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Genetic effects and heterosis for seed yield and physio-biochemical traits in chickpea (*Cicer arietinum*)

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ABSTRACT

A 8-parent diallel analysis was taken to investigate the genetic effects and heterosis for seed yield and 6 physio-biochemical characters in chickpea (*Cicer arietinum* L.) under timely and late sown conditions at research farm of Rajasthan Agricultural Research Institute, Durgapura, Jaipur, Rajasthan during winter (*rabi)* seasons of 2020–21 and 2021–22. Significant disproportion of GCA and SCA variances depicted that both additive and non-additive gene action plays a vital role for genetic control of all the traits. Though the relative amount of GCA/SCA was less than unity for all traits under study signifying that non-additive gene plays a key role under the environments studied. The parents CSJ-515, CSJD-884 and RSG-963 emerged as good general combiners for seed yield, additionally the parents CSJ 515 and RSG 963 were considered as good general combiners for CC and PV, whereas parent CSJD-884 for MSI, TCC and PC. The crosses CSJD 884 × RSG 963, CSJD 884 × RSG 973, CSJD 884 × Avrodhi, CSJD 884 × HC 5, RSG 963 × CSJ 515, RSG 974 × HC 5 and CSJ 515 × HC 5 showed consistent SCA effect and heterobeltiosis for seed yield and one or more heat tolerant physio-biochemical traits and projected that these crosses would provide enviable transgressive segregate for heat tolerance.

Keywords: Combining ability, Gene action, Half diallel, Heat stress, Heterobeltiosis

Chickpea (*Cicer arietinum* L.) ranks as the third-largest food legume produced world-wide behind the field pea and common bean (Grasso *et al.* 2022). It holds numerous bioactive compounds that are connected to human health (Keyimu *et al.* 2020). About 95% of the total chickpea area is in developing countries. South and West Asia regions account for about 90% of the world chickpea production. India, Pakistan, Turkey, Iran and Syria are major producers in this region. It has played a major role in realization of pulse revolution in India making the country near self-sufficient in pulses. There has been remarkable increase in chickpea production and productivity in the country during 2014–15 to 2021–22. From level of 7.33 million tonnes in 2014–15, chickpea production rose to an all-time high of 13.98 million tonnes during 2021–22 (Anonymous 2022). Although there has been overall growth in chickpea production in the country, it is seriously challenged by various biotic and abiotic stresses. Simultaneously, increasing episodes of heat stress (HS) events under the uncertainties of global climate have imposed serious challenge on plant growth and yield in chickpea. The high temperature (30–35°C) with hot dry wind during the flowering stage inhibits the vital process of plants resulting in poor pod and seed setting and ultimately causing yield loss in late-sown chickpea (Jha *et al.* 2019 and Jameel *et al.* 2021). The breeding for thermo-tolerance in chickpea for late-sown areas requires sympathetic physiological responses of the crop to high-temperature apprehension which will facilitate to discover the traits to be used for assortment in breeding programme.

Studies on physiological phenomena have been made in chickpea (Devasirvatham *et al.* 2013, Jumrani and Bhatia 2014, Rani *et al.* 2020), whereas, genetics of the changes in such physiological phenomena have not been well recognized yet. Knowledge of breeding behaviour, particularly the combining ability and form of gene action for the different traits, is required for further perfection. The diallel mating design is a widely used model to predict the ability of line to combine with other and genetic composition of inbred variants in a series of crosses. Therefore, the present study was carried out to gather required genetic information under timely and late sown (heat stress) conditions.

MATERIALS AND METHODS

An experiment was conducted to study the combining ability, extent of heterosis and inbreeding depression for

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seed yield and 6 physio-biochemical traits in chickpea at research farm of Rajasthan Agricultural Research Institute, Durgapura, Jaipur, Rajasthan during winter (*rabi)* seasons of 2020–21 and 2021–22. The 8 parental lines included RSG-888 (P_1), CSJD-884 (P_2), RSG-963 (P_3), RSG-973 (P_4), RSG-974 (P_5), CSJ-515 (P_6), Avrodhi (P_7) and HC-5 (P_8) on the basis of heat tolerance were crossed in half diallel mating to produce the F_1 hybrids and by selfing produced the F_2 populations. The 8 parents, 28 crosses and their F_2 populations were evaluated in a randomized block design with 3 replications under timely sown (E_1) situation i.e. 1st November and late sown (E_2) situation i.e. 1st December. Observations were recorded for seed yield per plant (SY, g), relative water content (RWC, %), membrane stability index (MSI, %), total chlorophyll content (TCC, µg/g), carotenoid content (CC,µg/g), pollen viability (PV, %) and Proline content (PC, µmol/g) as per standard methods.The sample size in each plot was 5 individual plants for parents and F_1 hybrids and 20 individual plants for F_2 populations. The analysis of combining ability was performed according to Griffing (1956) method 2 and model I (fixed effect model). The heterobeltiosis and inbreeding depression were calculated according to Fonseca and Patterson (1968) and Allard (1960) respectively.

RESULTS AND DISCUSSION

Significant disproportion of GCA and SCA variances depicted that both additive and non-additive gene action plays a vital role for genetic control of all the traits (Table 1). The overall estimation of GCA effects exposed that the parent P6 and P8 exhibited enviable GCA effects for seed yield in both generations under E1 and E2 (Supplementary Table 1). Likewise, the parent P7 demonstrated a significant positive GCA effect under E_1 though the parent P_2 and P_3 in the E_2 in both F_1 and F_2 generations. The parent P_6 is an excellent general combiner for seed yield also exhibits considerable positive GCA for CC and PV in both environments. Likewise, the parent P_8 also exhibited good GCA for MSI, TCC, PV and PC and materialized as a good general combiner in both F_1 and F_2. Further, the parent P_7 also exhibited good combining ability for PV in both F_1 and F_2 under E_1 environment. The parent P_2 and P_3 performed better under E_2 and emerged as good general combiners for MSI, TCC and PC. The other good combiner (P_3) for seed yield also depicted good general combining ability for CC and PV and emerged as a good general combiner in F_1 and F_2 under E_2. It means, these parents undeniably possess the genes for heat tolerance. The parents possessing good general combining ability in chickpea for yield was reported earlier by researchers (Jha *et al.* 2019, Gaur *et al.* 2020, Ghasemi *et al.* 2022) but limited studies have been observed on combining ability for physic-biochemical traits like RWC, MSI, CC, TCC and PC.

In autogamous crops like chickpea, specific combining ability effect has comparatively a lesser amount of applicability because it is worth of the non-additive gene effect. Jinks and Jones (1958) emphasized that the superiority of the hybrids might not indicate their ability to yield transgressive segregants, rather SCA would provide satisfactory criteria. Though, if hybrids exposes elevated SCA as well as high mean which has at least one fine parent for a particular trait, it is estimated that this cross would give enviable progenies in further generations. In this experiment, SCA for seed yield was found to be absolutely

Table 1 Analysis of variance for general and specific combining ability under timely (E_1) and late sown (E_2) conditions for yield and physio-biochemical traits in chickpea

Character	Env.	Source of variation							
		GCA (df =7)		SCA (df =28)		Error (df=70)		GCA/SCA ratio	
		F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2
SY	E_1	4.72**	4.49**	2.08**	1.66**	0.19	0.17	0.20	0.24
	E_2	4.87**	3.68**	1.42**	1.33**	0.10	0.13	0.30	0.25
RWC	E_1	10.88**	4.83*	18.18**	15.99**	1.93	1.84	0.05	0.02
	E_2	8.81**	7.28**	16.44**	14.72**	0.67	1.91	0.04	0.03
MSI	E_1	28.13**	35.34**	11.45**	18.16**	0.82	1.57	0.21	0.17
	E_2	57.23**	39.19**	10.79**	10.91**	0.62	1.67	0.46	0.34
TCC	E_1	15.14**	14.0**	4.21**	3.30**	0.55	0.39	0.33	0.39
	E_2	8.61**	6.83**	4.41**	3.20**	0.42	0.39	0.17	0.19
CC	E_1	0.54**	0.34**	0.21**	0.14**	0.04	0.06	0.25	0.30
	E_2	0.98**	0.62**	0.29**	0.27**	0.04	0.03	0.31	0.20
PV	E_1	13.36**	16.22**	4.74**	8.0**	0.43	0.51	0.25	0.17
	E_2	2.64**	2.99**	3.11**	5.06**	0.52	0.41	0.07	0.05
PC	E_1	1.63**	0.75**	0.57**	0.37**	0.05	0.06	0.25	0.19
	E_2	1.19**	0.57**	0.39**	0.31**	0.05	0.06	0.28	0.17

*, ** Significant at 5 and 1% levels, respectively.

Table 2 Estimates of GCA and SCA in parents and crosses for yield and physio-biochemical traits under timely and late sown conditions in chickpea

Parent/Cross	Env.	SY		RWC		MSI		TCC		CC		PV		PC	
		F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2
P_1	E_1	-1.26**	-1.24**	-1.81**	-1.08**	-0.58*	-2.46**	-1.09**	-1.45**	-0.42**	-0.34**	0.11	-1.06**	-0.40**	-0.17*
	E_2	-1.29**	-1.27**	-1.01**	-1.38**	1.31**	1.28**	-0.59**	-0.28	-0.34**	-0.36**	-0.45*	-0.86**	-0.26**	-0.13
P_2	E_1	0.06	0.00	1.17**	0.33	2.43**	2.51**	1.91**	2.14**	0.06	0.09	0.57**	1.41**	0.09	-0.03
	E_2	0.95**	0.69**	0.34	0.86*	3.88**	2.58**	1.78**	1.24**	0.11	0.09	-0.25	0.28	0.39**	0.30**
P_3	E_1	0.09	0.11	0.52	-0.49	-1.49**	-1.59**	-0.27	-0.45*	0.29**	0.24**	-1.13**	-0.43*	-0.17*	-0.14
	E_2	0.33**	0.32**	1.04**	-0.21	-1.64**	-1.28**	-0.18	-0.14	0.37**	0.22**	0.92**	0.81**	0.03	-0.12
P_4	E_1	-0.15	-0.27*	0.7	1.34**	0.61*	-0.3	0.98**	0.32	-0.21**	-0.16*	-1.56**	-1.42**	-0.18**	-0.21**
	E_2	-0.13	-0.23*	1.07**	0.98*	1.90**	1.09**	0.02	-0.25	-0.36**	-0.27**	0.08	-0.19	-0.18**	-0.17*
P_5	E_1	-0.58**	-0.46**	0.48	-0.13	1.07**	1.01**	-1.78**	-1.35**	-0.01	0.06	-1.26**	-1.56**	-0.42**	-0.27**
	E_2	-0.49**	-0.17	-0.3	-0.18	-2.26**	-2.63**	-1.33**	-1.44**	-0.17**	-0.01	-0.78**	-0.49*	-0.44**	-0.28**
P_6	E_1	0.96**	0.84**	0.67	0.19	-1.57**	-0.83*	-0.21	-0.23	0.14*	0.12*	1.17**	0.48*	0.12	0.12
	E_2	0.56**	0.50**	0.26	-0.55	-2.12**	-1.26**	-0.11	-0.02	0.19**	0.12*	0.15	0.24	-0.18**	-0.06
P_7	E_1	0.31*	0.31*	-0.7	-0.17	-2.12**	-1**	-0.61**	0.06	-0.07	-0.08	1.34**	1.44**	0.1	0.15*
	E_2	-0.27**	-0.04	0.2	0.94*	-2.38**	-1.86**	-0.34	-0.13	-0.23**	-0.17**	0.02	-0.26	0.05	0.06
P_8	E_1	0.57**	0.72**	-1.02*	0.01	1.65**	2.65**	1.06**	0.97**	0.22**	0.1	0.74**	1.14**	0.84**	0.57**
	E_2	0.33**	0.39**	-1.61**	-0.46	1.30**	2.08**	0.76**	1.01**	0.42**	0.37**	0.32	0.48*	0.59**	0.40**
$P_1 \times P_2$	E_1	-0.61	0.23	1.19	4.34**	-3.56**	-4.90**	0.29	-1.27*	0.36*	0.49*	0.62	2.88**	0.10	0.53**
	E_2	0.52*	0.14	1.1	5.42**	-2.42**	-1.67	-0.08	1.54**	-0.54**	-0.28*	-2.87**	-4.04**	0.15	-0.05
$P_1 \times P_4$	E_1	1.67**	1.43**	4.30**	3.29**	-2.7**	-1.69	0.59	-1.79**	0.34*	-0.12	0.42	-0.62	-0.38*	-0.07
	E_2	0.72**	0.39	4.40**	1.92	0.19	-2.86**	1.69**	1.66**	-0.45**	0.19	-0.21	-2.57**	-0.18	0.18
$P_1 \times P_5$	E_1	0.09	0.32	2.44*	0.16	0.06	-1.71	0.44	2.90**	-0.09	-0.07	0.12	-0.49	-0.36*	-0.01
	E_2	0.81**	1.41**	1.63*	-2.41*	4.68**	4.93**	0.78	1.57**	-0.40*	-0.13	1.99**	2.73**	0.64**	0.85**
$P_1 \times P_6$	E_1	1.79**	0.59	2.77*	-0.24	2.45**	0.09	1.76**	0.77	-0.09	-0.19	1.36*	-4.19**	0.12	-0.59**
	E_2	0.16	0.84**	4.09**	1.31	-0.8	0.76	0.54	-0.96	0.61**	0.09	-0.27	-0.34	-0.09	0.22
$P_1 \times P_7$	E_1	0.47	0.82*	-2.32*	-1.72	0.43	-1.49	-2.89**	-0.98	0.19	0.40*	-0.14	-2.49**	0.38*	-0.01
	E_2	0.81**	0.27	-3.30**	-1.73	-0.37	-1.72	-0.96	-0.96	0.43**	0.69**	0.19	0.5	-0.31	-0.01
$P_2 \times P_3$	E_1	1.02**	1.59**	2.93**	3.35**	4.92**	5.74**	2.71**	2.91**	0.75**	0.32	1.52**	1.58**	-1.05**	-0.62**
	E_2	1**	1.51**	2.64**	4.91**	4.31**	2.33*	3.07**	1.34**	0.98**	0.99**	1.43*	1.63**	0.58**	0.27
$P_2 \times P_4$	E_1	1.05**	1.90**	2.63*	2.67*	2.71**	2.51*	2.01**	2.51**	0.58**	0.28	3.29**	3.58**	-0.58**	0.06
	E_2	1.43**	1.09**	3.52**	-1.12	2.57**	0.75	1.01	-0.59	0.66**	0.70**	2.93**	3.96**	0.81**	0.68**

Contd.

Table 2 (*Concluded*)

Parent/Cross	Env.	SY		RWC		MSI		TCC		CC		PV		PC	
		F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2
$P_2 \times P_7$	E_1	1.63**	0.33	4.9**	3.41**	6.04**	6.30**	3.39**	3.19**	0.59**	0.36	2.06**	2.38**	-1.30**	-1.05**
	E_2	1.45**	1.49**	4.18**	4.17**	6.92**	5.53**	3.40**	1.78**	0.36*	0.27*	1.99**	3.36**	0.81**	0.37
$P_2 \times P_8$	E_1	1.41**	0.03	2.38*	-0.29	2.17**	3.16**	1.62**	1.13*	-0.59**	-0.2	0.99	1.01	0.13	0.48*
	E_2	0.89**	0.11	3.67**	2.30*	1.46*	3.26**	-1.14*	-1.48**	0.61**	0.35**	1.36*	1.63**	0.49**	0.63**
$P_3 \times P_6$	E_1	2.71**	1.43**	4.02**	4.71**	2.40**	0.12	2.21**	2.81**	0.58**	0.56**	2.26**	3.85**	0.73**	0.40*
	E_2	2.37**	1.31**	4.16**	2.52*	2.82**	0.21	1.85**	2.44**	-0.41*	-0.55**	2.36**	4**	0.62**	0.81**
$P_3 \times P_7$	E_1	1.27**	0.81*	-2.22*	-3.45**	-1.60*	1.58	1.16*	-0.7	-0.42*	-0.24	4.42**	4.88**	0.79**	0.49*
	E_2	0.21	0.4	-1.57*	-5.40**	-0.99	0.35	1.30*	0.77	0.06	-0.02	1.83**	1.83**	0.09	-0.25
$P_4 \times P_7$	E_1	0.61	-0.32	-2.87*	0.28	2.38**	1.6	-1.36*	-0.17	0.29	0.09	-1.14*	-1.45*	-0.94**	-0.60**
	E_2	0.82**	1.74**	-2.39**	-0.17	1.89**	2.36*	-2.82**	-1.59**	-0.39*	-0.39**	-0.67	-0.5	-0.24	0.1
$P_4 \times P_8$	E_1	0.89*	1.14**	2.39*	2.25*	1.06	-0.55	-1.58**	-0.86	-0.28	-0.51*	-1.54**	-1.49**	-0.39*	-0.16
	E_2	0.59*	1.11**	-0.12	0.47	-1.82**	1.5	-1.49**	-1.61**	-0.17	-0.32*	0.36	0.76	0.36*	0.74**
$P_5 \times P_6$	E_1	-0.41	-0.1	-6.05**	-3.12**	3.78**	7.22**	1.08	0.6	-0.25	-0.51*	0.39	-1.35*	0.95**	0.53**
	E_2	-0.29	0.2	-4.26**	-2.56*	-0.29	1.73	1.23*	0.25	-0.31	-0.30*	0.06	0.3	-0.35*	0.34
$P_5 \times P_7$	E_1	0.4	1.51**	-6.12**	-3**	3.38**	4.05**	-1.13	-1.07*	-0.51**	-0.32	-3.78**	-3.65**	0	-0.79**
	E_2	0.59*	0.70*	-4.35**	-0.95	-1.44*	1.03	-0.49	0.35	-0.1	0.02	-1.14*	-0.54	0.18	-0.34
$P_5 \times P_8$	E_1	2.25**	1.54**	5.44**	5.10**	1.59*	1.63	3.85**	2.37**	0.84**	0.49*	3.82**	4.98**	0.54**	0.13
	E_2	0.79**	1.62**	7.24**	5.76**	3.87**	1.29	4.01**	3.46**	0.93**	0.96**	1.89**	2.40**	1.01**	0.2
$P_6 \times P_8$	E_1	1.81**	2.14**	5.57**	3.76**	4.51**	5.99**	2.22**	0.52	0.72**	0.43*	2.72**	2.95**	0.18	0.19
	E_2	2.20**	1.38**	4.16**	4.70**	4.92**	3.73**	2.91**	3.21**	0.61**	1.15**	1.63**	2.33**	0.50**	-0.08
SE (gi) ±	E_1	0.13	0.12	0.41	0.4	0.27	0.37	0.22	0.18	0.06	0.07	0.19	0.21	0.07	0.07
	E_2	0.09	0.11	0.24	0.41	0.23	0.38	0.19	0.18	0.06	0.05	0.21	0.19	0.07	0.07
SE (gi-gj)±	E_1	0.19	0.19	0.62	0.61	0.4	0.56	0.33	0.28	0.09	0.11	0.29	0.32	0.1	0.11
	E_2	0.14	0.16	0.37	0.62	0.35	0.58	0.29	0.28	0.09	0.07	0.32	0.29	0.1	0.11
ES (Sij)±	E_1	0.34	0.33	1.1	1.07	0.71	0.99	0.59	0.49	0.16	0.2	0.52	0.56	0.28	0.31
	E_2	0.25	0.28	0.65	1.09	0.62	1.02	0.51	0.49	0.16	0.13	0.57	0.51	0.18	0.2
SE (Sij-Sik)±	E_1	0.58	0.56	1.86	1.82	1.21	1.68	1	0.84	0.28	0.34	0.88	0.95	0.23	0.77
	E_2	0.42	0.48	1.1	1.85	1.05	1.73	0.87	0.84	0.27	0.22	0.97	0.86	0.3	0.34
SE (Sij-Ski)±	E_1	0.55	0.53	1.76	1.72	1.15	1.59	0.94	0.79	0.26	0.32	0.83	0.9	0.63	0.46
	E_2	0.39	0.45	1.04	1.75	0.99	1.63	0.82	0.79	0.25	0.21	0.91	0.81	0.28	0.32

*, ** Significant at 5 and 1% levels, respectively.

Table 3 Estimates of heterobeltiosis and Inbreeding depression for different characters under timely and late sown conditions in chickpea

Cross	Envn.	SY		RWC		MSI		TCC		CC		PV		PC	
		HB	ID	HB	ID	HB	ID	HB	ID	HB	ID	HB	ID	HB	ID
$P_1 \times P_2$	E_1	-9.97	-14.05	4.35	-5.18*	-5.82**	4.08	-1.23	9.58*	7.6	-2.12	2.15*	-1.05	4.1	-11.39
	E_2	-6.83	6.79	2.74	-6.88**	-0.73	-0.41	-7.21	-7.94	-4.56	-8.17	-3.21**	1.66	4.43	4.74
$P_1 \times P_5$	E_1	-13.74*	-8.07	1.34	1.42	-1.12	4.81	-0.62	-9.51*	-8.38	-1.04	-0.36	3.24**	7.96	-11.01
	E_2	-5.5	-22.57*	-1.19	4.78	4*	-1.08	2.16	-6.89	-19.20**	-14.00*	2.01	-0.39	9.78	-4.6
$P_1 \times P_6$	E_1	3.24	9.55	2.13	2.15	-1.5	4.51	8.26	8.43*	-4.68	2.93	2.48*	8.65**	-14*	-13.19
	E_2	-23.49**	-15.2	6.71**	4.16	-4.9**	-5.65	1.07	3.82	8.95	10.26*	0.4	0.8	0.41	-5.9
$P_2 \times P_3$	E_1	25.3**	-7.48	7.25**	0.47	5.28**	-1.82	12.15**	1.24	12.34**	7.5	2.90**	-0.7	13.56*	6.44
	E_2	24.81**	-5.39	5.58**	-2.85	5.36**	3.21	8.16*	7.61*	18.58**	1.04	2.79*	-0.39	14.52**	9.06*
$P_2 \times P_4$	E_1	22.29**	-8.99	6.73**	-1.06	5.11**	0.73	12.90**	1.88	14.97**	4.82	4.35**	-0.35	14.57*	9.2
	E_2	24.46**	6.17	4.98**	4.4	8.27**	4.62	-0.1	9.01*	24.79**	-4.05	3.17**	-1.15	14.95**	4.93
$P_2 \times P_7$	E_1	18.69**	9.65	6.96**	0.91	6**	-2.72	13.57**	-0.4	14.09**	4.62	1.74	-0.34	14.75**	8.99
	E_2	22.55**	-2.58	4.82**	-2.45	8.37**	1.98	8.89*	6.49	20.56**	-0.89	3.21**	-1.56	13.33**	8.42
$P_2 \times P_8$	$\mathbf{E_1}$	20.14**	9.06	6.97**	1.77	5.86**	-3.57	13.18**	3.48	-11.18*	-3.24	3.60**	-0.35	12.42*	7.67
	E_2	23.15**	11.95	7.79**	-1.3	5.51**	-3.23	-6.00	1.4	18.57**	4.12	3.23**	-0.78	12.34**	3.84
$P_3 \times P_6$	E_1	24.69**	8.54	6.71**	-0.3	7.95**	1.73	14.22**	0.79	10.92*	2.98	2.13*	-0.69	15.86**	-9.04
	E_2	30.24**	9.94	7.51**	3.73	8.83**	0.98	9.65*	-4.84	-6.98	5.4	4.38**	-1.53	15.82**	0.22
$P_3 \times P_7$	E_1	15.33*	1.71	-2.98	0.86	0.77	-7.74**	3.9	8.48*	-7.41	-0.33	2.43*	-0.34	-10.79*	1.72
	E_2	2.5	-9.82	-1.85	4.88	4	-5.68	7.9	-0.24	-5.87	1.59	3.59**	0.77	-1.46	9.22
$P_4 \times P_7$	E_1	5.95	7.81	-3.57	-7.10**	-0.08	0.09	-11.10*	-2.77	4.55	4.08	-3.82**	1.08	-9.94*	-11.39
	E_2	29.55**	-19.39*	-2.99	-4.85	1.8	-1.69	-25.78**	-8.72	-9.39	-6.69	-0.79	0.8	-8.81*	-2.65
$P_4 \times P_8$	E_1	12.5	-4.96	3.6	-3.2	3.59	1.45	-5.18	2.72	-10.63*	6.67	-1.44	0.36	6.55	-0.2
	E_2	35.46**	-6.96	-2.4	-3.18	1.77	-6.85*	-15.29**	-0.98	-7.08	0.52	0.79	0.00	3.04	-0.26
$P_5 \times P_8$	E_1	22.27**	1.68	6.18*	-1.35	5.7**	-2.12	10.80*	6.69	9.09*	6.79	4.68**	-0.34	10.34*	6.41
	E_2	24.52**	-18.28*	5.39**	-0.62	6.12**	2.19	12.35**	0.31	19.33**	-4.03	3.23**	-0.78	8.2	12.42**
$P_6 \times P_8$	E_1	20.72**	-4.72	6.72**	0.24	6.1**	-5.31*	10.57*	9.32**	9.59*	7.66	4.61**	1.02	12.27*	8.15
	E_2	27.94**	9.01	11.67**	-2.05	8.16**	-2.03	12.95**	-4.07	20.36**	-8.74*	4.03**	-0.78	4.89	10.38*
SE	E_1	0.62	0.59	1.96	1.92	1.28	1.77	1.05	0.88	0.29	0.36	0.93	1.01	0.32	0.35
	E_2	0.44	0.5	1.16	1.95	1.11	1.83	0.91	0.88	0.28	0.23	1.02	0.91	0.32	0.36

*, ** Significant at 5 and 1%, respectively.

considerable for 9 crosses under both the conditions, two crosses in E_1 and 5 crosses under E_2 condition (Table 2). Some, but not all, hybrids have a significant SCA effect on heat stress factors, viz. $P_2 \times P_3$ for MSI, TCC and CC, $P_5 \times P_6$ for RWC, MSI and CC; $P_4 \times P_8$ for RWC, TCC, CC, PV and PC; $P_3 \times P_7$ for PV; $P_1 \times P_4$ for PC; $P_2 \times P_4$ for PV in both conditions. While the cross $P_3 \times P_6$ for PV; $P_6 \times P_7$ for RWC; $P_5 \times P_8$ for RWC, TCC, CC and PC; $P_2 \times P_4$ for CC, PV and PC; $P_1 \times P_4$ for RWC; $P_2 \times P_7$ for MSI, TCC and PC; $P_6 \times P_8$ for MSI; $P_2 \times P_3$ for TCC and CC; $P_1 \times P_5$ for MSI and PV under E_2 condition. It was observed that the majority of top crosses for SCA effect resulted from crosses between parents with desirable good SCA effect from high × high general combiners, reproducing additive nature of genes and accumulation of encouraging genes from the parents. Conversely, crosses concerning low × low / high × low broad combiners revealed interactions of dominance/ additive × dominance, respectively. It is anticipated to facilitate these F_1s would give desirable segregants in later on generations for heat tolerance.

Among all the heterotic crosses, 7 crosses were observed more heterobeltiotic for seed yield under both environments, 2 crosses in E_1 and 4 crosses emerged as good heterotic crosses in E_2 (Table 3). Some, but not all, hybrids have a heterosis on heat stress factors. A privileged intensity of heterosis in a cross designated that the parents are genetically high dissimilated than other F_1s. As a consequence, the opportunities of achieving better-quality variants will augment with improve genetic distance among the parents. The present trend of heterosis is in harmony with the findings of Ghasemi *et al.* (2022). The considerable amount inbreeding depression among present materials was also observed for poles apart. Crosses namely $P_1 \times P_2$, $P_1 \times P_8$, $P_5 \times P_7$ for RWC; $P_4 \times P_5$ for CC in both the conditions; $P_1 \times P_5$ for TCC; $P_1 \times P_7$ for PC; $P_3 \times P_7$ for MSI; $P_3 \times P_8$ for seed yield; $P_7 \times P_8$ for seed yield, RWC and PC; $P_4 \times P_7$ for RWC under E_1 while $P_1 \times P_5$ for seed yield and CC; $P_1 \times P_8$ for MSI; $P_3 \times P_5$ for MSI and PC; $P_4 \times P_7$ for seed yield; $P_7 \times P_8$ for RWC and CC under E_2 conditions exhibited enviable inbreeding depression (significantly negative). In general, crosses viewing high heterobeltiosis also exhibit high inbreeding depression due to non-additive gene action. The segregating material generated through this study may be exploited for the selection of enviable recombinants in higher generations for developing high-potential varieties in chickpea. Therefore, the parents and crosses for diverse traits might be exploited in upcoming breeding programmes to generate huge amount of variation and to separate high yielding pure lines in normal and heat stress conditions.

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