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Earliness in Chickpea : A Key to Adaptation under Heat Stress

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ABSTRACT

Present investigation was conducted to screen seven genotypes for heat tolerance and evaluating their combining ability to identify best general and specific combiners for earliness to use in breeding program. For screening heat tolerant genotypes, observations were recorded on eight physiological parameters and for each trait promising genotypes under heat stress condition were identified. The genotype ICC 14815 indicated least deviation or closer to it in non stress and stress environments for individual traits. Further again, low score over all eight physiological parameters indicated less deviation and together with low HSI showed tolerance to heat stress. The other genotypes such as ICC 13124, ICC 14778 and PG 170 showed HSI of ≤1 therefore, may also be considered as heat tolerant. For analysis of combining ability, the parents were crossed in half diallel design and 21 crosses were generated. Early maturity had been considered as an important desirable trait in order to escape harmful effects of terminal heat stress for which significant variability was observed among all the parents and crosses. Three parents namely ICC 14815, ICC 16349 and ICC 13124 showed early maturity and three crosses viz., ICC 14815 × ICC 16348, ICC 14815 × ICC 16349 and PG 5 × ICC 16348 gave early flowering. Hence, the genotypes ICC 14815 and ICC 13124 were found to be heat tolerant with good combining ability for early maturity to use in hybridization program to develop heat tolerant varieties.

Keywords Chickpea, Combining ability, Diallel, Earliness, Heat stress.

INTRODUCTION

Chickpea is one of the important food legumes in the world and it is only cultivated species under the genus *'Cicer'*. It is a diploid with chromosome number 2n = 2x = 16 having a genome size of approximately 38.09 Mbp (Varshney *et al*. 2013) and it is a highly self-pollinated crop with an out crossing rate of less than 1%. *Cicer* genus belongs to family leguminoseae, sub-family papilionaceae and tribe cicereae. It encompasses 9 annual and 34 perennial wild species (Singh *et al.* 2008). Chickpea is a cheap and important source of protein for those people who cannot afford animal protein or who are largely vegetarian (Rasool

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et al. 2015). Furthermore, it is also a good source of minerals, unsaturated fatty acids, fiber and β-carotene and also plays an important role in maintaining soil fertility by fixing nitrogen at rates of up to 140 kg/ha/year (Flowers *et al*. 2010). India is the largest producer of chickpea, accounting for 65% of the total world production (FAOSTAT 2019). Though, India is the largest producer of this crop, its productivity is low as compared to other countries like Italy, Turkey, Iran, Sudan.

Chickpea production faces many challenges due to various abiotic stresses such as drought and low and high temperatures. Despite the continuous efforts to enhance the productivity of chickpea, unpredictable climate change is the major constraint for chickpea production as it increases the frequency of drought and temperature extremes, i.e., high (>30°C) and low (<15°C) temperatures (Rani *et al.* 2020). As chickpea is a heat sensitive crop, its potential yield is considerably reduced under high temperatures exceeding 35 °C (Kaushal *et al.* 2011). Global mean temperature will rise to 0.3°C per decade reaching to approximately 1 and 3°C above the present values by years 2025 and 2100, respectively. Yield reduction has been observed at a temperature of 30°C at 50% flowering and >30°C for 3-4 days at 100% flowering (Summerfield *et al.* 1984) and such conditions reduced the duration of flowering and pod filling, resulting in large yield losses. High temperature stress adversely affects plant physiological processes also. It necessitates development of crop varieties that can sustain and yield high in harsh climatic conditions by virtue of being resilient to warmer temperatures.

Several adaptive mechanisms are evoked by plants in response to exposure of high temperature. These adaptive mechanisms include early maturity, changing water potential, RWC, membrane injury, chlorophyll content and crop canopy temperature. Heat escape is an important adaptive mechanism which involves rapid plant development to enable the completion of the full life cycle prior to a coming heat event and avoids yield losses. Earliness plays a central role in genotype adaptation to current and new environments and cropping systems and has a powerful effect on yield and yield stability (Kumar and Abbo 2001). These include days to flowering, days to maturity, plant height, pod filling period, duration of flowering and others. Generally, breeders have used days to flowering as a key indicator of maturity duration (Monpara and Dhameliya 2013). Early maturity provides an escape mechanism under late incidence of high temperature stress and has been suggested as a good approach for chickpea breeding which suffers from terminal high temperature stress.

Another important trait, canopy temperature depression itself is a mechanism of heat escape, which enables plants to maintain physiological functions under elevated temperatures (Cornish *et al.* 1991). The metabolic activity in leaf tissues can be evaluated by measuring relative water content (%), that can be considered as an integrated measure of plant water status and used as the most meaningful index for dehydration tolerance (Kesici *et al.* 2013). High membrane stability, determined in terms of changes in ion leakage, is taken as an index of heat tolerance in several crops (Kumar *et al.* 2012). Thus, physiological characterization under high temperature stress may provide a better understanding of the adaptive traits that can be further integrated into breeding programs. Hence, the current study presents the heat tolerant chickpea lines with good combining ability for early maturity and the traits that offer promise to face the challenges of heat stress.

MATERIALS AND METHODS

The genotypes involved in the present study included five ICRISAT chickpea collections viz., ICC13124, ICC14778, ICC14815, ICC16348 and ICC16349 and two varieties released from Pantnagar namely, PG 5 and PG 170. All the seven parents were sown under two dates of sowing i.e. 30th November (Normal sowing) and 15th January (late sowing) during the crop season 2018-19. The normal sowing corresponds to non heat stress while late sowing to heat stress condition. The parents were evaluated for seven physiological traits at flowering and pod formation and one trait at harvesting stage in order to screen heat tolerant parents followed by detection of good combiners (parents as well as their half diallel crosses) for heat escape to use in breeding program.

In order to identify heat tolerant parents in the laboratory, physiological traits such as relative water content in percentage while chlorophyll ‘a’, chlorophyll ‘b’, total chlorophyll and carotenoid content in µg g^{-1} were assessed according to the procedure given by Talebi *et al*. (2013), whereas membrane stability index was measured by the method as given by Rahbarian *et al*. (2011). The observations on canopy temperature depression (CTD) and heat susceptibility index (HSI) were recorded at NEBCRC, GBPUAT, Pantnagar, USN, Uttarakhand under two dates of sowing. Heat susceptibility index indicated reduction in yield under heat stress condition as compared to non stress condition. It was calculated according to the formula given by Suresh *et al*. (2018) as HSI = $(1-Y_L/Y_N)/(1-X_L/X_N)$. Where, Y_L = mean yield of the line under late sown condition; Y_N = mean seed yield of the line under normal sown conditions; X_L= mean seed yield of all the lines under late sown conditions and X_N = mean seed yield of all the lines under normal sown condition. The data were subjected to factorial analysis of variance to find out significant differences among the parents. On comparing the genotypes, the parents with minimum deviation under non stress and stress condition and with low HSI may be considered as heat tolerant while with maximum deviation in two dates of sowing with high HSI as most heat susceptible genotypes.

To find out combining ability, the parents were crossed in a half diallel fashion in the previous year. The resulting 21 F_1 hybrids and parents were evaluated in a Randomized Block Design in *rabi* season 2018-2019. All the recommended agronomic practices were followed to raise a normal and healthy crop. The observations were recorded for traits viz., days to 50% flowering, days to maturity and their mean values were subjected to statistical analysis. The standard procedures developed by Griffing (1956) were followed to estimate the mean sum of squares (MSS) along with variances of SCA and GCA. Standard statistical tools were used to analyze the combining ability effects. Based on this, good general and specific combiners were identified for earliness.

RESULTS AND DISCUSSION

Plant response to high temperature was found to be diverse as significant variability occurred in plants for physiological traits at normal and heat stress conditions. Effect of heat stress on physiological parameters of chickpea at both flowering and pod formation stages are furnished in Table 1. In general, late sown high temperature stress condition significantly reduced all the physiological parameters except CTD. The genotypes responded differently for RWC over timely sown and late sown conditions. Reduction in RWC at stress level as compared to normal was low in

Table 1. Effect of heat stress on physiological traits in chickpea genotypes at both flowering and pod formation stage. ∞ = percentage change between normal and heat stress condition. *Figures in parenthesis indicate per cent of normal condition.

	Relative water content (RWC) (%)					
	Flowering			Pod formation		
Genotypes	Non heat stress	Heat stress	∞	Non heat stress	Heat stress	∞
PG 5	83.45	69.50	-16.71	75.61	64.62	-14.54
	(100)	(83.29)		(100)	(85.46)	
PG 170	82.72	71.30	-13.80	74.79	64.72	-13.46
	(100)	(86.20)		(100)	(86.54)	
ICC 14778	86.34	75.56	-12.49	80.35	70.07	-12.80
	(100)	(87.51)		(100)	(87.20)	
ICC 14815	86.47	75.75	-12.40	80.53	70.20	12.83
	(100)	(87.60)		(100)	(87.17)	
ICC 13124	86.60	75.69	-12.60	80.62	70.29	-12.81
	(100)	(87.40)		(100)	(87.19)	
ICC 16348	80.22	63.57	-20.75	71.56	55.10	-23.00
	(100)	(79.25)		(100)	(77.00)	
ICC 16349	81.03	65.83	-18.76	73.72	57.81	-21.58
	(100)	(81.24)		(100)	(78.42)	
ICC 16349	81.03	65.83	-18.76	73.72	57.81	-21.58
	(100)	(81.24)		(100)	(78.42)	83.83
Mean	83.83	71.03		76.74	64.69	

Table 1. Continued.

			Membrane stability index (MSI) (%)			
		Flowering			Pod formation	
Genotypes	Non heat stress	Heat stress	∞	Non heat stress	Heat stress	∞
PG 5	85.08	72.24	-15.09	79.29	67.07	-15.41
	(100)	(84.91)		(100)	(84.59)	
PG 170	84.34	72.05	-14.57	78.76	66.80	-15.19
	(100)	(85.43)		(100)	(84.81)	
ICC 14778	86.18	77.18	-10.44	81.30	69.71	-14.26
	(100)	(89.56)		(100)	(85.74)	
ICC 14815	86.34	77.27	-10.50	81.62	70.88	-13.16
	(100)	(89.50)		(100)	(86.84)	
ICC 13124	86.43	77.31	-10.55	81.90	71.34	-12.89
	(100)	(89.45)		(100)	(87.11)	
ICC 16348	83.28	62.86	-24.52	77.47	58.24	-24.82
	(100)	(75.48)		(100)	(75.18)	
ICC 16349	83.74	67.39	-19.53	78.31	64.87	-17.17
	(100)	(80.47)		(100)	(82.83)	
Mean	85.06	72.33		79.81	66.99	

Table 1. Continued.

			Chlorophyll a (µg g^{-1})			
		Flowering			Pod formation	
Genotypes	Non heat stress	Heat stress	∞	Non heat stress	Heat stress	∞
PG 5	11.66	9.88	-15.24	9.40	8.24	-12.34
	(100)	(84.76)		(100)	(87.66)	
PG 170	12.30	10.36	-15.85	11.47	9.52	-17.03
	(100)	(84.15)		(100)	(82.97)	
ICC 14778	12.53	10.55	-15.83	11.55	9.66	-16.34
	(100)	(84.17)		(100)	(83.66)	
ICC 14815	12.42	10.45	-15.86	11.49	9.58	-16.63
	(100)	(84.14)		(100)	(83.37)	
ICC 13124	12.36	10.39	-15.96	11.31	9.48	-16.13
	(100)	(84.04)		(100)	(83.87)	
ICC 16348	10.51	8.26	-21.36	8.37	5.53	-33.91
	(100)	(78.64)		(100)	(66.09)	
ICC 16349	10.25	7.17	-30.07	9.11	5.17	-43.28
	(100)	(69.93)		(100)	(56.72)	
Mean	11.72	9.58		10.39	8.17	

Table 1. Continued.

			Chlorophyll b (µg g^{-1})			
		Flowering			Pod formation	
Genotypes	Non heat stress	Heat stress	∞	Non heat stress	Heat stress	∞
PG 5	21.36	19.14	-10.38	19.76	14.50	-26.59
	(100)	(89.62)		(100)	(73.41)	
PG 170	23.53	21.37	-9.21	21.76	17.95	-17.48
	(100)	(90.79)		(100)	(82.52)	
ICC 14778	23.69	21.56	-8.99	21.95	18.15	-17.31
	(100)	(91.01)		(100)	(82.69)	
ICC 14815	23.81	21.86	-8.21	22.02	18.24	-17.15
	(100)	(91.79)		(100)	(82.85)	
ICC 13124	23.65	21.42	-9.43	21.69	18.05	-16.77
	(100)	(90.57)		(100)	(83.23)	
ICC 16348	19.92	16.53	-17.01	18.37	11.75	-36.04
	(100)	(82.99)		(100)	(63.96)	
ICC 16349	19.48	16.21	-16.80	16.80	8.36	-50.23
	(100)	(83.20)		(100)	(49.77)	
Mean	22.21	19.77		20.34	15.29	

Table 1. Continued.

Total chlorophyll content ($\mu g\ g^{-1}$)

		Flowering			Pod formation	
Genotypes	Non heat stress	Heat stress	∞	Non heat stress	Heat stress	∞
PG 5	33.01	29.02	-12.10	29.16	22.74	-22.00
	(100)	(87.90)		(100)	(78.00)	
PG 170	35.94	32.07	-11.49	33.23	27.47	-17.33
	(100)	(88.51)		(100)	(82.67)	
ICC 14778	36.22	32.10	-11.36	33.45	27.81	-16.98
	(100)	(88.64)		(100)	(83.02)	
ICC 14815	36.24	32.31	-10.84	33.51	27.82	-16.97
	(100)	(89.16)		(100)	(83.03)	
ICC 13124	36.01	31.81	-11.67	32.99	27.53	-16.55
	(100)	(88.33)		(100)	(83.45)	
ICC 16348	30.43	24.80	-18.51	26.74	17.28	-35.37
	(100)	(81.49)		(100)	(64.63)	
ICC 16349	29.74	23.38	-21.38	25.91	13.53	-47.79
	(100)	(78.62)		(100)	(52.21)	
Mean	33.94	29.36		30.71	23.45	

Table 1. Continued.

Carotenoid content ($\mu g\ g^{-1}$)

		Flowering			Pod formation	
Genotypes	Non heat stress	Heat stress	∞	Non heat stress	Heat stress	∞
PG 5	5.06	3.55	-29.83	4.33	3.14	-27.59
	(100)	(70.17)		(100)	(72.41)	
PG 170	6.48	4.46	-35.70	5.69	3.69	-31.21
	(100)	(64.30)		(100)	(68.79)	
ICC 14778	6.36	4.56	-30.63	5.73	3.81	-33.46
	(100)	(69.37)		(100)	(66.54)	
ICC 14815	6.29	4.45	-27.10	5.41	3.66	-33.60
	(100)	(72.90)		(100)	(66.40)	
ICC 13124	5.88	4.65	-33.49	5.39	3.40	-36.95
	(100)	(66.51)		(100)	(63.05)	
ICC 16348	5.74	3.69	-35.73	4.94	3.31	-32.95
	(100)	(64.27)		(100)	(67.05)	
ICC 16349	4.88	3.65	-35.78	4.46	2.75	-38.23
	(100)	(64.22)		(100)	(61.77)	
Mean	5.81	4.14		5.13	3.39	

Table 1. Continued.

Canopy temperature depression (°C)

		Flowering			Pod formation		
Genotypes	Non heat stress	Heat stress	∞	Non heat stress	Heat stress	∞	HSI
PG 5	-2.87	-3.03	5.79	-4.07	-4.70	15.56	1.14
	(100)	(105.79)		(100)	(115.56)		
PG 170	-3.63	-4.43	22.02	-2.80	-3.30	17.86	1.02
	(100)	(122.02)		(100)	(117.86)		
ICC 14778	-1.83	-2.43	32.73	-2.23	-2.60	16.44	0.51
	(100)	(132.73)		(100)	(116.44)		
ICC 14815	-2.03	-2.53	24.59	-2.40	-2.70	12.50	0.72
	(100)	(124.59)		(100)	(112.50)		
ICC 13124	-2.07	-2.50	20.95	-2.33	-2.80	20.02	0.73
	(100)	(120.95)		(100)	(120.02)		
ICC 16348	-2.17	-3.60	66.13	-3.50	-4.10	17.14	1.03
	(100)	(166.13)		(100)	(117.14)		
ICC 16349	-3.07	-3.80		2.70	-3.47		
	(100)	(123.90)	23.90	(100)	(128.41)	28.41	1.39
Mean	-2.52	-3.19		-2.86	-3.38		

ICC 14815, ICC 14778 and ICC 13124 at both flowering and pod formation stages. Although under stress condition it was high with 76% in ICC 14815, ICC 13124 and ICC 14778 at flowering which reduced to 70% at pod formation stage. However, ICC 16348 and ICC 16349 showed highest reduction thus may be considered as more susceptible towards heat stress. The susceptible genotypes showed lesser stability for membrane integrity as compared to resistant ones. Under heat stress condition, maximum MSI of 77% at flowering was observed in ICC 14778, ICC 14815 and ICC 13124 which declined to 70-71% at pod formation stage. These genotypes also showed least deviation at heat stress in comparison to non stress condition. Hence, above genotypes may be considered as good for heat tolerance with minimum deviation in RWC and MSI. Chlorophyll a, chlorophyll b and total chlorophyll content also decreased under higher heat stress level. Under heat stress condition, higher value of chlorophyll a with 10.4-10.6 μg g^{-1} and chlorophyll b with 21.4-21.9 μg g^{-1} at flowering stage decreased to 9.5-9.7 μg g^{-1} and 18-18.2 μg g^{-1} at pod formation stage, respectively, in three genotypes namely ICC 13124, ICC 14815 and ICC 14778. Similarly, same genotypes exhibited higher total chlorophyll content with values of 88-89 μg g^{-1} at flowering and 83-84 μg g^{-1} at pod formation stages under heat stress. Though reduction in chlorophyll a at both the stages was lowest in PG 5 followed by ICC 13124, ICC 14815 and ICC 14778 but for chlorophyll b and total chlorophyll content, PG 5 was not superior to resist change in deviation, whereas the less affected genotypes were ICC 14815, ICC 14778 and ICC 13124. Thus these three genotypes may be considered superior to resist change in chlorophyll content at high temperature. On the contrary, more susceptible for chlorophyll a and b as well as total chlorophyll content was ICC 16349 that showed highest deviation with lower values for above traits under stress condition therefore, considered as susceptible genotype for heat stress. Under stress condition of flowering stage, carotenoid content of ICC 14815, ICC 13124 and ICC 14778 was more with 4.5-4.7 μg g^{-1} at flowering and 3.4-3.8 μg g^{-1} at pod formation stage. But the genotype ICC 14815 showed lesser reduction in carotenoid content at flowering and PG 170 at pod formation stage. Though the genotype ICC 16349 showed maximum reduction at both the stages hence may be considered as susceptible. The value of CTD declined under high temperature condition due to stress. Under late sown heat stress condition, three genotypes ICC 14815, ICC 13124 and ICC 14778 showed higher CTD between -2.4 to -2.5 at flowering and -2.6 to -2.8 at pod formation stage. However, PG 5 at flowering and ICC 14815 at pod formation stage showed least deviation in CTD between normal and stress condition, thus maintained lower canopy temperature. Hence, these genotypes may be considered as tolerant to heat stress with respect to CTD.

Heat susceptibility index (HSI) indicated reduction in yield under heat stress condition as compared to non stress condition. The genotype ICC 14778 showed minimum HSI value followed by ICC 14815 and ICC 13124. Thus these genotypes showing low value of HSI may be identified as thermo insensitive as they exhibited less reduction in yield under heat stress as compared to non stress environment. However, the genotype ICC 16349 showed the higher heat susceptibility index therefore, may be considered as more susceptible to heat stress.

Table 2. Rank score of fourteen genotypes of chickpea evaluated for physiological parameters related to heat stress. FS – Flowering stage, PS- Pod formation stage, NS- Non stress, S- Stress.

Sl.No.	Genotypes	RWC		MSI		Chlorophyll a		Chlorophyll b		Total chlorophyll		Carotenoid		CTD		HS	Total
		FS	PS	FS	PS	FS	PS	FS	PS	FS	PS	FS	PS	FS	PS	NS/S	
1	PG5	10	7	9	6	1	1	6	5	6	5	6	4	1	6	11	84
2	PG170	5	5	8	5	4	7	4	4	4	4	1	1	6	9	8	75
3	ICC14778	3	2	3	4	3	5	3	3	3	3	8	11	11	7	1	70
4	ICC14815	2	4	4	2	5	6	2	2	2	2	4	8	10	5	2	60
5	ICC13124	4	3	5	1	6	4	5	1	5	1	12	2	4	10	3	66
6	ICC16348	13	13	13	13	9	10	11	8	10	10	5	3	13	8	9	148
7	ICC16349	11	12	12	8	13	11	10	11	11	11	10	13	7	12	13	165

Based on minimum reduction or increment at stress level for each parameter, each genotype was given scores from 1 to 7 at both the stages (Table 2). The genotype ICC 14815 (60) scored lowest points with 2 at HSI thus may be considered as most thermo insensitive. Since low score indicated less deviation and low HSI indicated tolerance to heat stress in terms of yield, the genotypes such as ICC 13124, ICC 14778 and PG 170 may also be considered as heat tolerant.

The studies pertaining to physiological parameters related to heat stress on chickpea have been conducted by several workers. In agreement with above findings, Upadhyaya *et al*. (2011) also reported yield loss for every degree increase in temperature. Kumar *et al.* (2017) reported that heat stress condition was unfavorable for seed yield in chickpea. Similarly, Prasad *et al.* (2018) reported effects of high temperature on pod set, seed set and yield. Kumar *et al.* (2012) reported that, CTD and RSI exhibited significant differences among the genotypes. Jain (2014) reported for minimum photosynthetic rate and cell membrane thermo instability. In addition to this, Wang *et al.* (2006) reported effect of heat stress on reduction of pod fertility, seed set and seed yield. Wahid *et al.* (2007) reported that high temperature adversely affects seed germination, photosynthesis, respiration, membrane stability and quality of seeds. Devasirvatham *et al*. (2012) observed that high temperature also reduced pollen production per flower, % pollen germination, pod set and seed number. Kumar *et al.* (2017) reported the effects of high temperature on physiological growth and yield parameters except CTD. But in the present study all the eight parameters including CTD were found to be highly affected by heat stress effects.

The analysis of variance for days to 50% flowering and days to maturity as well as analysis of variance for combining ability of parents was carried out before proceeding for detailed statistical analysis and the results were presented in Table 3. It was cleared from the table that genotypes differ significantly indicating the presence of sufficient genetic variability among experimental material. The results on analysis of variance for combining ability indicated that mean sum of squares due to general combining ability as well as specific combining ability were highly significant for both traits. Which indicated inherent genetic variability as revealed by significant differences among the parents and their crosses. This highlighted the importance of both additive gene action and non additive (dominance and epistasis) gene action for expressions.

Table 3. Analysis of variance studied for seven parents and twenty one F1's in chickpea and for general combining ability (GCA) and specific combining ability (SCA) for days to 50% flowering and early maturity in chickpea.

Source of variation	df	Days to 50% flowering	Days to maturity
Replication	1	0.09	2.57
Treatment	27	6.45*	9.44**
Error	27	2.58	1.42
SE	-	1.14	0.84
CD (1%)	-	4.45	3.31
CD (5%)	-	3.30	2.45
CV (%)	-	2.41	0.88
GCA	6	10.49**	23.57**
SCA	21	5.28*	5.40**
Error	27	2.579	1.423

The estimates of general combining ability effects for all the seven parents and specific combining ability effects for all the twenty one crosses for days to 50% flowering and days to maturity is helpful in identification of parents for earliness. At the same time estimates of specific combining ability effects help in the selection of superior cross combinations in developing commercial hybrids. Parents with significant GCA effect towards desirable direction were considered as good general combiners and those towards undesirable direction were considered as poor combiners. Similarly different crosses were also categorized as good specific combiners, average specific combiners and poor specific combiners.

For characters like days to 50% flowering and days to maturity, parents and crosses have an ability to mature early or starts flowering early were considered as desirable. Hence, parents and crosses showing significant GCA and SCA in negative direction were considered as desirable for early flowering and maturity. For days to 50% flowering , the range of GCA effect for parent varied from -1.48 to 0.80. Two parents showed the significant GCA effects. Out of which ICC 16349 (-1.48) exhibited significant negative GCA

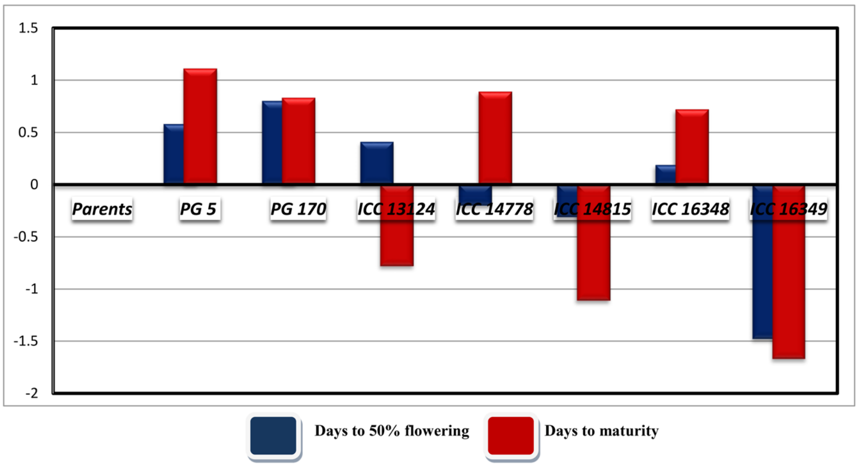

Fig. 1. Estimates of general combining ability (GCA) effect of parents.

value in desirable direction, while one parent PG 170 (0.80) showed the positive significant GCA for late flowering. The estimates of specific combining ability effects varied from – 2.93 to 2.85. Out of twenty one crosses, only five crosses showed significant effects. The cross PG 5 × ICC 16348 showed the highest significant SCA effect (-2.93) followed by ICC 14815 × ICC 16348 (-2.88) and ICC 14815 × ICC 16348 (-2.54) in desirable negative direction. Two crosses viz., PG 170 × ICC 14815 and PG 170 × ICC 16348 showed significant positive SCA effect of 2.85.

For days to maturity all seven parents showed significant GCA effect and out of these, three parents ICC 13124 (-0.78), ICC 14815 (-1.11) and ICC 16349 (-1.67) showed significant negative GCA in desirable direction. Remaining four parents PG5 (1.11), PG 170 (0.83), ICC 14778 (0.89) and ICC 16348 (0.72) showed significant GCA in positive direction. The value of GCA effect ranged between -1.68 to 1.11. The SCA effect for days to maturity ranged from -2.83 to 3.94. Out of twenty one cross combinations, five crosses showed the significant SCA effect. Among them, only one cross PG5 × ICC 16348 (-2.83) showed significant negative SCA effect in desirable direction. The remaining crosses viz., PG5 × ICC 14815 (3.50), PG 170 × ICC 13124 (3.94) ICC 14778 × IC0C 16348 (1.89) and ICC 16348 × ICC 16349 (1.94) showed the positive significant SCA effects.

The estimates of general combining ability

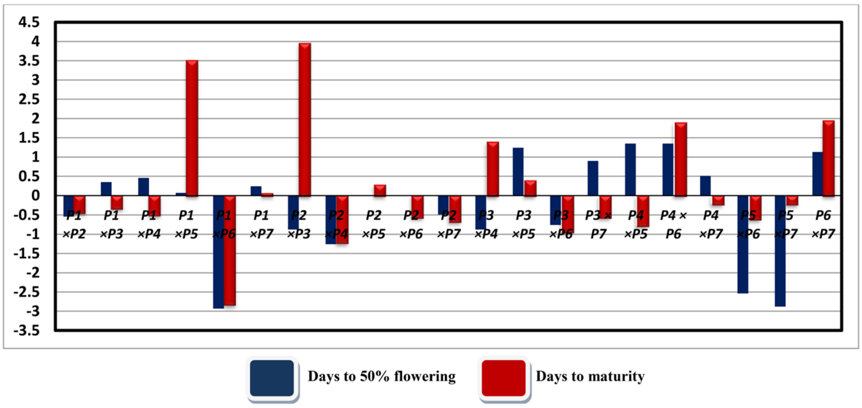

Fig. 2. Estimates of specific combining ability (SCA) effect of 21 F1's.

effects for all the seven parents for different traits related to heat escape were helpful in identification of parents with good GCA for specific traits (Fig.1). At the same time estimates of specific combining ability effects helped in the selection of superior cross combinations (Fig.2).). Earliness or early maturity is a heat adaptation strategy where early genotypes complete the initial seed setting and grain filling under favorable temperatures and avoid late incidence of heat stress. Three parents namely ICC 16349 (-1.67), ICC 14815 (-1.11) and ICC 13124 (-0.78) showed early maturity. The parent ICC 16349 showed superiority in days to maturity as well as days to 50% flowering hence, considered as good general combiner for earliness, while two parents ICC 13124 and ICC 14815 were considered good for days to maturity. Amongst crosses, three viz., ICC 14815 × ICC 16348, ICC 14815 × ICC 16349 and PG 5 × ICC 16348 were considered as desirable for early flowering. However, the cross ICC 14815 × ICC 16348 showed earliness with non significant reduction in yield. On the other side, two crosses PG 170 × ICC 16349 and ICC 13124 × ICC 14815 indicated significant SCA effects on yield with non significant effect on days to 50% flowering.

CONCLUSION

High temperature poses a serious threat to productivity maintenance and enhancement. For each physiological trait promising genotypes under late sown (high temperature) condition were identified and results showed that, genotypes ICC 14815, ICC 13124 and ICC 14778 were more thermo-insensitive as compared to other genotypes, thus can be used in breeding programs to develop heat tolerant varieties. Earliness favors plants to escape from the terminal high temperature stress and also promote an efficient utilization of available resources under stress condition to achieve higher grain yield. In the present experiment, ICC 13124 may be identified as heat tolerant genotype with good combining ability for early maturity and yield improvement.

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