Effects of high temperature at different developmental stages on the yield of chickpea

V. Devasirvatham[1,2], D.K.Y. Tan[1], P.M. Gaur[2], T.N Raju[1] and R.M. Trethowan[1]

[1]Faculty of Agriculture and Environment, Plant Breeding Institute, University of Sydney, Cobbitty, NSW 2570.
[2]International Crops Research Institute for Semi-Arid Tropics, Patancheru, 502324, Andhra Pradesh, India.
Corresponding author: [1]viola.devasirvatham@sydney.edu.au

Abstract

High temperature during the reproductive stage is a major limitation to yield of chickpea (*Cicer arietinum* L.). Chickpea yield is sensitive to variability in temperature and rising temperature in spring and post-rainy season exposes chickpea to heat stress in Australia and India, respectively. The objective of this research was to screen chickpea germplasm for heat tolerance by analysing the mean maximum and minimum temperatures at different developmental stages (vegetative, flowering and grain filling). A total of 167 genotypes were grown under two contrasting environments viz., heat stress (late season) and non-heat stress (normal season) in field conditions during 2009-10 (Year 1) and 2010-11 (Year 2) at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India. Principal Component Analysis (PCA) demonstrated seasonal temperature differences (normal and late seasons) very effectively. Large genetic variation was found among the genotypes for their response to heat stress. The maximum temperature during grain filling period (GF_{Max}) reduced the grain yield in chickpea. The inbred line ICCV 98902 had higher critical temperature (≥38˚C) during the grain filling period and produced reasonable grain yield under high temperature stress.

Key Words

Flowering, grain filling, temperature variables, vegetative phase

Introduction

High temperature (>30˚C) has been identified as a limitation to the growth of chickpea, the regulation of flower initiation and grain yield (Summerfield *et al.* 1984). Though chickpea is a cool season crop, it often experiences high temperature during the reproductive stage in the semi-arid tropics of India, in southern Australia and in the summer dominant rainfall region of northern New South Wales. Periods of high temperature are expected to increase due to climate change. Therefore there is a need to identify genetically diverse germplasm with heat tolerance in chickpea. The interaction between high temperature stress and developmental stages (vegetative, flowering and grain filling period) is unknown in chickpea. The main objective of this study was to determine the effect of temperature on the different developmental stages of chickpea and on genotype × environment (G × E) interaction.

Methods

Experimental design and management

Field experiments were conducted on a Vertisol over two growing seasons (normal and late) during 2009-10 (Year 1) and 2010-11 (Year 2) at the International Crops Research Institute for the Semi-Arid Tropics, Patancheru (17.53°N; 78.27°E; 545 m), India. Sowing methods are described in Gaur *et al*. (2007). A randomised complete block design (167 genotypes) with two replications was used for field experiments. Both normal and late planting was done in ridges and furrows (4 m row) with a plant spacing (inter and intra row) of 60 x 10 cm. Seeds were treated with 0.5% Benlate® + Thiram® mixture in both the sowings. Late seasons crops were irrigated optimally to avoid water stress. Two seeds per hill were sown and later thinned to one seedling. The experiments were maintained weed free by manual weeding. Insecticide sprayed to control pod borer (*Helicoverpa armigera*).

Measurements

Daily maximum and minimum temperatures were recorded in both seasons. Days to first flower (DFF), days to 50% flower (D50F), days to first pod (DFP), days to physiological maturity (DPM), plant biomass (g/plant) at harvest, and yield (g/plant) were recorded as described in Krishnamurthy *et al*. (2011). The plant growing days at different developmental stages (vegetative, flowering and grain filling period) were calculated. Vegetative period (V) was defined as the number of days from sowing to one day before flowering date. The days from first flower to first pod was considered the flowering period (F). The grain filling period (GF) was defined as the number of days from first pod to maturity. Then, the average maximum and minimum temperatures were calculated at different developmental stages (V_{Max}; V_{Min}; F_{Max}; F_{Min}; GF_{Max} and GF_{Min}).

Statistical methods

Partial least squares (PLS) were used to show the main variation pattern of the independent variables genotypes and temperature (V_{Max}; V_{Min}; F_{Max}; F_{Min}; GF_{Max} and GF_{Min}). Grain yield (dependent variable) was measured and the influence of temperature determined by calculating temperature from different developmental stages (Vargas *et al*. 1998). The PLS data were presented as biplots and Genstat 12th Ed. VSN International Ltd was used to perform PLS analysis, biplots, regression analysis and ANOVA.

Results

Temperature at different developmental stages of genotypes explained some of the variability in grain yield. The temperature variables were helpful to explain G × E interaction. In the biplots, the temperature variables are shown as vectors and genotypes as points (Fig 1). The significance of temperature variable on the G x E is related to distance from the origin. The longest vectors are the most significant. In Year 1 normal and late seasons, GF_{Max} had greatest influence on G x E. In Year 2 normal season, V_{Max} was an important variable whereas V_{Min} was the dominant factor in the late season (Fig 1). PCA demonstrated seasonal temperature differences (normal and late) very effectively. In late season trials in both years, the mean maximum temperatures in different growing periods explained >73% of total variance in two components (PC1, PC2). However the relationship between temperature variables and yield can be identified using simple linear regression analysis based on % variance. The order of temperature variable in each year and season is presented in Table 1. In the normal season for both years, GF_{Max} and GF_{Min} significantly influenced grain yield. In contrast, in late season trials in both years GF_{Min} and V_{Max} played important roles in the grain yield (Table 1). Overall, in normal season, the GF_{Max} temperature varied between 29.1 and 30.3˚C, a minimum low temperature (≤14˚C) was observed during the flowering period. In late season trials, the temperature stress was high during GF compared with other developmental stages. In Year-1,

GF_{Max} and GF_{Min} was high (39.2/ 24.2˚C) compared with Year-2 (37.1/ 23.2˚C) in the late season trials (Table 1).

The phenology (DFF; D50F; DFP and DPM), plant biomass and grain yield of 167 genotypes for each year and season and their interaction were calculated using ANOVA. The predicted mean for the yield in the normal season was 11.9 g/plant and in late season was 7.3 g/plant (data not shown). The most heat tolerant (ICCV 98902) and sensitive genotypes (ICC 5566 and ICC 7570) were selected from the biplots (see Table 2). The most heat tolerant genotypes were not affected by temperature variables i.e. they were not linked to any temperature variable in the biplots. The most heat sensitive genotypes were linked to temperature variables. The most heat tolerant genotype was ICCV 98902 which had the highest grain yield among the 167 genotypes in both years during the late season. In Year 2, ICCV 98902 had higher grain yield (27.22 g/plant) compared with Year 1 (9.51 g/plant) (Table 2). The average maximum temperature (≥39˚C) was the reason for lower yield during late season in Year 1 across all genotypes. In Year 2 the average maximum temperature only reached 37˚C (Table 1) during the late season. The plant biomass difference in the two seasons clearly explained the yield difference (Table 2). The difference between the yield and plant biomass of heat tolerant and sensitive genotypes was explained by growing season temperatures. The maximum temperature during F and GF was >39˚C and 35.7 - 37.5˚C during late season in Year 1 and Year 2, respectively, the tolerant genotype had the highest grain yield (Table 2). Overall, the period of GF (number of days) was reduced by 4-19 days in the sensitive genotypes during the late season. The heat tolerant genotype, ICCV 98902 had similar GF (60 days) in both late and normal season. However, at 39.4˚C the GF period of ICCV 98902 was reduced to 30 days and plant biomass was reduced (Table 2-Year 1). The same genotype in Year 2 did not reduce biomass and grain filling period at 36.7˚C. Therefore, the maximum temperature ≥38˚C was the critical temperature of ICCV 98902 for yield reduction in the field.

Discussion

The genotype response to these temperature variables is a useful method to characterise chickpea germplasm. Normal season grain filling period temperature was between 30 – 31˚C which is similar to the work of Berger *et al.* (2011). Sowing during early Feb (late season) exposed genotypes to high temperature during the grain filling period and was useful for selecting heat tolerant genotypes (Gaur *et al.* 2007). This was successfully used to predict genotypic difference. However, high temperature stress significantly reduced the growing period. Krishnamurthy *et al.* (2011) also suggested that chickpea plants were forced to maturity under high temperature, thus reducing the yield. The maximum temperature during the grain filling period played significant role in grain yield. Greater yield reduction in chickpea was found due to high temperature stress at pod development compared with at early flowering (Wang *et al.* 2006). The heat tolerant ICCV 98902 is a potential source for heat tolerance breeding.

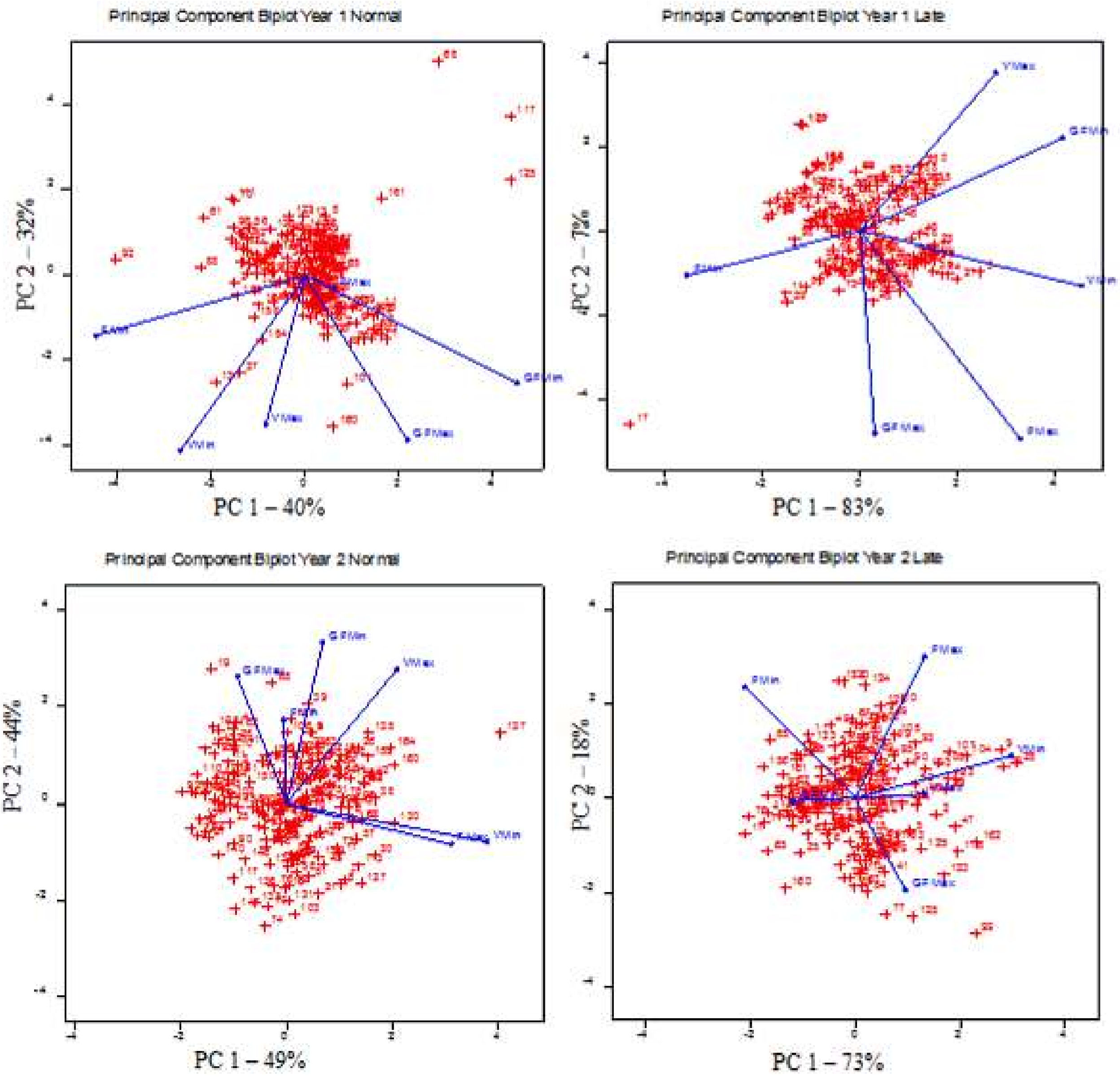

Figure 1. Biplot based on PLS (partial least squares) analysis of G x E for 167 chickpea genotypes showing the relationship with temperature and yield (g/plant) at ICRISAT – India during 2009-10 and 2010-11 (normal and late seasons)

Table 1. Developmental stages sensitive to max and min temperatures identified by simple linear regression based on % of variance among 167 chickpea genotypes grain yield at ICRISAT – India during 2009-10 (Year 1) and 2010-11 (Year 2) (normal and late seasons)

Temperature/ Growth stage	% variance				Temperature (˚C) Mean			
	Year 1 Normal	Year 1 Late	Year 2 Normal	Year 2 Late	Year 1 Normal	Year 1 Late	Year 2 Normal	Year 2 Late
V_{Max}	4.2^{3}	39.1^{2}	8.5^{4}	10.6^{1}	28.9± 0.23	34.1±0.16	28.1±0.27	32.6±0.36
F_{Max}	0.2^{5}	28.5^{5}	8.5^{4}	8.1^{4}	27.8± 0.23	37.4±0.16	27.9±0.27	35.9±0.36
					29.1±			

GF_{Max}	10.7[1]	18.6[6]	17.2[2]	7.2[5]	0.23	39.2±0.16	30.3±0.27	37.1±0.36
V_{Min}	3.5[4]	32.3[3]	9.6[3]	10.2[2]	16.5± 0.23	18.3±0.16	15.5±0.27	16.7±0.36
F_{Min}	0	31.8[4]	0.3[5]	10.1[3]	14± 0.23	21.5±0.16	10.4±0.27	19.2±0.36
GF_{Min}	8.8[2]	44.8[1]	18.3[1]	10.2[2]	15± 0.23	24.2±0.16	13.7±0.27	23.2±0.36
% variance	10	50	21	12				

Numbers 1-6 (in superscript) in vertical order refer to factors explaining significant amounts of G × E rank. S.E. were followed by the temperature mean

Table 2. The most heat tolerant and heat sensitive chickpea genotypes phenology, biomass and yield and the maximum and minimum temperatures (˚C) of chickpea developmental stages (genotypes data were obtained from the ANOVA table of two years, 2009-10 (Year 1) and 2010-11 (Year 2) and two seasons (normal and late))

	DFF (days)	D50F (days)	DFP (days)	DPM (days)	Plant Biomass (g/plant)	Grain Yield (g/plant)	V_{Max}	V_{Min}	F_{Max}	F_{Min}	GF_{Max}	GF_{Min}
Heat tolerant - ICCV 98902												
Yr1												
Normal	36	42	44	100	21.04	11.02	29.2	17.5	28.5	13.8	27.9	14.2
Late	46	50	53	82	13.96	9.51	33.9	18.2	38.5	21.6	39.4	24.1
Yr2												
Normal	36	45	47	106	37.45	19.21	28.3	17.3	27.4	9.3	29.7	13.0
Late	35	38	42	102	46.49	27.22	32.1	16.5	35.7	17.3	36.7	22.3
Heat sensitive - ICC 5566												
Yr1												
Normal	64	67	72	125	28.44	8.46	28.6	16	28.0	13.7	30.7	16.1
Late	66	70	72	106	5.08	0	35.2	19.3	40.5	25.1	39.5	25.3
Yr2												
Normal	61	68	68	113	23.02	6.07	27.9	14.2	29.7	10.7	30.9	15.0
Late	64	75	74	115	18.44	1.79	32.3	16.5	36.4	19.0	36.9	22.7
Heat sensitive - ICC 7570												
Yr1												
Normal	60	63	66	116	34.62	13.70	28.8	16.1	27.0	14.0	29.6	15.5
Late	55	59	60	100	8.81	0	34.6	18.8	37.4	21.2	39.5	24.9
Yr2												
Normal	66	69	74	115	26.50	4.33	28.0	13.9	29.9	11.6	31.3	15.6
Late	60	63	66	111	24.87	1.46	33.4	17.3	35.7	22.0	37.5	24.4

(DFF-days to first flower; D50F-days to 50% flowering; DFP-days to first pod; DPM-days to physiological maturity)

In chickpea, DFF depends on temperature which influences the time to maturity. Therefore DFF clearly plays an important role in crop adaptation. Though chickpea is a cool season crop, it has a higher critical temperature than other cool season legumes.

Conclusion

There was genetic variation in chickpea under high temperature. The maximum temperature during grain filling period reduced grain yield in chickpea. The genotype ICCV 98902 had a higher critical temperature (≥38˚C) during grain filling period and produced the highest grain yield under heat stress.

Acknowledgments

We thank the Grains Research and Development Corporation of Australia and National Food Security Mission (NFSM), Ministry of Agriculture, Government of India for their financial support. The first author also thanks Dr. Tariq Chattha for his statistical support.

References

Berger JD, Milroy SP, Turner NC, Siddique KHM, Imtiaz M, Malhotra R (2011). Chickpea evolution has selected for contrasting phonological mechanisms among different habitats. Euphytica 180, 1-15.

Gaur PM, Srinivasan S, Gowda CLL, Rao BV (2007). Rapid generation advancement in chickpea. Journal of SAT Agricultural Research 3(1) pp. 3.

Krishnamurthy L, Gaur PM, Basu PS, Chaturvedi SK, Tripathi S, Vadez V, Rathore A, Varshney RK, Gowda CLL (2011). Large genetic variation for heat tolerance in the reference collection of chickpea (*Cicer arietinum* L.) germplasm. Plant Genetic Resources 9, 59-69.

Summerfield RJ, Hadley P, Roberts EH, Minchin FR, Rawsthorne S (1984). Sensitivity of chickpea (*Cicer arietinum* L.) to hot temperatures during the reproductive period. Experimental Agriculture 20, 77-93.

Vargas M, Crossa J, Sayre K, Reynolds M, Ramirez ME, Talbot M (1998). Interpreting genotypes x environment interaction in wheat using partial least-squares regression. Crop Science 38, 679-689.

Wang J, Gan YT, Clarke F, McDonald CL (2006). Response of chickpea yield to high temperature stress during reproductive development. Crop Science 46, 2171–2178.