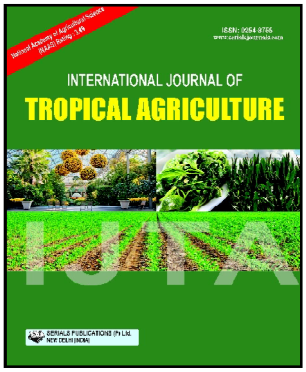

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Assessment of Genetic Variation for Morpho-physiological Traits under Elevated Temperatures in Chickpea

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Abstract: Fourteen chickpea genotypes were evaluated at 20/15°C and 25/20°C temperature under controlled condition for morpho-physiological analysis for growth and yield variations at Phytotron facility during *Rabi,* 2014-15 in FCRD with two replications. The exposer of chickpea plants to the temperature 25/20⁰C was found better than 20/15⁰C for crop phenology, morpho-physiological parameters and yield and yield contributing characters. The genotypes Vijay, Digvijay, Phule-G-12113 and Phule-G-12107 recorded higher photosynthetic rate, stomatal conductance, transpiration rate and total chlorophyll content and were found to be tolerant to high temperature stress. Phule-G-120107 and Phule-G-12113 recorded maximum proline content and minimum lipid peroxidation rate and thereby found to be tolerant to high temperature stress. Vijay, Digvijay, Phule-G-12113 and Phule-G-12107 recorded higher number of branches plant^{-1}, leaves plant^{-1}, leaf area plant^{-1}, pods plant^{-1}, seeds plant^{-1}, yield plant^{-1}, biomass plant^{-1} and harvest index. Thus, these genotypes exhibited tolerance to thermal stress. On the basis of this studies, the screened genotypes Phule-G-96006, JAKI-9218, BDNG-797, Phule-G-0609-15, Vishal, Phule-G-0405, Phule-G-0616-20-3, Phule-G-0408, Phule-G-12110 and SAKI-9516 can be grouped as susceptible to elevated temperatures, whereas, Phule-G-1211, Phule-G-12107, Vijay and Digvijay were grouped as tolerant to elevated temperatures.

Key words: Chickpea, elevated temperature, morpho-physiological traits, yield variation.

INTRODUCTION

Varying temperature is a major limitation to successful crop production throughout the world. It reduces the productivity by delay or prevention of crop establishment, destruction of established crop due to thermal stress, alteration of physiological and biochemical metabolism of the plant, reducing the quality of grain, forage, fibre, oil and other economically important products. The improvement in the genotypes is the only alternative for yield stability under temperature stress environment. Therefore, the improved chickpea genotypes with better heat and chilling stress tolerance efficiency and high yield will be suitable for cultivation in arid, cold and drought areas and can prove a boon to improve the economic status of poor farmers of dry land areas. To achieve this, an understanding of physiological processes associated with elevated temperature tolerance is pre-requisite. Chickpea productivity is constrained by several abiotic stresses and temperature is one of the most important determinants of crop growth over a range of environments and may limit chickpea yield. The effects of heat stress during the vegetative and reproductive growth stages using agronomic, phenological, morphological and physiological assessment has been studied in various crops. Such information on the influence of elevated temperature on the physiology and morphology of chickpea is rather scanty. Further the detrimental effects of high temperature on various growth and yield parameters are difficult to assess when growth conditions are favourable and growth habit is indeterminate. Relatively narrow genetic base of chickpea is another reason why high temperature has such a detrimental effect on growth and reproductive physiology. For these reasons chickpea tends to be sensitive to high temperature during the growth and reproductive stages. The determination of a heat response phenotype through screening is vital if the genetic control of heat tolerance in chickpea is to be understood and significant progress has made through plant breeding. Clearly, the research under high temperature stress shows that early phenology is the most important mechanism and pod set the primary yield component to be considered in heat tolerance breeding. Overall, the heat stress can be studied using a holistic approach that integrates genetic and physiological characterization of plant response help to define plant breeding targets. These combined approaches which include molecular tools and agronomic practices, will be pivotal to developing improved heat tolerant chickpea cultivars. Therefore, the present study was undertaken to study the effect of elevated temperatures on morpho-physiology and crop growth under controlled conditions.

MATERIAL AND METHODS

Fourteen chickpea genotypes were evaluated for growth and yield variation in Automated Polyhouses in pot culture at 20/15 and 25/20^{0}C day and night temperature. Five seedlings were grown in pots having growth media of clay, cocopit, vermiculite and perlite. The observations on crop phenology, morpho-physiological and biochemical parameters and yield contributing characters were recorded. The observations on net photosynthetic rate, transpiration rate and stomatal conductance were recorded with the help of portable Infrared Gas Analyzer (IRGA; Model Portable Photosynthesis System LI 6400, LI-COR Inc, Lincon, Nebraska, USA). Canopy temperature (CT) and CTD (°C) were recorded with the help of infra-red thermometer (IRT). SPAD index was estimated non-destructively, using SPAD-502 chlorophyll meter (Minolta Corp., Ramsey, NJ, USA). Proline content in leaf tissues were determined by using the acid ninhydrin reagent as per the method described by Bates *et al.,* (1). The level of lipid peroxidation is measured in terms of thiobarbituric acid reactive substance (TBARS) content. The data obtained from germination test, seedling test and physiological analysis for growth and yield variation were analysed by using factorial completely randomized design (14).

RESULTS AND DISCUSSION

High temperature can cause considerable pre and post-harvest damages including scorching of leaves, sunburn of leaves, stems and branches, leaf senescence and abscission, inhibition of shoot and root growth, deterioration seed quality and reduced yield. High temperature induce modifications in plants, may be direct as on existing physiological processes or indirect as altering the pattern of development. These responses may differ from one phenological stage to another. Although, physiological mechanisms of thermo-tolerance are relatively well understood, further studies are essential to determine physiological parameters viz; assimilate partitioning from source to sink, plant phenotypic flexibility which leads to thermo-tolerance and factors that modulate plant heat-stress response.

Phenological and morphological studies: At temperature 25/20^{0}C flowering was earlier (41.46 days) than 20/15^{0}C temperature (47.57 days). This is because of the fact that flowering initiation was favoured by elevated temperature (25/20^{0}C). The Vijay genotype flowered earlier (39.50 days) followed by Digvijay (40 days) at 25/20^{0}C temperature regime which indicated that 25/20^{0}C temperature was better for flowering. Genotype Vishal exhibited late flowering (50 days) at 20/15^{0}C temperature and was found to be sensitive to low temperature (20/15^{0}C). Therefore, the genotypes Vijay and Digvijay can be used for late sown conditions (Table 1). Srinivasan *et al.* (17) and Kumar *et al.* (9) reported that low temperature causes abortion of flower buds and flowering is delayed in chickpea.

The days to 50 per cent flowering varied with different temperatures. At temperature 25^{0}C flowering (50 per cent) was earlier (46.46 days) than 20/15^{0}C regime (52.46 days). This indicated that flowering was accelerated at high temperature (25/20^{0}C). The genotype Vijay showed early 50 per cent flowering (44.50 days) because initiation of flowering was earlier (Table 1). In the interaction between genotype and temperature, genotype Vijay at 25/20^{0}C regime recorded early 50% flowering (44.5 days). Genotype Vishal exhibited late 50 per cent flowering (55 days) at 20/15^{0}C regime because flowering was delayed due to low temperature (20/15^{0}C). Srinivasan *et al.* (17) and Kumar *et al.* (9) reported that low temperature delayed phenological stages of chickpea.

The physiological maturity was observed to be influenced by different temperature regimes. The exposer to 25/15^{0}C temperature regime showed early maturity (104.46 days) than 20^{0}C tempearture (113.25 days). This was because flowering was also earlier at 25/20^{0}C regime and consequently it hastened early maturity of plant (Table 1). The genotype Vijay matured earlier (98.50 days) at 25/15^{0}C and can be used for late sown conditions, while genotype SAKI-9516 took more days to mature (118.00 days) at 20/15^{0}C temperature regime and was found to be susceptible to low temperature (20/15^{0}C). Mahoney (11) and Clarke and Siddique (3) reported that for proper maturity and reproductive development high temperature (25/20^{0}C) is required in chickpea. Thus all the phonological stages were completed early due to elevated temperatures (25/20^{0}C) indicating the existence of escape mechanism.

Plant height is the genetically controlled character but it could be influenced by environmental conditions and management practices. It is well known that the plant height is drastically affected if the stress is severe during vegetative growth. The variation in plant height may be due to genotypic difference or influence of moisture and thermal stress. The plant height was found to be decreased at elevated temperature i.e. 25/20^{0}C (48.28 cm) as compared to 20/15^{0}C regime (52.10 cm). The genotype Phule-G-12107 recorded higher plant height (63.5 cm) than other genotypes, while genotype Vijay exhibited the least plant height (29.68 cm) as vegetative growth was less. Phule-G-12110 at 20/15^{0}C recorded higher plant hieght (66.8 cm) followed by Phule-G-12107 (65.9 cm) because low temperature (20/15^{0}C) favoured optimum plant height (Table 1). Smithson *et al.* (16) and Heidarvland *et al.* (4) reported that optimum condition for growth of chickpea is 18-26^{0}C temperature.

Number of branches is good yield contributing character as higher pods, seeds and finally yields. The number of branches was more at 25/20^{0}C regime (23.25) than 20/15^{0}C temperature (21.68) due to the optimum growth of branches favoured by 25/20^{0}C temperature. The genotype Phule-G-12107 produced higher number of branches (27.50) at 25/20^{0}C regime and was found to be tolerant to high temperature (25^{0}C), while Phule-G-0405 produced less branches (19.0) at 20/15^{0}C regime indicating that low temperature adversely affected number of branches (Table 1). Kiran *et al.* (7) reported high temperature causes pronounced growth of branches and leaves in chickpea.

Higher leaf area indicates more photosynthesis, dry matter and more yields. The leaf area increased at high temperature 25/20^{0}C regime (8.05dm^2) over 20/15^{0}C (7.49 dm^2) because 25/20^{0}C temperature favoured pronounced growth of leaves. The Phule-G-12113 performed best giving high leaf area (8.35 dm^2) because of optimum chlorophyll content and photosynthetic rate. However, the genotype BDNG-797 recorded the least leaf area (7.42 dm^2) due to low chlorophyll and photosynthetic rate (Table 1). Among the interactions, Phule-G-12113 recorded the highest leaf area (8.60 dm^2) at 25/20^{0}C regime and was found to be tolerant at high temperature (25/20^{0}C) and BDNG-797 recorded least leaf area (7.20 dm^2) at 20/15^{0}C temperature because low temperature was unfavourable for leaf growth. Macdonald *et al.* (10) reported higher leaf area of chickpea leaf was at high temperature.

Physiological parameters: Canopy temperature is strongly influenced by plant water status (Table 2). Plant water status has a direct bearing on vital physiological processes and morphological characteristics of plant, which are the primary determinants of seed yield. The canopy temperature varied as 17.25 and 22.24^{0}C at 20/15^{0}C and 25/20^{0}C temperature regimes respectively. At 20/15^{0}C temperature the canopy was found cooler (17.25^{0}C) than 25/20^{0}C (22.34^{0}C). The genotype Phule-G-0609-15 maintained cooler canopy (16.75) followed by Phule-G-12113 (16.85^{0}C) and Phule-G-12107 (16.90^{0}C) at 20/15^{0}C temperature indicating tolerance to low temperature (20/15^{0}C), while genotype SAKI-9516 recorded higher canopy temperature (23.30^{0}C) at 25^{0}C and was found to be susceptible to high temperature (25/20^{0}C). It is mainly due to the higher water deficit in the leaves. Krishnamurthy *et al.* (8) suggested canopy temperature and canopy temperature depression can be used to indentify tolerant and susceptible varieties in chickpea.

Canopy temperature depression indicates an ability of the plant to maintain cooler plant temperature in response to the atmospheric temperature to give higher yield even in stress conditions. The canopy temperature depression exhibited variation with different temperature regimes as values were -0.91 and -0.75^{0}C at 20/15 and 25/20^{0}C temperature respectively (Table 2). Canopy temperature was recorded highly negative in Phule-G-0609-15 (-1.55^{0}C) at 20^{0}C temperature regime and was found to be tolerant to low (20^{0}C)temperature, while the lowest was recorded in Phule-G-12110 (0.00^{0}C) at 25/20^{0}C temperature regime and was found susceptible to high temperature (25/20^{0}C).

SPAD index is a non-destructive measurement method used to determine leaf chlorophyll content. This index was used preferentially because there is strong relationship between readings of portable chlorophyll meter and leaf chlorophyll content and this has been demonstrated by several researches. The total chlorophyll content (SPAD index) was higher at 25/20^{0}C temperature (39.95) than 20/15^{0}C regime (33.35) as it required high temperature for the growth (Table 2). The genotype Digvijay recorded higher total chlorophyll content (51.18) followed by Vijay (47.65) at 25/20^{0}C temperature regime and indicated

Table 1
Phenological and morphological characters of chickpea genotypes as influenced by various temperature regimes (^{0}C)

Genotypes	*20/15*	*25/20*	*Mean*	*20/15*	*25/20*	*Mean*	*20/15*	*25/20*	*Mean*
	Days to Initiation of flowers			*Days to 50% flowering*			*Days to physiological maturity*		
Vijay	45.50	39.50	42.50	50.50	44.50	47.50	109.00	98.50	103.75
Digvijay	46.00	40.00	43.00	51.00	45.00	48.00	113.00	109.50	111.25
Phule-G-96006	49.00	41.50	45.25	52.50	46.50	49.50	114.50	105.50	110.00
JAKI-9218	48.00	42.00	45.00	53.00	47.00	50.00	114.00	104.50	109.25
BDNG-797	47.50	41.50	44.50	52.50	46.50	49.50	114.00	107.00	110.50
Phule-G-0616-20-3	49.00	43.00	46.00	54.00	48.00	51.00	114.00	104.00	109.00
Phule-G-12113	46.50	40.50	43.50	51.50	45.50	48.50	112.50	103.50	108.00
Vishal	50.00	44.00	47.00	55.00	49.00	52.00	108.50	100.50	104.50
Phule-G-12107	46.50	40.50	43.50	51.50	45.50	48.50	116.00	107.50	111.75
Phule-G-12110	47.50	41.50	44.50	52.50	46.50	49.50	112.50	101.50	107.00
Phule-G-0609-15	47.00	41.00	44.00	52.00	46.00	49.00	113.50	103.50	108.50
Phule-G-0405	48.50	42.50	45.50	53.50	47.50	50.50	114.00	104.50	109.25
Phule-G-0408	48.00	42.00	45.00	53.00	47.00	50.00	112.00	103.50	107.75
SAKI-9516	47.00	41.00	44.00	52.00	46.00	49.00	118.00	109.00	113.50
	E	**G**	**G x E**	**E**	**G**	**G x E**	**E**	**G**	**G x E**
SEm(±)	0.14	0.18	0.51	0.59	0.78	2.21	0.21	0.28	0.80
CD (1%)	0.53	0.77	NS	2.31	3.33	8.64	0.84	1.21	NS
	Plant height (cm)			*Branches plant^{-1}*			*Leaf area (dm^2) plant^{-1}*		
Vijay	31.20	28.15	29.68	21.00	22.00	21.50	7.35	7.87	7.61
Digvijay	39.90	38.30	39.10	19.50	23.50	21.50	7.58	8.09	7.83
Phule-G-96006	44.55	44.05	44.30	23.00	25.50	24.25	7.73	8.09	7.91
JAKI-9218	61.45	51.95	56.70	23.00	24.00	23.50	7.35	7.87	7.61
BDNG-797	44.20	44.40	44.30	24.00	25.00	24.50	7.20	7.65	7.42
Phule-G-0616-20-3	59.85	50.50	55.18	22.00	23.00	22.50	7.65	8.16	7.91
Phule-G-12113	65.40	55.35	60.38	19.50	20.50	20.00	8.11	8.60	8.35
Vishal	59.30	54.30	56.80	22.00	23.00	22.50	6.89	8.31	7.60
Phule-G-12107	65.90	60.90	63.40	24.50	27.50	26.00	7.80	8.31	8.06
Phule-G-12110	66.80	58.30	62.55	23.50	25.50	24.50	7.35	7.87	7.61
Phule-G-0609-15	45.90	46.25	46.08	20.00	20.50	20.25	7.65	8.16	7.91
Phule-G-0405	49.10	48.40	48.75	19.00	20.00	19.50	7.20	7.72	7.46
Phule-G-0408	46.75	46.95	46.85	21.00	22.50	21.75	7.35	7.87	7.61
SAKI-9516	49.15	48.15	48.65	21.50	23.00	22.25	7.65	8.09	7.87
	E	G	G x E	E	G	G x E	E	G	G x E
SEm(±)	0.31	0.42	1.18	0.20	0.27	0.76	0.02	0.03	0.08
CD (1%)	1.23	1.77	4.60	0.79	1.14	NS	0.09	0.12	0.32

G: Genotypes, E: Environment, G x E: Genotype x Environment

Table 2
Physiological parameters of chickpea genotypes as influenced by various temperature regimes (°C)

Genotypes	*20/15*	*25/20*	*Mean*	*20/15*	*25/20*	*Mean*	*20/15*	*25/20*	*Mean*
	Canopy temperature (°C)			*CTD (°C)*			*Chlorophyll content (SPAD index)*		
Vijay	17.70	23.10	20.40	-0.90	-0.75	-0.83	40.55	47.65	44.10
Digvijay	17.30	21.05	19.18	-1.35	-1.35	-1.35	45.08	51.18	48.13
Phule-G-96006	17.40	22.60	20.00	-0.50	-0.55	-0.53	21.50	28.35	24.93
JAKI-9218	17.00	22.65	19.83	-0.45	-1.05	-0.75	23.05	29.60	26.33
BDNG-797	17.50	22.35	19.93	-0.60	-0.75	-0.68	34.10	40.68	37.39
Phule-G-0616-20-3	16.80	22.65	19.73	-0.40	-0.65	-0.53	30.05	36.22	33.14
Phule-G-12113	16.85	21.25	19.05	-1.40	-0.90	-1.15	37.63	44.39	41.01
Vishal	17.50	22.85	20.18	-1.15	-0.80	-0.98	28.25	34.55	31.40
Phule-G-12107	16.90	22.20	19.55	-1.35	-1.35	-1.35	35.25	42.08	38.66
Phule-G-12110	17.60	22.65	20.13	-0.85	0.00	-0.43	39.43	46.39	42.91
Phule-G-0609-15	16.75	21.50	19.13	-1.55	-0.85	-1.20	37.20	43.85	40.53
Phule-G-0405	17.30	22.55	19.93	-0.70	-0.80	-0.75	30.10	36.65	33.38
Phule-G-0408	17.15	22.05	19.60	-0.65	-0.80	-0.73	33.48	40.10	36.79
SAKI-9516	17.80	23.30	20.55	-0.90	-0.65	-0.78	31.25	37.67	34.46
	E	**G**	**G x E**	**E**	**G**	**G x E**	**E**	**G**	**G x E**
SEm(±)	0.15	0.20	0.55	0.07	0.09	0.26	0.05	0.06	0.17
CD (1%)	0.58	NS	NS	NS	NS	NS	0.18	0.26	NS
	Photosynthetic rate (μmole CO_2 m^{-2} s^{-1})			*Stomatal Conductance (mmol H_2O m^{-2} s^{-1})*			*Transpiration rate (mmol H_2O m^{-2} s^{-1})*		
Vijay	16.04	18.09	17.07	0.20	0.23	0.22	4.62	5.76	5.19
Digvijay	16.79	18.84	17.82	0.20	0.23	0.22	5.56	6.12	5.84
Phule-G-96006	14.59	16.64	15.62	0.18	0.21	0.20	4.27	4.76	4.52
JAKI-9218	14.70	16.75	15.73	0.19	0.22	0.21	4.53	4.80	4.67
BDNG-797	15.36	17.41	16.38	0.18	0.21	0.20	4.44	5.05	4.74
Phule-G-0616-20-3	14.87	17.28	16.07	0.19	0.22	0.21	4.52	5.22	4.87
Phule-G-12113	15.65	17.70	16.68	0.19	0.22	0.20	5.13	5.75	5.44
Vishal	14.69	16.74	15.72	0.17	0.20	0.18	4.21	4.58	4.39
Phule-G-12107	15.62	17.67	16.65	0.19	0.22	0.21	5.25	5.49	5.37
Phule-G-12110	15.80	17.85	16.83	0.17	0.20	0.19	5.05	5.30	5.17
Phule-G-0609-15	15.66	17.71	16.68	0.17	0.20	0.19	4.58	4.94	4.76
Phule-G-0405	14.93	16.92	15.92	0.19	0.22	0.20	5.02	5.43	5.23
Phule-G-0408	15.27	17.32	16.30	0.16	0.19	0.18	4.88	5.08	4.98
SAKI-9516	15.23	16.98	16.10	0.17	0.20	0.19	4.49	4.87	4.68
	E	**G**	**G x E**	**E**	**G**	**G x E**	**E**	**G**	**G x E**
SEm(±)	0.01	0.01	0.04	0.002	0.004	0.01	0.02	0.03	0.09
CD (1%)	0.04	0.06	0.16	0.01	0.02	NS	0.10	0.14	0.36

that these genotypes are insensitive to high temperature (25/20^{0}C). Phule-G-96006 genotype recorded the lowest total chlorophyll content (21.50) at 20/15^{0}C temperature and was found to be sensitive to low temperature (20/15^{0}C). Nayyar *et al.* (13) reported that total chlorophyll content is optimum at 25-30^{0}C in chickpea.

The rate of photosynthesis is an important physiological parameter which governs the dry matter production and consequently the yield. More photosynthesis led to maximum accumulation of photo-assimilates from source to sink and ultimately gives maximum yield. The rate of photosynthesis was higher at 2520^{0}C temperature regime (17.42µmole $CO_2 m^{-2}s^{-1}$) than 20/15^{0}C regime (15.37 µmole CO_2 $m^{-2}s^{-1}$) because 25/20^{0}C temperature is favourable for photostnthetic rate (Table 2). The genotype Digvijay recorded higher photosynthetic rate (17.82 µmole CO_2 $m^{-2}s^{-1}$) due to more chlorophyll content, while Phule-G-96006 exhibited the least value (15.62 µmole CO_2 $m^{-2}s^{-1}$). The interaction of genotype Digvijay at 25/20^{0}C recorded the highest photosynthetic rate (18.84 µmole CO_2 $m^{-2}s^{-1}$) because more photosynthetic rate was favoured by high temperature (25/20^{0}C), while lowest was recorded in Phule-G-96006 (21.50 µmole CO_2 $m^{-2}s^{-1}$) at 20/15^{0}C and was found to be more sensitive to low temperature (20/15^{0}C).

Stomatal conductance plays important role in stomatal control. The closure of stomata is an early and one of the first responses of plants to water scarcity under field conditions and it is affected by temperature (Table 2). During stomatal closure, the flow of water is reduced, photorespiration is increased and the carbon uptake by the leaves is limited. The stomatal conductance increased at 25/20^{0}C temperature (0.21 mmole H_2O $m^{-2}s^{-1}$) over 20/15^{0}C regime (0.18 mmole H_2O $m^{-2}s^{-1}$). It was because of better stomatal conductance at high temperature (25/20^{0}C). The Vijay and Digvijay genotypes exhibited higher stomatal conductance (0.23 mmole H_2O $m^{-2}s^{-1}$) at 25/20^{0}C and were found to be insensitive to high temperature (25/20^{0}C), while Phule-G-96006 recorded lowest stomatal conductance (0.18 mmole H_2O $m^{-2}s^{-1}$) at 20/15^{0}C and was sensitive to low temperature (20/15^{0}C). According to Jain (5), stomatal conductance in chickpea increases with rise in temperature stress.

Transpiration is the removal of moisture from plant parts and it has significant impact on yield of crops. It is also one of the important parameter to measure water use efficiency (WUE) of agricultural crops. Stomatal conductance and transpiration are positively correlated and stomatal closure leads to reduced transpirational losses. The transpiration rate was higher at 25/20^{0}C temperature treatment (5.21mmoles H_2O $m^{-2}s^{-1}$) than 20/15^{0}C regime (4.77 mmoles H_2O $m^{-2}s^{-1}$) because at high temperature water loss is more from the leaves (Table 2). The Digvijay genotype recorded higher transpiration rate (5.84 mmoles H_2O $m^{-2}s^{-1}$) and Vishal recorded the least value (4.39 mmoles H_2O $m^{-2}s^{-1}$). The interaction of Digvijay genotype at 25/20^{0}C showed higher value (6.12 mmoles H_2O $m^{-2}s^{-1}$) as photosynthetic rate and stomatal conductance is also higher (Table 2). Tian *et al.* (18) reported heat stress increases transpiration rate in chickpea.

Biochemical studies: Osmotic adjustment is a mechanism to maintain water relations under osmotic stress. It involves the accumulation of a range of osmotically active molecules and ions including soluble sugars, sugar alcohol, proline, glycine betain, organic acid etc. Proline accumulation is the first response of plants exposed to heat stress in order to reduce injury to cells. Proline can act as a signaling molecule to modulate mitochondrial functions, influence cell proliferation or cell death and trigger specific gene expression, which can be essential for plant recovery from stress. Accumulation of proline under stress in many plant species has been correlated with stress tolerance, and its concentration has been shown to be generally higher in stress-tolerant than in stress-sensitive plants. The proline content was found to be increased at 25/20^{0}C temperature in all the genotypes (3.20µmoles/g) over 20^{0}C regime (1.07 µmoles/g). It indicated that heat stress increased proline content in plants. The genotype Phule-G-12110 recorded higher proline content (4.93 µmoles/g) followed by Phule-G-12113 (4.74 µmoles/g) indicating their heat stress tolerance (Table 3). Mufakheri *et al.* (12) reported that proline content increases with increase in temperature in chickpea.

Lipid peroxidation activity is an important parameter as it indicates the membrane injury and response of plant to it. The lipid peroxidation rate increased at 25^{0}C temperature (3.71 µmoles MDA/g) over 20^{0}C regime (1.89 µmoles MDA/g). This because may be of the reason that high temperature (25^{0}C) caused membrane injury to the plants. The genotype Phule-G-12113 (0.55 µmoles MDA/g) reported less lipid peroxidation rate at 20^{0}C temperature due to less membrane injury and exhibiting high tolerance to the elevated temperature, while Phule-0408 recorded higher lipid peroxiation rate (5.52 µmoles MDA/g) at 25^{0}C regime because it was found to be more susceptible to higher temperature (25^{0}C). Kaushal *et al.* (6) and Patel and Hanmantrajan (15) reported high temperature stress causes increase in lipid peroxidation activity in chickpea.

Yield and yield contributing charcters: The number of pods was more at 25^{0}C temperature (55.50) than 20^{0}C temperature (40.79) because pod development favoured higher temperature (Table 4). Genotype Digvijay produced higher number of pods (60.25) due to higher photosynthetic rate. JAKI-9516

Table 3
Biochemical characters of chickpea genotypes as influenced by various temperature regimes

Genotypes	*20/15^{0}C*	*25/20^{0}C*	*Mean*	*20/15^{0}C*	*25/20^{0}C*	*Mean*
	Proline content (µmoles g^{-1} fresh weight)			*Lipid peroxidation rate (µmoles MDA g^{-1} fresh weight)*		
Vijay	0.79	2.34	1.57	1.33	3.15	2.24
Digvijay	1.17	3.47	2.32	1.32	3.25	2.29
Phule-G-96006	0.53	2.22	1.37	1.75	3.57	2.66
JAKI-9218	0.80	2.38	1.59	1.85	3.67	2.76
BDNG-797	0.72	3.03	1.87	1.26	3.08	2.17
Phule-G-0616-20-3	0.99	3.19	2.09	1.80	3.62	2.71
Phule-G-12113	2.10	4.74	3.42	0.55	2.37	1.46
Vishal	0.48	2.86	1.67	1.18	3.00	2.09
Phule-G-12107	1.61	3.82	2.71	1.40	3.22	2.31
Phule-G-12110	2.25	4.93	3.59	1.62	3.44	2.53
Phule-G-0609-15	0.92	3.10	2.01	2.57	4.39	3.48
Phule-G-0405	0.82	3.20	2.01	2.86	4.68	3.77
Phule-G-0408	1.42	2.70	2.06	3.79	5.52	4.66
SAKI-9516	0.67	2.88	1.77	3.21	5.03	4.12
	E	**G**	**G x E**	**E**	**G**	**G x E**
SEm(±)	0.01	0.01	0.02	0.02	0.03	0.09
CD (1%)	0.02	0.03	0.07	0.09	0.13	NS

gave lower number of pods (36.75) because of low photosynthetic rate. In the interactions, genotype Digvijay at 25^{0}C produced the highest number of pods (70.50) and indicated tolerance to the high temperature (25^{0}C) , while Phule-G-96006 and Vishal genotypes produced the least pods (31) at 20^{0}C because low temperature (20^{0}C) had detrimental effect on pod development (Table 4). Boote *et al.* (2) and Kumar *et al.* (9) reported that high temperature produce more pods by hastening the reproductive development in chickpea.

The 25/20^{0}C day and night temperature was found to be favourable for production of seeds since there were more seeds per plant (64.24) compared to 20^{0}C regime (43.71) (Table 4). Digvijay genotype produced more seeds per plant (72.07) because it produced more pods per plant, while Vishal produced less seeds per plant (39.29) due less number of pods (Table 4). The genotype Digvijay favoured 25^{0}C temperature as their interaction gave the highest seeds per plant (88.13). Kumar *et al.* (9) reported high temperature resulted in higher number of seeds in chickpea.

The yield per plant varied with different temperature regimes as 10.09g and 8.74g at 25^{0}C and 20^{0}C temperature respectively (Table 4). Temperature 25^{0}C exhibited higher yield per plant because all yield contributing characters were Favourably influenced due to higher (25^{0}C) temperature. The genotype Digvijay produced higher yield per plant (12.01 g) over other genotypes because it produced higher number of pods per plant. The genotype Digvijay suited best to 25^{0}C temperature regime as it gave higher yield per plant (12.82 g) and was found to be

Table 4
Yield and yield attributes of chickpea genotypes as influenced by various temperature regimes

Genotypes	*20^{0}C*	*25^{0}C*	*Mean*	*20^{0}C*	*25^{0}C*	*Mean*	*20^{0}C*	*25^{0}C*	*Mean*	*20^{0}C*	*25^{0}C*	*Mean*
	Pods plant^{-1}			*Seeds per plant*			*Yield per plant (g)*			*Harvest index (%)*		
Vijay	50.50	68.00	59.25	51.51	83.64	67.58	10.30	12.36	11.33	43.51	48.56	46.04
Digvijay	50.00	70.50	60.25	56.01	88.13	72.07	11.20	12.82	12.01	45.34	49.19	47.27
Phule-G-96006	31.00	55.00	43.00	32.86	59.40	46.13	6.57	10.00	8.29	37.01	40.05	38.53
JAKI-9218	31.50	42.00	36.75	34.02	46.20	40.11	6.80	7.64	7.22	39.82	41.27	40.54
BDNG-797	41.00	51.50	46.25	45.30	59.74	52.52	9.06	9.36	9.21	40.11	42.41	41.26
Phule-G-06 16-20-3	36.50	48.00	42.25	38.33	51.36	44.84	7.67	8.73	8.20	42.26	44.89	43.58
Phule-G-12113	49.50	69.00	59.25	54.21	85.56	69.88	10.84	12.55	11.69	46.65	50.77	48.71
Vishal	31.00	44.00	37.50	31.93	46.64	39.29	6.39	8.00	7.19	40.27	44.26	42.26
Phule-G-12107	49.00	68.50	58.75	53.41	83.92	68.66	10.68	12.45	11.57	46.23	52.16	49.19
Phule-G-12110	46.00	64.50	55.25	48.53	77.40	62.96	9.71	11.73	10.72	44.87	48.07	46.47
Phule-G-0609-15	37.50	47.50	42.50	41.24	57.00	49.12	8.25	8.64	8.44	45.24	40.90	43.07
Phule-G-0405	37.00	46.50	41.75	38.85	49.76	44.30	7.77	8.45	8.11	41.75	44.00	42.87
Phule-G-0408	40.50	52.00	46.25	43.34	56.68	50.01	8.67	9.45	9.06	43.89	44.61	44.25
SAKI-9516	40.00	50.00	45.00	42.40	54.00	48.20	8.48	9.09	8.79	43.12	44.97	44.05
	E	**G**	**G x E**	**E**	**G**	**G x E**	**E**	**G**	**G x E**	**E**	**G**	**G x E**
SEm(±)	0.28	0.37	1.05	0.31	0.41	1.16	0.06	0.07	0.21	0.20	0.27	0.76
CD (1%)	1.10	1.58	4.11	1.21	1.74	4.53	0.22	0.31	0.81	0.80	1.15	2.99

tolerant to high temperature (25^{0}C), while Vishal genotype produced lower yield (7.19 g) and was susceptible to both temperature regimes 20 and 25^{0}C. The genotype Phule-G-96006 exhibited higher increase in yield from 6.57g to 10.00 g from 20^{0}C to 25^{0}C temperature respectively (Table 4). Therefore this genotypes can be suitable for late sowing where high temperature exists. Nayyar *et al.* (13) reported that high yield and harvest index at 30/25^{0}C temperature in chickpea.

The present study revealed that, harvest index was higher (45.44%) at 25^{0}C temperature as yield was also more at this temperature than 20^{0}C regime (42.86%). The Phule-G-12107 genotype gave higher harvest index (49.19%), while Phule-G-96006 recorded lower harvest index (38.53%) due to more biomass as compared to economic yield (Table 4). Nayyar *et al.* (13) reported that yield and harvest index were higher at 30/25^{0}C temperature in chickpea.

The exposer of chickpea plants to higher day temperature and lower night temperature (25/20^{0}C) was found better than 20/15^{0}C for crop phenology, morpho-physiological parameters and yield and yield contributing characters. Among the various genotypes viz., Digvijay, Vijay, Phule-G-12113 and Phule-G-12107 were found better for morpho-physiological traits. Amongst the various genotypes Phule-G-12107 and Phule-G-0405 performed better at elevated temperatures.

Thus, the genotypes Phule-G-12107 and Phule-G-0405 performed better at highly elevated temperatures, while Phule-G-0616-20-3 and Phule-G-0609-15 and Phule-G-0408 performed better at neutral and slightly elevated temperatures. Therefore, the genotypes, Phule-G-12107 and Phule-G-0405 can be used for further breeding programme for improvement in germination and seedling growth. The genotypes Digvijay, Vijay, Phule-G-12113 and Phule-G-12107 were better for morpho-physiological traits and yield contributing characters at 25/20^{0}C. Therefore, these genotypes can be used for yield improvement programme in future.

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