Table 1. Weekly weather data recorded at agromet observatory, V.N.M.K.V., Parbhani during the experimentation period of *kharif* season of 2015

SMW	Rainfall (mm)	RD	Temperature (⁰C)		Humidity		EVP	BSS	WS
			T_{max}	T_{min}	RH-I	RH-II	(mm)	(hrs)	(km/hr)
25	37.5	2.0	31.6	23.5	86	64	4.5	2.5	5.8
26	0.0	0.0	35.1	24.3	75	43	7.3	7.5	6.6
27	5.0	1.0	35.8	23.8	76	38	8.1	9.4	9.4
28	0.0	0.0	36.2	25.8	69	37	6.0	9.4	9.4
29	0.6	0.0	35.8	24.8	76	45	5.5	8.9	8.9
30	8.0	1.0	34.0	24.0	75	47	4.9	8.5	8.5
31	19.8	1.0	33.0	23.1	80	59	6.0	8.4	8.4
32	28.8	4.0	29.9	23.0	87	68	2.4	5.5	5.5
33	23.4	2.0	31.3	23.0	85	57	4.1	5.7	5.7
34	11.2	1.0	32.9	23.0	81	49	9.5	6.0	6.0
35	0.0	0.0	32.2	23.3	79	50	7.0	6.3	6.3
36	88.1	4.0	32.9	22.2	87	60	7.0	4.8	4.8
37	38.4	4.0	31.8	22.7	90	63	6.2	3.6	3.9
38	57.4	1.0	31.4	22.0	81	59	4.1	5.9	4.7
39	0.0	0.0	33.5	20.9	74	44	6.7	7.5	3.6
40	1.8	0.0	34.3	20.9	75	44	7.1	7.3	3.6
41	0.0	0.0	35.1	19.4	73	32	7.8	9.0	2.2
42	0.0	0.0	35.7	18.3	70	29	7.8	9.1	3.6
43	0.0	0.0	35.1	19.5	70	31	5.9	8.2	3.0
44	0.0	0.0	33.0	18.9	75	36	5.6	8.1	4.4
45	0.0	0.0	34.0	16.9	68	25	6.1	7.5	4.6
46	0.0	0.0	33.6	14.3	75	23	6.1	8.9	5.3
47	0.0	0.0	32.1	18.4	78	36	6.6	6.4	6.2
48	0.0	0.0	32.9	17.0	79	33	5.6	7.6	3.0
49	0.0	0.0	32.6	13.8	71	26	5.3	9.3	3.1
50	0.0	0.0	33.8	17.7	72	31	5.6	8.9	3.4
51	0.0	0.0	32.9	16.1	71	31	5.8	8.5	4.7
Total	320	21	-	-	-	-	-	-	-
Mean	-	-	33.4	20.7	77	43	6.1	7.3	5.4

3. RESULTS AND DISCUSSION

3.1 Phenophasic Duration of Pigeonpea

The data on mean number of days required to emergence was observed significantly highest in 26th SMW sowing and lowest in 25th SMW sowing (Table 2). The number of days taken by the crop for completion of this phenophases varied with the date of sowing. The earlier sown crop (25th SMW sowing) required significantly lowest time for emergence, whereas, late sown crop required significantly more time for emergence, and it was decreased as delayed sowing. It was observed due to the dry spell experienced during sowing to emergence (P_1) period of 26th, 27th, 28th and 29th SMW sowing (Table 1). Due to the dry spell, the emergence of 26th, 27th, 28th and 29th SMW sowing was not observed at regular interval of time and it was observed at a time in these four sowing dates. Amongst varieties, BDN-711 emerged significantly earlier, whereas, highest days were required for BSMR-853.

The data on mean number of days required to attain 50 % flowering, 50 % pod formation and physiological maturity showed significantly variation and it shows decrease in days to attain these phenological stages as delaying sowing, respectively. While, it was found significantly highest in 25th SMW sowing and lowest in 29th SMW sowing (Table 2). It may be observed due to the occurrence of more soil moisture stress as delaying sowing [16]. As a whole the earlier sowing required more time to achieve harvest maturity, which progressively decreased with delay in sowing. This is in close agreement with findings of Patel *et al.* [17] Patel *et al.* [18] Nagamani *et al*. [13] and he stated that the with delay in sowing, flowering was induced earlier, resulting in less vegetative growth and earliness and maturity. In case of 50 % flowering, BDN-711 flowered significantly earlier and BSMR-853 flowered late. However, BSMR-853 was found at par with BSMR-736. While, in case of 50 % pod formation and physiological maturity, BDN-711 significantly attained these phases earlier and late in BSMR-736. However, BSMR-736 was found at par with BSMR-853. It indicates that the BDN-711 is more drought tolerant than the BSMR-736 and BSMR-853 variety and it may due to the genetic influence.

3.2 Growth and Yield Attributes

Amongst the sowing date, significant difference in emergence count and final plant stand was found and emergence as well as final plant stand was observed highest in 27th SMW sowing, and it was significantly highest among all sowing dates (Table 2). Whereas, it was found at par 28th SMW and 29th SMW sowing. Lowest emergence and final plant stand was observed in 25th SMW sowing. It was because of sufficient soil moisture was not available to germinate seed, due to occurrence of dry spell immediate after 25th sowing date (Table 1). Increase in soil moisture stress decreased the mean emergence percentage and also time to emergence was progressively delayed in some treatments. Similar results were reported by Hosseini *et al*. [19] Vance *et al.* [20].

The significant difference in varieties pertaining to emergence count and final plant stand was found. However, BDN-711 variety showed significantly highest initial and final plant stand and it was found at par with BSMR-853. It may be due to drought tolerance genetic characteristics of variety.

Amongst the sowing date, significantly superior and highest total dry matter plant^{-1} was observed in 25th SMW and lowest in 26th SMW sowing (Table 2). This may be due to moisture stress and moisture variation, temperature variation prevailed during different treatments at different phenophases, as well as due to variation in growth attributing characters like no. of branches plant^{-1}, height and width of plant and yield attributing characters like pods plant^{-1}, yield plant^{-1}, seed weight, straw yield and biological yield. Because of biomass (i.e. straw yield and seed yield) it was varied, varies the dry matter. On the similar lines, [21] reported that, variation in growth attributes and yield attributes was observed within the years, due to prevailing different weather condition and [13] also reported similar reports. Significantly highest dry matter was observed in BSMR-853 and the lowest dry matter was observed in BDN-711 over the rest of other varieties. While, BSMR-853 was found at par with BSMR-736.

The 25th SMW sowing showed significantly highest no. pods plant^{-1}, seed yield plant^{-1} and seed weight, while lowest in 26th SMW sowing, except seed weight which was found lowest in 28th SMW sowing (Table 2). It might be due to, variation in no. of primary and secondary branches plant^{-1} (data is not presented) and due to moisture stress and moisture variation [16]. prevailed under different weather conditions within the crop growing period among different sowing dates. On similar lines Islam *et al.* [22]

Ram *et al.* [23] Singh *et al.* [21] reported that, variation in no. of pods plant^{-1} was observed during the different year due to prevailing different weather condition. Significantly highest no. pods plant^{-1}, yield plant^{-1} and seed weight was recorded in BDN-711, whereas, lowest in BSMR-853. It may be due reason stated earlier in above points.

Amongst the sowing date, 27th SMW sowing recorded significantly highest seed yield (418 kg ha^{-1}) and lowest (375 kg ha^{-1}) in 26th SMW sowing over rest of the treatments (Table 2). While it was found at par with 25th and 29th SMW sowing dates. Instead of highest seed yield should be record similar to highest no. pods plant^{-1}, seed yield plant^{-1} and seed weight recorded in 25th SMW sowing, it was recorded highest in 27th SMW sowing.

It may be due to the crop at branching to floral bud initiation (P_2) and 50 % flowering to 50 % pod formation (P_4) growth stage showed highly significant correlation with soil moisture at 15 and 30 cm layers of soil and mean soil moisture % at 15, 30 and 45 cm layers was recorded significantly highest in 27th SMW sowing [16]. The pigeonpea crop growth stages of flower bud initiation to pod development are critical and more sensitive stage to soil moisture and during this stage crop was seen under moisture stress, because of the early withdrawal of monsoon during the experimental year. And the probable reason of this findings may be occurrence of early season drought, induced lowest germination % in the first sowing (25th SMW), and which was availed more land space, available soil water for crop and nutrient, due to which recorded significantly highest yield attributes, but significant highest seed yield was recorded in 27th SMW sowing. Because of these reasons, final counted number of plants were noted highest in the 27th SMW sowing, which was resulted in highest seed yield. These results are in agreement with reported in past by Ram *et al.* [23] Singh *et al.* [21] but not agreed with the results of those reported by Patel *et al.* [18] Nagamani *et al.* [13] because of the present experimental study year was reported abnormal in respect to weather condition and their obtained experimental results of normal seasonal weather condition; they reported that yield decreases with decrease in total accumulation of GDD, HTU, PTU and PTI, with delay in sowing date.

Among the three varieties, highest seed yield per ha^{-1} was observed in variety BDN-711 and lowest in BSMR-853. The BDN-711 variety recorded significantly superior yield over all other varieties and it was found at par with BSMR-736. It may be due to its varietal characteristics, to give response and to produce more grain yield under same weather condition prevailed, and more water use efficiency. These results are in agreement with observations recorded earlier by Ram *et al.* [23] Singh *et al*. [21] Jaybhaye *et al.* [16].

3.3 Weather Indices

The weather indices are nothing but product of temperature and required growth period or day length or BSS and production potential for a given crop is of largely sensitive to temperature variations. As reported by Patel *et al*. [17] the importance of weather indices is that the duration of each growth phase determines the accumulation and partitioning of dry matter in different organs [10] as well as crop response to environmental and external factors. Reaumur was the first to suggest in 1735 that the duration of particular stages of growth was directly related to temperature and this duration for particular species could be predicted using the sum of daily air temperature [11].

3.3.1 Growing Degree Days (GDD)

Amongst the sowing dates, significant difference in GDD was found at all the phenophases, except 50 % pod formation to physiological maturity (P_5) stage and significantly highest GDD accumulated by 25th SMW sowing at all the phenophases except P_5, where, it was recorded highest in 26th SMW sowing. Significantly highest total GDD (2811 ^{o}C day) was accumulated by 25th SMW sowing, which was higher by 25 to 26 % as compared to other sowing dates (Table 3). However, the trend of GDD showed that, with delay in sowing date, there was decrease in total accumulated GDD to attain physiological maturity. It was mainly due to reduction in growing period in delayed sowing dates and also due to increased temperature, bright sunshine hours and decreased soil moisture availability during growing season in late sown crops because of early season drought and early withdrawal of monsoon (Table 1); and it forced to complete the productive phenophase in short time and forced early maturity in late sowing. Due to this more number of days were required for attainment of various phenophases in early sowing date as compared to later sowing dates. Reduced units of agroclimatic indices as delayed sowing dates was observed, because of low

Table 2. Plant count, days required to attain phenological stages, yield contributes and seed of pigeon pea under different dates of sowing and in different varieties

Treatments	Phenological stages						Yield contributing characters and seed yield					
	Emergence plant count (%)	Final plant stand (%)	Days to Emerg-ence (DAS)	Days to 50 % Flowering (DAS)	Days to 50 % pod formation (DAS)	Days to physiol-ogical maturity (DAS)	Dry matter plant^{-1} (g)	No. of pods palnt^{-1}	Seed yield plant^{-1} (g)	Seed weight (g)	Seed yield (kg ha^{-1})	Seed yield HUE (kg ha^{-1} °C day^{-1})
Dates of sowing												
25 SMW	30	29	6	134	149	169	196.9	85.9	28.0	10.7	397.2	0.14
26 SMW	69	69	42	130	145	166	35.1	57.3	11.7	10.0	374.7	0.18
27 SMW	97	95	33	125	141	160	40.0	65.4	14.5	10.4	417.7	0.20
28 SMW	91	90	28	121	135	154	35.9	60.2	12.4	9.7	381.7	0.18
29 SMW	92	92	21	113	127	147	38.2	63.1	13.8	10.1	410.9	0.20
S.E. ±	2.34	2.29	0.24	0.82	0.6	0.49	2.65	3.6	2.38	0.23	7.2	0.02
CD at 5%	6.77	6.63	0.69	2.37	1.74	1.42	7.68	10.41	6.89	0.68	20.83	0.05
Varieties												
BDN -711	80	79	26	119	135	156	64.0	72.0	20.0	11.1	414.3	0.19
BSMR-736	71	70	26	127	142	161	68.7	66.3	15.0	10.0	399.4	0.18
BSMR-853	77	76	26	127	141	161	75.0	60.8	13.3	9.4	375.5	0.17
S.E. ±	1.81	1.77	0.18	0.63	0.46	0.38	2.05	2.79	1.84	0.18	5.58	0.01
CD at 5%	5.24	5.1	NS	1.84	1.34	1.1	5.95	8.06	5.34	0.52	16.14	0.04
Interaction												
S.E. ±	4.06	3.94	0.41	1.42	1.04	0.85	4.60	6.23	4.13	0.40	12.48	0.03
CD at 5%	11.73	11.40	NS	NS	NS	2.47	NS	NS	NS	NS	NS	NS
G. Mean	76	75	26	125	139	159	69.2	66.4	16.1	10.2	396.4	

Table 3. Accumulated thermal indices (viz. GDD, HTU, PTU and PTI) at different phenophases under different sowing dates and in varieties

Treatments	**GDD (ºC day)**						**HTU (ºC day hrs)**					
Sowing dates:	**P1**	**P2**	**P3**	**P4**	**P5**	**Total**	**P1**	**P2**	**P3**	**P4**	**P5**	**Total**
25 SMW	508	1496	317	228	262	2811	3578	9273	2724	1838	2066	19479
26 SMW	463	847	274	226	299	2109	2616	6373	2225	1748	2595	15558
27 SMW	521	808	268	228	282	2106	2931	6074	2176	1782	2422	15385
28 SMW	496	864	256	199	272	2087	2857	6566	2091	1508	2340	15363
29 SMW	428	915	249	203	283	2078	2451	6833	2047	1572	2454	15357
S.E. ±	19.3	15.6	7.8	6.9	14.4	-	132.6	103.2	64.6	61.1	110.3	-
CD at 5%	55.7	45.0	22.5	19.8	NS	-	383.3	298.3	186.8	176.6	319.0	-
Varieties:												
BDN-711	470	950	246	231	301	2198	2816	6649	2070	1860	2452	15848
BSMR-736	494	1002	285	218	263	2262	2957	7187	2335	1655	2305	16439
BSMR-853	485	1005	287	203	274	2254	2887	7236	2352	1553	2368	16397
S.E. ±	14.9	12.1	6.0	5.3	11.1	-	102.7	79.9	50.0	47.3	85.5	-
CD at 5%	NS	34.8	17.4	15.4	NS	-	NS	231.0	144.7	136.8	NS	-
Interaction:												
S.E. ±	33.4	27.0	13.5	11.9	24.9	-	229.7	178.7	111.9	105.8	191.1	-
CD at 5%	NS	NS	NS	NS	NS		NS	NS	323.46	NS	NS	-
Correlation	-0.03	-0.05	-0.28	0.41	0.18	-	-0.02	-0.13	-0.21	0.49	0.04	-
Sowing dates:	**PTU (ºC day hrs)**						**PTI (ºC day growth day^{-1})**					
25 SMW	6767	18845	3705	2610	2944	34872	21.15	17.55	16.92	14.95	14.58	85.15
26 SMW	5923	10284	3169	2566	3336	25278	18.34	17.29	16.25	14.66	14.52	81.06
27 SMW	6634	9787	3089	2602	3133	25246	18.16	17.23	16.45	14.69	14.38	80.91
28 SMW	6335	10488	2952	2248	3031	25054	18.36	17.24	15.93	14.53	14.40	80.46
29 SMW	5526	11114	2906	2321	3182	25050	18.27	17.21	16.01	14.53	14.37	80.39
S.E. ±	242.2	199.1	88.9	78.7	160.6	-	0.03	0.01	0.08	0.07	0.07	-
CD at 5%	700.1	575.5	256.9	227.4	NS	-	0.08	0.04	0.25	0.22	NS	-
Varieties:												
BDN-711	6073	11700	2872	2643	3377	26666	18.86	17.32	16.80	14.95	14.45	82.38
BSMR-736	6370	12283	3300	2471	2937	27361	18.86	17.30	16.08	14.57	14.44	81.25
BSMR-853	6268	12322	3321	2294	3063	27267	18.86	17.30	16.06	14.50	14.47	81.19
S.E. ±	187.6	154.2	68.8	60.9	124.4	-	0.02	0.01	0.06	0.05	0.05	-
CD at 5%	NS	445.7	198.9	176.1	NS	-	NS	NS	0.19	0.17	NS	-
Interaction:												
S.E. ±	419.5	344.8	153.9	136.2	278.1	-	0.05	0.02	0.15	0.13	0.12	-
CD at 5%	NS	NS	444.89	NS	NS	-	NS	NS	NS	0.38	NS	-
Correlation	-0.02	-0.03	-0.26	0.42	0.19		-0.02	-0.08	0.50	0.32	-0.33	

P_1 - Emergence to branching *P_2 – Branching to floral bud initiation* *P_3- Floral Bud Initiation to 50 % flowering* *P_4 - 50 % Flowering to 50 % pod formation* *P_5 - 50 % Pod formation to maturity*

temperature prevails during vegetative phases and increased temperature coincided at reproductive phases [24].

The GDD required to attain in different phenological stages in pigeonpea varieties revealed that, the significant difference in varieties pertaining to GDD was found at all phenophases except emergence to branching (P_1) and 50 % pod formation to physiological maturity (P_5). BSMR-853 was observed highly significant at branching to floral bud initiation (P_2) and at floral bud initiation to 50 % flowering (P_3) and was found at par with BSMR-736. Whereas, BDN-711 was found highly significant at 50 % flowering to 50 % pod formation (P_4) and was found at par with BSMR-736. Significantly highest total GDD (2262 ^oC day) was accumulated by BSMR-736 as compared to other varieties and lowest (2198 ^oC day) in BDN-711 (Table 3). The difference in the GDD of the different cultivars may be due to the inherent character of the varieties or due to the difference in the maturity dates of the varieties. This is in confirmation with Nandini and Sridhara [25] Patel *et al.* [17] Patel *et al*. [18] Gowda *et al.* [26] Nagamani *et al.* [13].

The interaction between date of sowing and different varieties was found to be non-significant at all the phenophases.

3.3.2 Helio Thermal Unit (HTU)

Amongst the sowing date, significant difference in HTU was found at all the phenophases and the trend was found exactly similar to GDD. It is because of there was not recorded significant difference in the bright sunshine hours at the experimental site (Table 1). However, highest total HTU (19479 ^oC day hrs) was accumulated by 25th SMW sowing and lowest (15357 ^oC day hrs) by 29th SMW sowing (Table 3). The variation in HTU amongst sowing date because of reduction in growing period, increase in length of bright sunshine hours as well as less GDD was accumulated in delayed sowings. However, in general decreasing trend in total accumulated HTU with delayed sowing date was observed. These results are in conformity with in past [18] and Nagamani *et al.* [13]. Similar results were reported by Singh *et al*. [21] early sowing required higher agro climatic indices as compared to late sowing. Heat units for different phenological studies decreased with delay in sowing if *kharif* pigeon pea.

The significant difference in varieties pertaining to HTU was found at all phenophase except P_1 and P_5 and trend was observed exactly similar to GDD, it is because of reason stated as above in GDD. Whereas, significantly highest maximum total HTU was accumulated by BSMR-736 (16439 ^oC day hrs) over the varieties BDN-711 and BSMR-853 and lowest (15848 ^oC day hrs) in BDN-711 (Table 3). It may be due to varietal characters i.e. the early maturity nature of BDN-711 and mid late maturing nature of BSMR-736 and BSMR-853. These results are in corroboration with that of reported by Patel *et al.* [18] and Singh *et al*. [21]. The interaction between date of sowing and different varieties was found to be non-significant at all the phenophases except at floral bud initiation to 50 % flowering phenophase. It may be due to wide variation in required days to attain different phenophase and GDD with respect to sowing dates and varieties. Similar were reported by Patel *et al.* [18].

3.3.3 Photo Thermal Unit (PTU)

Amongst the sowing date, significant difference in PTU was found at all the phenophases, except P_5 and the trend was found similar to GDD and HTU. However, significantly highest total PTU (34872 ^oC day hrs) was accumulated by 25th SMW and lowest (25050 ^oC day hrs) in 29th SMW (Table 3). While at, P_1, 25th SMW was found at par with 27th and 28th SMW sowing and at P_4, 25th SMW was found at par with 26th and 27th SMW sowing. These results indicated that the total photo thermal units (PTU) accumulated from emergence to physiological maturity ranged between 25050 to 34872 ^oC day hrs among all sowing dates. As sowing date was delayed, decrease in total accumulated PTU to attain physiological maturity was observed. It may be due to reduction in growing period and decease in GDD and day length in later sowing dates. This could have also been happened because of more number of days required for attainment of various phenophases in early sowing date as compared to later sowing dates. The significant difference in varieties pertaining to PTU was found at all phenophase stages except P_1 and P_5 and trend was observed exactly similar to GDD, because of the all three verities grown under the same day length and ambient air temperature, in open field condition. However, significantly highest total PTU was accumulated by BSMR-736 (27361 ^oC day hrs) over the varieties BDN-711 and BSMR-853 and lowest total PTU (26666 ^oC day hrs) was accumulated by BDN-711 (Table 3). It may be due to genotypic variation and varietal characteristics of the early maturity nature of BDN-711 and mid-late maturing nature of BSMR-736 and BSMR-853. Similar results were reported by Nanda *et al.* [27] and Singh *et al.* [21]. The interaction between date of sowing and different varieties was found to be non-significant at all the phenophases except at P_3 phenophase. It may be due to wide variation in required days to attain different phenophase and GDD with respect to sowing dates and varieties.

3.3.4 Pheno Thermal Index (PTI)

Total accumulated PTI showed decreasing trend as delaying sowing date and statistically significant difference in PTI was found at all the phenophases, except P_5 amongst the sowing date. Significantly highest total PTI (85.15 ^oC day) was accumulated by 25th SMW sowing and lowest (80.39 ^oC day) in 29th SMW sowing (Table 3) as compared to other sowing dates. The results also indicated that total accumulated PTI from P_1 to P_5 ranged between 80.39 to 85.15 ^oC day among all sowing dates. With delay in sowing date, total accumulated PTI to attain physiological maturity was decreased. This could have been happened because of shortening of growing period in late sowing dates than early sowing date. It may be because of the reason stated earlier in PTU that, due to less number of days taken by late sowing dates to attain different phenophases as compared to earlier sowing date and due to less total GDD accumulated by different phenophases in late sowing dates as compared to early sowing date.

The significant difference in varieties pertaining to PTI was found at P_3 and P_4. Significantly highest total PTI was accumulated by BDN-711 (82.38 ^oC day) and lowest total PTI (81.19 ^oC day) was accumulated by BSMR-853 (Table 3). It may be due to genotypic variation and varietal character and also due to early maturity of BDN-711 and mid-late maturity of BSMR-736 and BSMR-853. On the similar line results are shown by Gowda *et al*. [26] for maize crop, the phenothermal index (PTI) in maize at different phenophases differed significantly due to influence of planting dates and more PTI accumulated in early sowings as compared to subsequent sowing dates.The interaction between date of sowing and different varieties was found to be significant at P_4 and non significant at remaining phenophases.

3.3.5 Seed yield heat use efficiency

Amongst the sowing date, significant difference in seed yield heat use efficiency (HUE) (kg ha^{-1} ^oC day^{-1}) was found. Significantly superior and higher HUE (0.87 kg ha^{-1} ^oC day^{-1}) was observed in 27th and 29th SMW sowing and it was found at par with 26th and 28th SMW sowing. While, lowest HUE (0.14 kg ha^{-1} ^oC day^{-1}) was observed in 25th SMW sowing (Table 3). According to data in Table 1, HUE did not decrease with delay in sowing date. This was may be due to large variation in grain yield, biological yield and total accumulated GDD among different sowing dates and it mainly depends upon the biological yield and total accumulated GDD [28]. This result is in conformity with the [21] and not in agreement with reported by Kumar *et al.* [8]. The significant difference in varieties pertaining to HUE was found. Significantly highest HUE (0.19 kg ha^{-1} ^oC day^{-1}) was observed in BDN-711 over the rest of other two varieties and BSMR-736 was showed at par (0.18 kg ha^{-1} ^oC day^{-1}), while lowest HUE (0.17 kg ha-1 oC day-1) was noted by BSMR-853. It may be because of the varietal characters and genotypic differences to take different time of GDD accumulation and differences in production of dry matter.

3.4 Yield Prediction Model Based on Phenothermal Indices

The equation on the basis of Table 4 reveals that weather indices (i.e. GDD, HTU, PTU and PTI) accounted for 42 %, 35 % and 44 % variation in the predicted yield at P_3, P_4 and P_5 stage, respectively. By using these equation, the yield at P_3 stage, P_4 stage P_5 stage can be predicted in general, one and half to one month, one month and half to one month respectively, in advance by using minimum values of weather parameters (*viz.*, maximum and minimum temperature, bright sunshine hours and day length). The similar model was reported by Patel *et al.* [18] for the same crop and by Jaybhaye *et al.* [29] for summer groundnut.

Data given in Table 5 revealed that error percentage in between predicted and actual recorded pigeon pea grain yield during *kharif* season 2015 at different phenophases are observed under estimated at P_3 (3.01 %), P_4 (7.26 %) and at P_5 (2.65 %). It means that the regression model developed for different

Table 4. The multiple regression equation fitted with weather parameter at different phenophases of pigeonpea

Sr. No.	Phenophase stage	Multiple regression equation	R^2
1.	Bud imitation to 50 % flowering (P_3) stage	$Y = -44.47 – 3.83 X_1 – 0.19 X_2 + 0.45 X_3 + 29.31 X_4$	0.42
2.	50 % flowering to 50 % pod formation (P_4) stage	$Y = 1087.09 – 8.97 X_1 + 0.03 X_2 + 0.84 X_3 – 60.83 X_4$	0.35
3.	50 % pod formation to physiological maturity (P_5) stage	$Y = 2273.04 – 2.34 X_1 – 0.09 X_2 + 0.28 X_3 – 131.08 X_4$	0.44

Whereas, X_1= GDD, X_2 = HTU, X_3 = PTU, X_4 =PTI, R^2 = Coefficient of determination

Table 5. Observed and predicted seed yield (kg ha^{-1}) of pigeon pea by multiple regression at various phenophases stages

Phenophase	Observed (kg ha^{-1}) (O)	Predicted (kg ha^{-1}) (P)	Difference / Error (kg ha^{-1}) (O-P)	Error (%)
P_3	396.42	384.83	11.59	3.01
P_4	396.42	369.56	26.86	7.26
P_5	396.42	386.16	10.26	2.65

P_3- Floral Bud Initiation to 50 % flowering *P_4 - 50 % Flowering to 50 % pod formation*
P_5 - 50 % Pod formation to maturity

Phenophases showed accurate and useful prediction because of it's error percentage is very less and it is ranged in between 2.65 to 7.65 percent.

Though the present yield prediction model based on weather indices was found helpful to assess the crop yield forecast in advance 45-50 days at P_3, 30-35 days at P_4 and 17-20 days at P_5 phenophase. However, validation of this regression model is required for location specific practical utility to predict accurate yield of pigeonpea under different climatic condition. Such information would be useful as discriminating feature for remote sensing applications. Similar models are reported earlier by workers, Patel *et al*. [18] Jaybhaye *et al.* [29].

4. CONCLUSION

After screening the three varieties of pigeonpea (viz. BDN-711, BSMR-736 and BSMR-853) and sowing dates w.e.f. 25th SMW to 29th SMW, it can be concluded that, 25th SMW is an optimum date for sowing during *kharif* season under normal seasonal weather condition in Central Maharashtra Plateau Agroclimatic Zone of Maharashtra (which is stated as assured rainfall zone). The 27th SMW date of sowing could be the optimum under prevailed delayed onset of monsoon or early season drought condition and in situation of light to medium drought year; out of three varieties, BDN-711 produced significantly higher seed yield under rainfed and early seasonal drought condition.

The crop sown in 25th SMW recorded highest total GDD (ºC days), HTU (ºC days hrs), PTU (ºC days hrs) and PTI (ºC days) and lowest GDD, HTU, PTU and PTI in 29th SMW. While, BSMR-736 recorded highest total GDD, HTU and PTU and lowest GDD, HTU, PTU and highest total PTI were recorded in BDN-711 and lowest total PTI was recorded in BSMR-853.

The yield prediction model based on weather indices at floral bud initiation to 50 % flowering (P_3) phenophase is helpful in assessing the crop yield one and half to one month in advance, at 50 % flowering to 50 % pod formation (P_4) phenophase is helpful in assessing the crop yield 30-35 days in advance and at 50 % pod formation to physiological maturity (P_5) phenophase is helpful in assessing the crop yield 17-20 days in advance. Accuracy of the developed multiple regression model is ranged in between 92-97 percent.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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