

**EFFECT OF TEMPERATURE REGIMES ON
PRODUCTIVITY IN CHICKPEA (*Cicer arietinum* L.)**

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CONTENTS

Sl. No.	Chapter Particulars
	CERTIFICATE
	ACKNOWLEDGEMENT
	LIST OF TABLES
	LIST OF FIGURES
	LIST OF PLATES
1.	INTRODUCTION
2.	REVIEW OF LITERATURE
	2.1 Morpho-phenological characters
	2.2 Dry matter accumulation and its distribution
	2.3 Growth Parameters
	2.4 Chlorophyll content and Relative water content in leaf
	2.5 Yield and yield Components
	2.6 Growing Degree days (GDD)
3.	MATERIAL AND METHODS
	3.1 Experimental site
	3.2 Meteorological conditions
	3.3 Soil and its characteristics
	3.4 Experimental details
	3.5 Observations recorded
	3.6 Yield and yield components
	3.7 Statistical analysis
4.	EXPERIMENTAL RESULTS
	4.1 Morpho-phenological parameters
	4.2 Temperature regimes for (T_{max} , T_{min} , T_{range}) for different phenological stages
	4.3 Dry matter accumulation and partitioning
	4.4 Growth parameters
	4.5 Biochemical parameters
	4.6 Yield and yield components
5.	DISCUSSION
	5.1 Morpho-phenological characters
	5.2 Dry matter accumulation and its distribution
	5.3 Growth parameters
	5.4 Biochemical parameters
	5.6 Yield and yield components
6.	SUMMARY AND CONCLUSIONS
	REFERENCES

LIST OF TABLES

Table No.	Title
1.	Physico-chemical properties of the soil of experimental plot
2.	Effect of temperature regimes on plant height (cm) and number of branches at different growth stages in chickpea
3.	Effect of temperature regimes on phenological characters at different growth stages in chickpea
4.	Effect of temperature regimes on accumulated T_{max} , T_{max} T_{range} and GDD for days to flower initiation and days to 50% flowering in chickpea
5.	Effect of temperature regimes on accumulated T_{max} , T_{max} T_{range} and GDD for days to pod initiation and days to physiological maturity in chickpea
6.	Effect of temperature regimes on leaf dry weight and stem dry weight ($g\ plant^{-1}$) at different growth stages in chickpea
7.	Effect of temperature regimes on pod weight and total dry weight at different growth stages in chickpea
8.	Effect of temperature regimes on leaf area ($dm^2\ plant^{-1}$) and leaf area index at different growth stages in chickpea
9.	Effect of temperature regimes on leaf area duration (days) and leaf area ratio ($dm^2\ g^{-1}$) at different growth stages in chickpea
10.	Effect of temperature regimes on specific leaf weight ($g\ dm^{-2}$) and absolute growth rate ($g\ day^{-1}\ *100$) values at different growth stages in chickpea
11.	Effect of temperature regimes on crop growth rate ($g\ dm^{-2}\ day^{-1}\ *1000$), relative growth rate ($g\ day^{-1}\ *1000$) and net assimilation rate rate ($g\ dm^{-2}\ day\ *1000$) at different growth stages in chickpea
12.	Effect of temperature regimes on SPAD values and relative water content (%) at different growth stages in chickpea
13.	Effect of temperature regimes chlorophyll a, b, total chlorophyll ($mg\ g^{-1}\ fr.\ wt.$) and chlorophyll a/b ratio at different growth stages in chickpea
14.	Effect of temperature regimes on yield and yield components in chickpea

LIST OF FIGURES

Figure No.	Title
1.	Weekly temperature data during crop growth period (2001-12)
2.	Monthly meteorological data for the experimental year 2011-12 and the average of 62 years (1950-2012) at Main Agricultural Research Station, University of Agricultural Sciences, Dharwad
3.	Layout of experimental site
4.	Effect of T_{range} for 50% flowering (A) and physiological maturity (B) on yield
5.	Effect of T_{max} (A) and T_{min} (B) Vs days to physiological maturity

LIST OF PLATES

Plate No.	Title
1.	General field view of the chickpea experimental plot

1. INTRODUCTION

Legumes occupy a unique position in Indian agriculture. They help to maintain the soil fertility by way of fixing atmospheric nitrogen. They also form an ideal component of cropping patterns involving cereals by presenting a situation where the proper exploitation of minerals and nutrients from the soil profile is made possible. It is popularly known as the poor man's meat as they are the important source of vegetable protein and help in fighting the malnutrition of predominantly vegetarian based diet, particularly seen in the vast majority of poor masses.

Chickpea (*Cicer arietinum* L.) is one of the important legume crops and being rich in protein content in its seeds and are used as a vegetable and dry bean. In fact, it is a multipurpose crop used in human diets, animal fodder and industries. The world production of chickpea is roughly three times that of lentil and world consumption is second only to dry bean among pulses crops marketed as a human food.

Chickpea remarkably predominates over other pulse crops in terms of both area and production. The year 2011-12 marked significant increase in area under chickpea (8.56 million ha), which is the highest in last 10 years. Similarly, the chickpea production (7.35 million tones) also surpassed last 50 years record with highest productivity (858 kg ha⁻¹), ever recorded in the history of India. The area under chickpea has increased from 6.45 million hectares in 1992-93 to 8.56 million ha in 2009-10. During 2010-2011, in India production of chickpea was 7.53 million ton from an area of 8.56 million hectares and average production of 0.77 t ha⁻¹, while the contribution of Asia was 7.36 million tons (89.4%) in 2011-2012.

Karnataka ranks fifth in the cultivation of chickpea with an area of 0.418 m ha⁻¹ and 0.231 mt of production and 582 kg ha⁻¹ of productivity. In Karnataka, Gulbarga district occupies the first position in chickpea area (0.124 m ha⁻¹), production (0.0631 mt) and productivity (713 kg ha⁻¹) followed by Bijapur, Bidar, Gadag, Dharwad districts.

Chickpea can thrive under good moisture conditions with day time temperature between 21 to 29 °C and night time temperature near 20 °C (Srinivasan *et al.*, 1998 and Siddique *et al.*, 1999). Length of crop maturity depends on available heat and moisture, but is usually in the range of 95-110 days depending on type of chickpea genotypes (Croser *et al.* 2003). Due to long tap root system, chickpea is relatively drought tolerant. They are not well adapted to high moisture areas, saline soil, which are slow to warm in spring and wet or waterlogged soils.

With the advent of *Green Revolution* technologies dominated by the semi-dwarf, nitrogen responsive and photo-insensitive varieties of rice and wheat, there was a dramatic shift in major cropping systems in northern India. Most of the chickpea crop has been replaced by HYV of wheat that can be sown successfully as late as in January. Similarly, availability of photo-insensitive varieties has led to substantial increase in area under rice during *khariif*. Rice fields are generally vacated late up to November end making the available varieties of chickpea unfit for cultivation. High soil moisture even at harvest in North-East plains delays sowing of chickpea after rice. Expansion of irrigation facilities further added to conspicuous reduction in area under chickpea in north Indian states due to diversion of chickpea area to wheat and mustard. As a result, the chickpea area reduced from 3.2 m ha to 1.0 m ha in Northern states, while increased from 2.6 m ha to 4.3 m ha in Central and Southern states during the past three decades. Thus, there has been shift in chickpea area from cooler long duration and highly productive environment to warm, short duration, rainfed and less productive environment. The increase in area of chickpea in Central and Southern states was possible due to development of short duration, high yielding varieties with less photothermal sensitivity.

Temperature rise and variability in rainfall in recent years might be one of the potent factors for stagnation in agricultural production, which revolves around 210-215 million tonnes in India, since last several years. It might be due to the effect of weather abnormalities like droughts, floods, cold and heat waves despite the advanced technology. This is mainly attributed to climate change.

Since, high yield potential cultivars are expected to have low drought resistance/tolerance; such cultivars may not be the best options for areas with weather abnormalities. Moisture stress coupled with rise in temperature is the most important factor limiting potential yields. In order to increase average chickpea yields in India, drought resistance may be an attribute of greater importance than yield potential.

In the view of recent climate change situation, the weather parameters are highly influencing the crop productivity simultaneously due to global warming, where in there is a increase in day temperature and drastic reduction in the night temperature. Such situations are abrupt and short duration with much such cycle during crop growth period. The climatic variability and predicted climatic change are major concern in agriculture because of their potential threat to crop productivity. Among the various factors affecting production, the increase in average surface temperature may have a major impact. In spite of projected enhancement in photosynthesis due to more availability of CO₂ (Aggarwal 2003), increased temperature in future environment may result in reduced crop productivity.

Temperature is an important factor controlling plant growth and development (Zinn *et al.*, 2010). Daily seasonal temperature above optimum become a limiting factor for crop production when they coincide with critical stages of development (Thuzar 2010). IPCC (2007) has projected 1.6 to 3.8°C increase in global average air temperature at the critical stage may cause considerable yield losses. Moreover, the rise in temperature is reported to be a greater during the *rabi* season and thus, crop grown in the *rabi* season are more vulnerable.

Pulse are sensitive to change in temperature and particularly cool - season pulse crop are more sensitive to high temperature. High temperature may affect the productivity of pulse crops as both duration and rate of grain filling are sensitive to change in temperature. With its high nutritional value protein, essential amino acid, valuable source of energy and essential nutrient such as calcium, zinc, iron for the vegetarian populations.

The chickpea crop often experiences abnormally high temperature (>35⁰ C) during reproductive phase that adversely affect its productivity due poor fertilization and development of reproductive organ (Wang *et al* 2006). However, low temperature (0 to 10⁰C) at early flowering stage may also lead to excessive floral abortion causing low pod and seed set in chickpea (Srinivas *et al* 1998). In general high temperature induced potential loss in yield with decreased flower, pod production and seed set in chickpea.

It is established that chickpea is sensitive to the variation in the day and night temperatures, which affect ultimately the productivity. Hence, considering all the above mentioned facts it is necessary to evaluate chickpea under varied temperature regime by varying the dates of sowing, so that the critical stages of the chickpea crop will coincide with change in day and night temperature. The response of crop growth and yield under such varied temperatures indicates its level of tolerance. Therefore, present study was undertaken with following objectives.

1. Effect of temperature regimes on physiological and biochemical parameters in chickpea.
2. Effect of temperature regimes on yield and yield components in chickpea.

2. REVIEW OF LITERATURE

Pulses have been traditionally recognized as indispensable basic ingredient in the diets of vast majority of vegetarian Indians as they provide a perfect mix of high biological value in cereal based diet. Pulse production in India has been practically stagnant for the last few decades. The cropped area as well as production is fluctuating. Considerable basic research is needed to maximize the productivity.

Temperature is the prominent factor among the major ecological variables that determine the natural distribution of plants. Habitats occupied by flowering plants show dramatic differences in the prevailing temperature during the period of active growth, ranging from near freezing environment to over 50^o C. Moreover, in many habitats, the same plant is subjected to a wide seasonal variation in temperature regime and even diurnal fluctuation can exert considerable effect on productivity. The thermal regime is critical by way of affecting plant phenology, developmental plasticity, growth rates, yield components and the final yield. Growth and development process follow distinct temperature curves, displaying a peak or a plateau at what is defined as an optimum temperature. In the present review, an attempt has been made in this chapter to review the available literature on different characters with special reference to temperature regimes on growth parameters and yield, morphological characters, phenological development, physiological and biochemical parameters like chlorophyll, RWC, apart from weather parameters.

2.1 Morpho-phenological characters

2.1.1 Plant height and number of branches

Singh *and Rai* (1980) reported that, there was a positive correlation between plant height and the number of plants per unit area due to more competition for light. Comparing various planting dates showed that planting date of November 6th had the highest plant height because of the increase in duration of the growth period. Longer growing period at autumn sown chickpea had positive effect on plant height and branches per plant Saim and Ufuk (2003).

Rezvani and Sadeghi (2005) reported that the plant height increased as the duration of growth period increased, similarly, Rahemi and Soltani (2005), and Goldani *et al.* (2000) observed that the plant height increased with high densities and early planting dates.

Morphological characters *viz.* plant height, number of branches and number of leaves were recorded highest in chilling tolerant genotypes at early stages of development (30 and 60 DAS), whereas, at later stages (90 and 120 DAS) these characters were recorded highest in chilling sensitive genotypes (Abha and Raina 2011).

2.1.2 Phenological Characters

2.1.2.1 Days to flower initiation

The progress of flowering in chickpea is significantly influenced by temperature and can be described by the accumulation of thermal time $\{(Max T^0 - Min T^0)/2\}$: assuming base temperature 0} also reported by Roberts *et al.* (1985), when sufficient heat units have been accumulated the plant will enter a reproductive phase and start flowering. It is at this point that chickpea tolerance of stress is significantly reduced, temperature below 15^oC cause flower initiation, sub-zero temperature can cause flower, pod and seed abortion and severe frost can cause total defoliation and death (Clark *et al* 2004). Temperature greater than 35^oC can also cause flower loss and water stress. Flowering chickpea are also sensitive to water logging with a similar response to low temperature with flower and pod abortion and leaf senescence (Cowie *et al.*, 1996).

Lejeune-He´naut *et al.* (1999) reported that plants are more susceptible to frost after floral initiation has commenced. Early flowering increases the chance that the flower will be exposed to frost. Saim and Ufuk (2003) reported that the longer growing period of autumn sown chickpea had positive effect on days to flowering.

The optimal time to sow chickpea was depend on the interaction between the environment and the available varietal germplasm. In chickpea mean daily temperature less than 15°C has been shown to cause floral abortion (Clarke and Siddique, 2004), flowering initiation in chickpea has been described as a photothermal response, but in most environments temperature regime is the main determinant. The optimum sowing date that in results flowering to occur when the risk of cold temperatures was low and it is especially important to avoid frost during flowering, which can kill chickpea plants.

Long days, exceeding 32°C hasten flower formation in chickpea. However, anthesis & pod setting is adversely affected when day time maximum temperature reaches more than 35°C. A chickpea genotype ICC 10685 is identified as a highly sensitive to heat stress, that failed to set pod even below 35°C and this sensitive time was compared with heat tollerent line viz, ICC 92944, ICC 1205, ICC 15164. Further, significant variation in growth is recorded among the genotypes (Basu and Chaturvedi 2009).

2.1.2.2 Days to 50% flowering

Srinivasan *et al.* (1998) reported that during reproductive phase, low temperature (<15°C) is detrimental to normal flowering and pod development, which causes prolonged reproductive phase, floral abortion, poor pollen germination, impaired ovule development, failure in pod set and reduction in seed filling that drastically affects the crop productivity (Nayyar and Gupta 2007).

Craufurd *et al.* (1996) evaluated that twenty-nine diverse genotypes of cowpea (*Vigna unguiculata*) that were grown in approximately 30 photothermal environments in Nigeria and Niger, with mean temperatures ranging from 19°C to 30°C, photoperiods from 10 to 16 h d⁻¹ and saturation vapour pressure deficits from 0.5 to 3.1 kPa. Twelve of these genotypes were insensitive to photoperiod. The time of flowering of these photoperiod insensitive genotypes showed a similar response to temperature. Time to flowering was also delayed by mean pre-flowering saturation deficits greater than 1.5 kPa. The implications of these responses to temperature and saturation deficit for phenological adaptation were highlighted for cowpea improvement.

Srinivasan *et al.* (1998), Clarke (2001), reported that the reproductive structures can withstand temperature of 8°C minimum to 22°C maximum during the coldest period. The most advantageous temperature range for normal flowering, fertilization and seed set is 10 to 14°C (average minimum temperature) and 25 to 31°C (average maximum temperature). Temperature within the chilling range can limit the growth and vigor of chickpea at all phenological stages but it is considered most damaging to yield at reproductive stage. The northern parts of the Indian subcontinent and southern Australia are the most affected regions due to chilling as the temperature is below 15°C at flowering (Bakht *et al.*, 2006 and Berger and Turner 2007).

Performance of an early maturing chickpea genotype ICCV 96029 under two contrasting temperature environments - low temperature conditions of the field and warm conditions of the glasshouse - in order to assess the chilling damage, if any. It was hypothesized that cold might limit the yield potential of plants as compared to those growing under warm conditions (Kumar *et al.*, 2010).

Devasirvatham (2011) evaluated under two contrasting environment viz., heat stress and non heat stress in controlled environment. Heat stress (35/20 and 40/25°C) was applied at flowering stage to plants to grow in growth chamber to study the pollen and pistil behavior including flower abortion and pod set, compared to control (28/16°C).

2.1.2.3 Days to pod initiation

Savithri *et al.* (1980) identified a mutant for higher fruit set at lower temperatures on the basis of differences in malic acid concentration between the mutant and more cold-sensitive chickpea plants.

Wang *et al.* (2006) observed that effect of high temperature stress during reproductive development on pod fertility, seed set, and seed yield of chickpea (*Cicer arietinum* L). 'Myles' desi and 'Xena' kabuli chickpea were grown in a controlled environment under 20/16°C day/night air temperatures (control). High (35/16°C) and moderate (28/16°C) temperature stresses were imposed for 10 d during early flowering and pod development.

Compared to the control, the early flowering high temperature stress decreased ($P < 0.01$) pod production by 34% for Myles and 22% for Xena, whereas high temperature stress during pod development decreased ($P < 0.05$) seeds per plant by 33% for Myles and 39% for Xena.

An experiment conducted by Gupta (2011) to determine extent of variation in photothermal requirement of phenological duration in 52 chickpea genotypes of segregating generation at three different soil temperature *i.e.* 24.5°C, 21.5 °C and 18.5 °C. Highly significant mean squares due to genotypes were observed for all the characters except photothermal index (PTI) of flowering duration and biological yield. The highly significant variances clearly indicated that the presence of considerable amount of genetic variability in a studied genotype. The GDD heliothermal unit of podding and seed filling duration although had high heritability but low genetic advance.

2.1.2.4 Days to pod filling

Plants stressed at 35/16°C during flowering produced 34% fewer pods in desi chickpea and 29% fewer in kabuli chickpea than the check that remained at 20/16°C. The decreased number of pods per plant was due to both decreased pods on main stem (53%) and on branches (22%). Nearly 90% of the pods formed during the period of high temperature stress were sterile, whereas, a portion of the pods produced under the low temperature were fertile (Gan *et al.*, 1996).

Srinivasan *et al.* (1998) reported that for the reproductive phase, low temperature is detrimental to normal flowering and pod development, which causes prolonged reproductive phase, floral abortion, poor pollen germination, impaired ovule development, failure in pod set and reduction in seed filling that drastically affects the crop productivity.

The adverse effects of low day-time temperatures (15/5 vs. 20/8°C; 15/0 vs. 20/8°C) on pod and seed set as reported earlier (Srinivasan *et al.*, 1998) may also be due to the negative influence of day temperature on pollen function. Dickson and Boettger (1984) reported that low night temperature was less important in bean (*Phaseolus vulgaris* L.) when the following day was also cool ($< 20^{\circ}\text{C}$), as pollen would grow too slowly to complete fertilization leading to reduced pod and seed set.

An experiment conducted by Nayyar *et al.* (2007) two chickpea type Desi and Kabuli to elucidate the relative response of the governing the differential cold sensitivity stages. At the time of initial seed filling (pod size ~1 cm), a set of plants growing under warm conditions of glasshouse (temperature 17/28 $\pm 2^{\circ}\text{C}$ as average night and day temperature) was subjected to cold condition of the field (2.3 / 11.7 $\pm 2^{\circ}\text{C}$ as average night and day temperature), while another set maintained control *i.e.*, warm condition. The chilling condition results in increase in the loss of chlorophyll, reduced in water status of leaves, which occurred greater, extend in Kabuli type than in Desi, whereas rate of duration of seed filling, seed weight, harvest index decreased greatly in Kabuli type.

2.1.2.5 Physiological Maturity

Summerfield *et al.* (1988) observed that chickpea reproductive phase suffers considerably from high temperatures (35/18 °C, day/night). Under such thermal conditions, grain yield is reduced to 33% compared to 30/10 °C day/night conditions. According to Wery and Lecoœur (1993), critical temperature during the reproductive phase, which includes flowering, filling and enlargement of seeds, is evaluated with 30 °C. Recorded temperatures showed that critical temperature was exceeded only during the pods maturity phase duration.

Ludlow and Muchow (1990), Subbarao *et al.* (1995) observed that enhancing early maturity could lead the chickpea crops to escape from severe soil water depletion that generally occurs during the reproductive stage. 'ICCV 2', an early maturing chickpea variety, successfully evolved for yield stability in shorter duration drought-prone environments.

Rajin *et al.* (2003) observed that the photothermal response of three Kabuli chickpea (*Cicer areintinum*.L.) cultivars, at different growth stages, rate of development from emergence to flowering and sowing to harvest were strongly and positively associated with mean temperature during those periods.

All phenological stages considered (sowing to emergence, flowering to podding to physiological maturity and physiological maturity to harvest maturity) depended upon accumulated thermal time (T_t) above a base temperature (T_b) of 1 °C.

Soltani (2006) noticed that the differences among cultivars for critical temperatures and critical photoperiod were small and a base temperature of 0° C, lower optimum temperature of 21°C, upper optimum temperature of 32°C, ceiling temperature of 40 °C. The cultivars required 24.7°C–32.2°C physiological days (*i.e.*, number of days under optimum temperature from emergence to flowering, from 4.3 from first-pod to beginning seed growth and 30.3°C from beginning seed growth to maturity).

2.2 Dry matter accumulation and its distribution

Muchow *et al.* (1986) observed that the decrease in crop biomass production is frequently observed in response to water deficit. This could either arise from a decrease in the extent of solar radiation intercepted by the canopy or a decrease in the efficiency with which the intercepted radiation is used to accumulate dry matter. In a similar study, Siddique *et al.* (1999) reported that the loss in accumulation efficiency is be associated with a decline in photosynthesis capacity in green gram.

Subedi *et al.* (1995) investigated that effects of temperature on the vegetative growth of six genotypes under mean temperature regimes of 16°C, 19°C, 21°C, 25°C, 27°C and 30°C. Value of the base (T_b) and optimum (T_o) temperatures for different processes were estimated from linear regressions of rate, number or weight variables against mean temperature. The T_b values for plant height, leaf area production and dry matter production were very similar at 15.7°C, 16.0°C and 15.9°C, respectively. The value of T_b for growth is higher than for development. There were no marked differences in T_b or T_o within genotypes for growth processes.

As the leaf, stem pod dry weight decreased during seed filling (Davis *et al.*, 1999) assimilates redistribution to the seed was also affected. Leport *et al.* (1999) showed that there was a genetic variation in the decrease in leaf dry matter that suggested that up to 60% of the dry matter in leaves and stem may contribute to final seed weight. Davis *et al.* (1999) suggested that up to 30% of the dry matter from pod wall may contribute to seed growth.

2.3 Growth Parameters

Deshmukh and Bhapker (1979) concluded that rapid early growth and maintenance of LAI at reasonably high level with higher NAR during pod formation and grain filling stage had great influence on seed yield, but their studies, indicated that the environmental interaction is lacking. Sexena and Sheldrake (1978) showed that variance ratio of RGR indicated no significance effect of date of sowing but indicates significant difference among the cultivars and their interactions with time of planting. On the other hand, sowing date and cultivar and their interactions were significant for NAR.

Prasad *et al.* (1978) recorded low values for NAR, RGR, and CGR in initial stages of growth, which reached maximum by 85-91 days after sowing in chickpea, the time corresponding to reproductive phase. Similar observation were also recorded by Haloi *et al.* (1986), that date of sowing had a marked influence on RGR during flowering to pod development stage.

Field grown chickpea and lentil under adequate soil moisture also showed a peak rate of net assimilation rate (NAR) and crop growth rate (CGR) during flowering and pod development stage when the day temperature remained between 20° C and 25° C (Prasad *et al.*, 1978).

Haloi and Baldev (1986) observed that increase in LAI continued for a considerable period even after flower initiation in different dates of sowing. October sown crop showed higher LAI that was achieved, only after initiation of reproductive phase. This indicates vegetative growth continues during reproductive phase also. Such competition and reproductive phase was also pointed by Katiyar *et al.* (1981).

Haloi and Baldev (1986) observed that LAI was influenced by the date of planting. Significantly higher LAI was recorded at 90 DAS and 105 DAS. Among all the genotypes, significantly higher leaf area index (LAI) was noticed in DG 36 (1.693), DG 46 (1.469), DG 51 (1.464), Pusa 256 (1.192) and BGD 72 (1.127) as compared to Pusa 372 (1.084). The genotypic differences, which expressed more clearly under various planting conditions are in line with the observations reports made by Uprety and Sirohi (1987), Aggarwal and Koundal (1988) and Rahangdale *et al.* (1994).

Haloi and Baldev (1986) reported that the higher NAR at early sowing appears to be due to combined effect of better soil moisture, high mean temperature and more solar radiation due to relative longer days. As the sowing are delayed the temperature during Nov-Dec are low and continue to remain low for Jan- Feb. Similar findings of high NAR in earlier sowing and at early stages of crop growth was recorded by Sexena and Sheldrake (1978) and Katiyar *et al.* (1981), in chickpea.

Temperature can affect plant leaf area *via* its effects on rate of leaf appearance, on the rate and duration of individual leaf expansion, and on leaf senescence (Craufurd *et al.*, 1997). Temperature and photoperiod can also regulate leaf area *via* their effects on the duration of leaf production period (Hammer *et al.*, 1993).

Dapaah *et al.* (2000) observed that there is an average 47% higher leaf area duration (LAD), 72% higher maximum leaf area index (LAI) and greater utilization coefficient. Late October to early November crops yielded more than the mid- to late November-sown crops because of the leaf area of the former increased most rapidly, achieved a higher maximum LAI and LAD and consequently intercepted more photosynthetically active radiation (PAR). They also had faster pod growth rates and 26% of stored assimilates contributed to pod growth compared with 13% in late October to early November and 5% in December-sown crops.

Singh *et al.* (2005) studied that effect of temperature on crop growth rate in six chickpea genotypes, *viz.*, Pusa 256, Pusa 372, BGD 72 (released varieties) and DG 36, DG 46 and DG 51 (advance lines) grown under different planting dates. DG 36 showed higher leaf area index (LAI), crop growth rate (CGR) expressed on per day and per growing degree days (GDD), compared to other genotypes. Pusa 372 showed the lowest values of these traits. The minimum requirement of GDD values was recorded in the genotype DG 36.

Singh *et al.* (2005) reported that advance breeding line DG 36 showed maximum CGR value between 30–60 DAS (1.41) and 90–105 DAS (6.03). While at 60–90 DAS, DG 46 showed maximum CGR value (4.87). Released variety, Pusa 372 recorded minimum CGR between 30–60 DAS (0.87) and between 90–105 DAS (3.49). Between 60–90 DAS, Pusa 256 showed minimum CGR (3.19) value. The positive association between leaf area index and crop growth rate was also reported by Hsiao (1973), Summerfield *et al.* (1979).

Chickpea genotype DG 36 showed higher LAI, CGR per day and per GDD at all the growth stages and planting dates. However, Pusa 372 showed least values of above three traits. It was confirmed that the genotypes, which have higher LAI, CGR per day and per GDD are better for increasing the chickpea productivity under stress environment (Singh *et al.*, 2005). Similar observations were also reported by Uprety and Sirohi (1987).

2.4 Chlorophyll content and Relative water content in leaf

Photosynthesis provides the raw material and energy required for growth and all other biochemical processes. It is light dependant process and illumination of each green leaf and the manner in which the canopy covered determines the net photosynthesis, growth and yield. Chlorophyll has not always been shown to have a strong relationship with photosynthetic rate under normal conditions. But, at lower intensities it becomes the deciding factor in rice (Janardhan, 1977).

2.4.1 Chlorophyll content

Mafakheri *et al.* (2010) observed that the drought stress imposed during vegetative growth or anthesis significantly decreased chlorophyll *a*, chlorophyll *b* and total chlorophyll content in chickpea genotypes.

Photosynthesis, transpiration, stomatal conductance and yield were higher but sub-stomatal CO₂ concentration was lower under drought stress conditions than under control conditions.

Chickpea germplasm were physiologically characterized for thermotolerance and screening techniques developed based on membrane stability, photosynthetic efficiency (quantum yield, ratio of variable to maximal chlorophyll fluorescence Fv/Fm) and pollen germinability (Basu and Chaturvedi 2009). The foliar resistance was much higher (above 40^o C) than reproductive component like pollen germination (usually occurs below 35^o C).

2.4.2 Relative water content

Among several methods used to characterize internal plant water status under drought condition, relative water content (RWC) is an integrative indicator, used successfully to identify drought resistant crops (Rosales *et al.*, 2004). Under natural conditions, drought usually occurs in association with high temperature and this resulting in photo-inhibition of photosynthesis system observed in *Lupines sp* (French and Turner, 1991). Pandey *et al.* (1984) reported that the temperature of leaves increased as leaf RWC decreased in grain legumes. Also, Lawn (1982), observed that reduced water vapour conductance was accompanied by higher leaf temperature.

Drought avoidance and/or tolerance were observed in Chickpea (*Cicer areintinum.L*) in the form of delayed senescence and maturity (Thomson *et al.*, 1997 and Leport *et al.*, 1998). However, these species had lower yields and *WUE* when compared to *Vicia feba* and *Pisum sativum*. Poor early growth and dry matter production and sensitivity to low temperatures at flowering and early podding are the major causes of low yield and *WUE* in these species, especially in chickpea (Siddique and Sedgley, 1986).

A decrease in the relative water content (RWC) in response to drought stress has been noted in wide variety of plants as reported by Nayyar and Gupta (2006), that when leaves are subjected to drought, leaves exhibit large reductions in RWC and water potential. Exposure of plants to drought stress substantially decreased the leaf water potential, relative water content and transpiration rate, with a concomitant increase in leaf temperature in lentil (Siddique *et al.*, 2001).

2.5 Yield and yield Components

2.5.1 Seed Yield

Summerfield *et al.* (1984) observed that chickpea reproductive phase suffers considerably from high temperatures (35/18 °C, day/night). Under such thermal conditions, grain yield is reduced to 33% per cent compared to that under normal conditions such as 30/10 °C day/night. According to Wery *et al.* (1993), critical temperature during the reproductive phase, which includes flowering, filling and enlargement seeds of chickpea is evaluated with 30°C. Recorded temperatures showed that critical temperature was exceeded only during the pods maturity phase duration.

Chickpea can experience yield losses upto 50 per cent due to cold stress (Sexena and Johansen, 1990) depending upon the sensitivity of the stress and sensitivity of genotype. Hence, incorporation of cold tolerance in chickpea cultivars is an important requisite for winter sowing of chickpea (Bakht *et al.*, 2006).

Ganguly (1992) has pointed out that seeding dates have a major role on chickpea yield, as they determine the environmental conditions for crop growth. Saxena *et al.*, (1993) reported that seeding date has a profound effect on growth and yield of chickpea and late seeding causes yield reduction through reduction in pre and post flowering periods (Eshel, 1968).

Ramteke (1995) studied the physiological basis of yield variation in 15 chickpea genotypes during *rabi* season under rainfed condition. The genotypes Annigeri- 1, ICCV 2 and K850 showed better performance. Ganguly and Bhattacharya (2001) reported 53.70 per cent reduction in seed yield under late sown condition compared to normal seeding. Deshmukh *et al.* (2004a) reported that cultivar Phule, G 96006 maintained highest yield under drought condition as well as under irrigated condition.

However, the yield data of individual genotypes showed a great variation in both irrigated as well as rainfed conditions. The yield in *desi* chickpea under irrigated condition ranged from 963 to 1583 kg ha⁻¹. In *Kabuli*, the yield ranged from 921 to 1820 kg ha⁻¹ under irrigated and 569 to 1070 kg ha⁻¹ under rainfed condition. Summerfield *et al.* (1984) observed lower grain yields with greater exposure to hot days (30-35°C), during the reproductive period. Prince *et al.* (2010) reported that cold temperature induces flower abortion, pollen and ovule infertility, causes breakdown of fertilization and affected seed filling, leading to low seed set and ultimately low grain yield.

Yield attributes like pod and seed weight and plant biomass of these plants were less than the plants were exposed to high temperature for short duration only at flowering and podding stages. These findings suggest that 3.1°C increase in growth temperature may enhance vegetative growth and photosynthesis in chickpea but may not influence the plant yield (Sangeeta *et al.*, 2009).

Patra *et al.* (2011) reported that, performance of five high yielding bold seeded chickpea under different temperature conditions revealed that 25° - 30°C temperature was optimum for various seed/seedling vigour tests for chickpea as compared to other temperatures. Mainly day lengths and temperatures influenced chickpea phenology, growth and yield, but increased day length coupled with higher temperature at flowering and pod development stages of late sown crops enhanced maturity and gave the lowest grain yield in both the years (1077 and 1154 kg ha⁻¹) as reported by Ahmed *et al.* (2011).

Effect of mild temperature stress (MTS) on reproduction dynamics and yield components of two prominent chickpea genotypes *viz.* Pusa 1103 (*desi*) and Pusa 1105 (*Kabuli*). Exposure to MTS was given by raising the plants in a polytunnel where the average air temperature was moderately higher (~5°C) than ambient. The rate of both flower and pod production was higher under ambient temperature. Days to initiation of flowering and podding was advanced by 12 and 10 days, respectively and this duration of flower and pod production increased significantly under MTS. Overall, MTS showed significant impact on reproductive dynamics followed by reduced yield. (Bahuguna *et al.*, 2012).

2.5.2 Hundred Seed Weight

Saim and Ufuk (2003) noticed that the longer growing period of autumn-sown chickpeas affected positively the characters contributing to yield, 100-seed weight, which in turn contributed to increased seed yield. However, 100 seed weight and days to flowering were important for autumn sowing and days to flowering.

Shamsi (2010) reported that planting date, density and their mutual effect had no significant impact on the weight of 100 grains. Rastegar (1998) reported that plant density could not produce any significant difference to the weight of chickpea 100 seeds.

2.5.3 Harvest Index

Leport *et al.* (1999) studied that the total dry matter accumulation, water use, both in the pre- and post-podding phases. Apparent redistribution of stem and leaf dry matter during pod filling varied from 0 to 60% among genotypes, and suggests that this characteristic may be important for a high harvest index and seed yield in chickpea.

Devasirvatham *et al.* (2011) reported that sowing time may vary in different locations depending on the temperatures experienced at different stages of crop development. Temperature is therefore the most important for growth that governs yield and high temperatures during the reproductive stage in chickpea is a major cause of yield loss. Heat stress (35/20 and 40/25°C) was applied at the flowering stage to plants grown in the growth chamber to study pollen and pistil behaviour including flower abortion and pod set, compared with the control (28/16°C). The high temperatures reduced pod set by reducing pollen viability. The pollen of tolerant line (ICCV92944) was fully viable at 35/20°C and partially viable at 40/25°C, while the pollen of sensitive line (ICC5912) was fully sterile at 35/20°C. These results suggest that selection for pollen viability could improve the heat tolerance of chickpea. Mafakheri1 *et al.* (2010) showed that mesophyll resistance is the basic determinate of rate of photosynthesis under drought stress conditions in chickpea.

Under drought conditions the drought tolerant variety 'Bivaniej' gave the highest yield, whereas, the drought sensitive variety 'Pirouz' gave the lowest yield. Drought stress at anthesis phase reduced seed yield more severe than that on vegetative stage.

2.6 Growing Degree days (GDD)

Bisnoi and Taneja (1990) showed that with the increase of average temperature in the crop season, phenological stages are advanced rapidly due to availability of higher thermal units over a short period of time in cowpea. This may result in forced maturity. One, thus, needs a variety, which takes less GDD for physiological maturity. Ghadekar *et al.* (1992) reported that early sowing resulted in highest accumulation of heat sum and photothermal units causing better growth and yield.

Singh *et al.* (2005) observed that growth rate per GDD was significantly higher in 15 November planting (0.201 g) followed by 30 November planting (0.142 g) and 15 December planting (0.086 g) during 30–60 DAS. Between 60–90 DAS significant differences were recorded between all the three dates of planting, while at during 90–105 DAS significant differences were recorded in 15 November planting (0.372 g) followed by 30 November planting (0.344 g) and 15 December planting (0.261 g). The higher growth rate per GDD was recorded in early maturing and high yielding genotypes.

3. MATERIAL AND METHODS

A field experiment was conducted during *rabi* 2011-12 to assess the effect of temperature regimes (temperature regimes) on productivity in chickpea and its impact on yield and yield components. The details of materials used and techniques adopted during the course of investigations are described in this chapter.

3.1 Experimental site

The field experiment was conducted in plot No. 126 of E-block, Main Agricultural Research Station (MARS), University of Agricultural Sciences, Dharwad. The MARS is situated at 15°12' N latitude and 76°34' E longitude with an altitude of 678 meters above the mean sea level (MSL).

3.2 Meteorological conditions

The daily meteorological data recorded during the period of experimentation (2011-12) and average of last 61 years of meteorological data is collected from MARS unit, University of Agricultural Sciences, Dharwad presented in graph 1. The total rainfall received during the period of experimentation was 307.1 mm. The mean maximum temperature during the crop growth period was 31.16°C while the mean minimum temperature was 16.18°C. The relative humidity ranged from 43 to 73% during 2011-12.

The weekly mean temperature data recorded during the period of experimentation (2011-12) T_{max} remained almost constant for first to eight date of sowing, a maximum temperature was around 30°C, the mean minimum was around 18.2 to 14.76 °C and the temperature range was 12 to 20°C (Fig.2).

3.3 Soil and its characteristics

The experimental site consisted of medium deep black soil. A composite soil samples was collected from experimental field and subjected for analysis of its physical and chemical properties as per the standard procedures (Table 1).

3.4 Experimental details

One genotype namely Annigeri-1 in combination with eight different weekly dates of sowing, (temperature regimes) were chosen for the present experiment.

3.4.1 Temperature regimes (Dates of sowing)

T ₁	: 39 th Standard week (1.10.11 to 7.10.11)
T ₂	: 40 th Standard week (07.10.11 to 14.10.11)
T ₃	: 41 st Standard week (14.10.11 to 21.10.11)
T ₄	: 42 nd Standard week (21.10.11 to 28.10.11)
T ₅	: 43 rd Standard week (28.10.11 to 04.11.11)
T ₆	: 44 th Standard week (04.11.11 to 11.11.11)
T ₇	: 45 th Standard week (11.11.11 to 18.11.11)
T ₈	: 46 th Standard week (18.11.11 to 25.11.11)

3.4.2 Genotype and its salient features

The genotype Annigeri-1 was obtained from Main Agricultural Research Station (MARS), University of Agricultural Sciences, Dharwad. It is a high yielding variety, matures in 90-95 days and gives an average yield of 8-10 q ha⁻¹ in rainfed and 20- 25 q ha⁻¹ in irrigated condition. It is a drought resistant variety and recommended for both intercropping and sole cropping in zone 1, 2, 3 and 8 in Karnataka.

3.4.3 Experimental details

The experimental soil was brought to a fine tilth by once ploughing and two times harrowing after harvest of previous general crop of onion (*kharif*). Experimental plots were levelled with wooden planks to bring the field to a fine tilth.

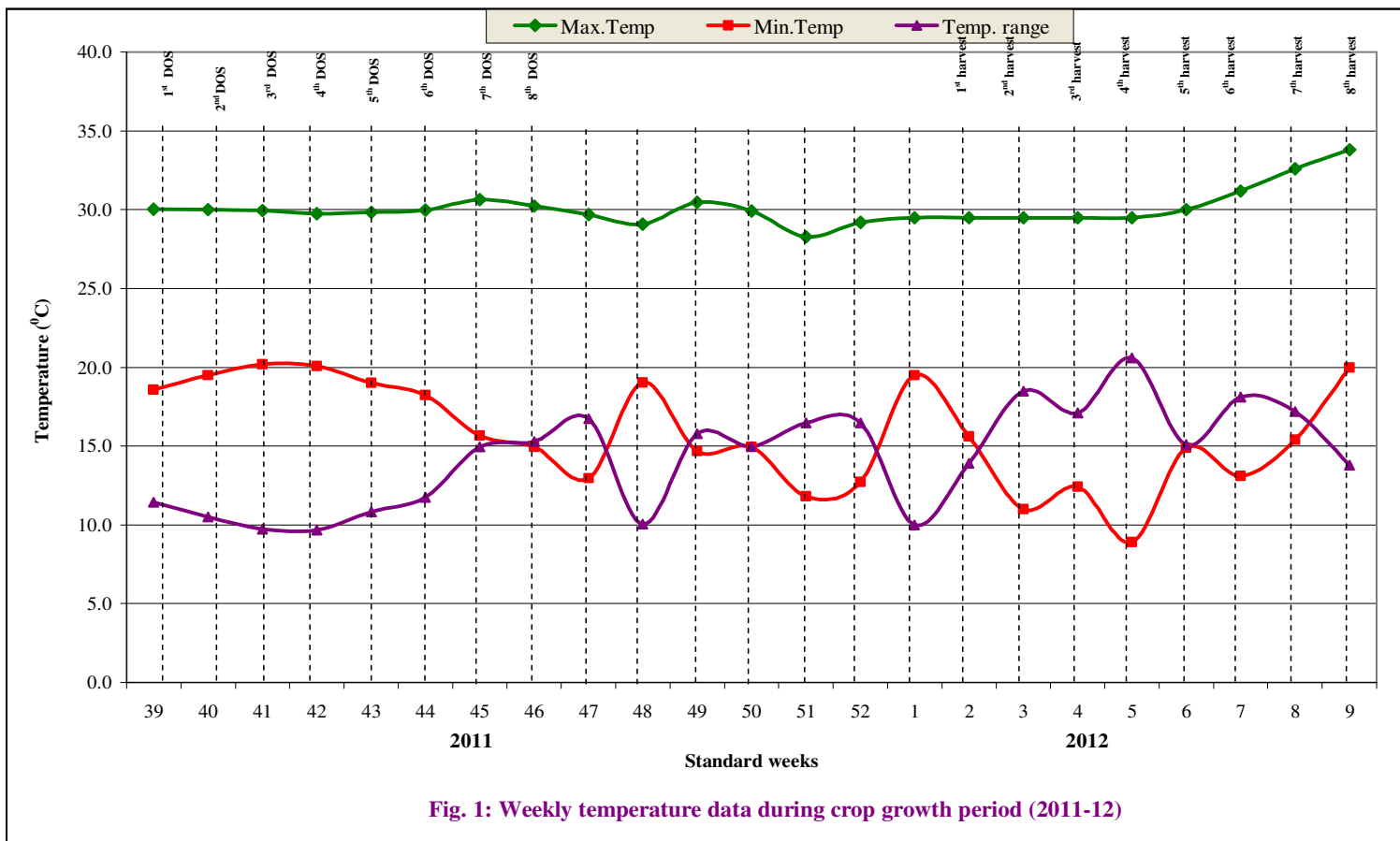


Fig. 1: Weekly temperature data during crop growth period (2011-12)

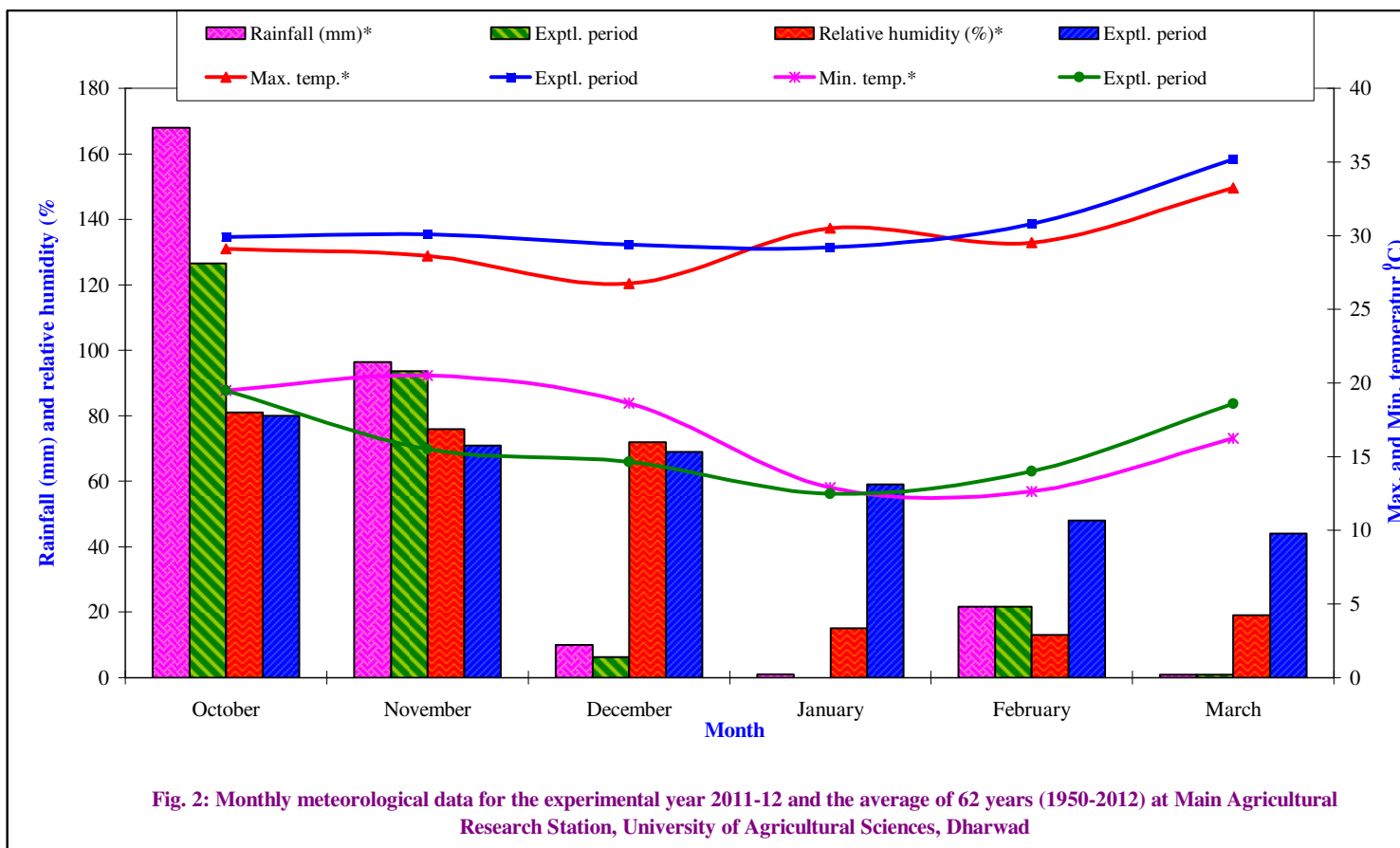


Fig. 2: Monthly meteorological data for the experimental year 2011-12 and the average of 62 years (1950-2012) at Main Agricultural Research Station, University of Agricultural Sciences, Dharwad

Table 1. Physico-chemical properties of the soil of experimental plot

Soil parameters	Value	Method employed	Reference
Physical properties			
Coarse sand (%)	7.20	International pipette method	Piper (1967)
Fine sand (%)	12.25		
Silt (%)	28.70		
Clay (%)	51.85		
Textural class	Clay		
Bulk density (Mg m^{-3})	1.31	Core sampler method	Dastane (1967)
Chemical properties			
Soil pH (1:2.5 soil water suspension)	7.54	Potentiometric method	Sparks (1996)
Electrical conductivity (dS m^{-1}) (1:2.5 soil water extract)	0.39	Conductometric method	Sparks (1996)
Organic carbon (g kg^{-1})	5.80	Walkley and Black's wet oxidation method	Sparks (1996)
Available N (kg ha^{-1})	264.52	Modified Kjeldahl's method	Subbiah and Asija(1956)
Available P (kg ha^{-1})	22.00	Olsen's method	Sparks (1996)
Available K (kg ha^{-1})	401.00	Flame photometer method	Sparks (1996)

A recommended dose of fertilizers of $N:P_2O_5:K_2O$ ($kg\ ha^{-1}$) = 25-50-0 was applied in furrows opened for dibbling seeds in the form of DAP, urea and muriate of potash (MOP) at the time of sowing.

Sowing was carried out as per the treatment detailed earlier by hand dibbling seeds in furrows at a distance of 30 cm between the rows and 10 cm between the plants. One to two seeds were dibbled per hill. The light irrigation was provided after each date of sowing for establishment and rest of the crop was maintained on residual moisture. Thinning of seedlings was done to retain one seedling per hill at 15 days after sowing. One hand weeding at 30 days after sowing (DAS) and one intercultivation at 45 DAS was done to remove the weeds. Complete care was taken to control pests and diseases during the crop growth period. The crop was harvested as and when the genotypes attained harvestable maturity.

3.4.3 Design and plan of layout

The experiment was laid out in a randomised block design (RBD) with three replications. One genotype (Annigeri-1) in combination with eight different dates of sowing, (temperature regimes) were considered for the present experiment. The plan of layout is depicted in Fig.1 and the general view of the experiment is depicted in Plate.1

3.4.4 Plot size

Gross plot size = $3.6\ m \times 2.4\ m = 7.68\ sq.meters$

Net plot size = $3.3\ m \times 1.8\ m = 5.94\ sq.meters$

3.5 Observations recorded

The observations recorded at every 30 days interval to assess the influence of temperature regimes (dates of sowing) associated with growth development and yield. The details of observation taken and standard procedures were adopted, which are described in detail which is as follows.

3.5.1 Morpho-phenological characters

The observations on plant height and the number of days taken for different phenological stages were recorded in randomly selected five tagged plants in the plot.

3.5.1.2 Plant height (cm)

The perpendicular distance from the ground level to the tip of the longest branch was measured in centimetre at 30 days interval.

3.5.1.3 Number of branches

The number of branches per plant were counted at 30 days intervals and mean values of five plants were expressed as number of branches per plant.

3.5.1.4 Days to Flower Initiation

The number of days from sowing to the opening of first flower in a randomly selected five tagged plants and was expressed in days.

3.5.1.3 Days to 50% flowering (days)

The number of days from sowing to 50 per cent flowering were noted when 50 per cent of plants in each plot flowered and was expressed in days.

3.5.1.5 Days to pod initiation

The number of days taken from sowing to first pod visible in a randomly selected five tagged plants and was expressed in days.

3.5.1.5 Days to pod filling.

The number of days taken from sowing to early seed in any single plant fills the pod cavity completely in a randomly selected five tagged plants and was expressed in days.



Plate1. General view of the chickpea experimental plot

3.5.1.4 Days to physiological maturity

The number of days taken from sowing to complete maturity of pod /seed in selected plants was recorded based on yellowing of 50% of plants and pods, and was expressed in days.

3.5.2 Dry matter production and its distribution

Dry matter production and its distribution was accounted from three plants, which were uprooted in random in each treatment at 30 days interval and were separated into leaf, stem and reproductive parts. These samples were air dried and then dried in hot air oven at 80°C to a constant weight was attained and their dry weight was recorded. It was expressed as g per plant.

3.5.3 Growth parameters

The observations on leaf area and its associated characters and growth parameters were recorded at different stages.

3.5.3.1 Leaf area (dm² plant⁻¹)

Leaf lets were separated from rachis of the five plants. Leaflets from each treatment were selected randomly and were traced on graph paper. The dry weight of it was noted and used for computing leaf area per plant on dry weight basis.

3.5.3.2 Leaf area index (LAI)

The LAI was calculated by dividing the leaf area per plant by the land area occupied by the plant (Sestak *et al.*, 1971).

$$\text{LAI} = \frac{\text{Leaf area per plant (dm}^2\text{)}}{\text{Land area occupied by the plant (dm}^2\text{)}}$$

3.5.3.3 Specific leaf weight (g dm⁻²)

The specific leaf weight (SLW) indicates the leaf thickness and was determined by method as suggested by Radford (1967) and is expressed as g dm⁻².

$$\text{SLW} = \frac{\text{Leaf dry weight (g)}}{\text{Leaf area (dm}^2\text{)}}$$

LEGEND

T₁ : 39nd Standard week (1.10.11 to 7.10.11)

T₂ : 40nd Standard week (07.10.11 to 14.10.11)

T₃ : 41nd Standard week (14.10.11 to 21.10.11)

T₄ : 42nd Standard week (21.10.11 to 28.10.11)

T₅ : 43nd Standard week (28.10.11 to 04.11.11)

T₆ : 44nd Standard week (04.11.11 to 11.11.11)

T₇ : 45nd Standard week (11.11.11 to 18.11.11)

T₈ : 46nd Standard week (18.11.11 to 25.11.11)

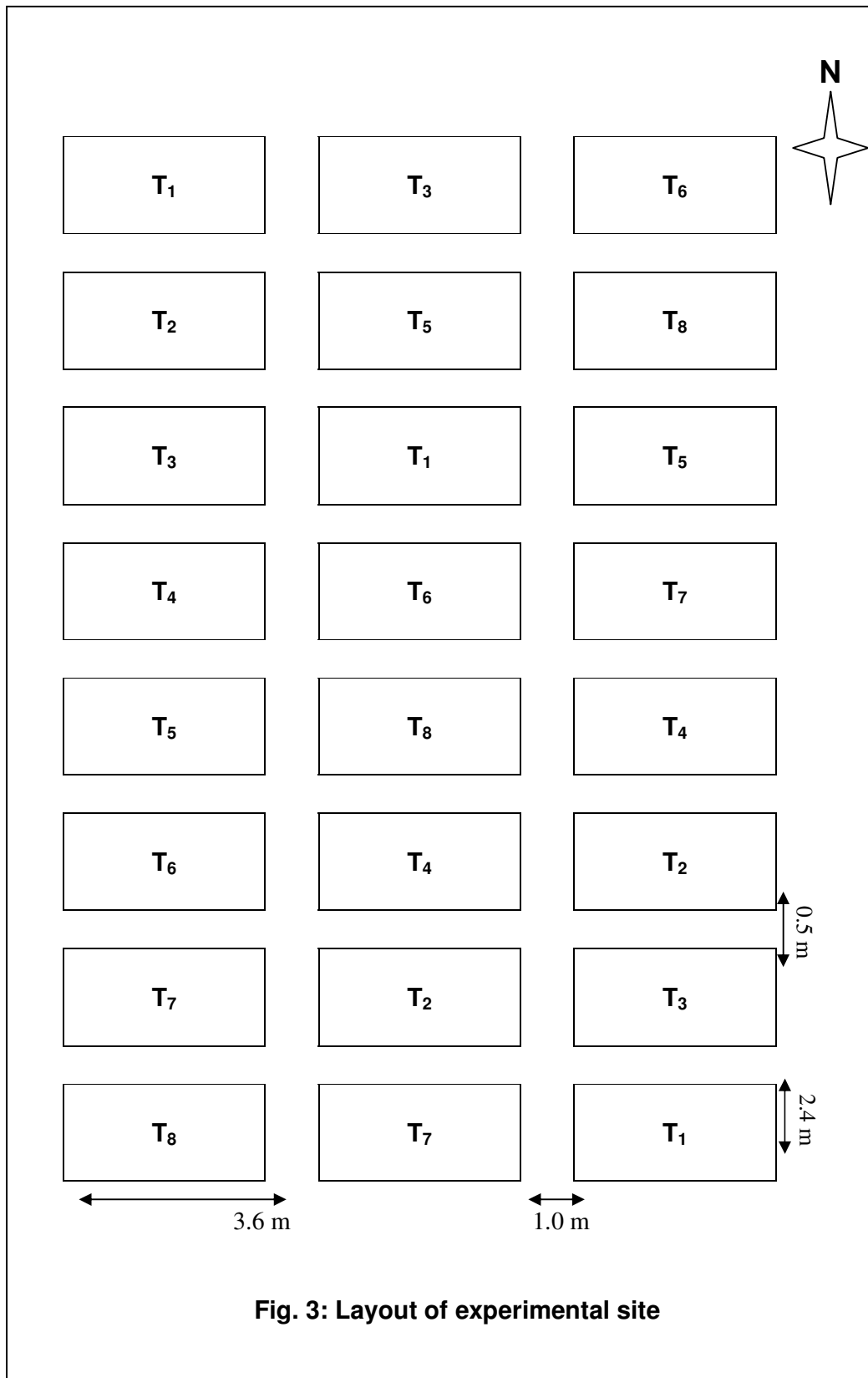


Fig. 3: Layout of experimental site

3.5.3.4 Absolute growth rate (g day^{-1})

Absolute growth rate (AGR) expresses the dry weight increases per unit time and was calculated by using the following formula (Radford, 1967) and expressed as g per plant per day.

$$\text{AGR} = \frac{(W_2 - W_1)}{(t_2 - t_1)}$$

Where,

W_1 and W_2 = Total dry weight per plant (g) at time t_2 and t_1 , respectively

$t_2 - t_1$ = duration from t_1 to t_2 in days

3.5.3.5 Crop growth rate ($\text{g dm}^{-2} \text{day}^{-1}$)

Crop growth rate (CGR) was worked out by adopting the formula of Watson (1947) and expressed as $\text{g dm}^{-2} \text{day}^{-1}$.

$$\text{CGR} = \frac{W_2 - W_1}{t_2 - t_1} \times A$$

Where,

W_1 and W_2 = Total dry weight per plant (g) at time t_1 and t_2 , respectively

A = Ground area covered by the plant (dm^2)

$t_2 - t_1$ = duration from t_1 to t_2 in days

3.5.3.6 Relative growth rate ($\text{g g}^{-1} \text{day}^{-1}$)

It is the rate of increase in the dry weight per unit dry weight already present and is expressed as $\text{g g}^{-1} \text{day}^{-1}$ (Blackman, 1919). Relative growth rate at various stages was calculated as follows

$$\text{RGR} = \frac{(\log_e W_2 - \log_e W_1)}{(t_2 - t_1)}$$

Where,

W_1 = Total Dry weight of plant (g) at time t_1

W_2 = Total Dry weight of plant (g) at time t_2

$t_2 - t_1$ = Time interval in days

3.5.3.7 Net assimilation rate ($\text{g dm}^{-2} \text{day}^{-1}$)

Net assimilation rate is the rate of dry weight increase per unit leaf area per unit time (Watson, 1952). It was calculated by following the formula of Gregory (1926) and expressed as $\text{g dm}^{-2} \text{day}^{-1}$.

$$\text{NAR} = \frac{(W_2 - W_1)}{(t_2 - t_1)} \times \frac{(\log_e A_2 - \log_e A_1)}{(A_2 - A_1)}$$

Where,

A_1, W_1 = Leaf area (dm^2) and dry weight of the plant (g), respectively at time t_1

A_2, W_2 = Leaf area (dm^2) and dry weight of the plant (g), respectively at time t_2

$t_2 - t_1$ = Time interval in days

3.5.2.8 SPAD Values

The chlorophyll meter or SPAD meter is a simple, portable diagnostic tool that measures the greenness or relative chlorophyll content of leaves (Inada, 1963 and 1985; Kariya *et al.*, 1982). Meter readings are given in Minolta Company defined SPAD (Soil Plant Analysis Development) values that indicate relative chlorophyll contents.

3.5.3.9 Relative water content

Relative water content was estimated at 30 days interval after sowing in all sowing dates. Leaflets of fourth leaf from top were taken for recording observations. Leaflets (20 no.) were collected and weighed immediately up to three decimals. This was taken as fresh weight (FW). Then leaflets were floated in petridishes containing distilled water and allowed to take up water for four hours. After four hours, leaflets were blotted gently and weighed. This was referred to as the turgid weight (TW). After recording turgid weight, the leaflets were dried in an oven at 80°C for 48 hours and the dry weight (DW) was recorded. RWC (%) was calculated by the formula given by Kramer (1983).

$$\text{RWC (\%)} = \frac{\text{Fresh weight} - \text{Dry weight (g)}}{\text{Turgid weight} - \text{Dry weight (g)}} \times 100$$

3.5.3.10 Leaf area duration (days)

Leaf area duration is the integral of leaf area index over a growth period (Watson 1952). LAD for various growth periods was worked out as per the formula of Power *et al.* (1967) and expressed in days.

$$\text{LAD} = \frac{(L_i - L_{(i+1)})}{2} \times (t_2 - t_1)$$

Where,

L_i = LAI at i^{th} stage

$L_{(i+1)}$ = LAI at $(i+1)^{\text{th}}$ stage

$t_2 - t_1$ = Time interval between i and $(i + 1)$ stage (days).

3.5.3.11 Leaf area ratio ($\text{dm}^{-2} \text{g}^{-1}$)

Leaf area ratio (LAR) was worked out by adopting the formula of Duncan *et al.*, (1981) and expressed in $\text{dm}^2 \text{g}^{-1}$.

$$\text{LAR} = \frac{\text{Green leaf area (dm}^{-2}\text{)}}{\text{Total dry matter (g)}}$$

3.5.4 Biochemical parameters

3.5.4.1 Chlorophyll content in leaf

The effects of temperature on the plant are largely mediated by their effects on chemical reactions. In only few instances, the biochemistry of the plant has been studied in relation to temperature, although in many cases, biochemical differences have been attributed to temperature and other climatic factors. Both chlorophyll and relative water content in leaf are main parameters to be influenced by temperature.

3.5.4.2 Chlorophyll content in leaf

The chlorophyll content was measured by following the method of Shoaf and Livm (1976). Fresh leaf tissue (100 mg) was cut into small pieces and incubated in 10 ml of dimethyl sulfoxide (DMSO) in dark for 24 hours. After the incubation period, the sample was kept in a boiling water bath for five minutes.

Later, the optical density was measured at 663 and 645 nm in UV-VIS Spectrophotometer. The care was taken to make the volume to 10 ml with DMSO, wherever the volume was reduced during boiling. Chlorophyll-a, chlorophyll-b and total chlorophyll contents were calculated using the formulae given below.

$$\text{Chlorophyll-a} = 12.7 (A_{663}) - 2.69 (A_{645}) \times \frac{V}{1000 \times w \times a}$$

$$\text{Chlorophyll-b} = 22.9 (A_{645}) - 4.68 (A_{663}) \times \frac{V}{1000 \times w \times a}$$

$$\text{Total Chlorophyll} = 20.2 (A_{645}) - 8.02 (A_{663}) \times \frac{V}{1000 \times w \times a}$$

Where: A_{645} = Absorbance of the extract at 645 nm
 A_{663} = Absorbance of the extract at 663 nm
 A = Path length of Cuvette (cm)
 w = Fresh weight of the sample (g)
 v = Volume of extract (ml)

3.6 Yield and yield components

Five plants tagged earlier for recording various morphological observations were harvested at physiological maturity to record the data on the following yield and yield components.

3.6.1 Seed yield per plant (g plant^{-1})

The pods obtained from five plants were threshed and cleaned to obtain grain yield per plant in grams.

3.6.2 Hundred seed weight (g)

The weight of hundred seeds (g) was recorded from the seed samples obtained from each treatment and expressed in g.

3.6.3 Haulm yield (g)

After shelling the seeds from the pods of plants, the left out crop residue was taken as haulm yield per net plot. The haulm yield per hectare was computed from plot yield and expressed as haulm yield in kg per ha.

3.6.4 Harvest index (%)

Harvest index (HI) is defined as ratio of economic yield to total biological yield (Donald, 1962) and expressed in percentage. The harvest index of chickpea was worked out using following formula.

$$\text{Harvest index (\%)} = \frac{\text{Economic yield (g plant}^{-1}\text{)}}{\text{Total biological yield (g plant}^{-1}\text{)}} \times 100$$

3.6.5. Growing Degree Days (GDD)

GDD are calculated by taking the average of the daily maximum and minimum temperatures compared to a base temperature, T_{base} , (usually 5°C). As an equation:

$$GDD = \left(\sum \frac{T_{max} - T_{min}}{2} \right) - T_b$$

T_b = Base temperature below which crop growth ceases

T_b (base temperature) for chickpea: 5 °C

3.7 Statistical analysis

The data collected from the experiment was subjected to statistical analysis as described by Gomez and Gomez (1984). The levels of significance used in 'F' and 't' tests was P=0.05. The least significant differences (LSD) values were calculated wherever the 'F' test was significant by Duncan's Multiple Range Test (DMRT).

4. EXPERIMENTAL RESULTS

An experiment was carried out during *rabi* 2011–2012 to assess the effect of temperature regimes on productivity in chickpea and its influence on yield and their components. The results obtained from this experiment are presented under different heads.

4.1 Morpho-phenological parameters

4.1.1 Plant height (cm)

The data on plant height at 30 DAS indicated significant differences due to temperature regimes (Table 2). The plant height decreased from first date of sowing to second date of sowing and then after the plant height increased continuously upto eighth date of sowing. Among the temperature regime treatments, plant height recorded was significantly maximum at eighth date of sowing (22.80 cm), which was on par with all the treatments except first, second and third date of sowing.

Significantly, minimum plant height was recorded in second date of sowing (17.80 cm), which was followed by third (18.80 cm) and first date of sowing (19.70 cm). The per cent increase for plant height was higher in eighth date of sowing (19.13%) over first date of sowing. However, second date of sowing (-6.96%) and third date of sowing (-1.74%) recorded decreased plant height over first date of sowing.

At 60 DAS, plant height was recorded lowest in first date of sowing compared to all other date of sowing and then after the plant height increased continuously upto fifth date of sowing but decreased in sixth date of sowing and again increased in seventh and eighth dates of sowing. Among the temperature regime treatments, significantly maximum plant height was recorded in seventh date of sowing (44.80 cm) followed by eighth date of sowing (44.20 cm) and it was on par with other treatments except first dates of sowing (34.50 cm) and second dates of sowing (34.50 cm). Significantly minimum plant height was recorded in first date of sowing (34.50 cm).

The per cent increase for plant height was highest in seventh date of sowing (29.95%) followed by eighth date of sowing (28.12%), while second date of sowing (13.53%) recorded lower per cent decrease in plant height over first date of sowing. From the Table 2, it is also evident that subsequent observations recorded at 90 DAS and at harvest, followed the similar trend as that of the observations recorded at 30 and 60 DAS.

The plant height was followed an increasing trend from first dates of sowing to eighth dates of sowing. At harvest, plant height was increased from first date of sowing to fifth date of sowing then after decreased in sixth, seventh and eighth date of sowing. Among the temperature regime treatments significantly maximum plant height (54.9 cm) was recorded with fourth date of sowing, which was on par with rest of the treatments except first date of sowing (48.64 cm) and second dates of sowing (49.50 cm).

At 90 DAS, the higher per cent increase in plant height was recorded in fifth date of sowing. (13.69%) and minimum plant height was recorded in second date of sowing. (2.74%) over first date of sowing. At harvest, the per cent increase in plant height was higher in fifth date of sowing (11.11%) while it was lower in second date of sowing (1.92%) over first date of sowing.

4.1.2 Number of branches

Influence of temperature regimes on number of branches are shown in (Table 2). In general, the number of branches increased from 30-60 DAS irrespective of treatments and it differed significantly among the treatments.

The number of branches increased from first date of sowing upto fifth date of sowing then after decreases gradually. At 30 DAS, maximum number of branches per plant (9.2) was recorded in fifth date of sowing, while lower number of branches (7.8) were seen in eighth date of sowing, which was on par with first and second dates of sowing.

Table 2. Effect of temperature regimes on plant height (cm) and number of branches at different growth stages in chickpea

Treatments	Plant height (cm)				Number of branches			
	30 DAS	60 DAS	90 DAS	At harvest	30 DAS	60 DAS	90 DAS	At harvest
T ₁ - 39 th standard week (1 st Oct – 7 th Oct)	19.2 ^{bcd}	34.5 ^c	43.8 ^c	48.6 ^c	8.10	10.00 ^{c-d}	10.80 ^{bc}	10.80 ^c
T ₂ - 40 th standard week (8 th Oct – 14 th Oct)	17.8 ^d (-6.96) [*]	39.2 ^{bc} (13.53)	45.0 ^{bc} (2.74)	49.5 ^{bc} (1.92)	8.50	10.20 ^a	11.00 ^{bc}	11.00 ^{bc}
T ₃ - 41 st standard week (15 th Oct – 21 st Oct)	18.8 ^{cd} (-1.74)	41.8 ^{ab} (21.06)	48.4 ^{ab} (10.36)	52.1 ^{abc} (7.20)	8.80	11.50 ^{ab}	12.70 ^{ab}	12.70 ^{a-c}
T ₄ - 42 nd standard week (22 nd Oct – 28 th Oct)	21.7 ^{abc} (13.04)	42.7 ^{ab} (23.77)	48.4 ^{ab} (10.34)	54.9 ^a (12.89)	9.00	12.10 ^b	13.10 ^a	13.10 ^{ab}
T ₅ - 43 rd standard week (29 th Oct – 4 th Nov)	20.3 ^{a-d} (6.09)	43.3 ^{ab} (25.41)	49.8 ^a (13.69)	54.0 ^a (11.11)	9.20	12.80 ^b	13.40 ^a	13.40 ^a
T ₆ - 44 th standard week (5 th Nov – 11 th Nov)	21.8 ^{ab} (13.91)	41.7 ^{ab} (20.97)	49.1 ^a (12.02)	52.3 ^{abc} (7.61)	9.00	12.50 ^b	13.20 ^a	13.20 ^{ab}
T ₇ - 45 th standard week (12 th Nov – 18 th Nov)	20.3 ^{a-d} (6.09)	44.8 ^a (29.95)	50.1 ^a (14.22)	53.0 ^{ab} (9.05)	8.00	9.60 ^b	10.70 ^{bc}	10.70 ^c
T ₈ - 46 th standard week (19 th Nov – 25 th Nov)	22.8 ^a (19.13)	44.2 ^{ab} (28.12)	49.3 ^a (12.55)	52.6 ^{abc} (8.30)	7.80	9.50 ^d	10.40 ^c	10.40 ^c
Mean	20.4	41.5	48.0	52.1	8.55	11.03	11.91	11.91
SEm±	0.9	1.6	1.3	1.2	0.69	0.54	0.62	0.69
LSD at 5%	2.7	4.9	3.6	3.6	NS	1.66	1.89	2.11

DAS – Days after sowing

NS – Non-significant

* Per cent increase / decrease over treatment T₁

Means followed by the same letter do not differ significantly at 5%

At 60 DAS, the number of branches increased upto fifth date of sowing and decreased their after from sixth to eighth date of sowing. Among the temperature regime treatments, significantly higher number of branches (12.80) were noticed in fifth date of sowing followed by sixth (12.50), fourth date of sowing (12.10), whereas, lower number of branches (9.50%) were seen at eighth date of sowing, which was followed by seventh and first dates of sowing. Similar trend was observed at 90 DAS and also at harvest. At harvest, lower number of branches (10.4) was recorded in eighth date of sowing followed by seventh, first and second dates of sowing, respectively.

4.1.3 Days to flower initiation

The data with respect to days to flower initiation indicated significant difference among the temperature regime treatments presented in Table 3. The number of days to first flower initiation increased in first date of sowing to fourth date of sowing but decreased there after upto eighth date of sowing. Among the temperature regimes, fourth date of sowing (43.7 days) took significantly maximum number of days for first flower initiation, while all treatments were on par with fourth date of sowing except sixth and seventh date of sowing. The lowest was recorded in treatment eighth date of sowing (39 days) followed by seventh and second dates of sowing.

The highest per cent increase for days to first flower initiation (2.42%) was recorded by fourth date of sowing over first date of sowing. However eighth date of sowing (-8.59%) recorded lower per cent decrease in plant height over first date of sowing.

4.1.4 Days to 50 per cent flowering

It is observed from the Table 3 that temperature regime treatments differed significantly with respect to days to 50 per cent flowering. The number of days to fifty percent flowering decreased gradually from first date of sowing up to eighth date of sowing. Among the temperature regimes, fourth date of sowing took significantly maximum number of days (50 days) for 50 per cent flowering, which was on par with all other treatments except first and seventh dates of sowing and the lowest was recorded in eighth date of sowing (45.3 days). The per cent increase was maximum (8.70) in seventh date of sowing, while minimum in fourth date of sowing (-1.45).

4.1.5 Days to pod initiation

The data with respect to days to number of pod initiation indicated significant differences among the temperature regimes Table 3. The number of days to pod initiation increased in first date of sowing to fourth date of sowing but decreased there after upto eighth date of sowing. Among the temperature regimes treatments, fourth date of sowing (55 day) recorded significantly higher number of days to pod initiation, which was on par with third (52.7 days) and sixth (53 days) dates of sowing. The minimum number of days to pod initiation recorded in first date of sowing (49.0 days). The maximum per cent increase (12.24) was recorded in seventh date of sowing, while the per cent decrease was minimum (1.43) in fifth date of sowing over first date of sowing.

4.1.6 Days to pod filling

The data with respect to days to number of pod filling indicated significant differences among the temperature regimes (Table 3). The number of days to pod filling increased in first date of sowing to fourth date of sowing but decreased their after upto eighth date of sowing. Among the temperature regimes treatments, fourth date of sowing (63.3 day) recorded significantly higher number of days to pod filling, which was on par with third (64.3 days) and sixth (60.3 days) dates of sowing. The minimum number of days to pod filling recorded in first dates of sowing (56.3 days), which was on par with all other treatments except first, second and third dates of sowing. The maximum per cent increase (14.28) was recorded in third date of sowing, while the per cent decrease was minimum (0.73) in seventh date of sowing over first date of sowing.

4.1.7 Days to physiological maturity

It was observed from the Table 3 that temperature regimes differed significantly with respect to days to physiological maturity.

Table 3. Effect of temperature regimes on phenological characters at different growth stages in chickpea

Treatments	Days to flower initiation	Days to 50% flowering	Days to pod initiation	Days to pod filling	Days to physiological maturity
T ₁ - 39 th standard week (1 st Oct – 7 th Oct)	42.7 _{ac}	46.0 _{bc}	49.0 _d	56.3 _c	83.4 _{ab}
T ₂ - 40 th standard week (8 th Oct – 14 th Oct)	40.7 _{abc} (-4.69)*	47.3 _{abc} (3.62)	49.7 _{cd} (1.42)	59.0 _{bc} (4.73)	84.7 _{ab} (1.56)
T ₃ - 41 st standard week (15 th Oct – 21 st Oct)	42.7 _{ab} (0.08)	47.7 _{abc} (-1.45)	52.7 _{abc} (7.56)	64.3 _a (14.28)	87.4 _a (4.79)
T ₄ - 42 nd standard week (22 nd Oct – 28 th Oct)	43.7 _a (2.42)	50.0 _a (8.69)	55.0 _a (12.24)	63.3 _a (12.25)	86.4 _a (3.59)
T ₅ - 43 rd standard week (29 th Oct – 4 th Nov)	42.3 _{ab} (-0.93)	48.0 _{abc} (4.35)	49.7 _{cd} (1.43)	57.7 _c (2.47)	84.5 _{ab} (1.32)
T ₆ - 44 th standard week (5 th Nov – 11 th Nov)	41.7 _{ab} (-2.34)	48.7 _{ab} (5.80)	53.0 _{ab} (8.16)	60.3 _{ab} (7.10)	84.8 _{ab} (1.68)
T ₇ - 45 th standard week (12 th Nov – 18 th Nov)	40.3 _{b-c} (-5.62)	46.0 _{bc} (8.70)	50.3 _{bcd} (2.64)	56.7 _c (0.73)	80.3 _b (-3.74)
T ₈ - 46 th standard week (19 th Nov – 25 th Nov)	39.0 _c (-8.66)	45.3 _c (-1.52)	51.3 _{bcd} (4.68)	59.7 _{abc} (6.04)	81.1 _b (-2.75)
Mean	41.6	47.4	51.3	59.7	84.1
SEm _±	1.0	1.5	0.9	1.5	1.4
LSD at 5%	3.0	4.5	2.9	4.6	4.3

* Per cent increase / decrease over treatment T₁

Means followed by the same letter do not differ significantly at 5%

Table 4. Effect of temperature regimes on accumulated T_{max} , T_{min} , T_{range} and GDD for days to flower initiation and days to 50% flowering in chickpea

Treatments	Days to flower initiation				Days to 50% flowering			
	T_{max}	T_{min}	T_{range}	GDD	T_{max}	T_{min}	T_{range}	GDD
T ₁ - 39 th standard week (1 st Oct – 7 th Oct)	30.12a	18.02a	12.15d	819.81a	30.11	17.65a	12.50d	868.55 a
T ₂ - 40 th standard week (8 th Oct – 14 th Oct)	30.06a	17.08ab	13.12c	758.84ab	29.87	17.10ab	12.77d	868.75 a
T ₃ - 41 st standard week (15 th Oct – 21 st Oct)	29.86a	16.82ab	13.18c	787.24ab	30.01	16.63ab	13.36cd	860.65 a
T ₄ - 42 nd standard week (22 nd Oct – 28 th Oct)	30.05a	16.25bc	13.92b	724.45bc	30.05	16.11bc	13.89bc	830.50 ab
T ₅ - 43 rd standard week (29 th Oct – 4 th Nov)	30.04a	15.55cd	14.52ab	746.15b	29.82	15.07b	14.75cd	837.20 ab
T ₆ - 44 th standard week (5 th Nov – 11 th Nov)	29.74ab	14.81d	14.79a	723.22bc	29.57	14.34bd	15.23d	830.80 ab
T ₇ - 45 th standard week (12 th Nov – 18 th Nov)	29.42b	14.34d	15.13a	740.17b	29.41	14.79d	14.74d	852.20 a
T ₈ - 46 th standard week (19 th Nov – 25 th Nov)	29.37b	14.76d	14.62ab	665.61c	29.40	15.04cd	14.37cd	774.65 ab
Mean	29.81	15.92	13.93	747.10	29.77	15.82	14.04	840.30
SEm _±	0.15	0.38	0.24	20.26	0.452	0.381	0.310	19.80
LSD at 5%	0.44	1.15	0.75	61.64	NS	1.156	0.940	60.05

NS – Non-significant

* Per cent increase / decrease over treatment T₁

Means followed by the same letter do not differ significantly at 5%

The days to physiological maturity increased in first date of sowing to fourth date of sowing but decreased there after upto eighth date of sowing, although values were on par with each other. Among the temperature regimes, third date of sowing (87.4 days) recorded maximum number of days to maturity, which was on par with all other treatments except seventh and eighth dates of sowing. The minimum number of days to maturity (81.1 days) was recorded in eighth date of sowing followed by seventh date of sowing (80 days).

4.2 Temperatures recorded (T_{max} , T_{min} , T_{range}) during different phenological stages

4.2.1 Days to flower initiation

4.2.1.1 Mean maximum temperature (T_{max})

The data with respect days to flower initiation differed significantly in responses to the temperature regimes presented in (Table 4). Among the temperature regimes the effect of mean maximum temperature on number of days to first flower initiation was maximum in first date of sowing (30.12 °C) to sixth date of sowing (29.74 °C) but decreased their after upto eighth date of sowing.

Among the temperature regimes, the mean maximum temperature was recorded, maximum in fourth date (30.05°C) of sowing, while all other treatments were on par with fourth date of sowing except seventh (29.42 °C) and eighth dates of sowing (29.37 °C). The mean maximum was recorded, minimum in eighth date of sowing (29.37 °C) followed by seventh date of sowing (29.42 °C).

4.2.1.2 Mean minimum temperature (T_{min})

The data with respect days to flower initiation differed significantly in responses to the mean minimum temperature (T_{min}) regimes presented in Table 4. Among the temperature regimes, the effect of mean minimum temperature on number of days to first flower initiation was maximum in first date of sowing to sixth date of sowing but decreased their after upto eighth date of sowing. Among the temperature regimes, the higher mean minimum temperature was recorded, in first date (18.02°C) of sowing, followed by second and third dates of sowing (17.08, 16.82°C, respectively). The lowest mean minimum was recorded in seventh dates of sowing (14.34 °C) followed by eighth (14.76 °C), sixth (14.81°C) and fifth dates of sowing (29.42 °C).

4.2.1.3 Mean temperature range (T_{range})

The data regarding the influence of mean range temperature (T_{range}) on number of days to flower initiation at different growth stages were presented in Table 4. Among the temperature regimes the the effect of mean range temperature on number of days to first flower initiation was decreased from first date of sowing to sixth date of sowing and increased in seventh date of sowing and again decreased in eighth date of sowing. Among the temperature regimes, the higher mean range temperature was recorded, maximum in seventh date of sowing (15.13°C), followed by sixth (14.79 °C), eighth (14.62 °C) and fifth dates of sowing (14.52 °C). The lowest mean range was recorded in first dates of sowing (12.15 °C) followed by second (13.12 °C), third (13.18°C) and fifth dates of sowing (29.42 °C).

4.2.1.4 Growing degree days (GDD)

The data pertaining to effect of growing degree on days to flower initiation indicated significant differences among the temperature regimes Table 4. Among the temperature regimes the effect of GDD on number of days to first flower initiation on was decreased from in first date of sowing to eighth dates of sowing continuously.

Among the temperature regimes, the maximum GDD was recorded, in first date of sowing (819.81), followed by second (758.84), third dates of sowing (787.24). The minimum GDD was recorded in eighth date of sowing (665.61) followed by sixth (723.22¹) and fourth date of sowing (724.45).

4.2.2 Days to 50% flowering ($^{\circ}\text{C}$)

4.2.2.1 Mean maximum temperature (T_{max})

The data with respect days to fifty percent flowering differed significantly in responses to mean maximum temperature (T_{max}) regimes presented in (Table 4). Among the temperature regimes the effect of mean maximum temperature on number of days to fifty percent flowering was maximum in first date of sowing there after decreased continuously upto eighth date of sowing. Among the temperature regimes, the mean maximum temperature was recorded maximum, in first date of sowing (30.11°C). The mean maximum was recorded higher in, eighth date of sowing (29.40°C) followed by seventh date of sowing (29.42°C).

4.2.2.2 Mean minimum temperature (T_{min})

The data presented in (Table 4) indicated significant differences in days to fifty percent flowering due to mean minimum temperature (T_{min}) regimes. Among the temperature regimes the effect of mean minimum temperature on number of days for fifty percent flowering decreased in first date of sowing to seventh date of sowing but increased in eighth date of sowing.

Among the temperature regimes treatments, the higher mean minimum temperature was recorded in first dates (17.65°C) of sowing, followed by second and third dates sowing (17.10 , 16.63°C , respectively). The mean minimum was recorded minimum in seventh date of sowing (14.79°C) followed by eighth (15.04°C), sixth (14.81°C) and sixth dates of sowing (14.34°C).

4.2.2.3 Mean temperature range (T_{range})

The data regarding the influence of mean range temperature (T_{range}) on days to fifty percent flowering (Table 4). Among the temperature regimes, the effect of mean range temperature on number of days to days to fifty percent flowering decreased from first date of sowing to fifth date of sowing and increased in sixth date of sowing and again decreased in seventh and eighth dates of sowing. Among the temperature regimes, the higher mean range temperature was recorded minimum in sixth date of sowing (15.23°C), followed by seventh (14.74°C), eighth (14.37°C) and third dates of sowing (13.36°C). The lowest mean range was recorded in first date of sowing (12.50°C) followed by second (12.77°C) date of sowing.

4.2.2.4 Growing degree days (GDD)

The data pertaining to effect of growing degree (GDD) on days to fifty percent flowering indicated significant difference among the GDD's (Table 4). The effect of GDD on number of days to fifty percent flowering was decreased from in first date of sowing to sixth date of sowing and their after decreased upto eighth date of sowing continuously. Among the GDD, the maximum GDD was recorded, maximum in first date of sowing (868.55), which was at par with all other treatments. The minimum GDD was recorded minimum in eighth date of sowing (774.65) followed by sixth (830.80), fifth (837.20) and fourth dates of sowing (830.50).

4.2.3.3 Days to pod initiation

4.2.3.3.1 Mean maximum temperature (T_{max})

The data with respect days to pod initiation differed significantly in responses to mean maximum temperature (T_{max}) Table 5. Among the temperature regimes the effect of mean maximum temperature on number of days to pod initiation decreased from first date of sowing to upto eighth date of sowing. Among the temperature regimes treatments, the mean maximum temperature was recorded maximum in fourth date (30.04°C) of sowing. The mean maximum was recorded maximum in eighth date of sowing (29.40°C) followed by seventh date of sowing (29.42°C).

4.2.3.3.2 Mean minimum temperature (T_{min})

The data regards to the days to pod initiation differed significantly in responses to the temperature regimes (Table 5). Among the temperature regimes the effect of mean minimum temperature on number of days to first flower initiation decreased from first date to eighth date of sowing. The mean minimum temperature was recorded, maximum in first date (17.36°C) of sowing followed by second and third dates of sowing (17.16 , 16.51°C , respectively).

Table 5. Effect of temperature regimes on accumulated T_{max} , T_{min} , T_{range} and GDD for days to pod initiation and days to physiological maturity in chickpea

Treatments	Days to pod initiation				Days to physiological maturity			
	T_{max}	T_{min}	T_{range}	GDD	T_{max}	T_{min}	T_{range}	GDD
T ₁ - 39 th standard week (1 st Oct – 7 th Oct)	30.04	17.36 a	12.69d	916.40 ab	29.80	16.24 a	13.55d	1495.05 ab
T ₂ - 40 th standard week (8 th Oct – 14 th Oct)	29.90	17.16 a	12.74d	926.35 ab	29.70	15.93 a	13.78cd	1514.35 ab
T ₃ - 41 st standard week (15 th Oct – 21 st Oct)	30.01	16.51 ab	13.45 cd	966.20 a	29.66	15.57 ab	14.10cd	1427.10b c
T ₄ - 42 nd standard week (22 nd Oct – 28 th Oct)	30.04	15.88 bc	14.10 bc	896.55 ab	29.65	15.10 abc	14.61bc	1388.20 c
T ₅ - 43 rd standard week (29 th Oct – 4 th Nov)	29.78	14.93 cd	14.83ab	867.25 b	29.61	14.41 c	15.22ab	1428.35 bc
T ₆ - 44 th standard week (5 th Nov – 11 th Nov)	29.54	14.52 d	15.02a	902.60 ab	29.54	14.22 c	15.36ab	1433.35 bc
T ₇ - 45 th standard week (12 th Nov – 18 th Nov)	29.42	14.64 d	14.81 ab	936.05 ab	29.68	14.20 c	15.45a	1458.30abc
T ₈ - 46 th standard week (19 th Nov – 25 th Nov)	29.40	14.80 cd	14.60 ab	872.30 b	30.09	14.65 bc	15.48a	1544.85 a
Mean	29.80	15.72	14.00	910.41	29.60	15.11	14.71	1461.10
SEm _±	0.26	0.38	0.24	21.3	0.38	0.36	0.26	26.89
LSD at 5%	NS	1.14	0.72	64.6	NS	1.10	0.80	81.58

NS – Non-significant

* Per cent increase / decrease over treatments over T₁

Means followed by the same letter do not differ significantly at 5%

The lowest mean minimum was recorded in sixth dates of sowing (14.52 °C), which was on par with eighth (14.80 °C), seventh (14.64 °C) and fifth dates of sowing (14.93 °C).

4.2.3.3.3 Mean temperature range (T_{range})

The data pertaining to the influence of mean range of temperature on number of days to pod initiation Table 5, indicated that the effect of mean range temperature on number of days to first pod initiation decreased from first date of sowing to fifth date of sowing and their after increased in sixth date of sowing but it was on par with seventh and eighth dates of sowing. The mean minimum temperature recorded maximum in sixth date of sowing (15.02 °C), followed by fifth (14.79 °C), seventh (14.81 °C) and eighth dates of sowing (14.60 °C). The mean minimum was recorded minimum in first date of sowing (12.69 °C) followed by second (13.74 °C) and third (13.45 °C) dates of sowing.

4.2.3.3.4 Growing degree days (GDD)

The data with respect to effect of growing degree on days to pod initiation indicated significant differences among the temperature regimes (Table 5). Among the temperature regimes the effect of GDD on number of days to pod initiation increased from in first date of sowing to third date of sowing and decreases in fourth and fifth dates of sowing but again increased upto eighth date of sowing. The mean GDD was recorded maximum in third date of sowing (966.20), which was at par with all other treatments except fifth and eighth dates of sowing. The mean GDD was recorded minimum in fifth date of sowing (724.4) which was at par with all other treatments except third date of sowing.

4.2.4 Days to physiological maturity

4.2.4.1 Mean maximum temperature (T_{max})

The influence of mean maximum temperature (T_{max}) on days to physiological maturity differed significantly in responses to the temperature regimes (Table 5). The effect of mean maximum temperature on number of days to physiological maturity decreased from first date of sowing sixth date of sowing but increased their after upto eighth date of sowing. The mean maximum temperature was recorded, maximum in eighth date of sowing (30.09 °C). The mean maximum was recorded minimum in sixth date of sowing (29.54 °C).

4.2.4.2 Mean minimum temperature (T_{min})

The data with respect to T_{min} for days to physiological maturity differed significantly in responses to the temperature regimes (Table 5). Among the temperature regimes the effect of mean minimum temperature on number of days to physiological maturity was maximum in first date of sowing to sixth date of sowing but decreased their after upto eighth date of sowing. The mean minimum temperature was recorded maximum in second date of sowing (15.93 °C), followed by first (16.24 °C) third (15.57) and fourth dates of sowing (15.10 °C). The mean minimum was recorded minimum in seventh dates of sowing (14.20 °C) followed by, sixth (14.22 °C) fifth (14.41 °C) and eighth dates of sowing (14.65 °C).

4.2.4.3 Mean temperature range (T_{range})

The data pertaining to the influence of mean range temperature (T_{range}) on number of days to physiological maturity (Table 5) indicated that the effect of mean range temperature on number of days to physiological maturity increased from first date of sowing upto eighth date of sowing. The mean range maximum temperature recorded maximum in eighth date of sowing (18.02 °C), which was on par with seventh (15.45 °C), sixth (15.36 °C) and fifth dates of sowing (15.22 °C). The mean minimum range recorded minimum in first date of sowing (13.55 °C) followed by second (13.78 °C) and third dates of sowing (14.10 °C).

4.2.4.4 Growing degree days (GDD)

The data with respect to the effect of growing degree on days (GDD) for physiological maturity indicated significant differences among the temperature regimes (Table 5). Among the temperature regimes treatments, the effect of GDD on number of days to physiological maturity decreased from in first date of sowing to eighth date of sowing. The mean GDD recorded maximum in eighth date of sowing (1544.85), followed by first (1495.05), second (1514.35) and seventh dates of sowing (1458.30).

Table 6. Effect of temperature regimes on leaf dry weight and stem dry weight (g plant⁻¹) at different growth stages in chickpea

Treatments	Leaf dry weight (g plant ⁻¹)				Stem dry weight (g plant ⁻¹)			
	30 DAS	60 DAS	90 DAS	At harvest	30 DAS	60 DAS	90 DAS	At harvest
T ₁ T ₁ - 39 th standard week (1 st Oct – 7 th Oct)	1.31 ^{c-d}	3.89 ^{bc}	2.52 ^{c-d}	1.83 ^{c-d}	1.03 ^b	4.07 ^{b-d}	6.26 ^{c-d}	6.35 ^b
T ₂ T ₂ - 40 th standard week (8 th Oct – 14 th Oct)	1.47 ^{b-d}	3.98 ^b	2.57 ^{c-d}	2.17 ^{b-d}	1.12 ^{ab}	4.09 ^{b-d}	6.67 ^{b-d}	6.78 ^{ab}
T ₃ T ₃ - 41 st standard week (15 th Oct – 21 st Oct)	1.58 ^{a-d}	4.02 ^b	3.08 ^{bc}	2.40 ^{b-d}	1.38 ^{ab}	4.49 ^{a-c}	6.83 ^{a-c}	6.95 ^{ab}
T ₄ T ₄ - 42 nd standard week (22 nd Oct – 28 th Oct)	1.72 ^{a-c}	4.65 ^a	3.53 ^{ab}	2.48 ^{a-c}	1.67 ^a	4.61 ^{a-c}	7.12 ^{a-c}	7.70 ^a
T ₅ T ₅ - 43 rd standard week (29 th Oct – 4 th Nov)	2.05 ^a	4.93 ^a	4.02 ^a	3.27 ^a	1.43 ^{ab}	4.93 ^a	7.94 ^a	7.98 ^a
T ₆ T ₆ - 44 th standard week (5 th Nov – 11 th Nov)	1.92 ^{ab}	4.79 ^a	3.72 ^{ab}	2.96 ^{ab}	1.48 ^{ab}	4.71 ^{ab}	7.67 ^{ab}	7.75 ^a
T ₇ T ₇ - 45 th standard week (12 th Nov – 18 th Nov)	1.20 ^{c-d}	3.62 ^{bc}	2.30 ^{c-d}	1.62 ^{c-d}	1.01 ^b	3.92 ^{c-d}	5.88 ^{c-d}	5.97 ^b
T ₈ T ₈ - 46 th standard week (19 th Nov – 25 th Nov)	1.14 ^d	3.38 ^c	2.16 ^d	1.54 ^d	1.02 ^b	3.68 ^d	5.54 ^d	5.62 ^b
Mean	1.55	4.16	2.99	2.28	1.27	4.31	6.74	6.89
SEm±	0.17	0.18	0.26	0.27	0.17	0.23	0.38	0.40
LSD at 5%	0.51	0.55	0.72	0.79	0.52	0.69	1.16	1.22

DAS – Days after sowing

Means followed by the same letter do not differ significantly at 5%

The mean GDD recorded minimum in fourth date of sowing (665.61), which was on par with all other treatments except first (1495.05), second (1514.35) and eighth dates of sowing (1544.85).

4.3 Dry matter accumulation and partitioning

4.3.1 Leaf dry weight (g plant⁻¹)

The data on leaf dry weight (Table 6) revealed that the leaf dry weight increased from 30 to 60 DAS and then after it decreased upto 90 DAS and it continued to decrease till harvest. At all the stages, leaf dry weight under different temperature regimes differed significantly, except at harvest. At 30 DAS, significantly higher leaf dry weight (2.05 g) was observed in sixth date of sowing, which was significantly higher over all other temperature regimes. It was followed by fifth date of sowing (1.92 g) and fourth dates of sowing (1.72 g). The eighth date of sowing recorded significantly lower leaf dry weight (1.14 g), which was on par with seventh, second and first dates of sowing.

Observations recorded at 60 and 90 DAS also showed a significant increase in leaf dry weight due to temperature increase. Sixth date of sowing recorded significantly higher leaf dry weight, which was on par with fourth and fifth dates of sowing. Eighth date of sowing (3.38 g) recorded significantly lower leaf dry weight. The similar trend was also followed at 90 DAS. At harvest, drastic reduction in leaf dry weight was noticed when compared to 60 DAS. The fifth date of sowing (2.96 g) recorded significantly higher leaf dry weight, while eighth date of sowing (1.54 g) recorded significantly lower leaf dry weight.

4.3.2 Stem dry weight (g plant⁻¹)

The effect of temperature regimes on dry matter accumulation in stem is presented in Table 6. The data indicated that there was an increased in dry weight of stem as growth advances from 30 to 60 DAS and then it remained almost constant at 90 DAS and harvest in all the treatments. Among the stages maximum stem dry weight observed at harvest.

The effect of temperature regime differed significantly with all growth stages. From 30 DAS, the stem dry weight increase from first date of sowing to fourth date of sowing and then after it decreased continuously upto eighth date of sowing. Higher stem dry weight was observed at fourth date of sowing (1.67 g), while significantly lower values at seventh date of sowing (1.01 g), which was on par with all other treatments except fourth date of sowing. Similar trend was also observed at 60, 90 DAS and at harvest.

4.3.3 Pod dry weight (g plant⁻¹)

The data on dry weight of reproductive parts as influenced by the temperature regimes is presented in (Table 7). It is observed that there was an increase in dry weight of reproductive parts as growth advanced till harvest. At 60 DAS, the pod weight increased from first date of sowing to fifth date of sowing and then after it decreased continuously upto eighth date of sowing. Significantly higher dry weight of reproductive parts (4.84 g) was noticed at fourth dates of sowing. Significantly lower dry weight of reproductive part was recorded in eighth (0.93 g) date of sowing, which was on par with all other treatments except fifth (4.84 g), fourth (4.36 g) and sixth (4.54 g) dates of sowing.

At 90 DAS, the pod weight increased from first date of sowing to fifth date of sowing and then after it decreased continuously upto eighth date of sowing. Similar trend was also followed at harvest. It was observed that there was a profound increase in dry weight of the reproductive parts as compared to rest of the treatments, where the pod dry weight was found maximum (15.2 and 16.10, respectively). In fourth date of sowing, which differed significantly from rest of the treatments in both the stages, whereas, eighth date of sowing recorded significantly lower dry weight of pods (7.59 g and 8.36 g, respectively) at both the stages (60 DAS and harvest) and it was on par with seventh and first date of sowing.

4.3.4 Total dry weight (g plant⁻¹)

The results pertaining to total dry matter (TDM) indicated that the total dry weight increased from 30 DAS to at harvest in all the treatments.

Table 7. Effect of temperature regimes on pod weight and total dry weight at different growth stages in chickpea

Treatments	Pod weight (g plant ⁻¹)			Total dry weight (g plant ⁻¹)			
	60 DAS	90 DAS	At harvest	30 DAS	60 DAS	90 DAS	At harvest
T ₁ - 39 th standard week (1 st Oct – 7 th Oct)	1.10 ^d	8.42 ^c	9.46 ^{c-d}	2.34 ^c	9.06 ^{cd}	17.20 ^{cd}	17.64 ^{cd}
T ₂ - 40 th standard week (8 th Oct – 14 th Oct)	2.08 ^{c-d}	10.04 ^d	10.90 ^c	2.59 ^{bc} (10.68)*	10.15 ^{cd} (12.50)	19.28 ^{cd} (12.14)	19.85 ^{bc} (12.48)
T ₃ - 41 st standard week (15 th Oct – 21 st Oct)	3.17 ^{bc}	12.19 ^c	13.41 ^b	2.96 ^{abc} (26.50)	11.68 ^{bc} (28.90)	22.10 ^{bc} (28.51)	22.76 ^b (28.99)
T ₄ - 42 nd standard week (22 nd Oct – 28 th Oct)	4.36 ^{ab}	15.20 ^b	16.52 ^a	3.39 ^{ab} (44.87)	13.62 ^{ab} (50.30)	25.85 ^{ab} (50.33)	26.70 ^a (51.35)
T ₅ - 43 rd standard week (29 th Oct – 4 th Nov)	4.84 ^a	16.10 ^a	17.93 ^a	3.48 ^a (48.72)	14.70 ^a (62.20)	28.06 ^a (63.16)	29.18 ^a (65.40)
T ₆ - 44 th standard week (5 th Nov – 11 th Nov)	4.54 ^a	15.34 ^a	17.01 ^a	3.40 ^{ab} (45.30)	14.04 ^{ab} (54.92)	26.73 ^{ab} (54.45)	27.72 ^a (57.10)
T ₇ - 45 th standard week (12 th Nov – 18 th Nov)	1.03 ^d	7.87 ^d	8.73 ^{c-d}	2.21 ^c (-5.56)	8.47 ^d (-6.57)	16.05 ^d (-6.69)	16.32 ^{cd} (-7.48)
T ₈ - 46 th standard week (19 th Nov – 25 th Nov)	0.93 ^d	7.59 ^d	8.36 ^d	2.16 ^c (-7.69)	8.09 ^d (-10.70)	15.29 ^d (-11.07)	15.52 ^d (-12.01)
Mean	2.76	11.59	12.79	2.82	11.23	21.32	21.96
SEm±	0.40	0.64	0.71	0.26	0.84	1.60	1.21
LSD at 5%	1.22	1.94	2.15	0.80	2.56	4.85	3.68

DAS – Days after sowing

* Per cent increase / decrease over treatment T₁

Means followed by the same letter do not differ significantly at 5%

The maximum total dry weight was noticed at harvest in all the temperature regime treatments and the rate of increase was very high from 60 to 90 DAS (Table 7).

At 30 DAS, the total dry weight increased from first date of sowing to fifth date of sowing and there after it decreased continuously upto eighth date of sowing. Among temperature regime treatments, fifth date of sowing (3.48 g) recorded significantly higher total dry weight as compared to other treatments. It was followed by fifth (3.48 g) and third date of sowing (26.5 g), whereas, eighth date of sowing recorded significantly lower total dry weight (2.16 g), which was on par with seventh (2.21 g), first (2.34 g) and second dates of sowing (2.59 g).

The total dry weight increased from first date of sowing to fifth date of sowing and there after it decreased continuously upto eighth date of sowing at 60 DAS. Similar trend was followed at harvest also. The treatment fifth date of sowing (14.70 g) produced significantly higher total dry weight, which was significantly higher compared with rest of the treatments.

It was followed by fourth (13.62 g) and sixth dates of sowing (14.04), whereas, eighth date of sowing recorded significantly lower dry weight (8.09 g) followed by seventh (8.47 g) and first dates of sowing (9.06 g) compared to other treatments, but it was on par with seventh, first and second dates of sowing. Similar trend was observed at 90 DAS also. At harvest, the treatment, fifth date of sowing continued to record significantly higher total dry weight (29.18 g), which was on par with fourth and sixth dates of sowing, whereas, significantly lower total dry weight (15.52 g) was recorded in eighth date of sowing followed by seventh and first dates of sowing.

4.4 Growth parameters

4.4.1 Leaf area ($\text{dm}^2 \text{ plant}^{-1}$)

The data presented in Table 8 indicated that the significant differences in leaf area among the treatments at all the stages of crop growth. The leaf area increased from 30 to 60 and 90 DAS and thereafter it decreased towards maturity.

The leaf area increased from first date of sowing to fifth date thereafter it decreased continuously upto eighth date of sowing. Similar trend was followed at 60, 90 and at harvest also. Among the temperature regimes, fifth date of sowing produced significantly higher leaf area ($2.93 \text{ dm}^2 \text{ plant}^{-1}$) at 30 DAS, which was significantly higher compared to rest of the treatments. However, eighth date of sowing ($1.94 \text{ dm}^2 \text{ plant}^{-1}$) recorded significantly lower leaf area, which was on par with seventh ($1.96 \text{ dm}^2 \text{ plant}^{-1}$) date of sowing.

Similarly, at 60 DAS, fifth date of sowing ($6.22 \text{ dm}^2 \text{ plant}^{-1}$) continued to produce significantly higher leaf area compared to all other temperature regime treatments, while it was on par with sixth ($6.08 \text{ dm}^2 \text{ plant}^{-1}$) and fourth ($5.92 \text{ dm}^2 \text{ plant}^{-1}$) date of sowing. Significantly lower leaf area ($4.52 \text{ dm}^2 \text{ plant}^{-1}$) was recorded in eighth date of sowing and it was followed by seventh ($1.96 \text{ dm}^2 \text{ plant}^{-1}$), second ($5.15 \text{ dm}^2 \text{ plant}^{-1}$) and first ($2.13 \text{ dm}^2 \text{ plant}^{-1}$) dates of sowing. Similar trends were also noticed at 90 DAS with respect to leaf area per plant.

At harvest also, significantly higher leaf area (4.56) recorded in fifth date of sowing, while the lower value of leaf area ($2.41 \text{ dm}^2 \text{ plant}^{-1}$) was recorded at eighth date of sowing which was on par with other treatments except fifth ($4.56 \text{ dm}^2 \text{ plant}^{-1}$), third ($3.41 \text{ dm}^2 \text{ plant}^{-1}$) and sixth ($4.15 \text{ dm}^2 \text{ plant}^{-1}$) dates of sowing.

4.4.2 Leaf area index (LAI)

The data on the effect of temperature regimes on leaf area index is presented in Table 8. It was revealed that leaf area index increased progressively upto 90 DAS and declined thereafter untill maturity, irrespective of treatments.

Among the temperature regime treatments at 30 DAS, the leaf area index increased from first date of sowing to fifth date of sowing and their after it decreased continuously upto eighth date of sowing. Similar trend was also followed at 60, 90 DAS and at harvest.

Table 8. Effect of temperature regimes on leaf area (dm² plant⁻¹) and leaf area index at different growth stages in chickpea

Treatments	Leaf area (dm ² plant ⁻¹)				Leaf area index			
	30 DAS	60 DAS	90 DAS	At harvest	30 DAS	60 DAS	90 DAS	At harvest
T ₁ - 39 th standard week (1 st Oct – 7 th Oct)	2.13 ^{c-d, c}	5.07 ^b	3.53 ^c	2.70 ^c	0.71 ^{cd}	1.69 ^b	1.18 ^c	0.90 ^e
T ₂ - 40 th standard week (8 th Oct – 14 th Oct)	2.38 ^{b-d}	5.15 ^b	3.58 ^c	3.13 ^{bc}	0.79 ^{bc} (11.89)*	1.72 ^b (1.51)	1.19 ^c (1.27)	1.04 ^d (15.76)
T ₃ - 41 st standard week (15 th Oct – 21 st Oct)	2.54 ^{a-c}	5.16 ^b	4.26 ^b	3.41 ^{a-c}	0.85 ^{ab} (19.51)	1.72 ^b (1.74)	1.42 ^b (20.53)	1.14 ^c (26.04)
T ₄ - 42 nd standard week (22 nd Oct – 28 th Oct)	2.74 ^{ab}	5.92 ^a	4.80 ^{ab}	3.52 ^{a-c}	0.91 ^{ab} (28.92)	1.97 ^a (16.64)	1.60 ^a (35.81)	1.17 ^c (30.07)
T ₅ - 43 rd standard week (29 th Oct – 4 th Nov)	2.93 ^a	6.22 ^a	5.23 ^a	4.56 ^a	0.98 ^a (37.85)	2.07 ^a (22.63)	1.74 ^a (47.98)	1.52 ^a (68.49)
T ₆ - 44 th standard week (5 th Nov – 11 th Nov)	2.87 ^a	6.08 ^a	4.92 ^a	4.15 ^{ab}	0.96 ^a (35.05)	2.03 ^a (19.85)	1.64 ^a (39.20)	1.38 ^b (53.55)
T ₇ - 45 th standard week (12 th Nov – 18 th Nov)	1.96 ^{d-e}	4.80 ^{bc}	3.36 ^c	2.44 ^c	0.65 ^d (-7.78)	1.60 ^{bc} (-5.36)	1.12 ^c (-4.93)	0.81 ^e (-9.81)
T ₈ - 46 th standard week (19 th Nov – 25 th Nov)	1.94 ^e	4.52 ^c	3.24 ^c	2.41 ^c	0.65 ^d (-8.72)	1.51 ^c (-10.90)	1.08 ^c (-8.33)	0.80 ^e (-10.80)
Mean	2.44	5.36	4.12	3.29	0.81	1.79	1.37	1.10
SEm _±	0.13	0.16	0.19	0.40	0.04	0.04	0.04	0.03
LSD at 5%	0.40	0.49	0.57	1.21	0.13	0.12	0.14	0.10

DAS – Days after sowing

* Per cent increase / decrease over treatment T₁

Means followed by the same letter do not differ significantly at 5%

At 30 DAS, fifth date of sowing showed a significantly higher LAI (0.98) over rest of the treatments and it was followed by sixth (0.96) and seventh date of sowing (0.91), while temperature regime, fourth date of sowing (0.65) recorded significantly lower leaf area index compared to other treatment, which was at par with seventh (0.65) and first dates of sowing (0.71). The per cent increase for leaf area index was higher in fifth date of sowing (37.85%) over first date. However, eighth date of sowing (-8.72%) and seventh date of sowing (-5.36%) recorded decreased LAI over first date of sowing. Similar trend was also observed at 60 and 90 DAS.

At harvest, slightly decline in LAI was noticed. The treatment fifth date of sowing recorded maximum (1.52) LAI, which was significantly higher over all the treatments, while lower value of the LAI (0.80) was observed in eighth date of sowing, which was on par with seventh and first date of sowing. The per cent increase for leaf area index was higher in fifth date of sowing (68.49%) over first date of sowing. However, eighth date of sowing (-10.80%) and seventh date of sowing (-9.81%) recorded decreased plant height over first date of sowing.

4.4.3 Leaf area duration (LAD, days)

The data pertaining to leaf area duration (LAD) is presented in Table 9 and it indicated that LAD increased from 30-60 to 60-90 DAS. LAD differed significantly between the temperature regime treatments at all growth stages. At 30-60 DAS, the leaf area duration increased from first date of sowing to fifth date of sowing and there after it decreased continuously upto eighth date of sowing. Similar trend was also observed at 60 - 90 and 90 - Harvest. The fifth date of sowing recorded significantly higher LAD (46 days) and it differed significantly with rest of the treatments, but it was on par with sixth (44.7 day) and fourth (43.3 day) dates of sowing. Significantly lower LAD (32.3 day) was recorded in eighth date of sowing, which was on par with first (36 day), second (37.6 day) and seventh (33.8 day) dates of sowing. Similar trend was also noticed at 60-90 DAS, whereas, fifth date of sowing (57 days) continued to have the higher LAD over all other treatments, but was on par with sixth (55 day) date of sowing.

At 90 DAS to harvest, gradual decrease in LAD was noticed, where fifth date of sowing (49 days) recorded significantly higher LAD, which was on par with sixth (45.3 day) date of sowing. Significantly lower LAD (28.3 days) recorded in eighth date of sowing followed by seventh (29 day) and first (31.3 day) dates of sowing.

4.4.4 Leaf area ratio (LAR, $\text{dm}^2 \text{g}^{-1}$)

It is observed from the Table 9 that temperature regime differed significantly at different growth stages with respect to leaf area ratio. Among the temperature regimes, treatment at 30 DAS, the leaf area ratio decreased from first date of sowing to second date of sowing and their after increased continuously upto eighth date of sowing, Second date of sowing recorded significantly higher LAR ($0.918 \text{ dm}^2 \text{ g}^{-1}$) over rest of the treatments and it was on par with first ($0.908 \text{ dm}^2 \text{ g}^{-1}$), third ($0.858 \text{ dm}^2 \text{ g}^{-1}$), seventh ($0.887 \text{ dm}^2 \text{ g}^{-1}$) and eighth ($0.898 \text{ dm}^2 \text{ g}^{-1}$) dates of sowing. The treatment fourth date of sowing recorded significantly lower LAR ($0.808 \text{ dm}^2 \text{ g}^{-1}$) compared to other treatments, but it was on par with fifth, sixth and third date of sowing. Similarly, at 60 DAS, eighth date of sowing ($0.558 \text{ dm}^2 \text{ g}^{-1}$) recorded significantly higher LAR, which was on par with seventh ($0.567 \text{ dm}^2 \text{ g}^{-1}$) and first ($0.560 \text{ dm}^2 \text{ g}^{-1}$) dates of sowing.

At 90 DAS and harvest, no significant difference between the temperature regimes were recorded among the treatments with respect to LAR. At 90 DAS among the temperature regime, higher LAR observed in, eighth date of sowing ($0.212 \text{ dm}^2 \text{ g}^{-1}$) followed by sixth date of sowing ($0.184 \text{ dm}^2 \text{ g}^{-1}$). Similarly at harvest, with second date of sowing ($0.158 \text{ dm}^2 \text{ g}^{-1}$) recorded higher LAR, while fourth date of sowing ($0.132 \text{ dm}^2 \text{ g}^{-1}$) recorded significantly lower LAR.

4.4.5 Specific leaf weight (SLW, mg dm^{-2})

Response of temperature regimes showed a profound effect on the specific leaf weight (SLW) at various growth stages and it is presented in Table 10. It indicated that the temperature regimes and their effects differed significantly at all the growth stages.

Table 9. Effect of temperature regimes on leaf area duration (days) and leaf area ratio (dm² g⁻¹) at different growth stages in chickpea

Treatments	Leaf area duration (LAD)			Leaf area ratio (LAR)			
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	At harvest
T ₁ - 39 th standard week (1 st Oct – 7 th Oct)	36.0 ^{cd}	43.0 ^c	31.3 ^e	0.908 ^{ab}	0.560 ^a	0.206	0.153
T ₂ - 40 th standard week (8 th Oct – 14 th Oct)	37.6 ^{cd}	43.1 ^{bc}	31.1 ^{de}	0.918 ^a	0.507 ^b	0.186	0.158
T ₃ - 41 st standard week (15 th Oct – 21 st Oct)	38.5 ^{bc}	47.1 ^b	38.3 ^{cd}	0.858 ^{abc}	0.442 ^c	0.193	0.150
T ₄ - 42 nd standard week (22 nd Oct – 28 th Oct)	43.3 ^{ab}	53.6 ^a	41.6 ^{bc}	0.808 ^c	0.434 ^c	0.186	0.132
T ₅ - 43 rd standard week (29 th Oct – 4 th Nov)	45.7 ^a	57.3 ^a	48.9 ^a	0.842 ^{bc}	0.423 ^c	0.186	0.156
T ₆ - 44 th standard week (5 th Nov – 11 th Nov)	44.7 ^a	55.0 ^a	45.3 ^{ab}	0.844 ^{bc}	0.433 ^c	0.184	0.150
T ₇ - 45 th standard week (12 th Nov – 18 th Nov)	33.8 ^{cd}	41.0 ^{cd}	29.0 ^e	0.887 ^{ab}	0.567 ^a	0.209	0.149
T ₈ - 46 th standard week (19 th Nov – 25 th Nov)	32.3 ^d	38.8 ^d	28.3 ^e	0.898 ^{ab}	0.558 ^a	0.212	0.155
Mean	39.0	47.6	37.2	0.872	0.494	0.206	0.152
SEm _±	1.7	1.2	1.6	0.020	0.016	0.009	0.008
LSD at 5%	5.2	3.7	5.0	0.060	0.049	NS	NS

NS – Non-significant

DAS – Days after sowing

Means followed by the same letter do not differ significantly at 5%

Table 10. Effect of temperature regimes on specific leaf weight (g dm⁻²) and absolute growth rate (g day⁻¹*100) values at different growth stages in chickpea

Treatments	Specific leaf weight (g/dm ²)				Absolute growth rate (AGR)		
	30 DAS	60 DAS	90 DAS	At harvest	30-60 DAS	60-90 DAS	90 DAS - Harvest
T ₁ - 39 th standard week (1 st Oct – 7 th Oct)	0.62 ^{bc}	0.77 ^{cd}	0.71 ^{abc}	0.68 ^{abc}	22.41 ^{bc}	27.11 ^{c-d}	1.50 ^{e-f}
T ₂ - 40 th standard week (8 th Oct – 14 th Oct)	0.62 ^{bc} (0.00)	0.77 ^{bc} (0.00)	0.73 ^{abc} (2.80)	0.69 ^{ab} (1.47)	25.21 ^{bc}	30.33 ^{c-d}	1.87 ^{d-e}
T ₃ - 41 st standard week (15 th Oct – 21 st Oct)	0.62 ^{bc} (0.00)	0.78 ^{abc} (1.29)	0.72 ^{abc} (1.40)	0.70 ^{ab} (2.93)	29.07 ^{ab}	34.72 ^{bc}	2.21 ^{c-d}
T ₄ - 42 nd standard week (22 nd Oct – 28 th Oct)	0.63 ^{bc} (1.61)	0.79 ^{ab} (2.59)	0.74 ^{ab} (3.14)	0.71 ^{ab} (4.41)	34.10 ^a	40.77 ^{ab}	2.85 ^{bc}
T ₅ - 43 rd standard week (29 th Oct – 4 th Nov)	0.70 ^a (12.90)	0.79 ^a (2.59)	0.77 ^a (7.80)	0.72 ^a (5.88)	37.40 ^a	44.52 ^a	3.74 ^a
T ₆ - 44 th standard week (5 th Nov – 11 th Nov)	0.67 ^{ab} (8.06)	0.79 ^{ab} (2.59)	0.75 ^a (6.04)	0.71 ^{ab} (5.34)	35.46 ^a	42.31 ^{ab}	3.29 ^{ab}
T ₇ - 45 th standard week (12 th Nov – 18 th Nov)	0.61 ^c (-1.16)	0.75 ^{de} (-2.59)	0.69 ^{bc} (-2.81)	0.66 ^{bc} (-2.94)	20.86 ^{bc}	25.26 ^d	2.15 ^{f-g}
T ₈ - 46 th standard week (19 th Nov – 25 th Nov)	0.59 ^c (-4.83)	0.74 ^e (-3.89)	0.66 ^c (-70.4)	0.64 ^c (-5.88)	19.77 ^{Sc}	24.00 ^d	0.77 ^g
Mean	0.63	0.77	0.72	0.69	28.21	34.40	2.24
SEm±	0.17	0.05	0.18	0.16	2.70	2.51	0.21
LSD at 5%	0.52	0.15	0.53	0.47	8.11	7.72	0.63

DAS – Days after sowing

* Per cent increase / decrease over treatment T₁

Means followed by the same letter do not differ significantly at 5%

The SLW showed a significant differences among temperature regimes at 30, 60 and 90 DAS and slight decline at harvest.

At 30 DAS, a constant specific leaf weight maintained from first date of sowing to fifth date of sowing and there after it decreased continuously upto eighth date of sowing. Similar trend was also observed at 60 and 90 DAS. The fifth date of sowing (0.70 mg dm^{-2}) recorded significantly higher SLW, which was on par with all other treatment except seventh and eighth date of sowing, whereas, at 60 DAS fifth date of sowing (0.79 mg dm^{-2}) recorded significantly higher SLW as compared to other treatments and it was followed by fourth and sixth dates of sowing. Lower SLW (0.74 mg dm^{-2}) was noticed in eighth date of sowing, which was on par with seventh (0.61 mg dm^{-2}) and first (0.62 mg dm^{-2}) date of sowing.

Similar trend was noticed at 90 DAS with fifth date of sowing (7.77 mg dm^{-2}) sustained to have higher SLW over other treatments and on par with sixth (0.75 mg dm^{-2}), first (0.71 mg dm^{-2}), second (0.73 mg dm^{-2}) and fourth (0.71 mg dm^{-2}) dates of sowing. While at harvest, similar trend was followed as that of 90 DAS. The per cent increase for specific leaf weight was higher in fifth date of sowing (7.80%) over first date of sowing. However, eighth date of sowing (-6.50%) and seventh date of sowing (-3.99%) recorded decreased SLW over first date of sowing.

At harvest, the specific leaf weight increased from first date of sowing to fifth date of sowing and their after it decreased continuously upto eighth date of sowing. The treatment, fifth date of sowing (6.70 mg dm^{-2}) recorded significantly higher SLW, which was on par with all other treatment except seventh (0.66 mg dm^{-2}) and eighth (0.64 mg dm^{-2}) date of sowing. Lower SLW (0.74 mg dm^{-2}) was noticed in eighth date of sowing, which was on par with seventh (0.66 mg dm^{-2}) and first (0.68 mg dm^{-2}) date of sowing. The per cent increase for specific leaf weight was higher in fifth date of sowing (6.06%) over first date of sowing. However, eighth date of sowing (-5.66%) and seventh date of sowing (-1.85%) recorded decreased SLW over first date of sowing.

4.4.6 Absolute growth rate ($\text{g day}^{-1} \times 100$)

The results on absolute growth rate (AGR) indicated significant differences among the treatments as represented in Table 10. The AGR in all the treatments increased from 30-60 DAS to 60-90 DAS. The AGR differed significantly due to temperature regime treatments.

During 30-60 DAS, the AGR increased from first date of sowing to fifth date of sowing and their after decreases continuously upto eighth date of sowing Similar trend was observed at 60-90 DAS and 90 DAS- harvest. The fifth date of sowing (37.40 g day^{-1}) recorded significantly higher AGR, over all the treatments, which did not differ significantly with fourth (34.10 g day^{-1}) and sixth (35.46 g day^{-1}) dates of sowing. However, eighth date of sowing (19.77 g day^{-1}) found to have the lowest AGR among all the treatments, but it was on par with seventh (20.86 g day^{-1}), second (25.21 g day^{-1}) and first (22.41 g day^{-1}) dates of sowing.

Similar trend was also observed at 60-90 DAS and 90 DAS-harvest, where fifth date of sowing continued to have recorded significantly higher AGR (44.5 g day^{-1} and 3.74 g day^{-1} , respectively) at both the stages, which was followed the sixth (42.31 g day^{-1} and 3.29 g day^{-1} , respectively) date of sowing. Significantly lower AGR at both stages (24.00 g day^{-1} and 0.77 g day^{-1} , respectively) was recorded in eighth date of sowing, which was followed by seventh (22.26 g day^{-1} and 2.15 g day^{-1} , respectively) date of sowing.

4.4.7 Crop growth rate ($\text{g dm}^{-2} \text{ day}^{-1}$)

The data presented in Table 11 indicated significant differences in crop growth rate (CGR) among the temperature regime treatments at all the stages. CGR increased continuously upto 90 DAS- harvest in all the treatments at all the stages and there was a decline in CGR with advancement in crop growth. Maximum CGR was recorded at 60-90 DAS and decreased thereafter. During 30-60 DAS, CGR values increased from first date of sowing to fifth date of sowing and their after it decreased continuously upto eighth date of sowing. Similar trend was observed at 60-90 DAS and 90 DAS-harvest.

Table 11. Effect of temperature regimes on crop growth rate ($\text{g dm}^{-2} \text{day}^{-1} \times 1000$), relative growth rate ($\text{g day}^{-1} \times 1000$) and net assimilation rate rate ($\text{g dm}^{-2} \text{day} \times 1000$) at different growth stages in chickpea

Treatments	Crop growth rate (CGR)			Relative growth rate (RGR)			Net assimilation rate (NAR)		
	30-60 DAS	60-90 DAS	90 DAS - Harvest	30-60 DAS	60-90 DAS	90 DAS - Harvest	30 DAS	60 DAS	90 DAS
T ₁ - 39 th standard week (1 st Oct – 7 th Oct)	7.47 ^{c-d}	9.04 ^{c-d}	0.50 ^{bc}	19.60 ^{ab}	9.27	0.37 ^b	28.73 ^c	27.66 ^b	2.09 ^d
T ₂ - 40 th standard week (8 th Oct – 14 th Oct)	8.40 ^c	10.14 ^{bc}	0.62 ^{bc}	19.78 ^{ab}	9.28	0.42 ^b	30.53 ^{bc} (6.28) *	30.62 ^{ab} (10.69)	2.43 ^c (16.06)
T ₃ - 41 st standard week (15 th Oct – 21 st Oct)	9.69 ^b	11.57 ^b	0.74 ^{bc}	19.87 ^{ab}	9.23	0.43 ^b	34.15 ^{abc} (18.89)	32.11 ^{ab} (16.10)	2.51 ^c (19.89)
T ₄ - 42 nd standard week (22 nd Oct – 28 th Oct)	11.37 ^a	13.59 ^a	0.95 ^{a-c}	20.13 ^{ab}	9.28	0.47 ^{ab}	35.89 ^{ab} (24.96)	33.16 ^a (19.90)	3.00 ^b (43.11)
T ₅ - 43 rd standard week (29 th Oct – 4 th Nov)	12.47 ^a	14.84 ^a	1.25 ^a	20.86 ^a	9.36	0.57 ^a	37.16 ^a (29.37)	33.86 ^a (22.42)	3.34 ^a (59.57)
T ₆ - 44 th standard week (5 th Nov – 11 th Nov)	11.82 ^a	14.10 ^a	1.10 ^{ab}	20.53 ^{ab}	9.32	0.53 ^{ab}	36.02 ^{ab} (25.41)	33.53 ^a (21.24)	3.16 ^a (51.00)
T ₇ - 45 th standard week (12 th Nov – 18 th Nov)	6.95 ^{c-d}	8.42 ^{c-d}	0.31 ^c	19.44 ^{ab}	9.21	0.25 ^c	28.57 ^c (-0.55)	27.17 ^b (-1.75)	1.40 ^e (-32.93)
T ₈ - 46 th standard week (19 th Nov – 25 th Nov)	6.59 ^d	8.00 ^d	0.26 ^c	19.12 ^b	9.28	0.22 ^c	28.16 ^c (-1.97)	27.12 ^b (-1.97)	1.20 ^f (-42.78)
Mean	9.32	11.24	7.12	19.92	9.30	0.41	32.41	30.72	2.45
SEm _±	5.10	6.00	2.01	0.50	0.22	0.11	1.80	1.61	0.10
LSD at 5%	14.12	17.20	6.04	1.62	NS	0.10	5.50	4.88	0.22

DAS – Days after sowing

NS – Non-significant

Means followed by the same letter do not differ significantly at 5%

Among the temperature regime treatments, fifth date of sowing ($12.47 \text{ g dm}^{-2} \text{ day}^{-1}$) recorded significantly higher CGR value, which was on par with fourth and sixth ($11.82 \text{ g dm}^{-2} \text{ day}^{-1}$) date of sowing, while lower CGR ($6.59 \text{ g dm}^{-2} \text{ day}^{-1}$) was observed in eighth date of sowing, which was significantly lower compared to all other treatments, but it was on par with seventh ($6.95 \text{ g dm}^{-2} \text{ day}^{-1}$) and eighth ($6.59 \text{ g dm}^{-2} \text{ day}^{-1}$) dates of sowing treatments.

At 60-90 DAS, fifth date of sowing continued to record significantly higher CGR ($14.84 \text{ g dm}^{-2} \text{ day}^{-1}$), which was significantly higher over rest of the treatments and was on par with sixth ($14.10 \text{ g dm}^{-2} \text{ day}^{-1}$), fourth ($13.59 \text{ g dm}^{-2} \text{ day}^{-1}$) dates of sowing treatments. However eighth date of sowing exhibited a lower CGR ($8.0 \text{ g dm}^{-2} \text{ day}^{-1}$) and it was followed by seventh ($8.42 \text{ g dm}^{-2} \text{ day}^{-1}$) and first ($9.04 \text{ g dm}^{-2} \text{ day}^{-1}$) dates of sowing.

Similar trends were noticed at 90 DAS-harvest, where fifth date of sowing sustained to have higher CGR ($1.25 \text{ g dm}^{-2} \text{ day}^{-1}$) compared to rest of the treatments and followed by fourth ($0.95 \text{ g dm}^{-2} \text{ day}^{-1}$) and sixth ($1.10 \text{ g dm}^{-2} \text{ day}^{-1}$) dates of sowing. While, eighth date of sowing recorded significantly lower CGR ($2.6 \text{ g dm}^{-2} \text{ day}^{-1}$) but it was on par with rest of the treatments except fourth ($0.95 \text{ g dm}^{-2} \text{ day}^{-1}$) and fifth ($1.25 \text{ g dm}^{-2} \text{ day}^{-1}$) dates of sowing.

4.4.8 Relative growth rate (RGR, g day^{-1})

The effect of temperature regimes on relative growth rate (RGR) is presented in Table 11. It is evident that irrespective of the temperature regime treatments there was decline in RGR as crop growth advances and maximum RGR was noticed at 30-60 DAS.

At 30-60 DAS, RGR values were increased from first date of sowing to fifth date of sowing and their after decreased continuously upto eighth date of sowing. Similar trend was also observed at 60-90 DAS and 90 DAS-harvest. Among the temperature regime treatments, fifth date of sowing showed significantly higher RGR (20.86 g day^{-1}), which was on par with all the treatments except eighth (19.12 g day^{-1}) date of sowing. Among the treatments significantly lower RGR (19.12 g day^{-1}) was recorded in eighth date of sowing (20.53 g day^{-1}).

During 90 DAS to harvest fifth date of sowing recorded significantly higher RGR (0.57 g day^{-1}) which was significantly more compared to eighth date of sowing, while it did not differ significantly among the treatments. Significantly lower RGR (0.22 g day^{-1}) was recorded by eighth date of sowing.

4.4.9 Net assimilation rate (NAR, $\text{g dm}^{-2} \text{ day}^{-1}$)

Observations on net assimilation rate (NAR) are presented in Table 11. It showed a steady decline in the net assimilation rate with advancement in crop growth irrespective of treatments. The NAR observed at 30-60 DAS was highest and it decreased thereafter. Significant differences were noticed among the temperature regimes *ie.*, sowing dates at all the stages of crop growth.

During 30-60 DAS, NAR values were increased from first date of sowing to fifth date of sowing and their after decreases continuously upto eighth date of sowing, Similar trend was followed at 60 and 90 DAS. Among the temperature regimes treatments fifth date of sowing recorded significantly higher NAR ($37.16 \text{ g dm}^{-2} \text{ day}^{-1}$) over all other treatments. However, it was on par with third, fourth ($35.89 \text{ g dm}^{-2} \text{ day}^{-1}$) and sixth ($36.02 \text{ g dm}^{-2} \text{ day}^{-1}$) dates of sowing. The minimum NAR ($28.16 \text{ g dm}^{-2} \text{ day}^{-1}$) was noticed in eighth date of sowing, which was significantly lower compared to rest of the treatments but did not differ significantly with seventh ($28.57 \text{ g dm}^{-2} \text{ day}^{-1}$), second ($30.53 \text{ g dm}^{-2} \text{ day}^{-1}$) and first ($28.73 \text{ g dm}^{-2} \text{ day}^{-1}$) dates of sowing. Similarly at 60-90 DAS, fifth date of sowing recorded significantly higher NAR ($33.86 \text{ g dm}^{-2} \text{ day}^{-1}$), which was followed by sixth ($33.53 \text{ g dm}^{-2} \text{ day}^{-1}$) date of sowing. Significantly lower NAR ($27.12 \text{ g dm}^{-2} \text{ day}^{-1}$) by eighth date of sowing when compared to all other treatments. Similar trend was also observed at 90 DAS- harvest.

The per cent increase for NAR was higher in fifth date of sowing (29.37%) over first date of sowing. However, eighth date of sowing (-1.97%) and seventh date of sowing (-0.55%) recorded decreased NAR over first date of sowing.

4.4.10 SPAD values

The data related to SPAD values is presented in Table 12. It showed significant differences in SPAD values between various temperature regime treatments.

Among the temperature regime treatments, the SPAD values increased from first date of sowing to upto eighth date of sowing continuously. Similar trend was followed at 60 and 90 DAS.

At 30 DAS, eighth date of sowing recorded significantly higher SPAD value (27.8), which was on par with seventh date of sowing (25.3), whereas, first date of sowing recorded significantly lower (18.6) SPAD value. All the treatments were on par with first date of sowing except eighth and seventh date of sowing. At 60 DAS, second date of sowing recorded significantly higher SPAD value (42.9), which was on par with sixth (42.4) and third dates of sowing (38), while, fourth date of sowing recorded significantly lower SPAD values (31.2).

Similar trend was also noticed at 90 DAS with eighth date of sowing, recording significantly higher SPAD value, which was on par with fourth (60.7) and third (52.8) dates of sowing.

4.4.11 Relative water content (RWC, %)

Results obtained on relative water content (RWC) revealed that the temperature regimes at 30, 60, 90 DAS differed significantly (Table 12). Among the temperature regime treatments, the RWC decreased from first date of sowing continuously upto eighth date of sowing.

At 30 DAS, first date of sowing recorded significantly higher (85.17%) relative water content, followed by second (84.26%) and fourth (83.21%), but was on par with fourth and fifth dates of sowing. While significantly lower RWC (81.45%) was recorded by seventh date of sowing followed by eighth date of sowing (81.45%). Similar trend was also followed at 60 and 90 DAS. The per cent decrease in eighth date of sowing recorded maximum (-5.06%) and minimum in second date of sowing, recorded lowest (-0.93%) over first date of sowing.

4.5 Biochemical parameters

4.5.1 Chlorophyll 'a' content (mg g^{-1} fr. wt.)

The data on effect of temperature regimes on chlorophyll 'a' content in leaf at different growth stages is presented in Table 13. It was observed that chlorophyll content decreased at later stage of crop growth i.e., 60 DAS. Significant differences in chlorophyll 'a' content was found among the treatments of temperature regimes.

At 30 DAS, chlorophyll 'a' content decreased continuously from first date of sowing to eighth date of sowing. Similar trend was also followed at 60 and 90 DAS. Among the treatments, second date of sowing (1.627 mg g^{-1} fr. wt.) recorded significantly higher chlorophyll 'a' content over all other treatments, but did not differ significantly with third (1.169 mg g^{-1} fr. wt), fourth (1.601 mg g^{-1} fr. wt) and fifth (1.519 mg g^{-1} fr. wt) dates of sowing. Similarly, lower chlorophyll 'a' content (1.490 mg g^{-1} fr. wt.) was observed in eighth date of sowing, which is on par with seventh (1.143 mg g^{-1} fr. wt), fifth (1.159 mg g^{-1} fr. wt) and fourth (1.601 mg g^{-1} fr. wt) dates of sowing.

Similar trend as that of 30 DAS, was observed at 60 DAS also, where all the temperature regime treatments recorded higher chlorophyll 'a' content over first date of sowing (2.295 mg g^{-1} fr. wt). The treatment sixth date of sowing exhibited significantly higher chlorophyll 'a' content (2.204 mg g^{-1} fr. wt.) over rest of the treatments.

The observations recorded at 90 DAS revealed that a significant reduction in chlorophyll 'a' content. The treatment first date of sowing exhibited significantly higher chlorophyll 'a' content (1.178 mg g^{-1} fr. wt.) over all other treatments which was on par with the content in leaf up to sixth dates of sowing. While eighth date of sowing recorded significantly lower chlorophyll 'a' content (1.069 mg g^{-1} fr. wt.) than any other treatments however it did not differ significantly with eighth date of sowing.

4.5.2 Chlorophyll 'b' content (mg g^{-1} fr. wt.)

The data regarding the influence of temperature regimes on chlorophyll 'b' content in a leaf at different growth stages were presented in Table 13, where, the chlorophyll 'b' content decreased at the later stages of the crop growth and it differed significantly with all the temperature regime treatments at all the stages.

Table 12. Effect of temperature regimes on SPAD values and relative water content (%) at different growth stages in chickpea

Treatments	SPAD values			Relative Water Content (RWC)		
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
T ₁ - 39 th standard week (1 st Oct – 7 th Oct)	18.6 ^c	34.9 ^{bc}	52.9 ^c	85.17 ^a	76.45 ^a	71.24 ^{ab}
T ₂ - 40 th standard week (8 th Oct – 14 th Oct)	17.4 ^c	42.9 ^a	58.4 ^{bc}	84.26 ^a (-1.07)	75.95 ^a (-1.48)	71.56 ^{ab} (0.45)
T ₃ - 41 st standard week (15 th Oct – 21 st Oct)	17.5 ^c	38.0 ^{ab}	52.8 ^c	84.38 ^a (-0.93)	75.32 ^a (-1.31)	72.08 ^{ab} (1.18)
T ₄ - 42 nd standard week (22 nd Oct – 28 th Oct)	20.8 ^{bc}	31.2 ^c	60.7 ^{ab}	83.21 ^{ab} (-2.30)	75.45 ^a (-2.08)	72.47 ^a (1.73)
T ₅ - 43 rd standard week (29 th Oct – 4 th Nov)	22.0 ^{bc}	33.9 ^{bc}	58.3 ^{bc}	83.10 ^{ab} (-2.43)	74.86 ^{ab} (-2.51)	72.10 ^{ab} (1.21)
T ₆ - 44 th standard week (5 th Nov – 11 th Nov)	21.6 ^{bc}	42.4 ^a	57.0 ^{bc}	82.78 ^{ab} (-2.81)	74.53 ^{ab} (-4.24)	71.14 ^{ab} (0.14)
T ₇ - 45 th standard week (12 th Nov – 18 th Nov)	25.3 ^{ab}	33.6 ^{bc}	58.1 ^{bc}	81.45 ^b (-4.37)	73.21 ^{bc} (-5.23)	70.35 ^{ab} (-1.25)
T ₈ - 46 th standard week (19 th Nov – 25 th Nov)	27.8 ^a	35.4 ^{bc}	66.7 ^a	80.87 ^b (-5.06)	72.45 ^c (-5.23)	70.05 ^b (-1.67)
Mean	21.36	36.52	58.12	83.15	74.78	71.38
SEm _±	1.81	1.84	2.10	83.15	74.77	71.37
LSD at 5%	5.50	5.59	6.38	2.18	1.76	1.92

DAS – Days after sowing

* Per cent increase / decrease over treatment T₁

Means followed by the same letter do not differ significantly at 5%

Table 13. Effect of temperature regimes chlorophyll a, b, total chlorophyll (mg g⁻¹ fr. wt.) and chlorophyll a/b ratio at different growth stages in chickpea

Treatments	Chlorophyll 'a'			Chlorophyll 'b'			Total chlorophyll			Chlorophyll a/b ratio		
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
T ₁ - 39 th standard week (1 st Oct – 7 th Oct)	1.642 ^a	2.295	1.178 ^a	0.522 ^a	0.808 ^a	0.392 ^a	2.164 ^a	3.103 ^a	1.570 ^a	3.149 ^d	2.840	3.005 ^c
T ₂ - 40 th standard week (8 th Oct – 14 th Oct)	1.627 ^a	2.275	1.166 ^{ab}	0.500 ^{ab}	0.801 ^a	0.384 ^{ab}	2.127 ^a	3.076 ^{ab}	1.550 ^{ab}	3.257 ^{cd}	2.840	3.036 ^c
T ₃ - 41 st standard week (15 th Oct – 21 st Oct)	1.619 ^{ab}	2.258	1.154 ^{a-c}	0.492 ^{ab}	0.779 ^{ab}	0.369 ^{a-c}	2.111 ^a	3.037 ^{a-c}	1.523 ^{a-c}	3.293 ^{cd}	2.898	3.126 ^{bc}
T ₄ - 42 nd standard week (22 nd Oct – 28 th Oct)	1.601 ^{a-c}	2.217	1.130 ^{a-c}	0.465 ^{a-c}	0.766 ^{ab}	0.361 ^{a-c}	2.066 ^{ab}	2.984 ^{a-d}	1.491 ^{a-d}	3.444 ^{abc}	2.894	3.128 ^{bc}
T ₅ - 43 rd standard week (29 th Oct – 4 th Nov)	1.519 ^{a-c}	2.204	1.125 ^{a-c}	0.450 ^{bc}	0.752 ^{ab}	0.352 ^{a-c}	1.969 ^{bc}	2.957 ^{b-d}	1.477 ^{a-d}	3.377 ^{bc}	2.930	3.193 ^{ab}
T ₆ - 44 th standard week (5 th Nov – 11 th Nov)	1.497 ^{bc}	2.188	1.102 ^{a-c}	0.436 ^{bc}	0.744 ^{ab}	0.342 ^{a-c}	1.933 ^c	2.932 ^{c-d}	1.444 ^{b-d}	3.434 ^{abc}	2.940	3.219 ^{ab}
T ₇ - 45 th standard week (12 th Nov – 18 th Nov)	1.493 ^c	2.162	1.089 ^{bc}	0.419 ^c	0.727 ^b	0.328 ^{bc}	1.912 ^c	2.889 ^d	1.417 ^{c-d}	3.563 ^{ab}	2.972	3.315 ^a
T ₈ - 46 th standard week (19 th Nov – 25 th Nov)	1.490 ^c	2.150	1.069 ^c	0.413 ^c	0.721 ^b	0.320 ^c	1.903 ^c	2.871 ^d	1.390 ^d	2.980 ^a	2.980	3.338 ^a
Mean	1.561	2.219	1.127	0.462	0.762	0.356	2.023	2.981	1.483	3.312	2.912	3.170
SEm _±	0.038	0.036	0.026	0.020	0.019	0.017	0.035	0.037	0.032	0.063	0.043	0.046
LSD at 5%	0.114	NS	0.078	0.060	0.058	0.052	0.107	0.113	0.097	0.190	NS	0.138

NS – Non-significant

DAS – Days after sowing

Means followed by the same letter do not differ significantly at 5%.

At 30 DAS, chlorophyll 'b' content in leaf decreased from first date of sowing to eighth date of sowing. Similar trend was followed at 60 and 90 DAS. The first date of sowing recorded significantly higher chlorophyll 'b' content ($0.522 \text{ mg g}^{-1} \text{ fr. wt.}$), which was on par with second, third and fourth dates of sowing treatments. Eighth date of sowing exhibited significantly lower chlorophyll 'b' content ($0.413 \text{ mg g}^{-1} \text{ fr. wt.}$), which was followed by seventh ($0.419 \text{ mg g}^{-1} \text{ fr. wt.}$), sixth ($0.436 \text{ mg g}^{-1} \text{ fr. wt.}$), fifth ($0.450 \text{ mg g}^{-1} \text{ fr. wt.}$) and fourth ($0.465 \text{ mg g}^{-1} \text{ fr. wt.}$) date of sowing.

Similar trend was observed at 60 DAS, where first date of sowing recorded significantly higher chlorophyll 'b' content ($0.808 \text{ mg g}^{-1} \text{ fr. wt.}$), whereas eighth date of sowing recorded significantly lower chlorophyll 'b' content ($0.721 \text{ mg g}^{-1} \text{ fr. wt.}$), which was at par with all other treatments except first ($0.808 \text{ mg g}^{-1} \text{ fr. wt.}$) and second date of sowing ($0.801 \text{ mg g}^{-1} \text{ fr. wt.}$).

Eventhough a decrease in chlorophyll 'b' content was observed in 90 DAS, the temperature regime treatment had shown a significant differences among them. Among the temperature regime treatments, first date of sowing recorded significantly higher chlorophyll 'b' content ($0.392 \text{ mg g}^{-1} \text{ fr. wt.}$), which was at par with all other treatments except seventh and first date of sowing. The temperature regime ie., eighth date of sowing exhibited lower chlorophyll 'b' content ($0.320 \text{ mg g}^{-1} \text{ fr. wt.}$) as compared to all other treatments except first ($0.392 \text{ mg g}^{-1} \text{ fr. wt.}$) and second date of sowing ($0.384 \text{ mg g}^{-1} \text{ fr. wt.}$).

4.5.3 Total chlorophyll content ($\text{mg g}^{-1} \text{ fr. wt.}$)

Though the total chlorophyll content was highest at 60 DAS in general, but total chlorophyll content showed a decreasing trend as crop attained maturity irrespective of temperature regimes. At 30 DAS, total chlorophyll content decreased gradually from first date of sowing to eighth date of sowing. Similar trend was followed at 60 and 90 DAS. Among the treatments, first date of sowing recorded significantly higher total chlorophyll content ($2.164 \text{ mg g}^{-1} \text{ fr. wt.}$), which was at par with second, third and fourth date of sowing. The first date of sowing recorded significantly lower total chlorophyll content ($1.903 \text{ mg g}^{-1} \text{ fr. wt.}$), which did not differ significantly with seventh ($1.912 \text{ mg g}^{-1} \text{ fr. wt.}$), eighth ($1.903 \text{ mg g}^{-1} \text{ fr. wt.}$) and fifth dates of sowing ($1.969 \text{ mg g}^{-1} \text{ fr. wt.}$) (Table 13).

Similar observations were also noticed at 60 DAS, where first date of sowing continued to record significantly higher total chlorophyll content in leaf ($3.103 \text{ mg g}^{-1} \text{ fr. wt.}$) over rest of the treatments, which was at par with second, third and fourth dates of sowing. Among the treatments, significantly lower total chlorophyll content ($2.871 \text{ mg g}^{-1} \text{ fr. wt.}$) was recorded in eighth date of sowing and followed by seventh ($2.889 \text{ mg g}^{-1} \text{ fr. wt.}$) and it was at par with sixth ($2.932 \text{ mg g}^{-1} \text{ fr. wt.}$) and fifth date of sowing ($2.957 \text{ mg g}^{-1} \text{ fr. wt.}$).

At 90 DAS, first date of sowing has significantly higher total chlorophyll content ($1.570 \text{ mg g}^{-1} \text{ fr. wt.}$), which was on par with second, third, fourth and fifth dates of sowing. The treatment second date of sowing recorded significantly lower total chlorophyll content ($1.390 \text{ mg g}^{-1} \text{ fr. wt.}$) when compared to all other treatments, but was on par with seventh ($1.417 \text{ mg g}^{-1} \text{ fr. wt.}$), sixth ($1.444 \text{ mg g}^{-1} \text{ fr. wt.}$), fifth ($1.477 \text{ mg g}^{-1} \text{ fr. wt.}$) and fourth dates of sowing ($1.491 \text{ mg g}^{-1} \text{ fr. wt.}$).

4.5.4 Chlorophyll a/b ratio

The data on chlorophyll a/b ratio is presented in Table 13, which indicated significant differences among the treatments, dates of sowing. At 30 DAS, chlorophyll a/b ratio were increased gradually from first date of sowing to fourth date of sowing, and their after decreased in fifth date of sowing and again increased upto eighth date of sowing. Among the temperature regimes, seventh date of sowing (3.563) recorded significantly higher chlorophyll a/b ratio, which was on par with the treatments seventh, eighth and fourth dates of sowing. Significantly lower chlorophyll a/b ratio (3.149) was observed in first date of sowing, which was on par with second and third dates of sowing. Among the treatments, eighth date of sowing continued to have higher chlorophyll a/b ratio (2.980) at 60 DAS, while no significant difference was found among the treatments. The treatment, first date of sowing recorded lower chlorophyll a/b ratio (2.840) followed by second date of sowing (2.212).

Table 14. Effect of temperature regimes on yield and yield components in chickpea

Treatments	Grain yield (g plant ⁻¹)	Haulm yield (g plant ⁻¹)	Harvest index (%)	100 seed weight (g)	Yield (q ha ⁻¹)
T ₁ - 39 th standard week (1 st Oct – 7 th Oct)	7.14 ^{cd}	2.32	40.49 ^{bc}	20.14	21.89 ^b
T ₂ - 40 th standard week (8 th Oct – 14 th Oct)	8.32 ^{cd} (16.39) *	2.58 (11.21)	41.90 ^{bc} (3.48)	20.62 (2.35)	22.80 ^b (4.18)
T ₃ - 41 st standard week (15 th Oct – 21 st Oct)	9.98 ^{bc} (39.69)	3.43 (47.84)	43.85 ^b (8.29)	20.76 (3.04)	24.92 ^{ab} (13.82)
T ₄ - 42 nd standard week (22 nd Oct – 28 th Oct)	12.80 ^{ab} (79.16)	3.62 (56.03)	47.93 ^a (18.38)	21.17 (5.11)	25.42 ^{ab} (16.11)
T ₅ - 43 rd standard week (29 th Oct – 4 th Nov)	14.20 ^a (98.81)	3.73 (60.78)	48.67 ^a (20.20)	21.50 (6.72)	28.54 ^a (30.37)
T ₆ - 44 th standard week (5 th Nov – 11 th Nov)	13.36 ^a (86.99)	3.65 (57.34)	48.20 ^a (19.03)	21.32 (5.84)	27.53 ^a (25.77)
T ₇ - 45 th standard week (12 th Nov – 18 th Nov)	6.45 ^d (-9.65)	2.28 (-1.72)	39.54 ^c (-2.35)	19.37 (-3.84)	17.80 ^c (-18.70)
T ₈ - 46 th standard week (19 th Nov – 25 th Nov)	6.11 ^d (-14.41)	2.25 (-3.02)	39.39 ^c (-2.73)	18.87 (-6.30)	15.46 ^c (-29.40)
Mean	9.80	2.98	43.75	20.47	23.04
SEm _±	1.04	0.32	1.18	0.87	1.29
LSD at 5%	3.16	NS	3.58	NS	3.92

NS – Non-significant

* Per cent increase / decrease over treatment T₁

Means followed by the same letter do not differ significantly at 5%.

4.6 Yield and yield components

The results of effect of temperature regimes on yield and its various yield components in chickpea are presented in Table 14. It is clear that, seed yield (g plant^{-1}), harvest index (%) and yield (q ha^{-1}) recorded significant differences among the temperature regimes.

4.6.1 Seed yield (g plant^{-1})

Among all treatments, seed yield (g plant^{-1}), was increased from first date of sowing to fifth date of sowing and then after it decreases continuously upto eighth date of sowing. Among the temperature regime treatments fifth date of sowing recorded significantly higher grain yield (14.20 g) followed by sixth (13.36 g) and fourth date of sowing (12.80 g) which were at par among themselves. Significantly lower seed yield was observed in eighth date of sowing followed by seventh (6.45 g), which were on par with eighth (6.11 g), first (7.14 g), second (8.32 g) and third dates of sowing (9.98 g). Seed yield per cent increase was maximum with fifth (98.81 %), while lowest in second date of sowing over first date of sowing. However per cent decrease was noticed in treatments seventh (-9.50 %) and eighth dates of sowing (-14.41 %).

4.6.2 Haulm yield (g plant^{-1})

It is evident from Table 14 that there was no significant differences in haulm yield due to temperature regime treatments. However among the treatments, haulm yield were increased from first date of sowing to fifth date of sowing and then after decreases continuously upto eighth date of sowing. Among the temperature regime treatments fifth date of sowing recorded higher haulm yield (3.73 g) while eighth date of sowing recorded lower haulm yield. The per cent increase in haulm yield was highest (60.78 g) in fifth date of sowing, while lowest per cent increase was recorded as 11.21 in second date of sowing over first date of sowing. While, per cent decrease values were noticed in the treatments seventh (-1.72 g) and eighth date of sowing (-3.02 g).

4.6.3 Harvest index (%)

The data on the harvest index is specified in Table 14. It indicates significant differences due to various temperature regime treatments. Among the temperature regime treatments, harvest index was increased from first date of sowing to sixth date of sowing and then after it decreased continuously upto eighth date of sowing. The fifth date of sowing recorded higher value of harvest index (48.67%) followed by sixth date of sowing (48.20%) and fourth date of sowing (47.93%). Significantly lower value of harvest index was noticed in eighth date of sowing (39.39%) followed by seventh (39.54%) but both were on par with third (43.85%) and second dates of sowing (41.90%).

The per cent increase in harvest index value recorded highest in fifth date of sowing (20.20%) over first date of sowing, while lowest was (3.48%) in second. However the per cent decrease in harvest index value were noticed in seventh (-2.35%) and eighth (-2.73%) dates of sowing over first date of sowing.

4.6.4 100-seed weight (g)

The data on 100-seed weight is presented in Table 14 indicated that no significant influence of temperature regimes on 100-seed weight. However 100-seed weight increased from first date of sowing to fifth date of sowing and then after decreased continuously upto eighth date of sowing. The temperature regime treatment fifth dates of sowing recorded significantly higher (21.50 g) 100-seed weight and eighth date of sowing recorded significantly lower (18.87 g). The per cent increase in 100-seed weight was recorded maximum (6.72%) in fifth date of sowing, whereas, lower 100 seed weight recorded in second date of sowing (2.35%) over first date of sowing. And per cent decrease value recorded maximum in eighth date of sowing (-6.30%) and minimum in seventh date of sowing (-3.38%) over first date of sowing.

4.6.5 Yield (q ha^{-1})

The data related to seed yield quintals per ha revealed significant differences due to temperature regime treatments (Table 14).

Among the temperature regimes treatment, the yield increased from first date of sowing to fifth date of sowing and then after decreased continuously upto eighth date of sowing. The fifth date of sowing maintained significantly higher yield (28.54 q ha^{-1}) followed by sixth (27.53 q ha^{-1}), but it was on par with third (24.92 q ha^{-1}) and first (21.89 q ha^{-1}) dates of sowing. While, significantly lower yield (15.46 q ha^{-1}) was recorded in eighth date of sowing followed by seventh date of sowing (17.80 q ha^{-1}).

The per cent increase in yield was recorded maximum (30.37%) in treatment fifth date of sowing, while the lowest (4.18 %) in second date of sowing over first dates of sowing. while the per cent decrease over first date of sowing was recorded in treatment seventh (-18.70) and eighth dates of sowing (-29.40%).

5. DISCUSSION

Pulses are widely recognized to be an impressive symbol of agricultural economy being a major source of protein in vegetarian diet and also improve the soil fertility through nitrogen fixing capability. Among different legume crops grown in the country, chickpea (*Cicer arietinum* L.) is the premier pulse crop of Indian subcontinent, which contributes a lot in supplementing production due to its adaptability to suboptimal soil water conditions. It is an excellent source of major nutrients including vitamins, unsaturated fatty acids and minerals like Ca and P that can meet different nutritional need in human diet.

In chickpea, there is a need to achieve breakthrough in seed yield by improving physiological and morphological efficiency in response to present climate change scenario. Several attempts have been made to improve the yield potential of chickpea, but they are primarily focused on better management practices and genetic improvement. Due to changing climatic condition, sharp rise in temperature and erratic rainfalls are potent reason for the yield reduction in chickpea. Among these factors variation in the temperature in both day and night are predominant factors among the various abiotic factors. So, it is obvious that developing a module for right time of sowing under varying climatic factors is a great challenge for the researchers. Recent studies have shown that varying temperature during different stages of crop growth may be potent reason for reduction of yield in chickpea. Under present changing climatic conditions, it is important to improve the adaptability of genotype to give better yield under fluctuating environmental factors.

5.1 Morpho-phenological characters

The influence of different temperature regimes had a significant effect on plant morphological characters like plant height, number of branches, days to flower initiation, days to fifty per cent flowering, days to pod initiation, days to pod filling and physiological maturity. Recent studies proved that these parameters differed significantly under varying temperature. Eventhough, plant height is genetically controlled, but several studies indicated that plant height is decreased or increased by the effect of temperature. Remarkable variation in plant height was observed at all the stages by the effect of temperature regimes. Increase in the night temperature, which retards growth drastically to a greater extent as the lower night temperature hinder both uptake and transport of nutrients and also affects the translocation of assimilates.

In the present study, plant height and number of branches differed significantly among temperature regime treatments (date of sowing). Significantly higher plant height, number of branches recorded in eighth dates of sowing (Nov 18th), which was on par with all other treatments except first (Oct 1st), second (Oct 7th) and third dates of sowing (Oct 21st). The results of the present investigation are in conformity with the findings of Saim and Ufuk (2003), who reported that the increase in plant height and number of branches was attributed to the increased duration of the crop *i.e.* growing period, which is evident by the number of days taken for maturity was higher in these sowing dates (Table 2).

The knowledge on influence of temperature regime on flowering is of interest in understanding genetic mechanism for regulating flowering and mechanism to manipulate the flowering by altering the sowing date to consolidate with predicted temperature and other abiotic stresses. The data with respect days to flower initiation differed significantly in responses to temperature regimes (Table 3). Among the temperature regimes, more the number of days to first flower initiation increased in first date of sowing (39th standard week) to fourth date of sowing (42nd standard week) but decreased there after upto eighth date of sowing (46th standard week). Among the temperature regimes, fourth date (42nd standard week) of sowing (43.7 days) took significantly maximum number of days for first flower initiation, while all treatments were on par with fourth date of sowing except sixth and seventh dates of sowing. As it is established that temperature played a greater role in flower initiation in chickpea, as reported by several workers (Siddique., 2004). The temperature below 15 °C cause flower initiation and the temperature greater than 35 °C can also cause flower loss and water stress. Flowering in chickpea is also sensitive to water logging with a similar response to low temperature with flower and pod abortion and leaf senescence (Cowie *et al.*, 1996).

From the present is clear that the T_{max} of 30°C and T_{min} of 16°C with a GDD of 725 (days) under October 22st (42nd standard week) took higher number of days for flower initiation i.e., greater growing period. Saim and Ufuk (2003), reported that the longer growing period of autumn sown chickpea had positive effect on days to flowering. Further, they also reported that greater the growing period has increased the plant height similarly on the present investigation also the plant height and number of branches also showed positive association with growing period. From the Fig. 2 it is clear that the T_{max} remained almost constant for first to eighth date of sowing. However, T_{min} decreased from first date of sowing to eighth date of sowing, from 18.2°C to 14.76°C , respectively. Hence, the lower temperatures enhanced the growing period and also for days to flower initiation by 4 days in 42nd week (4th day of sowing) sowing when compared to eighth day of sowing.

The data with respect to days to fifty percent flowering differed significantly in responses to temperature regimes (Table 3). Temperature regimes on number of days to fifty percent flowering indicated that from first date of sowing (39th standard week) it decreased continuously upto eighth date of sowing (46th standard week). Among the temperature regimes, fourth dates of sowing (50 days) took significantly maximum number of days for, fifty percent flowering while, all other treatments were on par with fourth dates of sowing except, first (46 days), seventh (46 days) and eighth dates of sowing (45 days). As it is established that temperature played a greater role in days to fifty percent flowering in chickpea, as reported by several workers (Srinivasan *et al.*, (1998). During reproductive phase, low temperature, ($<15^{\circ}\text{C}$) is detrimental to normal flowering and pod development, which causes prolonged reproductive phase, floral abortion, poor pollen germination, impaired ovule development, failure in pod set and reduction in seed filling that drastically affects the crop productivity (Nayyar and Gupta 2006).

The days to flowering generally decreased as the temperature decreased with $<15^{\circ}\text{C}$ detrimental to normal flowering, which cause floral absorption and poor pollen germination, impaired ovule development and failure in development of reproductive parts. Similarly, long days, exceeding 32°C hasten flower formation in chickpea. However, anthesis & pod setting is adversely affected when day time maximum temperature reaches more than 35°C (Basu and Chaturvedi, 2009 and Devasirvatam 2007). From the present it is clear that the T_{max} of 30.05°C and T_{min} of 16.11°C with a GDD of 830 (days) under October 22st (42nd standard week) took higher number of days fifty percent flowering i.e., greater growing period. The T_{min} was maintained around 15°C up to 49th standard week by that time 4th and 5th date of sowing recorded higher number of days for 50% flowering. Further, during 50 to 52 week the temperature reached around 10°C , which coincide the number of days for 50% flowering under 6, 7 and 8th day of sowing there by reducing the number of days for 50% flowering (Fig. 2).

Among the temperature regimes, the number of days to pod initiation in fourth date of sowing (42th standard week) recorded significantly higher number of days to pod filling, which was on par with third (41st standard week) and sixth (44th standard week) date of sowing. The minimum number of days to pod initiation recorded in first dates of sowing (39th standard week). Fourth date of sowing (55 days) recorded significantly higher number of days to pod initiation, which was on par with third (52.7 days) and sixth (53 days) dates of sowing. The minimum number of days to pod initiation was recorded in first dates of sowing (49 days). The number of days for pod initiation follows the trends of days to flower initiation and days for 50% flowering, which was under the influence of period of T_{min} played a major role for flowering in chickpea. Similar to present study the role of T_{min} during flowering was also confirmed by several workers. Wang *et al.*, (2006) observed that effect of high temperature stress during reproductive development on pod fertility, seed set, and seed yield of chickpea (*Cicer arietinum* L). Highly significant mean squares due to genotypes were observed for all the characters except photothermal index (PTI) of flowering duration and biological yield.

The number of days to physiological maturity increased in first date of sowing (39th standard week) to fourth date of sowing (42nd standard week) but decreased their after upto eighth date of sowing (45nd standard week), although values were on par with each other. Among the temperature regimes, third date of sowing (87.4 days) recorded maximum number of days to maturity, which was on par with all other treatments except seventh (80 days) and eighth dates of sowing (81 days).

The minimum number of days to maturity (81 days) was recorded in eighth dates of sowing followed by seventh dates of sowing (80 days). As it is established that temperature played a greater role in days to physiological maturity in chickpea, as reported by several workers. Summerfield *et al.*, (1984) observed that chickpea reproductive phase suffers considerably from high temperatures (35/18 °C, day/night). Under such thermal conditions, grain yield is reduced to 33% per comparison to that under lenient conditions such as 30/10 °C day/night. According to Wery *et al.*, (1993), critical temperature during the reproductive phase, which includes flowering, filling and enlargement of seeds chickpea, is evaluated with 30 °C. Recorded temperatures showed that critical temperature was exceeded only during the pods maturity phase duration. From the present it is clear that the T_{max} of 29.6°C and T_{min} of 15.1°C with a GDD of 1388 (days) under October 22st (42nd standard week) took higher number of days pod initiation i.e., greater growing period. Rajin *et al.*, (2003) observed that the photo thermal response of three Kabuli chickpea (*Cicer areintinum.L.*) cultivars, at different growth stages, rate of development from emergence to flowering and sowing to harvest were strongly and positively associated with mean temperature during those periods. All phenological stages considered (sowing to emergence, flowering to podding to physiological maturity and physiological maturity to harvest maturity) depended upon accumulated thermal time (T_i) above a base temperature (T_b) of 1 °C.

5.2 Dry matter accumulation and its distribution

The amount of total dry matter produced is an indication of the overall efficiency of utilization of resources and better interception of light. Even if the dry matter production in general is the indication of the efficiency of a genotype, the pattern in which it is distributed among various plant parts specifically in pod and seed is an indicator of better performance of that genotypes. The enhanced productivity of crop through physiological approach is mainly achieved by coordinating processes to synthesize maximum dry matter and partitioning of the major quantum of this increased dry matter into effective yield. Poor translocation of assimilates to the reproductive parts is the major constraint in chickpea but by improving canopy architecture and increasing the productivity through manipulation of source-sink relationship (Basuchoudhari *et al.*, 1996).

Accumulation of leaf dry matter increased from sowing to 60 DAS and their after it decreased. Among the sowing dates 42nd and 43rd standard week recorded higher leaf dry weight and least were recorded in 46th and 45th standard week sowing. However, the stem dry weight showed a continues increase in dry weight from sowing to harvest, however the rate of increase was at its minimum from 90 DAS to harvest. Similar to leaf dry weight, among the different dates of sowing, the stem dry weight also recorded higher values in 42nd, 43rd and 44th standard week sowing. Exactly same trend was noticed in pod weight and total dry weight from 60 DAS to harvest as that of stem dry weight similar trend as that of stem dry weight and pod dry weight.

The rate of decrease in biomass of chickpea was generally attributed to terminal stress for moisture coupled with increase in day temperature as the crop attains maturity. Such a decreased accumulation of dry matter at later stage is being reported by several workers. (Muchow *et al.*, 1986, Subedi *et al.*, 1995, Siddique *et al.*, 1999, Davis *et al.*, 1999 and Leport *et al.*, 1999). From the present study, it is evident that the higher dry matter was accumulated in 42nd standard week (29th October), 43rd standard week (29th October) and 44th standard week (5th November), recorded higher leaf, stem, pod and total dry matter when compared to other dates of sowing. This is attributed to lower GDD values (1388-1433 degree days). Such a lower accumulated T_{min} values (14.2 -15.1 °C) and an optimum of T_{max} values around 29°C (Table 4 and 5).

On the contrary lower accumulation of dry matter in leaf, stem, pod and total dry matter is contributed to higher GDD values and higher T_{min} values. Similar observations were made by Muchow *et al.*, (1986) observed that the decrease in crop biomass production is frequently observed in response to water deficit. This could either arise from a decrease in the extent of solar radiation intercepted by the canopy or a decrease in the efficiency with which the intercepted radiation is used to accumulate dry matter, or a combination of both in green gram.

These observations were also in agreement with Subedi *et al.* (1995), who investigated that effects of temperature on the vegetative growth of six genotypes under mean temperature regimes of 16°C, 19°C, 21°C, 25°C, 27°C and 30°C. Value of the base (T_b) and optimum (T_o) temperatures for different processes were estimated from linear regressions of rate, number or weight variables against mean temperature. The T_b values for, leaf area production and dry matter production were very similar at 15.7°C, 16.0°C and 15.9°C, respectively.

This decline in leaf and stem dry weight at later stage of crop growth might be due to translocation of stored photosynthates towards reproductive organs. Among the treatments, leaf dry weight and stem dry weight were significantly higher with fifth and followed by fourth dates of sowing, while increase in leaf dry weight may be due to increased leaf thickness with dark green leaves, while the increase in stem dry weight could be attributed to increase in stem thickness and increased number of branches, which are in accordance with the study of Siddique *et al.*, (1999), who reported that the loss in accumulation efficiency is associated with a decline in photosynthesis capacity in green gram.

As the leaf, stem dry weight decreased during seed filling the assimilates redistribution to the seed was evaluated (Davis *et al.* 1999). Leport *et al.*, (1999) in two studies showed that there was a genetic variation in the decrease in leaf dry matter that suggested that up to 60% of the dry matter in leaves and stem may contribute to final seed weight. Davis *et al.*, (1999) suggested that upto 30% of the dry matter from pod wall may contribute to seed growth. It is evident that in the present study also during pod filling stage the decrease in dry matter was minimum up to harvest. Hence, major contribution may be attributed to pod yield, by the pod wall.

5.3 Growth parameters

The crop yield is mainly dependent on the interplay of various physiological and biochemical functions of plant in addition to the impact of climatic condition of growing environment. The cause and effect relationship is difficult to understand mainly because of complexing in understanding the interplay of several processes and functions, which ultimately lead to changes not only in growth, development and physiology but also on the productivity, which is most complex character. So, growth analysis technique has made substantial contribution to the current understanding of the physiological basis of yield. The leaf area, leaf area index (LAI), leaf area duration (LAD), leaf area ratio (LAR), specific leaf weight (SLW), absolute growth rate (AGR), crop growth rate (CGR), relative growth rate (RGR), net assimilation rate (NAR) are important growth parameters influencing yield and which depends not on genotype and also environmental factors like temperature, relative humidity and growing degree days and management practices.

The leaf area and leaf area index (LAI) values increased from sowing to 60 DAS and thereafter it decreased as crop attained maturity. Among the sowing dates 43rd, 44th and 42nd standard weeks recorded significantly higher leaf area and leaf area index (LAI) and least were recorded in 45th and 46th standard week. However, leaf area and leaf area index (LAI) showed a continuous increase in both leaf area and leaf area index value up to 90 DAS but decreased from 90 DAS to harvest. However, the rate of decrease was at its minimum from 90 DAS to harvest. The rate of decrease in leaf area and leaf area index of chickpea was mainly attributed to terminal stress for moisture coupled with increase in day temperature as crop attains maturity. Such a decreased leaf area and leaf area index values at later stages is being reported by several workers (Deshmukh and Bhapkar 1979, Haloi and Baldev 1986, Dapaah *et al.*, 1999, and Singh *et al.* 2005). From the present study, it is evident that the higher leaf area and leaf area index values were observed in 43rd, (29th Octo) 42nd (22nd Octo) and 44th standard weeks (5th Oct), when compared to other dates of sowing. This is attributed to lower GDD values (1388-1433) degree days. Such a lower GDD values is because of lower accumulation of T_{min} (14.2 to 15.1°C) and an optimum of T_{max} (29°C). The interplay of growth and T_{min} is an important aspect, as the T_{min} during vegetative period made to accumulate more dry matter on a result of maintenance of higher leaf area and leaf area index.

On the other hand, lower leaf area and leaf area index values at different growth stages attributed to higher GDD values and higher T_{min} values (Table 4 and 5).

Similar observations were also made by several workers Deshmukh & Bhapker, (1979) who concluded that rapid early growth and maintenance of LAI at reasonably high level with higher NAR during pod formation and grain filling stage had greater influence on seed yield. Haloi and Baldev (1986) observed that LAI was largely influenced by dates of planting. Significantly higher LAI recorded at 90 DAS, in the present study are in the line with the observations reported by Uptery and Sirohi (1987), Aggarwal and Koundal (1988) and Rahangdale *et al.*, (1994).

The temperature can affect leaf area via its effects on rate of leaf senescence, on the rate and durations of individual leaf expansion, and on leaf senescence (Craufurd *et al.*, 1997). Temperature and photoperiod can also regulate leaf area via their effects on duration of leaf productions period (Hammer *et al.*, 1993).

Dapaah (1999) observed that 72% of higher maximum leaf area index under late October and early November dates of sowings and yielded more than mid to late sown crops. This is attributed to the leaf area formed and increased most rapidly, achieved a higher maximum LAI, as it was also observed from present study (Table 6). Further they also had faster pod growth rates and 26% of stored assimilation contributed to pod growth compared with 13% in late October to early November and 5% in late November sown crops yield.

The specific leaf weight (SLW) and LAD (leaf area durations) increased from sowing to 60 DAS and thereafter it decreased. Among the sowing dates 43rd (29th October) and 44th (5th Nov) standard week recorded significantly higher SLW values and least were recorded 45th (12th Nov) and 46th (19th Nov) standard week. However, SLW showed a continuous increase in Specific leaf weight (SLW) from sowing to 90 DAS. However, the rate of increase was at its minimum from 90 DAS to harvest. Similar to SLW among the different dates of sowing, the leaf area duration (LAD) also recorded higher values in 43rd, 44th and 42nd standard weeks. The rate of decrease in SLW in crop biomass of chickpea was generally attributed to terminal stress for temperature regime treatments. *i.e.*, increase in day temperature. Such an increase in temperature, affects SLW and LAD as crop attains maturity.

From the present study, it is confirmed that higher SLW and LAD observed in 45th standard week (29th October) and 44th standard week (5th Nov) and 42nd standard week (22nd Octo) recorded higher specific leaf weight and leaf area duration values compared to other dates of sowing. Similar observations of higher LAD under late October sowings were also observed by Dapaah (1999). Further, they also reported that higher LAD and LAI recorded greater utilization efficiently, as a result of more interrupted PAR during October late sown crop. Maintenance of higher LAD during grand growth or later grand growth period will have higher beneficial effects on most of growth parameters.

Leaf area ratio is inverse of SLW and hence lower values are beneficial for higher yield in general. The leaf area ratio (LAR), which is the function of leaf area, indicates the leaf area produced per unit dry matter. The leaf area ratio value decreased from sowing to till the harvest. Among the sowing dates 40th standard week (Octo 8th) 39th standard week (1st Octo) 45th standard week (12th Nov) and 46th standard week (19th Nov) recorded a higher leaf area ratio values. However, the LAR value continuously decreased from 30DAS till the harvest. The rate area of decrease in LAR in chickpea was generally because of terminal stress for increase in day temperature as the crop attains maturity.

The AGR (absolute growth rate) and CGR (crop growth rate) indicated a significant difference due to temperature regimes. The AGR value increased from sowing to 60-90 DAS and thereafter it decreased drastically. Among the sowing dates 42nd standard week (22nd Octo), 43rd standard week (29th Octo) and 44th standard week (5th Nov) recorded continues increase in AGR values, similar trend was observed with respect to crop growth rate (CGR) values.

The rate of decrease in crop biomass of chickpea was generally due to terminal stress for moisture and increase in day temperature as crop attains maturity. Such a decreased accumulation of AGR and CGR values at later stages is reported by several scientists.

Prasad *et al.* (1978) recorded low value for CGR in initial stages of growth (30-60 DAS), which was reached maximum 85-91 days and thereafter sowing in chickpea, the time corresponding to reproductive phase.

A field growth chickpea and Lentil under adequate soil moisture also showed a peak rate of CGR during flowering and pod development stage when the day temperature remained below 30-25°C (Prasad *et al.* 1978 Singh *et al.*, (2005) observed that the maximum CGR value below 30-60 DAS, while at 60-90 DAS showed maximum CGR value. From the current study, it is concluded that higher AGR and CGR values in 42nd standard week (22nd Octo), 43rd standard week (29th Octo) and 44th standard week (5th Nov) recorded higher value of AGR & CGR compared to other sowing dates. This is because of lower GDD values (1388-1433 degree days) and an optimum of T_{max} value 29°C. It is also clear from the present investigation that relative growth rate (RGR) and NAR also followed the similar trend as that of AGR and CGR.

Saxena and Sheldrake (1978) showed that variance ratio of RGR indicates no significance effect on date of sowing but indicates a significant differences among cultivars and time of planting. Deshmukh and Bhapker (1979) concluded that rapid early growth and maintenance of LAI at reasonably high level with higher NAR during pod formation and grain filling stages had influence on seed yield. Prasad *et al.* (1978) recorded low value of NAR, RGR in initial stages of growth, which reaches maximum 60-90 DAS in chickpea, the time-corresponding to reproductive phase. Similar observations were also recorded by Haloi and Baldev (1986) that the date of sowing had marked influence on RGR and NAR during flowering to pod development stage. They also reported that higher NAR at early sowing appears to be due to combined effect of better soil moisture, high mean temperature (29°C) and more solar radiation due to relative longer days. Similar finding of high NAR in early sowing and at early stages of crop growth was recorded by Saxena and Sheldrake (1978) and Katiyar (1981), in chickpea.

SPAD value point out the total chlorophyll present in the leaves. Significantly higher SPAD values were recorded with 46th standard week (19th October) followed by 41st standard week (15th October) and the least were recorded in all other dates of sowing except 46th and 41st standard week respectively. But, in case of relative water context (RWC), significantly higher RWC values recorded in 39th (1st Octo) 40th (8th Octo) and 41st standard week (15th Octo), which were on par with all other treatment except 45th standard week (12th Nov) and 46th standard week (19th Nov). The RWC (%) value decreased from sowing to 90 DAS. Maintenance of higher RWC under initial growth stages is because of higher moisture availability and it decreased as the terminal stress was observed during later stages.

Under natural conditions, drought usually occurred in association with high temperature and this resulting in photoinhibition of photosynthesis system observed in *Lupines* sp (French and Turner, 1991). Pandey *et al.* (1984) reported that the temperature of leave increased as leaf RWC decreased in grain legumes. Also, Lawn *et al.*, (1982) observed that reduced water vapour conductance was accompanied by higher leaf temperature.

Thomson *et al.* (1997) and Leport *et al.* (1998) reported that drought avoidance/tolerance were observed in chickpea, in the form of delayed senescence and maturity. However, these species had lower yield and WUE when compared with *Vicia feba* and peas (*Pisum sativum*). Poor early growth and dry matter production and sensitivity to low temperature at flowering and early podding are the major cause of low yield and WVE in these species, especially in chickpea (Siddique and Sedgley, 1986).

A decrease in the relative water content (RWC) in response to drought stress has been noted in wide variety of plants as reported by Nayyar and Gupta (2006) that when leaves are subjected to drought leaves exhibit large variation in RWC and water potential. From the present study, it is concluded that the higher percentage of RWC was observed in 39th standard week (1st October), 40th standard week (8th Octo) and 41st standard week (15th Octo) followed by 42nd standard week (22nd Octo) 43rd standard week (29th Octo) and 44th standard week (5th Nov) when compared to other dates of sowing. This is attributed to higher GDD values (1427-1544) degree days) is because of higher accumulations of minimum temperature i.e. T_{min} value (15.5-16.24°C) and optimum of T_{max} 29.6°C.

5.4 Biochemical parameters

It is well known that the thousands of biochemical reactions are concurrently undergoing in plants ultimately decide the plant growth and development as a result, determines the final yield.

Chlorophyll has been rightly designated as pigments of life, because of its control role in living systems responsible for harvesting sunlight and transforming its light energy into biochemical energy essential for life. In the present study, it was observed that the effect of temperature regimes had profound influence on chlorophyll content in leaf.

Chlorophyll a, chlorophyll b and total chlorophyll content in leaf, increased from sowing to 60 DAS, and thereafter it decreased as crop attained maturity as a natural phenomenon. Among the sowing dates 39th standard week (Oct 1st), 40th standard week (Oct 8th) recorded significantly higher chlorophyll a, chlorophyll b and total chlorophyll and the least were recorded in 45th standard week (12th Nov) and 46th standard week (19th Nov).

However, the chlorophyll a, chlorophyll b and total chlorophyll showed a continuous increase in chlorophyll content in leaf upto 60 DAS, but decreased from 60 DAS to 90 DAS. However, the decrease was minimum from 60 DAS to 90 DAS. The rate of decrease in chlorophyll content was generally attributed to terminal stress for moisture coupled with increase in day temperature as crop attains maturity. Such a decrease in chlorophyll content values at later stages is being reported by Mafakheri *et al.* (2010).

From the present investigation it is evident that the higher chlorophyll content was observed under October whole month dates of sowing, which is a normal sowing dates since long time. On the contrary the ratio of chlorophyll a/b was significantly higher under 3rd week of October to 1st week of November month sowing dates. It was observed from the present study that the higher ratio for chlorophyll a/b under November sowing has reduced most of the growth parameters (LA, LAI, AGR, CGR, RGR and NAR). Similar trend for these growth (early sowing) parameters was also observed when the ratio was at its minimum. However, the optimum values were maintained under the sowing dates of 3rd week of October to 1st week of November, as most of the growth parameters recorded higher values resulting in higher yields.

Interestingly, earlier dates of sowing (Oct 1st week to Oct 3rd week) and delayed sowing dates (Nov 2nd week to Nov 4th week) have recorded significantly lower duration for physiological maturity (80 to 83 days). However, Oct 4th week (42nd standard week) to Nov 1st week (44th standard week) enhanced the crop duration for physiological maturity to around 87 days. Here, T_{min} , T_{max} and GDD values played an important role in determining the growth and development and ultimately the yield. This lower accumulation of GDD and T_{min} might have reduced the evapotranspiration values and maintained the soil moisture, while other recording high T_{min} and GDD values might have encouraged the moisture stress. This may be attributed to lower GDD values (1427 to 1514 degree days). Such a lower GDD values is because of lower accumulation of T_{min} (15.57 to 16.24^oC) and the optimum of T_{max} 29.5^oC, for optimum chlorophyll a/b ratio. Similar observations were also reported by Mefakhari *et al.* (2010) observed that the drought stress imposed during vegetative growth or anthesis decreased chlorophyll a, chlorophyll b and total chlorophyll content in chickpea genotypes.

5.5 Yield and yield components

Seed yield is the manifestation of morphological, physiological, biochemical, biophysical and growth parameters. In general, the yields of crop plant is attributed to the total assimilation achieved during the growing seasons and the way it is partitioned between the desired storage structures and rest of the plant parts. The seed yield in chickpea depends upon the accumulation of photo-assimilates during the growing period and the way in which they are partitioned between desired storage organs of plant. Seed yield and its related parameters in chickpea were influenced by the effect of temperature regime, which indicates variation in temperature regimes have a marked influence on the distribution of assimilates between the vegetative and reproductive organs.

In the present study, it is revealed that the effect of temperature regimes (date of sowing) had a marked influence on seed yield (g plant⁻¹), haulm yield (g plant⁻¹), 100 seed weight (g), harvest index (%) and yield (kg ha⁻¹), which are most important yield determining components in chickpea. Among the sowing dates 43rd standard week (29th Oct), 44th standard week (5th Nov) and 42nd standard week (22nd Oct) recorded significantly higher seed yield when compared to 45th standard week (12th Nov) and 46th standard week (19th Nov).

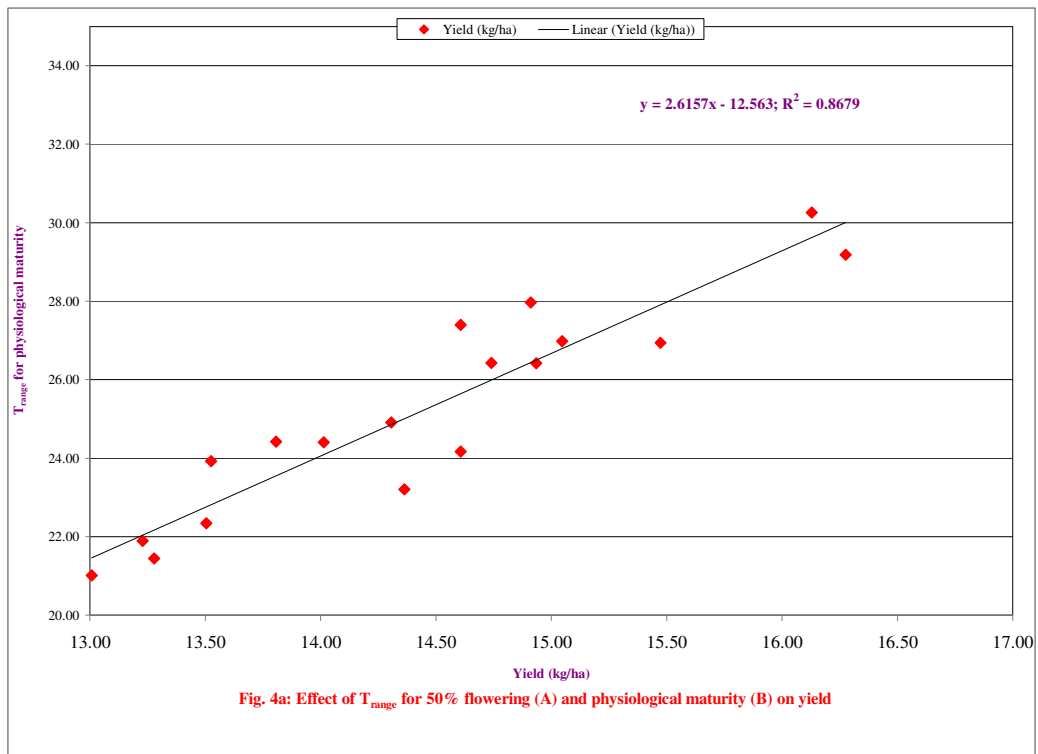
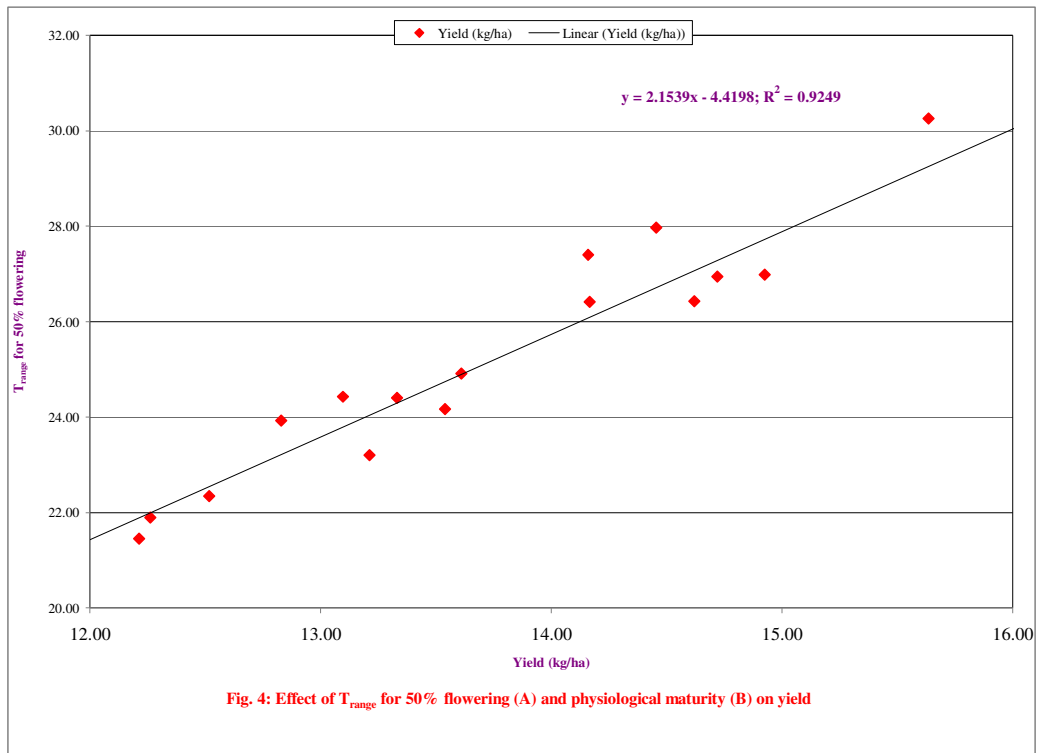


Fig. 4a: Effect of Trange for 50% flowering (A) and physiological maturity (B) on yield

Similarly the yield components responsible for enhancing the yield also recorded exactly a similar trend as it was noticed in seed yield, for haulm yield and harvest index, and yield (kg ha^{-1}). However, the test weight (100 seed weight) did not record any significant differences among sowing dates.

In general, the rate of decrease in crop biomass of chickpea was generally attributed to terminal stress for moisture, also the increase in day temperature as the crop attains maturity. Such a decreased accumulation of assimilates at later stages is being reported by several workers (Summerfield *et al.*, 1984; Bakht *et al.*, 2006; Ganguly., 1992; Ramteke, 1995; Ganguly and Bhattacharya, 2001; Deshmukh *et al.*, 2004a; Sangeeta *et al.*, 2009; Patra *et al.*, 2011).

From the present investigation, it is evident that the higher rate of assimilation was observed in 43th standard week (29th Oct), 44th standard week (5th Nov) and 42nd standard week (22nd Oct) when compared to other dates of sowing. This is mainly attributed to lower GDD values (1388 to 1433 degree days). Such a lower GDD value is because of lower accumulation of T_{\min} (14.2 to 15.1^oC) and an optimum of T_{\max} 29.5^oC.

From the present study, though T_{\max} , T_{\min} and GDD play an important roll in determining various phenological, dry matter accumulation and distribution, growth parameter, chlorophyll and RWC as a result its impact on final yield. Though there was no perfect association between T_{\max} , T_{\min} and GDD values with yield, but strong linear regression was obtained between yield and accumulated T_{range} for both 50% flowering and physiological maturity (Fig 4 and 5). Hence T_{range} for 50% flowering and physiological maturity influence greatly on final yield rather than only T_{\max} , T_{\min} and GDD values. From the Fig. 4 (A and B) the accumulated trange during 50% flowering and physiological maturity played a major role in determining the final yield. A strong significant relation was obtained indicating the influence of Trange during total crop growth period (50% flowering and physiological maturity) on yield in chickpea rather that only Tmin or Tmax. Hence, it may be inferred from present study that the variation or fluctuation in Tmin and Tmax during crop growth period had grater impact on chickpea growth resulting on final economic yield.

Similar observations made by Summerfield *et al.* (1984) reported that chickpea reproductive phase suffers considerably from high temperature (35/18^oC, day/night). Under such thermal condition the grain yield is reduced to 33% compared under normal conditions such as 30/10^oC day/night. According to Wery *et al.*, (1993), critical temperature during reproductive phase where flowering, pod filling and enlargement of seeds of chickpea is evaluated with 30^oC. There is a faster pod growth rates and 26% of stored assimilates contributed to pod growth compared with 13% in October to early November.

Ganguly (1992) has pointed out the dates of sowings have a major role on chickpea yield, as they determined by the environmental condition of crop growth. Saxena *et al.* (1976) reported that the dates of sowing has a profound effect on growth and yield of chickpea and later dates of sowing causes yield reduction, through the reduction in pre and post flowering period (Eshel, 1968). Similarly in the present study reduced pre and post flowering period were reduced for early and later sowing dates. Ramteke (1995) studied a physiological basis of yield variation in 15 chickpea genotypes during *rabi* season under rainfed condition. The variety Annigeri-1 showed a better performance because of its thermo tolerance nature.

Yield attributes like pod, seed yield and plant biomass were less when exposed to higher temperature for a short duration at flowering and podding stage. These findings suggest that 3.1^oC increase in growth temperature may enhance vegetative growth and photosynthesis in chickpea but may not influence the plant yield (Sangeeta *et al.*, 2009). Patra *et al.*, (2011) observed that the performance of high yielding chickpea under different temperature condition revealed that 25^o to 30^oC temperature was optimum for better seed yield in chickpea compared to other temperature, similar results were also obtained from the present study. Saim and Ufuk (2003) noticed that longer growing period of autumn sown chickpea affected positively characters contributing to yield, 100 seed weight, which inturn contributed to increased seed yield, however 100 seed weight and days to flowering were important for autumn sowing and days to flowering. In this present study also higher yields were recorded for enhanced duration of the crop. Devasirvatham *et al.* (2007) reported that sowing time may vary in different locations depending on the temperature experienced at different crop development stage.

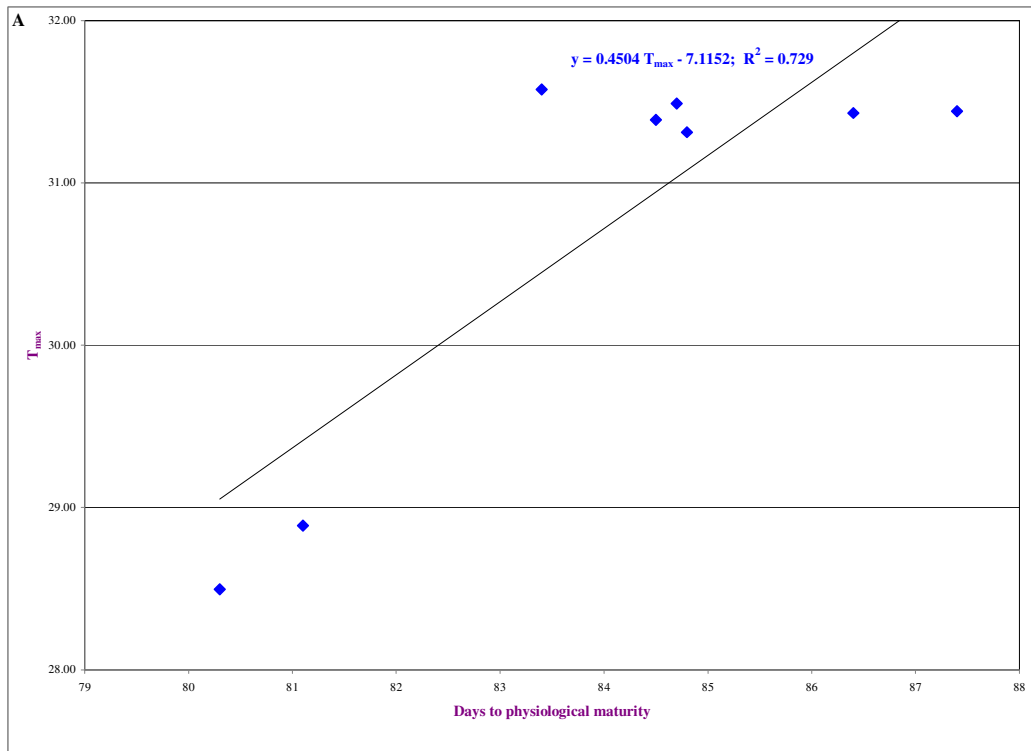
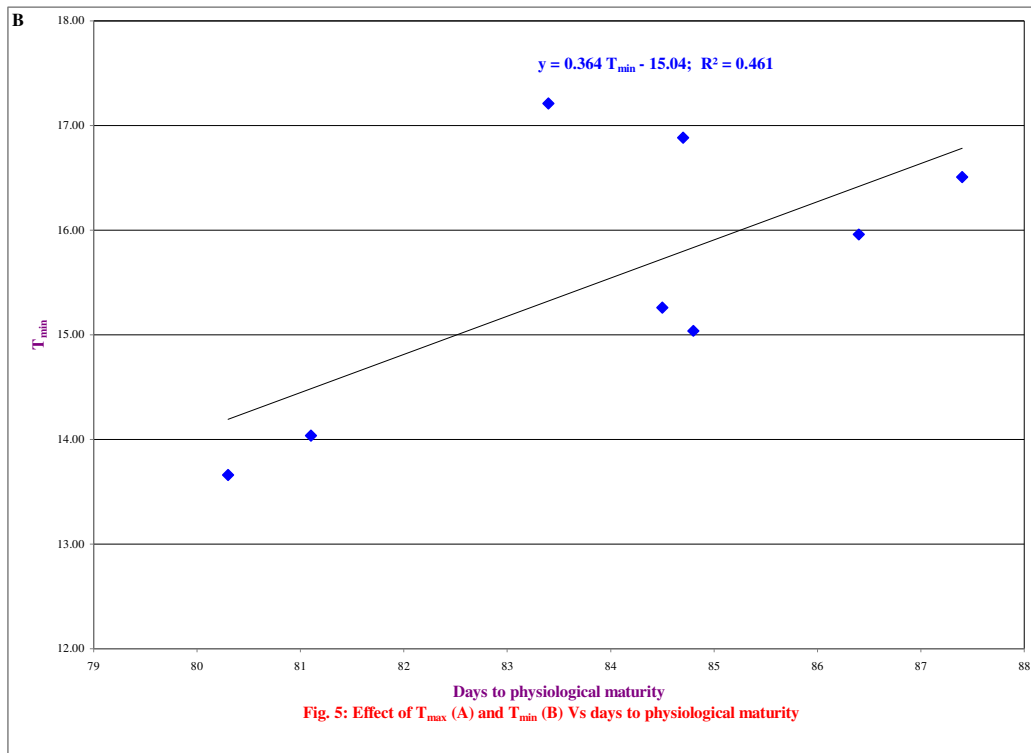


Fig. 5: Effect of T_{max} (A) and T_{min} (B) Vs days to physiological maturity

Temperature therefore the most important for growth that governs yield and high temperature during reproductive phase of chickpea is a major cause of yield loss.

It is also confirmed that the T_{max} and T_{min} temperatures played a major role in enhancing the yield in chickpea which is independent of sowing dates. Under present changing scenario of climate change, the earlier recommended dates of sowing are to be corrected or re-evaluated again for getting higher productivity.

Future line of work

- Physiological and metabolic bases of cold stress, including the role of phytohormones (especially ABA) and at molecular level.
- The available genotypes available needs to be characterized for temperature tolerance and grouped into different GDD viz., genetical, environmental induced, beneficial for productivity under thermal stress.
- The influence of temperature regimes on various biophysical parameters and their relationship with productivity and tolerance nature may be investigated.

6. SUMMARY AND CONCLUSIONS

A field experiment was conducted during *rabi* season of 2011-12 at Main Agricultural Research Station (MARS), University of Agricultural Sciences, Dharwad to assess the effect of temperature regimes on productivity in Chickpea (*Cicer arietinum* L) genotype and its impact on yield and yield components. The experiment consisted of one genotype and eight temperature regimes (dates of sowing). The crop was sown at weekly intervals (standard weeks) starting from 39th Standard week (1.10.11 to 7.10.11) to 46th Standard week (18.11.11 to 25.12.11). The variation in sowing date created a variation in growth temperature and designated as T₁, T₂, T₃, T₄, T₅, T₆, T₇, and T₈ to indicate the different temperature regimes. The results of present study are summarized here under.

- Significant differences were observed among the temperature regimes, with respect to various morpho-phenological characters such as plant height, number of branches, days to flower initiation, days to 50% flowering, days to pod initiation, days to pod filling, days to physiological maturity.
- Significantly higher plant height and number of branches were recorded in eighth dates of sowing (Nov 18th). Remarkable variation in plant height was observed at all the stages by the effect of temperature regimes. Increase in the night temperature, which retards growth drastically to a greater extent. The number of branches and number of nodes are important morphological characters, which are directly related to yield.
- From the present study it is clear that the T_{max} of 30°C and T_{min} of 16°C with a GDD of 725 (days) under October 22st (42nd standard week) took higher number of days for flower initiation *i.e.*, greater growing period.
- Among the temperature regimes, fourth dates of sowing (50 days) took significantly maximum number of days for fifty percent flowering. It is clear that the T_{max} of 30°C and T_{min} of 16.1 °C with a GDD of 830 (degree days) under October 22nd (42nd standard week) took higher number of days fifty percent flowering *i.e.*, greater growing period.
- Days to pod initiation in fourth date of sowing (42th standard week) recorded significantly higher number of days to pod filling, while the minimum number of days to pod initiation recorded in first dates of sowing (39th standard week). The T_{max} of 29.6°C and T_{min} of 15.1°C with a GDD of 1388 (degree days) under October 22st (42nd standard week) took higher number of days pod initiation *i.e.*, greater growing period.
- Among the temperature regimes, third date of sowing (87.4 days) recorded maximum and the number of days to maturity (81 days) was recorded in eighth dates of sowing followed by seventh dates of sowing (80 days). October 22st (42nd standard week) took higher number of days pod initiation *i.e.*, greater growing period, where the T_{max} of 29.6°C and T_{min} of 15.1°C with a GDD of 1388 (days).
- It is evident that the higher dry matter was accumulated in 42nd standard week (29th October), 43rd standard week (29th October) and 44th standard week (5th November), recorded higher leaf, stem, pod and total dry matter when compared to other dates of sowing. This is attributed to lower GDD values (1388-1433 degree days). Such a lower accumulated T_{min} values (14.2 -15.1 °C) and an optimum of T_{max} values around 29°C.
- The higher leaf area and leaf area index values were observed in 43rd, 42nd and 44th standard weeks (Oct.29) (Oct.22) when compared to other dates of sowing. This is attributed to lower GDD values (1388-1433) degree days. Such a lower GDD values is because of lower accumulation of T_{min} (14.2 to 15.1°C) and an optimum of T_{max} (29°C).
- Higher SLW and LAD observed in 45th standard week (29th October), 44th standard week (5th November) and 42nd standard week (22nd October) recorded higher specific leaf weight and leaf area duration values compared to other dates of sowing.

This is attributed to lower GDD (1388-1433 degree days), lower accumulation of GDD values is because of lower T_{\min} value (14.2 – 15.1°C) and an optimum of T_{\max} values around (29°C).

- It is concluded that higher AGR and CGR values in 42nd standard week (22nd October), 43rd standard week (29th October) and 44th standard week (5th November) recorded higher value of AGR and CGR compared to other sowing dates. This is because of lower GDD values (1388-1433 degree days) and an optimum of T_{\max} value 29°C. It is also clear from the present investigation that relative growth rate (RGR) and NAR also affected the similar trend as that of AGR and CGR.
- Significantly higher SPAD values were recorded with 46th standard week (19th October) and the least were recorded in all other dates of sowing except 46th and 41st standard week respectively. Higher percentage of RWC was observed in 39th standard week (1st October) , 40th standard week (8th October). when compared to other dates of sowing. This is attributed to higher GDD values (1427-1544 degree days) is because of higher accumulations of minimum temperature *i.e.* T_{\min} value (15.5-16.24°C) and optimum of T_{\max} 29.6°C.
- Among the sowing dates 39th standard week (1st Oct), 40th standard week (8th Oct) recorded significantly higher chlorophyll a, chlorophyll b and total chlorophyll and the least were recorded in 45th standard week (12th Nov) and 46th standard week (19th Nov). On the contrary the ratio of chlorophyll a/b was significantly higher under 3rd week of October to 1st week of November month sowing dates.
- T_{\min} , T_{\max} and GDD values played an important role in determining the growth and development and ultimately the yield. This lower accumulation of GDD and T_{\min} might have reduced the evapo-transpiration values and maintained the soil moisture, while other recording high T_{\min} and GDD values might have encouraged the moisture stress.
- In the present study, it is revealed that the effect of temperature regimes (date of sowing) had a marked influenced on seed yield (g plant⁻¹), haulm yield (g plant⁻¹), 100 seed weight (g), harvest index (%) and yield (Kg ha⁻¹), which are most important yield determining components in chickpea. Similarly the yield components responsible for enhancing the yield also recorded exactly a similar trend as it was noticed in seed yield, for haulm yield and harvest index, and yield (kg ha⁻¹). However, the test weight (100 seed weight) did not record any significant differences among sowing dates. The present investigation, it is evident that the higher rate of assimilation was observed in 43th standard week (29th Oct), 44th standard week (5th Nov) and 42nd standard week (22nd Oct) when compared to other dates of sowing. This is mainly attributed to lower GDD values (1388 to 1433 degree days). Such a lower GDD value is because of lower accumulation of T_{\min} (14.2 to 15.1°C) and an optimum of T_{\max} 29.5°C.

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EFFECT OF TEMPERATURE REGIMES ON PRODUCTIVITY IN CHICKPEA (*Cicer arietinum* L.)

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ABSTRACT

A field experiment was conducted during *rabi*, 2011-2012 at Main Agricultural Research Station, University of Agricultural Sciences, Dharwad to assess productivity in chickpea. The experiment consisted of chickpea genotype, Annigeri-1 and eight temperature regimes (dates of sowing) laid out in a randomised block design (RBD) with three replications. The crop was sown at weekly intervals (standard weeks) starting from 39th week to 46th week. Among the sowing dates, 43rd, 44th and 42nd week recorded significantly higher seed yield when compared to 45th and 46th standard weeks. Significantly higher plant height and number of branches were recorded in eighth dates of sowing. The number of days for flower initiation, 50% per cent flowering and pod initiation increased up to 42nd weeks of sowing and then decreased.

It is evident that the higher dry matter and its distribution along with higher leaf area LAI, SLW, LAD, AGR, CGR, RGR and NAR values was observed in 42nd standard week (29th October), 43rd standard week (29th October) and 44th standard week (5th November), when compared to other dates of sowing. This is attributed to lower GDD values (1388-1433 degree days) and lower accumulated T_{min} values (14.2 -15.1^oC) and an optimum of T_{max} values around 29^oC. Further, November dates of sowing recorded significantly higher yield (28.54 q ha⁻¹) and harvest index (48.67%).

The sowing dates 39th standard week (1st Oct), 40th standard week (8th Oct) recorded significantly higher chlorophyll a, chlorophyll b and total chlorophyll. However, the ratio of chlorophyll a/b was significantly higher under 3rd week of October to 1st week of November month sowing dates. It is also confirmed that the T_{max} and T_{min} temperatures played a major role in enhancing the yield in chickpea which is independent of sowing dates.