Indian J. Genet. Plant Breed., (2023); 83(2): 273-277

https://doi.org/10.31742/ISGPB.83.2.15

ISSN: 0975-6906

www.isgpb.org

SHORT RESEARCH ARTICLE

Gene action and combining ability for yield and other quantitative traits under timely and late sown conditions in chickpea (*Cicer arietinum* L.)

Rekha Choudhary, S. K. Jain*, Mahaveer P. Ola and Deepak Gupta

Abstract

An investigation was carried out to understand the nature and magnitude of gene action in 28 F1 hybrids of chickpea (*Cicer arietinum* L.) under timely (E1) and late sown (E2) conditions. The analysis of variance revealed a considerable amount of genetic variability among the materials under study in both environments. The significant difference of general combining ability (GCA) and specific combining ability (SCA) variances indicated that both additive and non-additive gene action played an important role in the genetic control of all the traits under both E1 and E2 conditions. The study identified CSJ-515 and HC-5 as the best combiners for seed yield and it contributing traits under both environments, whereas Avrodhi in timely sown and CSJD-884 and RSG 963 under late sown conditions. Significantly higher specific combining ability, heterosis, and heterobeltiosis were recorded in the crosses, CSJD 884 x RSG 963, CSJD 884 x RSG 973, CSJD 884 x Avrodhi, RSG 963 x CSJ 515 in both the environment, while CSJD 884 x RSG 963 and RSG 973 x Avrodhi in late sown conditions. The identified F1 hybrids may be suitable for the improvement of grain yield in chickpeas for specific environments.

Keywords: Gene action, investigation, Avrodhi, heterosis

Chickpea (*Cicer arietinum* L.) is the major diploid (2n=16), self-pollinating grain legume crop with a rich source of protein (15–22%), carbohydrates (50–58%), fat (3.8–10.20%), vitamins, and micronutrients (Madurapperumage et al. 2021). The protein content in chickpea genotypes rasnges from 12.6 to 30.5% (Singh 1985) and both *kabuli* and *desi* cultivars have marginal differences in protein contents. Kaur et al. (2019) reported tha the average crude protein content in *desi*, *kabuli* and wild species was found to be 25.31, 24.67 and 24.30%, respectively. In India, chickpeas are grown in an area of 9.85 mha with a production of 11.99 mt and a productivity of 1217 kg/ha (Anonymous 2021). However, India covers about 70% of the acreage and is the world leader in terms of production. Yet, India imports about 0.5 mt of chickpeas annually (Sharma et al. 2020) to ensure the supply and requirements of the growing population.

Moreover, production and productivity has been stagnated in recent years. Therefore, intensive research work is needed to enhance the yield potential of chickpeas through genetic improvement of chickpea. As grain yield is a complex trait and inherited polygenically, the enhancement of the genetic potential of a chickpea genotype is of a tremendous challenge. The diallel analysis is one of the important approaches to recognizing the type and extent of gene effects and checking the ability of parents to make superior combinations. Since chickpea is a self-pollinated crop and the capacity for utilization by hybrid vigor will depend upon the type of gene action and magnitude of heterosis observed in different combinations to exploit the useful variability. The heterosis and inbreeding depression will have a straightforward effect on the breeding methodology employed in genetic gain. Therefore, a study was conducted to understand the nature and magnitude of gene action and degree of heterosis through the combining

Division of Genetics and Plant Breeding, Rajasthan Agricultural Research Institute, Durgapura, Jaipur, Rajasthan, India.

***Corresponding Author:** S. K. Jain, Division of Genetics and Plant Breeding, Rajasthan Agricultural Research Institute, Durgapura, Jaipur, Rajasthan, India, E-Mail: skjain.pbg.coalalsot@sknau.ac.in

How to cite this article: Choudhary R., Jain S.K. and Ola M.P. and Gupta D. 2023. Gene action and combining ability for yield and other quantitative traits under timely and late sown conditions in chickpea (*Cicer arietinum* L.). Indian J. Genet. Plant Breed., **83**(2): 273-277.

Source of support: Nil

Conflict of interest: None.

Received: Jan. 2023 **Revised:** March 2023 **Accepted:** April 2023

ability analysis using diverse parents and crosses for an efficient breeding strategy.

Eight parents, namely, RSG-888 (P1), CSJ-884 (P2), RSG-963 (P3), RSG-973 (P4), RSG-974 (P5), CSJ-515 (P6), Avrodhi (P7) and HC-5 (P8) were crossed in a diallel fashion in all possible combinations (excluding reciprocals) at Research Farm, Rajasthan Agricultural Research Institute (SKNAU), Durgapura, Jaipur during *rabi* 2019-20 and 2020-21 and the parents as well as the 28 F_1 hybrids were evaluated in randomized block design with three replications in rows of 3 m length under timely (E1) and late sown (E2) conditions in *rabi* 2021-22. The row-to-row and plant-to-plant distance were kept at 30 and 10 cm, respectively. Observations were recorded on days to first flowering, days to 50% flowering, days to first pod formation, days to last pod development, days to maturity, first pod height (cm), plant height (cm), number of primary branches/plant, number of secondary branches/plant, number of pods/plant, number of seeds/pod, biological yield/plant (g), seed yield/plant (g), harvest index (%) and 100-seed weight (g). The combining ability analysis for parental genotypes and their crosses was carried out following method 2 and model I (fixed effect model) of Griffing (1956). Relative heterosis was projected as a percent increase or decrease in F_1s over the mid parent as F_1-MPx100/MP and Heterobeltiosis as F_1-BPx100/BP (Fonseca and Patterson 1968), where F_1 is the mean of F_1s, MP is mean of parents and BP is mean of the better parent. Inbreeding depression was expressed as a per cent decrease observed in F_2 over F_1 as F_1-F_2 x 100/F_1, where F_2 is the mean of F_2s.

The analysis of variance represents a considerable amount of genetic variability among the materials under study in both environments (Table 1). The significant difference of general combining ability (GCA) and specific combining ability (SCA) variances indicated that both additive and non-additive gene actions played important role in the genetic control of all the traits in both E1 and E2 conditions. Further, their variance ratio (predictability ratio) was less than unity illustrating the prevalence of non-additive gene actions. As reported earlier, the study indicated the importance of additive and non-additive gene actions (Salimath and Bahl 1985; Amadabade et al. 2014; Jha et al. 2019). The parent CSJ-515 and HC-5 exhibited enviable GCA effects for seed yield per plant under both environments. Likewise, the parent Avrodhi demonstrated a

Table 1. Analysis of variance for general and specific combining ability for different characters in chickpea under timely sown (TS) and late sown (LS) conditions

Characters	Source of variations							
	GCA		SCA		Error		GCA/SCA ratio	
	TS (E_1)	LS (E_2)	TS (E_1)	LS (E_2)	TS (E_1)	LS (E_2)	TS (E_1)	LS (E_2)
Df	7		27		70		-	-
DFF	17.46**	7.94**	6.05**	2.64**	0.46	0.30	0.30	0.33
DF	5.14**	8.01**	3.15**	3.17**	0.21	0.29	0.14	0.22
DFP	5.82**	7.37**	1.74**	1.69**	0.26	0.31	0.31	0.43
DLP	2.43**	3.40**	2.86**	2.25**	0.30	0.21	0.07	0.13
DM	17.91**	7.16**	9.59**	3.57**	0.81	0.58	0.16	0.18
FPH	4.81**	12.31**	2.62**	3.17**	0.36	0.64	0.16	0.38
PH	36.30**	18.01**	21.22**	11.75**	2.46	2.60	0.15	0.14
PB	0.24**	0.19**	0.17**	0.18**	0.05	0.03	0.13	0.09
SB	1.56**	0.54*	1.20**	0.96**	0.25	0.22	0.12	0.04
PP	200.02**	20.07**	65.49**	13.58**	11.46	0.57	0.29	0.12
SP	0.047**	0.05**	0.023**	0.03**	0.00	0.00	0.19	0.15
BY	55.11**	72.11**	10.50**	13.21**	0.37	0.66	0.45	0.47
SY	4.72**	4.87**	2.08**	1.42**	0.19	0.10	0.20	0.30
HI	62.12**	39.44**	20.67**	12.80**	3.10	4.08	0.28	0.34
SW	1.08**	2.10**	1.62**	1.71**	0.33	0.27	0.05	0.11

*, **Significant at 5 and 1 per cent levels, respectively, Df= Degree of freedom; DFF= Days to first flowering; DF= Days to 50% flowering; DFP= Days to first pod formation; DLP= Days to last pod development; DM= Days to maturity; FPH= First pod height (cm); PH= Plant height (cm); PB= Number of primary branches/plant; SB= Number of secondary branches/plant ; PP= Pods/ plant; SP= Seeds/pod; BY= Biological yield/ plant (g); SY= Seed yield/plant (g); HI= Harvest index (%) and SW= 100-seed weight (g)

Table 2. Best crosses of chickpea on the basis of significant sca effects, heterosis, heterobeltiosis and inbreeding depression for grain yield and its major components in chickpea under E_1 and E_2 conditions

Crosses	Envn.	Seed yield/plant (g)					100-Seed weight (g)			Number of pods/plant			Harvest index (%)		
		SCA	GCA	H	Hb	ID	H	Hb	ID	H	Hb	ID	H	Hb	ID
$P_1 \times P_2$	E_1	-0.61	PxG	1.26	-9.97	-14.05	15.31**	4.80	12.09**	-6.70	-10.31	-0.72	-2	-12.77	-20.66
	E_2	0.52*	PxG	34.57**	-6.83	6.79	0.11	-1.08	-7.84	8.63**	2.31	-13.63	-3.11	-11.34	-2.23
$P_1 \times P_4$	E_1	1.67**	Px P	28.68**	14.21	0.96	2.36	-0.46	2.34	21.80**	17.70*	10.29**	17.21**	13.68*	9.21
	E_2	0.72**	PxP	43.9**	10.01	4.21	8.60*	5.28	1.08	7.49**	5.46*	5.50	14.54*	13.7	19.33**
$P_1 \times P_5$	E_1	0.09	Px P	-0.80	-13.74*	-8.07	5.69	2.58	-0.60	-14.76*	-22.66**	6.81	-8.15	-8.82	-5.96
	E_2	0.81**	PxP	27.78**	-5.50	-22.5*	13.6**	10.03*	1.91	-1.72	-5.32*	-10.63	-5.66	-5.91	-17.25*
$P_1 \times P_6$	E_1	1.79**	PxG	27.30**	3.24	9.55	1.79	-1.48	2.79	-3.65	-14.12*	-0.74	18.15**	12.62*	-8.41
	E_2	0.16	PxG	12.59	-23.4**	-15.20	8.84*	5.33	0.74	-6.26**	-12.32**	-3.06	11.37	9.64	-13.54*
$P_1 \times P_7$	E_1	0.47	PxP	10.53	-6.96	-6.88	4.54	3.90	8.25	8.54	-0.34	5.81	5.86	2.77	-4.61
	E_2	0.81**	PxP	39.96**	5.98	1.84	12.26**	4.57	6.86	2.51	-0.66	2.05	6	4.07	-5.92
$P_2 \times P_3$	E_1	1.02**	GxG	29.01**	25.3**	-7.48	21.70**	13.42**	9.65*	23.04**	22.18**	-0.22	5.08	-2.15	0.26
	E_2	1**	GxG	29.83**	24.81**	-5.39	19.56**	14.91**	5.91	20.54**	16.82**	7.90	-0.52	-5.43	7.92
$P_2 \times P_4$	E_1	1.05**	GxP	22.53**	22.29**	-8.99	13.57**	13.48**	4.24	20.72**	20.52**	-4.32	-9.26	-21.37**	-31.2**
	E_2	1.43**	GxP	44.11**	24.46**	6.17	11.75**	11.41*	2.30	18.64**	13.08**	4.05	-8	-16.37*	-24.4**
$P_2 \times P_7$	E_1	1.63**	GxP	26.37**	18.69**	9.65	13.13**	10.77*	7.69	31.11**	24.15**	-0.51	3.17	-10.52	13.59
	E_2	1.45**	GxP	40.23**	22.55**	-2.58	13.71**	8.80*	10.88**	20**	13.02**	3.55	-7.47	-16.72*	-0.86
$P_2 \times P_8$	E_1	1.41**	GxG	27.41**	20.14**	9.06	14.40**	12.14**	7.07	24.30**	19.35**	-8.69**	-0.14	-16.09**	4.04
	E_2	0.89**	GxG	40.23**	23.15**	11.95	13.91**	9.50*	18.47**	15.87**	12.92**	-2.44	0.11	-6.74	13.76
$P_3 \times P_6$	E_1	2.71**	GxG	42.23**	24.69**	8.54	18.60**	11.12*	10.98*	30.54**	20.64**	4.53	13.88*	3.62	-18.92*
	E_2	2.37**	GxG	39.95**	30.24**	9.94	18.98**	13.82**	12.68**	24.97**	10.56**	1.93	5.49	-0.18	17.28*
$P_3 \times P_7$	E_1	1.27**	GxP	26.19**	15.33*	1.71	14.49**	4.64	-1.47	18.59**	13.05	-4.01	27.50**	18.05**	3.07
	E_2	0.21	GxP	13.23	2.50	-9.82	13.69**	4.74	-1.29	22.93**	12.43**	4.44	9.14	3.01	-0.04
$P_4 \times P_7$	E_1	0.61	PxP	12.6*	5.95	7.81	14.15**	11.68**	12.60**	0.10	-5.06	-2.56	13.75*	13.63*	10.26
	E_2	0.82**	PxP	31.36**	29.55**	-19.39*	9.98**	5.54	5.2	3.20	1.91	-2.06	10.80	9.59	-5.47

$P_4 \times P_8$	E_1	0.89*	PxG	19.08**	12.5	-4.96	4.51	2.36	5.54	11.81	7.52	-2.33	21.28**	16.94**	-1.46
	E_2	0.59*	PxG	38.12**	35.46**	-6.96	10.82**	6.84	-3.57	2.93	0.61	-1.14	14.74*	11.73	-4.24
$P_5 \times P_7$	E_1	0.40	PxP	3.22	-0.66	-15.44*	-4.24	-6.5	-1.82	-4.25	-5.50	0.25	10.32	7.86	-33.1**
	E_2	0.59*	PxP	13.54	9.63	-14.72	4.53	0.4	6.18	-1.47	-2.08	-3.51	-0.62	-2.17	-12.79
$P_5 \times P_8$	E_1	2.25**	PxG	26.53**	22.27**	1.68	14.49**	11.90**	-0.37	17.84**	14.65*	1.36	7.08	0.93	-19.82*
	E_2	0.79**	PxG	28.24**	24.52**	-18.28*	14.33**	10.33*	-2.64	11.30**	6.82**	-1.22	-4.54	-6.61	-4.17
$P_6 \times P_8$	E_1	1.81**	GxG	26.92**	20.72**	-4.72	15.67**	12.75**	1.03	24.01**	18.36**	0.62	-2.75	-4.57	-12.40
	E_2	2.20**	GxG	49.99**	27.94**	9.01	16.12**	12.15**	-0.96	12.67**	5*	-1.92	-2.17	-5.51	-18.63*

*, ** Significant at 5 and 1 per cent levels, respectively. P=Poor, G= Good, Hb= Heterobeltiosis, H= Heterosis, ID= Inbreeding depression,

significant positive GCA effect under the E1 condition though the parent CSJD-884 and RSG 963 in the E2 condition. The parent CSJ-515 is an excellent general combiner for seed yield and furthermore, it exhibited significant positive GCA for plant height, no. of pods/ plant, biological yield/plant, and harvest index in both E1 and E2 conditions, although for no. of seeds/pod in only E1 condition (Supplementary Table S1). The parent HC-5 exhibited good GCA for plant height, seeds per pod, harvest index, and 100-seed weight under both E1 and E2 conditions while for pods per plant in only E1 condition. Parent Avrodhi exhibited good GCA for plant height, pods per plant, and seeds per pod in both environments; however, for the number of secondary branches/plant, pods per plant, and seeds per pod in only the E2 condition. The parent CSJD-884 was found superior for days to flowering, seed weight, biological yield, pods per plant, and seeds per pod in E1 and for biological yield per plant in E2 condition, while RSG 963 showed desirable GCA for days to 50% flowering in both the environments and for biological yield per plant in only E2 condition.

In self-pollinated crops like chickpea, SCA effects comprise comparatively less appropriate since it is expending of the non-additive gene effect exclusive of that it arises from complementary gene action or linkage effects and cannot be determined in pure lines. Jinks and Jones (1958) weighted that the preeminence of the hybrid may not delegate their capability to create transgressive segregants, rather, SCA would grant satisfactory measures. Though, if a hybrid enlightening high SCA as well as high *per se* performance which has at least one parent as a good general combiner for a particular trait, it is expected that this hybrid would make available for advantageous transgressive segregant in later generations (Singh et al. 1992). Estimates of the SCA effects of the crosses are recapitulated in Supplementary Table S2. Nine crosses in both environments, two crosses only in E1 and five crosses in only E2 condition, showed significant SCA effects for grain yield. None of these crosses depicted a significant SCA effect for all the traits studied but variable for different traits. However, many of these crosses had high SCA effects for yield-related traits like the number of primary and secondary branches/plant, pods per plant, seeds per pod, biological yield per plant, harvest index, and 100-seed weight, indicating their importance toward yield contribution. The crosses showed a high SCA effect resulting from crosses between parents with good x good or good x poor/poor x good general combiners, reflecting additive x additive type of gene action and accumulation of favorable genes from the parents and are especially relevant in self-pollinating crops like chickpea (Nagaraj et al. 2002; Jha et al. 2019). Crosses namely CSJD 884 x RSG 963, CSJD 884 x HC 5, RSG 963 x CSJ 515, CSJ 515 x HC 5 possessed good x good parent in both environments, while crosses particularly RSG 888 x CSJD 884, RSG 888 x CSJ 515, CSJD 884 x RSG 973, CSJD 884 x Avrodhi, RSG 963 x Avrodhi and RSG 973 x HC 5 concerning good x poor/poor x good parents. Using the biparental progeny selection method, it is possible to obtain some transgressive segregants from crosses combining good x good and good x poor combiners. The higher SCA effect was observed in the cross flanked by poor x poor general combiners might be due to the non-additive gene effects reflected and interactions of dominance x dominance gene action and could be conquered through hybridization and further selection. A wide range of heterosis and heterobeltiosis has been expressed for seed yield per plant under both E1 and E2 conditions. Among all the heterotic crosses, seven crosses under both environments, two in only E1, and five in only E2 condition were observed more heterobeltiotic for seed yield per plant (Table 2). Crosses that showed desirable relative heterosis and heterobeltiosis for seed yield were also heterotic for at least one or more component traits of yield. An overall evaluation of relative heterosis for seed yield per plant in both environments revealed that the maximum relative heterosis over mid-parent was observed by cross RSG-963 x CSJ-515 (E1) and CSJ-515 x HC-5(E2) while heterosis over better parent was observed by cross CSJ-884 x RSG-963 (E1) and RSG-973 x HC-5 (E2). A higher level of heterosis in a cross indicated that the parents are genetically more diverse than other crosses. Thus the chance of obtaining superior segregants may increase with the increase in genetic distance between the parental lines (Hedge et al. 2007; Ghasemi et al. 2022). The inbreeding depression in F_2 was changeable for different crosses and traits in both timely and late-sown conditions (Table 2). In the case of seed yield per plant, pods per plant, 100-seed weight, and harvest index, there was heterosis in the Fl generation but inbreeding depression in the F_2 generation, showing the magnitude of non-additive genes for these traits in chickpeas. The segregating material generated through this study may be exploited for the selection of enviable recombinants in higher generations to develop high-potential varieties in chickpeas. Thus it is concluded that among eight parents taken for diallel analysis, parent CSJ-515 and HC-5 were good combiners for seed yield and contributing traits under both the environment while Avrodhi only in timely sown (E1) and CSJD-884 and RSG 963 in late sown (E2) environment. Crosses CSJD 884 x RSG 963, CSJD 884 x RSG 973, CSJD 884 x Avrodhi, RSG 963 x CSJ 515 in both, and CSJD 884 x RSG 963 and RSG 973 x Avrodhi in late sown conditions found better based on combining ability and heterobeltiosis and can be included in the breeding programme for improvement of grain yield in chickpea in specific environments.

Supplementary material

Supplementary Tables S1 and S2 are provided, www.isgpb.org

Authors' contributions

Conceptualization of research (SKJ, RC); Designing of the experiments (SKJ, RC); Contribution of experimental materials (RC, SKJ, MPO); Execution of field/lab experiments and data collection (RC, SKJ, MPO); Analysis of data and interpretation (SKJ, RC MPO, DG); Preparation of the manuscript (SKJ, RC MPO, DG)

References

Amadabade J., Arora A. and Sahu H. 2014. Combining ability analysis for yield contributing characters in chickpea (*Cicer arietinum* L.). Elect. J. Plant Breed., **5**: 664-670.

Anonymous 2021. Ministry of Agriculture and Farmers Welfare (DAC&FW), Government of India.

Fonseca S. and Patterson F.L. 1968. Hybrid vigour in seven parental diallel cross in common winter wheat (*Triticum aestivum* L.). Crop Sci., **8**: 85-88.

Ghasemi P., Karami E. and Talebi R. 2022. Study of heterosis, genetic depression and estimation of genetic parameters of some morphological traits in chickpea genotypes by generation mean analysis. Central Asian J. Plant Sci. Innov., **2**(1): 19-36.

Griffing B. 1956. Concept of general and specific combining ability in relation to diallel crossing system. Aust. J. Biol. Sci., **9**: 463-493.

Hedge V.S., Yadav S.S. and Kumar J. 2007. Heterosis and combining ability for biomass and harvest index in chickpea under a drought prone, short duration environment. Euphytica, **157**: 223-230.

Jha U., Kole P.C. and Singh N.P. 2019. Nature of gene action and combining ability analysis of yield and yield related traits in chickpea (*Cicer arietinum* L.) under heat stress. Indian J. agric. Sci., **89**: 500-508.

Jinks J.L. and Jones R.M. 1958. Estimation of components of heterosis. Genetics, **43**: 223-234.

Kaur K., Grewal S.K., Gill P.S. and Singh S. 2019. Comparison of cultivated and wild chickpea genotypes for nutritional quality and antioxidant potential**.** J. Food Sci. Technol., **56**(4): 1864-1876. Doi: 10.1007/s13197-019-03646-4.

Koul B., Sharma K., Sehgal V., Yadav D., Mishra M. and Bharadwaj C. 2022. Chickpea (*Cicer arietinum* L.) Biology and Biotechnology: From Domestication to Biofortification and Biopharming. Plants, **11**(21): 2926.

Madurapperumage A., Tang L., Thavarajah P., Bridges W., Shipe E., Vandemark G. and Thavarajah D. 2021. Chickpea (*Cicer arietinum* L.) as a Source of Essential Fatty Acids - A Biofortification Approach. Front. Plant Sci., **12**:734980.

Nagaraj K., Salimath P.M. and Kajjidoni S.T. 2002. Genetic variability created through biparental mating in chickpea (*Cicer arietinum* L.). Indian J. Genet. Plant Breed., **62**(2): 259-260.

Salimath P.M. and Bahl P.N. 1985. Heterosis and Combining ability for earliness in chickpea (*Cicer arietinum* L.). Indian J. Genet. Plant Breed., **45**(1): 97-100

Sharma, S. and Sharma R. 2020. "Chickpea economy in India," in Chickpea: Crop Wild Relatives for Enhancing Genetic Gains, (Ed: M. Singh) (Elsevier). doi: 10.1016/B978-0-12-818299-4.00009-9.

Singh U. 1985. Nutritional quality of chickpea (*Cicer arietiunum* L.): Current status and future research. Qual. Pl. Plant Foods Hum. Nutr., **35**: 339-351.

Singh O., Gowda C.L.L., Sethi S.C., Dasgupta T. and Smithson J.B. 1992. Genetic analysis of agronomic characters in chickpea. Theor. Appl. Genet., **83**: 956-962.

Supplementary Table S1. Estimates of GCA in six parents of chickpea for different characters under under timely and late sown conditions

Parents	Env.	DFF	DF	DFP	DLP	DM	FPH	PH	PB	SB	PP	SP	BY	SY	HI	SW
P_1	E_1	-0.84**	-0.06	0.33*	-0.64**	0.28	-0.88**	2.28**	0.11	-0.41**	-8.08**	-0.06**	-3.89**	-1.26**	0.38	-0.06
	E_2	0.66**	0.75**	0.50**	0.48**	-0.56*	-0.44	1.03*	-0.07	-0.20	-2.13**	-0.03	-3.72**	-1.29**	0.23	-0.64**
P_2	E_1	-1.18**	-0.92**	-0.17	-0.17	0.21	-0.68**	-1.76**	0.10	0.74**	2.72**	-0.03	4.57**	0.06	-5.28**	0.45**
	E_2	0.83**	-0.08	0.67**	0.54**	-0.36	-1.39**	-2.21**	0.04	0.22	0.03	-0.04*	5.34**	0.95**	-4.22**	0.05
P_3	E_1	-1.41**	-0.39**	-1.04**	-0.21	-0.52	-0.46*	-2.55**	-0.11	-0.13	-0.69	0.02	0.11	0.09	0.77	-0.47**
	E_2	-0.91**	-1.15**	-1.20**	-0.92**	-0.36	-1.06**	-1.70**	-0.14**	-0.07	-0.88**	-0.08**	1.17**	0.33**	0.31	-0.54**
P_4	E_1	-0.61**	-0.56**	-0.37*	-0.61**	-1.79**	-0.04	-0.16	-0.25**	-0.35*	-3.89**	-0.07**	-1.18**	-0.15	1.31*	0.16
	E_2	-1.11**	-0.88**	-1.07**	-0.63**	-1.06**	-0.62*	-0.18	-0.09	-0.41**	-0.64**	-0.03	-0.93**	-0.13	1.69**	0.07
P_5	E_1	-0.08	-0.29*	-0.94**	0.39*	-1.56**	-0.11	-0.39	0.21**	-0.06	-1.48	-0.08**	-0.58**	-0.58**	-2.12**	-0.35*
	E_2	-1.14**	-1.02**	-0.67**	-0.46**	-0.16	0.27	0.33	0.24**	-0.09	-0.35	-0.04*	-1.33**	-0.49**	-1.32*	-0.16
P_6	E_1	0.66**	0.21	0.43**	0.39*	-0.19	0.24	2.56**	0.09	-0.19	5.81**	0.03	0.88**	0.96**	1.93**	-0.19
	E_2	0.32	0.75**	1.10**	0.48**	0.07	0.27	1.39**	-0.03	0.18	2.31**	0.04*	0.77**	0.56**	1.61**	0.04
P_7	E_1	2.56**	0.78**	1.06**	0.73**	1.94**	0.97**	1.39**	0.01	0.43**	2.97**	0.06**	-0.14	0.31*	1.09*	0.07
	E_2	0.86**	0.85**	0.40*	0.11	1.64**	1.04**	1.30**	0.16**	0.13	1.70**	0.11**	-1.81**	-0.27**	1.56*	0.44**
P_8	E_1	0.89**	1.24**	0.73**	0.13	1.64**	0.95**	-1.39**	-0.15*	-0.03	2.64*	0.12**	0.22	0.57**	1.93**	0.38*
	E_2	0.49**	0.78**	0.27	0.41**	0.78**	1.94**	0.05	-0.11*	0.24	-0.04	0.08**	0.51*	0.33**	0.15	0.74**
SE (gi) ±	E_1	0.20	0.14	0.15	0.16	0.27	0.18	0.46	0.06	0.15	1.00	0.02	0.18	0.13	0.52	0.17
	E_2	0.16	0.16	0.16	0.14	0.23	0.24	0.48	0.05	0.14	0.22	0.02	0.24	0.09	0.60	0.15
SE (gi-gj) ±	E_1	0.30	0.20	0.23	0.24	0.40	0.27	0.70	0.10	0.23	1.51	0.03	0.27	0.19	0.79	0.26
	E_2	0.24	0.24	0.25	0.20	0.34	0.36	0.72	0.08	0.21	0.34	0.03	0.36	0.14	0.90	0.23

*, ** Significant at 5 and 1 per cent levels, respectively. Env.=Environment; E_1= Timely sown condition; E_2= Late sown condition; RSG-888 (P_1); CSJ-884 (P_2); RSG-963 (P_3), RSG-973 (P_4); RSG-974 (P_5); CSJ-515 (P_6) and AVRODHI (P_7), HC-5 (P_8)

Supplementary Table S2. Estimates of SCA in 28 crosses of chickpea for different characters recorded under timely and late sown conditions

Crosses	Env.	DFF	DF	DFP	DLP	DM	FPH	PH	PB	SB	PP	SP	BY	SY	HI	SW
$P_1 \times P_2$	E_1	-0.33	-0.64	-0.16	1.55**	-1.21	0.23	0.38	-0.30	0.71	-7.44**	-0.14**	-1.65**	-0.61	-1.68	-1.62**
	E_2	-0.90*	-0.72	-1.06*	-2.04**	-1.89**	0.78	5.80**	-0.35*	0.41	1.34*	-0.03	0.63	0.52*	-0.62	-2.03**
$P_1 \times P_3$	E_1	-1.43**	-0.50	0.37	2.25**	0.52	1.24*	7.43**	0.38*	0.94*	-4.46	0.01	-1.98**	-0.71*	4.21**	1.30**
	E_2	0.83	1.34**	1.81**	0.42	-0.89	-1.16	1.42	0.66**	1**	0.48	0.13**	-0.62	-1**	1.31	-1.11**
$P_1 \times P_4$	E_1	1.77**	1.33**	1.04*	1.65**	2.45**	-1.58**	-5.63**	-0.42*	-0.46	15.34**	-0.07	2.26**	1.67**	3.81**	-0.32
	E_2	0.37	0.08	0.68	-0.21	-1.86**	-1.40*	-4.63**	-0.25	-0.33	3.71**	-0.34**	2.73**	0.72**	2.89	0.28
$P_1 \times P_5$	E_1	-1.76**	1.73**	0.94*	0.31	0.55	-1.27**	2.21	-0.37*	-1.11**	-4.98	0.14**	2.25**	0.09	-2.95*	0.76
	E_2	0.40	0.21	0.28	-0.04	-1.09	-0.01	1.39	-0.11	-0.78*	-0.11	0.16**	2.61**	0.81**	-1.44	1.32**
$P_1 \times P_6$	E_1	-0.16	0.23	-1.09**	0.98*	0.85	-2.72**	-3.55**	0.18	-0.10	-3.79	-0.03	-0.06	1.79**	4.37**	-0.16
	E_2	0.60	-0.56	-0.49	0.69	-2.66**	-1.82**	-0.27	-0.17	-0.02	-3.47**	0.01	-1.45*	0.16	2.18	0.39
$P_1 \times P_7$	E_1	-1.06	-0.67	-1.39**	-1.35**	-2.61**	2.48**	6.16**	0.02	0.59	4.44	0.04	1.56**	0.47	-0.21	0.60
	E_2	-0.27	-0.66	0.21	1.39**	-0.56	0.38	3.59**	0.06	0.83*	-0.39	0.14**	1.82**	0.81**	0.41	1.28**
$P_1 \times P_8$	E_1	-2.39**	-1.14**	-1.06*	-2.09**	-3.98**	1.57**	2.14	-0.11	2.02**	-8.16**	0.01	-4**	-2.03**	-2.01	-0.54
	E_2	-1.57**	-1.92**	-0.99*	0.42	0.98	-0.29	3.38**	0.14	1.99**	-2.82**	0.08	0.02	-0.24	-2.57	1.57**
$P_2 \times P_3$	E_1	-4.09**	-2.30**	-0.46	-1.22**	-3.41**	-0.69	-2.96*	0.36*	-0.74	4.91	0.27**	3.38**	1.02**	-1.60	1.29**
	E_2	-0.33	0.51	-0.02	0.02	-1.42*	0.23	-2.57*	0.51**	0.05	1.99**	0.18**	2.96**	1**	-1.24	1.65**
$P_2 \times P_4$	E_1	0.11	2.20**	1.21**	0.18	2.52**	-0.74	-4.48**	0.36*	0.76	6.27*	0.13*	5.94**	1.05**	-3.88**	0.66
	E_2	-0.47	-0.09	-0.49	0.06	-0.06	-0.08	-5.31**	-0.07	-0.31	5.32**	0.17**	5.69**	1.43**	-3.41*	0.58
$P_2 \times P_5$	E_1	0.91	-0.40	-0.23	-1.49**	0.62	-2.74**	1.36	-0.26	0.21	2.09	0 .00	-0.34	-1.13**	-3.58*	0.41
	E_2	1.23**	1.04*	0.11	-0.11	0.38	-0.73	2.26	-0.03	-0.83*	1.20*	-0.19**	-2.21**	-1.47**	-4.44**	-0.79
$P_2 \times P_6$	E_1	0.51	0.76*	1.74**	-0.15	2.25**	-1.26**	10**	0.24	-0.96*	4.94	-0.06	-5.91**	-1.20**	8.99**	1.14*
	E_2	-0.57	0.28	-0.66	-0.04	-2.52**	-1.73**	9.6**	0.31*	0.33	-3.43**	-0.14**	-4.16**	-1.29**	8.92**	0.94*
$P_2 \times P_7$	E_1	-0.06	-3.80**	-0.89*	0.85	1.45*	-1.09*	-3.43**	0.40*	0.73	10.41**	0.30**	3.85**	1.63**	0.41	1.14*
	E_2	-0.43	-0.16	-0.29	0.66	1.58*	-0.27	-3.95**	0.68**	-1.18**	4.38**	0.29**	5.67**	1.45**	-2.74	1.34**
$P_2 \times P_8$	E_1	0.27	-0.27	-1.23**	0.78	-3.91**	1.17*	-3.65**	0.43*	1.65**	5.11	0.14**	3.16**	1.41**	-0.02	1.03*
	E_2	-0.40	0.24	0.18	-0.31	-0.56	-2.11**	-3.53**	0.35*	1.68**	2.12**	0.16**	2.50**	0.89**	-0.17	0.98*
$P_3 \times P_4$	E_1	2.34**	-1**	1.07**	-1.45**	3.59**	-1.10*	-1.63	-0.12	-0.04	-0.98	-0.15**	-4.1**	0.20	7.70**	1.03*
	E_2	0.6	0.64	1.04*	1.19**	0.28	-2.21**	-0.50	-0.05	0.17	-1.11	0.04	-1.72**	-0.51*	6.16**	1.21**
$P_3 \times P_5$	E_1	3.47**	1.73**	-1.69**	2.21**	-0.65	2.08**	5.61**	0.12	0.59	-3.43	-0.18**	-0.52	-0.71*	-2.61	-0.14
	E_2	-0.37	-0.22	-0.36	-0.31	-2.62**	-2.5**	5.06**	0.32*	0.46	0.51	-0.23**	-3.03**	-1.13**	-2.02	-0.61

$P_3 \times P_6$	E_1	1.74**	0.56	-0.39	-0.12	1.65*	-0.58	-3.52**	0.53**	2.09**	14.25**	0.16**	5.93**	2.71**	0.43	1.28**
	E_2	-2.17**	-1.99**	-2.12**	-1.91**	-0.52	0.17	-5.19**	0.22	1.25**	7.78**	0.16**	6.16**	2.37**	-1.47	1.67**
$P_3 \times P_7$	E_1	-1.49**	0	-0.03	-1.45**	-4.48**	-0.98*	-6.11**	0.63**	0.45	6.22*	0.02	-0.58	1.27**	5.22**	0.91*
	E_2	-2.37**	-2.76**	-2.09**	-1.21**	-1.42*	-0.27	-7.04**	0.13	0.17	4.99**	-0.11*	-0.24	0.21	-0.06	1.22**
$P_3 \times P_8$	E_1	3.17**	1.86**	0.31	-1.85**	1.49*	0.52	0.67	-0.52**	-0.22	-5.61*	0.03	-0.32	-0.50	0.57	-0.41
	E_2	-1*	-2.69**	-1.96**	-0.51	0.78	1.43*	2.87*	-0.10	-0.64	0.17	-0.21**	-1.64*	0.12	5.34**	-1.22**
$P_4 \times P_5$	E_1	-1.66**	1.23**	-0.69	-2.05**	-2.05**	-1.01*	0.22	0.26	2.12**	-11.43**	-0.02	-0.63	-1.76**	-6.84**	0.54
	E_2	-0.17	0.18	0.18	-0.61	0.74	-0.47	2.28	0.17	1.47**	-3.86**	0.06	-1.40*	0.09	3.27*	0.02
$P_4 \times P_6$	E_1	0.27	2.06**	-1.39**	-1.39**	0.92	1.30**	5.64**	-0.12	0.04	-10.65**	0.11*	0.31	-1.38**	-6.13**	0
	E_2	-0.63	-1.26**	-1.26**	-0.54	2.51**	0.36	7.46**	-0.02	-0.34	-1.73**	0.08	-2.23**	-1.30**	-5.18**	-0.78
$P_4 \times P_7$	E_1	0.04	0.83*	-0.03	-1.39**	-2.88**	1.20*	2.20	0.28	-1.40**	-2.98	0.07	-0.46	0.61	3.08*	1.59**
	E_2	-2.17**	-2.69**	-1.89**	-1.84**	-1.06	1.26	1.11	0.15	-0.72	-0.58	0.01	1.30*	0.82**	0.97	0.75
$P_4 \times P_8$	E_1	-1.29*	-0.30	-0.69	-0.79	-2.25**	-0.44	6.58**	-0.12	-0.31	3.85	0.15**	-2.02**	0.89*	6.94**	-0.51
	E_2	-1.13*	-0.96*	-0.09	-1.81**	-2.52**	0.32	6.26**	-0.11	-0.39	-0.77	0.05	-0.09	0.59*	2.26	0.5
$P_5 \times P_6$	E_1	1.07*	-2.87**	1.17**	1.28**	-5.65**	1.11*	-1.04	0.23	0.29	2.47	-0.01	-3.39**	-0.41	2.42	-0.98*
	E_2	-0.27	-0.12	-0.66	-1.04**	-0.72	0.41	0.47	0.38**	1.34**	-1.21*	0.02	-1.78**	-0.29	2.16	0.22
$P_5 \times P_7$	E_1	-1.83**	-0.10	-0.46	-1.39**	0.22	-0.16	-0.20	-0.47**	0.66	-3.96	-0.08	-1.30**	0.40	4.23**	-1.29**
	E_2	-1.47**	0.11	0.38	-1.34**	0.38	0.84	2.19	-0.48**	0.79*	-2.27**	-0.08	1.96**	0.59*	-0.33	0.08
$P_5 \times P_8$	E_1	-0.49	0.76*	-1.46**	-2.12**	0.85	-1.53**	-7.79**	0.36*	-0.24	10.54**	0.19**	3.20**	2.25**	3.81**	1.78**
	E_2	-1.77**	-1.82**	-1.49**	-1.64**	-0.76	-1.63*	-9.03**	0.36*	-0.12	4.04**	0.12**	3.40**	0.79**	-1.61	1.34**
$P_6 \times P_7$	E_1	-5.56**	-2.27**	-1.16**	-0.72	-1.81*	0.32	-0.62	-0.66**	0.12	-1.78	-0.12*	-2.40**	-1.78**	-3.27*	-1.15*
	E_2	0.40	1.34**	1.61**	-2.61**	-1.52*	-2.99**	-0.67	-0.28*	-0.08	0.50	-0.03	-5.50**	-1.8**	2.04	-1.57**
$P_6 \times P_8$	E_1	-0.56	-1.07**	-1.83**	0.21	-1.51*	-1.28**	-4.81**	0.45*	-0.78	9.25**	0.13*	6.16**	1.81**	-2.50	1.78**
	E_2	0.10	0.08	0.41	0.09	0.68	-1.33*	-3.72**	0.66**	-1.12**	3.91**	0.14**	7.69**	2.20**	-3.25*	1.45**
$P_7 \times P_8$	E_1	-2.46**	0.36	-0.46	0.21	-2.65**	-2.62**	3.53**	0.21	-0.46	0.39	-0.18**	-1.19*	-1.76**	-5.54**	-0.80
	E_2	-1.43**	-1.69**	-0.56	0.12	-0.56	-2.03**	4.53**	0.17	0.03	1.16	-0.03	-4.32**	-1.06**	4.52**	-1.90**
ES (Sij) ±	E_1	0.53	0.36	0.40	0.43	0.71	0.47	1.24	0.17	0.40	2.67	0.05	0.48	0.34	1.39	0.45
	E_2	0.43	0.43	0.44	0.36	0.60	0.63	1.25	0.14	0.37	0.60	0.05	0.64	0.25	1.59	0.41
SE (Sij-Sik) ±	E_1	0.91	0.61	0.68	0.73	1.20	0.80	2.11	0.29	0.68	4.54	0.08	0.81	0.58	2.36	0.77
	E_2	0.73	0.73	0.75	0.61	1.02	1.08	2.12	0.23	0.63	1.02	0.08	1.09	0.42	2.71	0.70
SE (Sij-Ski) ±	E_1	0.86	0.58	0.64	0.69	1.14	0.76	1.99	0.27	0.64	4.28	0.08	0.77	0.55	2.23	0.72
	E_2	0.69	0.69	0.70	0.58	0.96	1.01	2.00	0.22	0.59	0.96	0.07	1.03	0.39	2.55	0.66

*, ** Significant at 5 and 1 per cent levels, respectively. Env. =Environment; E_1= Timely sown condition; E_2= Late sown condition; RSG-888 (P_1); CSJ-884 (P_2); RSG-963 (P_3); RSG-973 (P_4); RSG-974 (P_5), CSJ-515 (P_6) and AVRODHI (P_7), HC-5 (P_8)