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Research Article

Characterization of Thermal Environment for Optimization of Growth and Yield in Chickpea in Kymore Plateau and Satpura Hills Agroclimatic Zone of Madhya Pradesh

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ABSTRACT

Field experiments were conducted during 2009-10 to 2010-2011 at research farm of JNKVV, Jabalpur for characterization of thermal environment for growth and yield optimization in chickpea. Popular chickpea cultivars (JG 315 and JG 11) were grown under irrigated conditions. Meteorological data were recorded. Three widely used thermal indices *viz*, growing degree days (GDD), heliothermal units (HTU) and photothermal units (PTU) were computed. The variability of days-to-anthesis could not be adequately explained by GDD values, while the days-to-physiological maturity and GDD values matched closely. Coefficient of variation of days-to-anthesis showed lower variability than the accumulated GDD. The optimal thermal conditions for higher biomass and yield were screened. It was found that the maximum temperature between 22 and 34 ^oC and minimum temperature between 7 to 15 ^oC are suitable for maximizing the chickpea yield (≥1.2 t ha^{-1}). The crop sown in the month of October accumulated higher GDD for both varieties in the first year (1872 and 1819) and second year (2025 and 1978). On an average, the GDD explained the variation in seed yield to the tune of 40% while PTU explained 14% yield variability. The HUE was higher under normal sowing date as compared to early and late sowing during both the years of experimentation. The chickpea cultivar JG 11 had higher HUE (1.84 and 0.95 kg ha^{-1} $^0C^{-1}$ d^{-1}) during both the years. Yields of chickpea cultivars were highly influenced by differential thermal environment, and cultivars vary greatly in their response to heat utilization which significantly explains the variability in economic yield.

Key words: GDD, PTU, HTU, Temperature, Biomass, Yield, Chickpea

Introduction

Chickpea is a long day plant and among many weather parameters, temperature is considered to be the prime determinant of its growth and development. The phenological development is closely followed the changes in weather conditions during crop growth period. Even under optimum irrigation, variation of temperature influences the growth and developmental processes of chickpea, because most of the biological and physiological processes are affected by temperature.

In India, chickpea is usually sown in the month of October/November, utilizing residual soil moisture from preceding monsoon rain. Limited moisture availability combined with high evaporative demand (onset of summer) of the atmosphere, finally terminates growth and forces the crop to mature. Thus the period of crop growth is limited, and is determined by prevailing temperature conditions.

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To find an impact of the thermal environment on growth and seed yield of chickpea, thermal indices viz., growing degree day (GDD), photothermal unit (PTU) and helio-thermal units (HTU) for two popular chickpea cultivars were calculated under varying sowing dates. The progress to flowering in chickpea is significantly influenced by temperature and can be described by accumulation of thermal time (Roberts *et al.,* 1985). When sufficient heat units are accumulated, the plant enters its reproductive phase and start flowering. Many studies on thermal indices and crop growth and yield of crop plants have been reported in India (e.g. Chakravarty and Sastry, 1983; Bishnoi *et al*., 1995; Agrawal *et al.*, 2003&2010; Srivastava *et al*., 2005&2011; Neog *et al*. 2005; Agrawal and Upadhyay, 2006; Chand *et al*., 2010; Singh *et al*., 2014).

Understanding the weather change over the period and adjusting the management practices for better harvest is a challenge in crop production. Response of crop to prevailing temperature and other weather variables during its growing period need a detailed study, for use in evaluating the impact of climate change. Essentially, thermal characterization for optimization of chickpea growth and yield helps in better crop management. This study was, therefore, conducted to characterize the thermal environment most favorable for growth and yield in chickpea.

Materials and Methods

Field experiments were conducted at Research Farm, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur (23^0 09′N, 79^0 58′ E, 411 m amsl) during two successive *rabi* seasons of 2009-10 and 2010-11. The soil was sandy clay loam having low organic carbon (0.47%), and electrical conductivity of 0.48 dS m^{-1}. The soil was low in N (260 kg ha^{-1}), very low in available P (9.0 kg ha^{-1}) and high in available K (345 kg ha^{-1}) with normal pH (6.72). Treatment consisted of six dates of sowing, starting from second week of October to last week of December at an interval of 15 days. The experiment was laid out in a split plot design with sowing dates in main plots and varieties in sub plots with three replications, as follows:

Main plot**:** Dates of sowing (D)

D_1**:** First fortnight of October (Oct. 11)

D_2**:** Second fortnight of October (Oct. 26)

D_3**:** First fortnight of November (Nov. 11)

D_4**:** Second fortnight of November (Nov. 26)

D_5**:** First fortnight of December (Dec. 11)

D_6**:** Second fortnight of December (Dec. 26)

Sub plots**:** Variety (V)

V_1**:** JG 315

V_2**:** JG 11

Seeds were treated with carboxin+thiram (vitavax power) @ 2 g kg^{-1} seed. The recommended dose of fertilizer 20-60-20 kg ha^{-1} N-P-K was applied uniformly. Fixed amount of irrigation (40 mm) were applied as and when soil moisture stress was recorded.

In order to relate crop growth parameters plant samples, phenology, and yield and yield attributes were recorded at different intervals. Daily weather data were taken from the agro-meteorological observatory situated near the experimental site.

The date of occurrences of different phenological events were recorded when 50% of the plants in each replication reached the respective stages. Daily data on temperature (maximum and minimum), rainfall and bright sunshine hours during the crop season were obtained from the Department of Physics & Agro-meteorology, JNKVV, Jabalpur. Various heat units were calculated as follows:

1. Growing degree days (Nuttonson, 1955), $GDD = (T_{max} + T_{min})/2 - T_t$

   (T_{max} and T_{min} are daily maximum and minimum temperature (^{0}C), T_t is the base temperature, taken as 5^0C.

2. Photo thermal units (Wilsie, 1962), $PTU = GDD \times L$

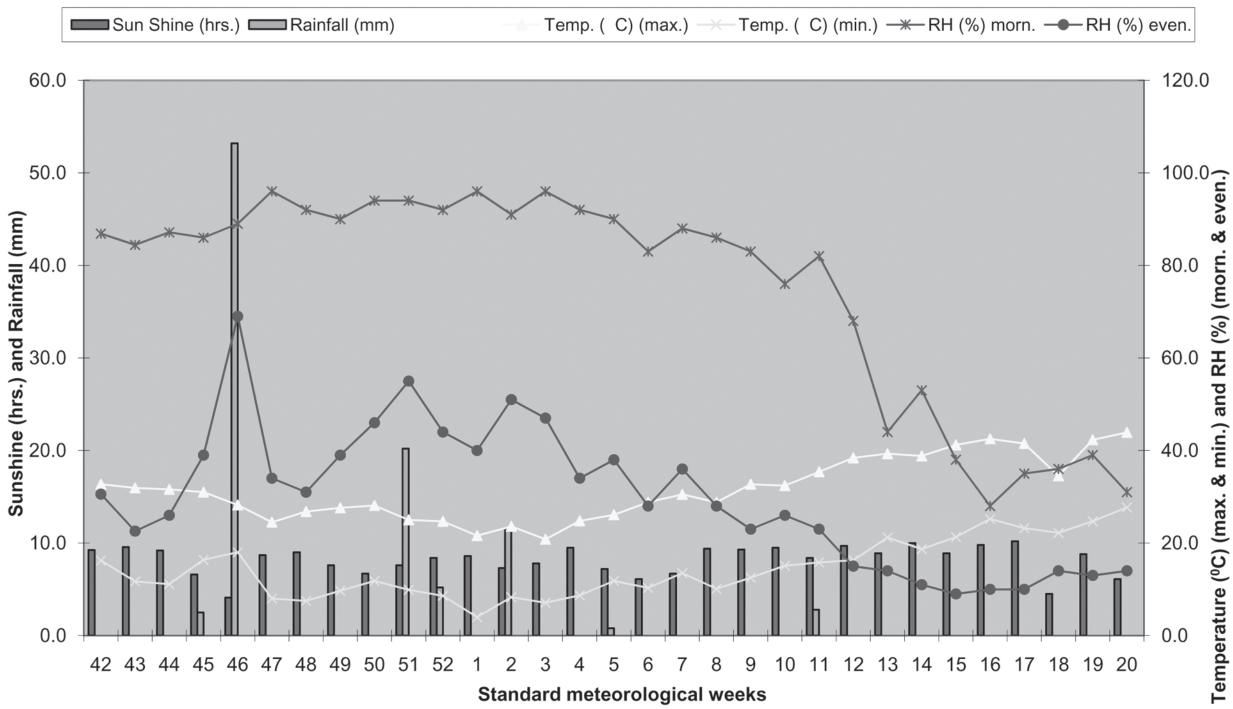

Fig. 1. weekly distribution of weather parameters at Jabalpur during 2009-10

where, GDD = Growing degree days L = Maximum possible sunshine hours

3. Helio-thermal unit (Rajput, 1980),

$$HTU = \sum_{i=1}^{n} GDD \times SSH$$

(SSH = Bright Sunshine Hours)

4. Heat use efficiency (Haider *et al.*, 2003), HUE = (Seed yield/GDD)*100

Results and Discussion

Weather conditions during crop growth period

Daily weekly data of weather parameters during crop period of the experimental years are presented in Fig. 1 & 2. The weekly maximum temperature during 2009-10 varied from 20.8^{0}C (3rd week) to 42.5^{0}C (16th week) while in 2010-11, it varied from 21^{0}C (1st week) to 38.3^{0}C (17th week). The minimum temperature had a range from 4.0^{0}C (1st week) to 25.2^{0}C (16th week) during 2009-10 and from 3.1^{0}C (1st week) to 21.1^{0}C (16th week) in 2010-11. The maximum temperature was higher for the entire season and the minimum temperature was lower during middle of the season in 2010-11 (Fig. 2). The relative humidity (RH) varied from 19% in 16th week to 75% in 51st week in the first season. The second crop season had fairly higher humidity (31% in 12th week to 73% in 48th week). Total rainfall was 96.3 and 95.1 mm distributed over 8 and 6 rainy days during first and second year, respectively. It is likely that the variation in temporal distribution of rainfall and its amount differentiated the crop growth and yields in two years. Total sunshine hours were 232 and 243 h in the first and second year, respectively.

Thermal indices from sowing to anthesis

Thermal indices from sowing to anthesis were calculated and number of days taken to attain the anthesis in varieties is given in Table 1. Varieties planted in the first fortnight of November and second fortnight of December months have taken similar number of days for anthesis, whereas higher number of days (52 and 53 days in the first and 47 and 48 days in second year for JG 315 and JG 11 varieties, respectively) were

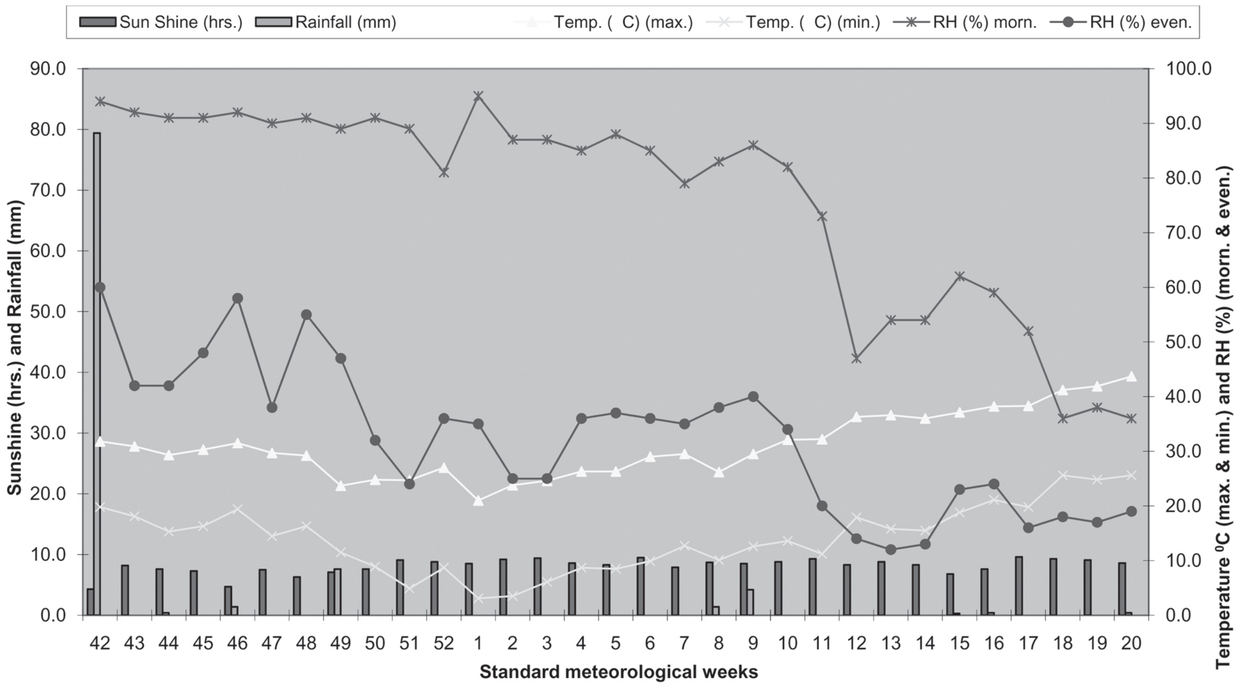

Fig. 2. Weekly distribution of weather parameters of Jabalpur durig 2010-11

Table 1. Thermal indices (from sowing to anthesis) of the chickpea cultivars under different treatments

Treatments	Sowing to anthesis							
	Days		GDD		HTU		PTU	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
D_1V_1	44	31	773	616.4	5934	4337	8629	6940
D_1V_2	48	34	822	677.8	6386	4539	9146	7618
D_2V_1	41	39	631	692	4514	4031	6895	7495
D_2V_2	43	41	662	722	4759	4031	7215	7807
D_3V_1	50	42	697	581	4621	3792	7397	6092
D_3V_2	51	45	708	596	4621	3927	7513	6246
D_4V_1	47	44	572	459	4306	3815	5977	4806
D_4V_2	46	46	556	487	4294	4073	5819	5110
D_5V_1	52	47	603	554	4594	4856	6368	6007
D_5V_2	53	48	618	572	4733	5006	6526	6205
D_6V_1	50	41	599	569	4239	4842	6458	6325
D_6V_2	50	43	599	604	4239	5100	6458	6725
Mean	48	42	653	594	4770	4363	7033	6448
SD	3.8	5.1	82.1	7.5	681.9	484.4	1017.0	932.0
CV (%)	7.9	12.2	12.6	13.0	14.3	11.1	14.5	14.5

required for the varieties sown in first fortnight of December. In the first year, days-to-anthesis was shorter (41 and 43 days) when the crop was sown in the last week of October. Similarly lesser days-to-anthesis period (31 and 34 days) were recorded for crop sown in the 2nd week of October. Siddique *et al*. (1999) reported that temperature was the dominant factor that affected chickpea (kabuli) phenology of different sowing dates and under different irrigation.

The crop sown in the month of October accumulated higher GDD (773 and 822 in the first year and 691 and 722 in second year in JG 315 and JG 11 varieties, respectively). The photothermal and heliothermal units were also higher in the first year.

The heat unit requirement of cultivars JG 11 is higher as compared to JG 315. To reach the anthesis, JG 315 required 672 degree days of GDD (range: 459 to 773), while for JG 11, 556 to 822 degree days were required to reach the anthesis. This clearly shows that heat requirement is higher for cultivar JG 11 than JG 315.

Thermal indices from sowing to physiological maturity

Thermal indices from sowing to physiological maturity and number of days taken by the varieties to attain physiological maturity are presented in Table 2. Early sowing relates to higher accumulation in GDD. Maximum GDD (2025 and 1873) were recorded for JG 315; GDD were 1978 and 1820 for JG 11 under crop sown during October in the year 2009-10 and 2010-11 respectively (Table 2). Heat unit decreased as the sowing was delayed from October to January in both the varieties. The heliothermal and photothermal units were also higher with sowing in second week of October in both the years as compared to the late sown crop. Shifting of sowing dates corresponded to changes in temperature causing the growth periods longer or shorter. In general, a progressive delay in sowing caused a decrease in thermal requirement as well as crop duration. Similar findings were reported by Agrawal and Upadhyay (2009). Pal *et al*. (1996) also reported that GDD, PTU and HTU requirements differ between crops and also among the varieties.

Number of days to attain the phenophases and their duration were remarkably altered by change in the date of sowing. Crop sown in October has taken larger number of days (132 and 138 in first and second year, respectively). Agrawal *et al*. 2002 and 2010 reported that days-to-maturity were the largest in early sown crop and this consistently decreased with subsequent sowing. Number of days taken for maturity was only 90 and 78 when the crop was sown in the last week of December and second week of January in the

Table 2. Thermal indices (from sowing to physiological maturity) of the chickpea cultivars under different treatments

Treatments	Sowing to Physiological Maturity							
	Days		GDD		HTU		PTU	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
D_1V_1	132	138	1872	2025	14041	14416	20408	22109
D_1V_2	128	135	1820	1978	13573	14049	19813	21582
D_2V_1	122	125	1663	1737	12082	12632	18027	18857
D_2V_2	119	123	1613	1700	11641	12316	17456	18435
D_3V_1	111	109	1475	1436	10485	11136	15938	15559
D_3V_2	109	107	1440	1400	10127	10810	15538	15151
D_4V_1	99	99	1317	1294	10128	10991	14283	14284
D_4V_2	101	96	1353	1235	10462	10440	14691	13571
D_5V_1	101	91	1445	1329	11414	11442	15998	15093
D_5V_2	95	89	1403	1282	11002	11035	15491	14520
D_6V_1	92	80	1388	1334	11349	11436	15644	15481
D_6V_2	90	78	1338	1290	10902	11044	15034	14942
Mean	108	106	1510	1503	11434	11812	16527	16632
SD	14	21	188	282	1264	1286	1979	2891
CV (%)	13	19	13	19	11	11	12	17

Table 3. Heat use efficiency (HUE) of chickpea cultivars under different treatments

Treatments	2009-10			2010-11		
	GDD	Seed yield	HUE	GDD	Seed yield	HUE
D_1V_1	1872	2221	1.19	2025	1502	0.74
D_1V_2	1819	2509	1.38	1978	1524	0.77
D_2V_1	1663	2709	1.63	1690	1027	0.61
D_2V_2	1613	2743	1.70	1700	1382	0.81
D_3V_1	1475	2536	1.72	1436	1237	0.88
D_3V_2	1440	2650	1.84	1400	1326	0.95
D_4V_1	1317	1851	1.41	1294	1058	0.82
D_4V_2	1353	2135	1.58	1235	1092	0.86
D_5V_1	1445	1563	1.08	1329	937	0.71
D_5V_2	1403	1913	1.36	1282	795	0.62
D_6V_1	1388	1117	0.80	1334	814	0.59
D_6V_2	1338	1351	1.01	1290	805	0.62
Mean	1510.50	2108.17	1.39	1503.33	1124.92	0.75
SD	187.98	553.66	0.32	282.09	266.09	0.12
CV(%)	12.44	26.26	22.98	18.76	23.65	15.99

first and second year, respectively. Differences in phenology between two seasons were also recorded, which can be attributed to photothermal conditions during crop growth period. In second year, durations of various phases and total crop duration were higher. Among the varieties, JG 315 took 110 and 108 days to attain maturity during the first and second year, respectively. Late planting was associated with warm atmosphere and longer day-length, which shortened the reproductive phase and hastened the crop maturity, resulting to lower seed yield. Similar findings were reported by Ahmed *et al.* (2011).

Heat Use Efficiency (HUE)

Higher heat use efficiency (1.84) was recorded for normal date of sowing (3rd week of November) (Table 3). The efficiency was higher in both varieties under normal date of sowing compared to early and late sowing. The HUE was (1.72 and 1.84 kg ha^{-1} $^{0}C^{-1}$ d^{-1}) for chickpea cultivar JG 315 and JG 11 during first year, and it was 0.88 and 0.95 during second year for both the varieties of chickpea, respectively.

Results reveal that HUE differed significantly between sowing dates and varieties. Our finding is in conformity with Agrawal *et al*. (2002), who reported that HUE was lower with delay in sowing. The highest efficiency (1.30 and 1.40) was recorded with 3rd date of sowing followed by 2nd and 4th sowing dates; the HUE was the least under 4th date of sowing. The crop received suboptimal thermal condition when the sowing was delayed, resulting in less HUE. Similar findings have been reported by Shahu *et al.* (2007). The thermal use efficiency for biological and seed yields was highest for November sowing (Agrawal and Upadhyay, 2009). Chand *et al*. (2010) reported that chickpea sown on 25 October produced significantly higher number of pods $plant^{-1}$, number of seeds $plant^{-1}$ and grain yield as compared to other dates of sowing. It also had higher GDD (1946 day-^{0}C) than 5 November sown crop (1829.9 day-^{0}C) between sowing and maturity. Amongst the dates of sowing, October 25, therefore exhibited maximum Heat Use Efficiency (HUE) of 1.06 grain kg ha^{-1} $^{0}C^{-1}$ d^{-1}.

Effect of thermal environment on biomass and yield

The different crop phases are influenced by different sowing dates and thermal conditions and are given in Table 4. The temperature fluctuation during reproductive phase is main factor

Table 4. Temperature during different growth stages and crop parameters at Jabalpur

Year/ Cultivars	Date of Sow-ing	Minimum Temperature (°C)			Maximum Temperature (°C)			Average Temperature (°C)			Seed yield (kg/ha)	Biomass (kg/ha)	HI (%)
		Veg.	Rep.	Mat.	Veg.	Rep.	Mat.	Veg.	Rep.	Mat.			
2009-10	D1	13.9	8.8	11.8	30.2	25.2	29.8	22.1	17.0	20.8	2221	5184	43
JG 315	D2	12.0	9.3	11.2	28.0	25.5	29.1	20.0	17.4	20.2	2709	6419	42
	D3	9.8	7.1	10.4	26.3	22.4	25.6	18.1	14.8	18.0	2536	6357	40
	D4	8.4	10.4	13.4	25.2	26.5	32.3	16.8	18.5	22.9	1851	4135	45
	D5	8.0	12.3	16	23.6	30.1	36.8	15.8	21.2	26.4	1563	3456	45
2009-10	D6	8.4	13.3	18.1	24.4	31.7	38.7	16.4	22.5	28.4	1117	2684	42
JG 11	D1	13.3	8.7	12.3	29.8	24.9	30.5	21.5	16.8	21.4	2509	5370	47
	D2	11.8	8.9	11.8	27.8	24.9	29.7	19.8	16.9	20.8	2743	6049	45
	D3	9.8	9.2	11.1	26.3	25.2	30.6	18.1	17.2	20.9	2650	6048	44
	D4	8.4	10.5	14.0	25.2	26.7	32.5	16.8	18.6	23.3	2135	4567	47
	D5	8.0	12.1	15.5	23.7	30.1	35.4	15.9	21.1	25.5	1913	4279	45
2010-11	D6	8.4	13.1	17.1	24.4	31.4	38.3	16.4	22.3	27.7	1351	3332	41
JG 315	D1	17.2	9.9	10.7	30.3	26.7	26.8	23.8	18.3	18.8	1502	3456	43
	D2	15.5	8.0	12.6	29.4	25.6	29.9	22.5	16.8	21.3	1027	2962	35
	D3	10.0	8.0	13.3	25.9	26.0	31.1	18.0	17.0	22.2	1237	3265	35
	D4	5.4	10.8	13.6	24.3	28.3	33.5	14.9	19.6	23.6	1058	3024	35
	D5	7.8	12.7	15.9	26.4	30.5	36.5	17.1	21.6	26.2	937	2839	33
2010-11	D6	10.2	14.4	16.1	27.6	33.5	36.4	18.9	24.0	26.3	814	2535	32
JG 11	D1	17.5	9.4	11.5	30.5	26.3	27.7	24.0	17.9	19.6	1524	3456	44
	D2	15.5	7.8	11.6	29.1	25.7	28.6	22.3	16.8	20.1	1382	3333	42
	D3	10.2	7.8	13.0	26.0	25.9	30.7	18.1	16.9	21.9	1326	3141	37
	D4	5.5	10.8	12.3	24.3	28.2	32.5	14.9	19.5	22.4	1092	3086	35
	D5	8.2	12.2	16.8	26.7	30.1	36.4	17.5	21.2	26.6	795	2530	31
	D6	10.3	14.2	16.4	27.7	33.5	36.4	19.0	23.9	26.4	805	2469	32

D_1 **:**Oct.11, D_2 **:** Oct.26, D_3 **:**Nov.11, D_4 **:** Nov.26, D_5 **:** Dec.11, D_6 **:** Dec.26
Veg.= Vegetative stage , Rep.=Reproductive stage , Mat.= Maturity stage

determining the biomass and seed yield of the crop. The variability in chickpea yield across dates of sowing was explained through temperature variation recorded during different growth stages. Significant inverse relationship was noted and seed yield started declining as the temperature rises above 20^{0}C (Agrawal and Upadhyay, 2006).

It was observed from the table that the temperature conditions during reproductive phase for higher seed yield were: 7.1-9.3, 22.4-25.5 and 14.8-17.4°C (minimum, maximum and mean temperature range); Similarly, for lower yields, values were 10.8-14.4, 28.2-33.5 and 19.5-24.0 °C.

On an average 3 to 6°C increase in temperatures during reproductive phase, reduced the seed yield significantly by the tune of 60 to 70 percent. A study was conducted to determine the effect of high temperature stress during reproductive development on pod fertility, seed set and seed yield of chickpea (*Cicer arietinum* L.), which reported that high temperature stress during pod development decreased seed yield by 53 to 59%. Yield reduction was greater due to the stress during pod development compared to the stress during early flowering (Wang *et al*., 2006).

It was observed from Table 4 that the minimum temperature conditions during vegetative phase were the determining factor for biomass fluctuation. The minimum temperature between 9.8 to 13.9°C and 5.4 to 8.4°C during vegetative phase were found for higher and lower biomass of the crops respectively.

Agrawal *et al*. (2010) reported that the chickpea yield attributing characters and seed yield was higher with November sown crop; yield reduction in all chickpea types was noted as crop was planted later than November. Higher seed yield was noted in the mean temperature in the range of 15-16^{0}C from flowering to physiological maturity stage of the crop. Agrawal *et al.* (2003) investigated effect of weather parameters on chickpea yield of three popular varieties during *rabi* season (from October to January). They reported that the crop yield was significantly influenced with total dry matter during flowering, and maximum temperature during vegetative stage and minimum temperature during reproductive phase. Rajput *et al.* (1986) reported that maximum temperature during vegetative phase had positive impact on biomass, but maximum and minimum temperature during reproductive phase had a negative impact. Sub optimal thermal regimes encountered for late planted crop was mainly responsible for biomass and yield reduction. Agrawal *et al.,* 2002 and 2010 also noted similar finding under climate conditions of this region.

Analysis of the data reveals that thermal condition during vegetative stage determines the biomass and the reproductive stage determines the yield.

Assessment of biomass through thermal indices

To evaluate the thermal sensitivity of the crop for its biomass production, best-fit polynomial second order regression equations were developed among the thermal indices with maximum biomass, and from two-year pooled data for each cultivar (Table 5), it was revealed that the variability of biomass to the tune of 31.8 per cent in JG 315 and 48.3 per cent in JG 11 could be explained through GDD; 11.6 and 11.8 per cent through PTU and 4.4 and 5.1 per cent by HTU in both the cultivars respectively. The variability can be explained by the curvilinear relationship of the thermal accumulation with biomass in chickpea cultivars. Since the heat unit accumulation explains the variability of biomass to a large extent, the maximum biomass values may be utilized for quantification of development and growth by GDD for modeling purposes. Srivatava *et al.* (2005) observed that 86% variation in biomass could be explained by GDD in *Brassica*.

Table 5. Thermal assessment of biomass as a function of GDD, PTU and HTU

Season	JG 315	R^2	JG 11	R^2
		GDD		
2009-10	$y = -0.018x^2 + 63.08x - 47425$	0.46*	$y = -0.030x^2 + 98.50x - 73884$	0.75*
2010-11	$y = -0.000x^2 + 3.461x - 114.$	0.18	$y = -0.002x^2 + 9.550x - 4970.$	0.42
Pooled	$y = -0.014x^2 + 47.42x - 34967$	0.32	$y = -0.016x^2 + 55.01x - 39911$	0.48
		PTU		
2009-10	$y = 1E-05x^2 - 0.449x + 6688.$	0.14	$y = -6E-05x^2 + 2.375x - 16818$	0.38
2010-11	$y = 1E-05x^2 - 0.449x + 6688.$	0.14	$y = -8E-06x^2 + 0.359x - 659.2$	0.28
Pooled	$y = -5E-05x^2 + 1.823x - 13371$	0.12	$y = -4E-05x^2 + 1.367x - 8738.$	0.12
		HTU		
2009-10	$y = -0.000x^2 + 6.449x - 37931$	0.13	$y = -0.000x^2 + 3.668x - 18930$	0.16
2010-11	$y = 0.000x^2 - 4.655x + 31835$	0.28	$y = 7E-05x^2 - 1.588x + 11926$	0.19
Pooled	$y = -3E-05x^2 + 0.897x - 3048$	0.04	$y = -3E-05x^2 + 1.039x - 3501.$	0.05

*Significant at 5% level

Table 6. Thermal assessment of seed yield as a function of GDD, PTU and HTU

Season	JG 315	R^2	JG 11	R^2
		GDD		
2009-10	$y = -0.006x^2 + 22.60x - 16829$	0.45	$y = -0.013x^2 + 43.62x - 32907$	0.73*
2010-11	$y = -0.001x^2 + 4.370x - 2824.$	0.71*	$y = -0.001x^2 + 4.370x - 2824.$	0.71
Pooled	$y = -0.005x^2 + 18.67x - 13952$	0.28	$0.008x^2 + 29.00x - 21655$	0.48*
		PTU		
2009-10	$y = 2E-05x^2 - 0.577x + 5755.$	0.66*	$y = -2E-05x^2 + 0.791x - 5299.$	0.34
2010-11	$y = 2E-05x^2 - 0.577x + 5755.$	0.66*	$y = -2E-06x^2 + 0.156x - 809.9$	0.60
Pooled	$y = -1E-05x^2 + 0.430x - 2879.$	0.12	$y = -1E-05x^2 + 0.474x - 3054.$	0.14
		HTU		
2009-10	$y = -1E-04x^2 + 2.597x - 15244$	0.16	$y = -3E-05x^2 + 0.936x - 4373.$	0.18
2010-11	$y = 0.000x^2 - 2.766x + 17732$	0.75	$y = 3E-05x^2 - 0.527x + 3498.$	0.47
Pooled	$y = 9E-06x^2 - 0.084x + 1244$	0.08	$y = -2E-06x^2 + 0.204x - 437.2$	0.09

*Significant at 5% level

Assessment of seed yield through thermal indices

Although seed yield is not entirely a function of temperature, variation in temperature particularly during pod formation, development and filling stage affects the yield to a great extent. Therefore, best-fit second order polynomial regression equations were developed to find out the extent of variability in seed yield under different micro-environment conditions during crop growth (Table 6). Since economic yield varied between years, two years data for each cultivar were pooled to reduce the effect, if any. It appears that variation in seed content may be explained by 27.5% through GDD, 12% through PTU and 8% through HTU in JG 315. The corresponding values for JG 11 were 49.9, 13.7 and 8.7%, respectively. These thermal indices can be incorporated in crop simulation model to quantify the yield variation under different agro-ecological regions. In a previous study, Srivastava *et al*. (2011) observed that GDD was able to account the variations in biomass, seed yield and oil content of *Brassica* to the tune of 75, 66 and 78% and PTU could explain 73, 66 and 77% variations, respectively.

Conclusions

The GDD can successfully calculate days-to-maturity but failed to predict days-to-anthesis. To attain its anthesis and physiological maturity, the crop required an average of 108 and 1511 of GDD values, respectively. The 40% variability in biomass and 39% in seed yield in chickpea could be accounted through GDD; while PTU and HTU indices were not able to explain the same. Late sowing reduced the biomass and seed yield due to prevalence of higher temperature at the reproduction stage of the crop. Range of minimum, maximum and mean temperatures of 7-15, 22-34 and 15-24°C could be most favouable for chickpea crop. The window of sowing of chickpea should be October 15 to November in Jabalpur region of Madhya Pradesh.

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