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Research Article

Heterosis, inbreeding depression and components of heterosis in chickpea (*Cicer arietinum* L.) under irrigated and rainfed conditions

B.L. Kumhar, D. Singh, N.R. Koli and Y.K. Sharma
College of Agriculture (SKNAU-Jobner), Lalsot,
Dausa (Rajasthan)-303 511
E-mail: kumharbl71@gmail.com

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Abstract
The present study was carried out to estimate degree of heterosis, inbreeding depression and components of heterosis (in terms of gene effects) for eleven traits in chickpea (*Cicer arietinum* L.) through generation mean analysis under irrigated and rainfed conditions. Five generations (P_1, P_2, F_1, F_2 and F_3) derived from five crosses of chickpea were evaluated in Compact Family Block Design with three replications under both the conditions. Significant differences were observed among the crosses, generations and environments for all the characters. The magnitude of heterosis and heterobeltiosis varied from -7.31 % to 46.39 % and from -13.20 % to 32.49 %, respectively between different crosses across both the conditions. In all the crosses, significant heterobeltiosis was observed in all the crosses for all the characters except for fruiting branches per plant under rainfed condition. All the crosses also revealed inbreeding depression for most of the characters, which is varied from -17.94 % to 18.42 % across both the conditions. The components of heterosis study revealed that the manifestation of heterosis was mainly due to dominance x dominance (l) followed by dominance (h) and additive x additive (i) components in most of the crosses for most of the characters under both the conditions, indicating role of non-additive gene action. The opposite signs of (h) and (l) components indicated duplicate type of epistasis for all the characters in all the crosses. The crosses RSG-888 x ICC-4958, BG-362 x RSG-931 and IPC-94-94 x RSG-888 involving bold seeded cultivars (ICC-4958, BG-362 and IPC-94-94) as one of the parent performed better in the cross combination had high *per se* performance and significant positive heterobeltiosis with low inbreeding depression in one or more of the yield contributing characters even in rainfed condition, thus, could be utilized in future breeding programme. The higher magnitude of non-additive gene action *viz*., dominance (h) and dominance x dominance (l) in controlling of most of the characters in all the crosses suggests the use of recurrent selection by way of intermating the desirable segregants or the use of biparental intermating of desirable segregants in early segregating generation followed by selection, which may be handled through pedigree method of breeding. Presence of duplicate type of epistasis suggested that selection intensity should be mild in early and intense in the later generations with increased homozygosity.

Key words
Heterosis, inbreeding depression, Chickpea, *Cicer arietinum*

Introduction

Chickpea (*Cicer arietinum* L.) is the third most important food legume (after dry bean and pea) globally, grown in over 40 countries representing all the continents. Over 90% of area, production and consumption are in developing countries. In 2013, the global production was 13.10 million tons from an area of 13.54 million ha giving an average productivity of 967.6 kg/ha (FAOSTAT, 2014). Presently, the most important chickpea producing countries are India, Australia, Pakistan, Turkey, Myanmar, Ethiopia, Iran USA, Canada and Mexico. India is the largest chickpea producer as well as consumer in the world sharing 69.75 and 70.71 per cent of the total area and production, respectively. In India chickpea cultivation was done on 9.60 million ha with production of 8.83 million tons in the year 2013. In spite of India being the largest chickpea producing country a deficit exists in domestic production and demand, which is met through imports. Chickpea has special significance in the diet of the predominantly vegetarian population of India as it contains more protein (23 %), which is complementary with cereals in amino acids profile. However, production and productivity of chickpea have been stagnant for the past three decades. One of the main reasons is its sensitivity to moisture stress at critical stages as more than 80% area under chickpea is rainfed (Dhiman *et al.*, 2006).

Chickpea is a strictly self pollinated crop and the scope for exploitation of hybrid vigour will depend on the direction and magnitude of heterosis and type of gene action involved. The estimates of heterosis and inbreeding depression together provide information about type of gene action involved in the expression of various quantitative traits and will have a direct bearing on the breeding methodology to be employed for varietal improvement. Drought is the single most important abiotic stress, which severely affects the productivity of chickpea under rainfed production system. Significant variation among genotypes for yield and yield contributing characters under moisture stress condition in chickpea has been observed by Kumar *et al.* (2004), Meena *et al.* (2006), Krishnamurty *et al.* (2011) and Mishra and Babbar (2014).

Therefore, keeping this in mind the present investigation was carried out to estimate degree of heterosis, inbreeding depression and components of heterosis (in terms of gene effects) for metric

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characters in five crosses of chickpea grown under irrigated and rainfed conditions using generation mean analysis.

Materials and methods

Plant material: Seven *desi* chickpea cultivars *viz.*, RSG-895 (Medium bold), RSG-888 (Medium bold), ICC-4958(Bold), IPC-94-94 (Bold), CSJD-901(Medium bold), RSG-931(Medium bold) and BG-362 (Bold) were crossed in five combinations *viz.*, RSG-895 x RSG-888, RSG-888 x ICC-4958, IPC-94-94 x RSG-888, CSJD-901 x RSG-931 and BG-362 x RSG-931. Five generations *viz.*, P_1, P_2, F_1, F_2 and F_3 of these five crosses were grown in compact family block design with three replications under both irrigated (two supplemental irrigations) and rainfed (on receding soil moisture) conditions at Research Farm, Agricultural Research Sub Station, Hanumangarh, Rajasthan, India. The average precipitation was 241.6 mm and average temperature was 32.26^{o}C. Seeds were sown in 3 meter long rows. Rows were spaced 30 cm apart and plant to plant distance was maintained at 10 cm. Parents were sown in two rows, F_1s in one row and F_2s and F_3s were sown in four rows of each cross. Among the eleven characters studied observations for plant height, fruiting branches per plant, pods per plant, seeds per pod, biological yield per plant, seed yield per plant, harvest index, 100-seed weight and protein content were recorded on 10 randomly selected plants from each of the P_1, P_2 and F_1 and on 20 randomly selected plants from each of the F_2 and F_3 generations. The observations for days to 50% flowering and days to maturity were recorded on the plot basis.

Analysis of variance: ANOVA was performed as per compact family block design for comparison of crosses as well as generations of each cross. Pooled analysis of variance was also done over two environments according to Panse and Sukhatme (1985). Standard statistical procedures (Snedecor and Cochran, 1968) were used to obtain means and variances for each generation and character, separately.

Estimation of heterosis and inbreeding depression: Per cent heterosis over mid parent and better parent (heterobeltiosis, as termed by Fonseca and Patterson, 1968) and inbreeding depression were calculated as follows:

$$\text{per cent heterosis over mid parent} = \frac{\overline{F}_1 - \overline{MP}}{\overline{MP}} \times 100$$

where, $\overline{F}_1$ = Mean value of the F_1 generation; $\overline{MP}$ = Mean value of the two parental mean values

$$\text{per cent heterosis over better parent} = \frac{\overline{F}_1 - \overline{BP}}{\overline{BP}} \times 100$$

where, $\overline{F}_1$ = Mean value of the F_1 generation; $\overline{BP}$ = Mean value of the better parent

$$\text{per cent heterosis over better parent} = \frac{\overline{F}_1 - \overline{F}_2}{\overline{F}_2} \times 100$$

Where, $\overline{F}_1$= Mean value of the F_1 generation
F_2= Mean value of the F_2 generation

The significance of mid parent heterosis, better parent heterosis and inbreeding depression were tested using‘t’ test.

Estimation of components of heterosis: From the genetic parameters estimated in un-weighted five-parameter model, components of heterosis in presence of digenic interactions were calculated using the relationship presented by Mather and Jinks (1971) as follows:

For positive heterosis,
Heterosis (+) = $\overline{F}_1 - \overline{P}_1$= ([h] + [l]) – ([d] + [i])

and for negative heterosis,
Heterosis (–) = $\overline{F}_1 - \overline{P}_2$= ([h] + [l]) –([–d] + [i])

Where, P_1 corresponds to the parent with the greater mean value and P_2 to the parent with the smaller mean value, but for the present purpose, either P_1 or P_2 may be the better parent, according to the character under consideration. [d], [h], [i], and [l] are additive gene effects, dominance gene effects, additive x additive gene effects and dominance x dominance gene effects, respectively.

Results and discussion

Analysis of variance: The analysis of variance revealed significant differences among crosses and among generations for all the studied characters under both the conditions (Table 1 and 2). The pooled analysis of variance over environments also showed highly significant differences among generations and environments for most of the characters in most of the crosses (Table 2).

Heterosis, inbreeding depression and components of heterosis: The results with regards to heterosis, inbreeding depression along with components of heterosis are presented in Table 3 and discussed here as under:

Heterosis is the superiority of F_1 over the mean of the parents or over the better parent or over the standard check (Hayes *et al*., 1955). However, heterosis particularly superiority over better parent (heterobeltiosis) is important in deciding the direction of future breeding programme by identifying the cross combinations, which may prove promising in conventional breeding programme. Early flowering and maturity are desirable to achieve higher yield in rainfed condition. Significant values of mid parent and better parent heterosis for these traits were found in most of the crosses under both the conditions (Table 3). The desirable significant and negative

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heterobeltiosis for days to 50% flowering was observed only in RSG-895 x RSG-888 under rainfed condition. This suggests that one of parent of this cross was also early in flowering hence; this cross can be utilized for development of an early flowering variety. Plant height is an economic character in most of the crops. Significant and positive heterosis over better parent for plant height was observed in RSG-895 x RSG-888 and BG-362 x RSG-931under irrigated; in RSG-888 x ICC-4958 under rainfed and in CSJD-901 x RSG-931 under both the conditions.

For fruiting branches per plant all the five crosses exhibited significant heterobeltiosis under irrigated, whereas under rainfed it was non-significant. The maximum significant positive heterobeltiosis was observed in RSG-895 x RSG-888 followed by BG-362 x RSG-931 and RSG-888 x ICC-4958 under irrigated and under rainfed in CSJD-901 x RSG-931 followed by IPC-94-94 x RSG-888 and BG-362 x RSG-931. As for as heterobeltiosis for pods per plant was concerned all the crosses exhibited significant and positive heterobeltiosis under both the conditions. The highest heterosis over better parent was observed in RSG-895 x RSG-888 followed by CSJD-901 x RSG-931 and BG-362 x RSG-931 under irrigated and in RSG-895 x RSG-888 followed by RSG-888 x ICC-4958 and BG-362 x RSG-931 under rainfed condition. For seeds per pod better parent heterosis was found non-significant in all the crosses except in RSG-888 x ICC-4958 under pooled and in CSJD-901 x RSG-931 under irrigated condition, where it was significant negative and not desirable. All the crosses exhibited significant heterobeltiosis for biological yield per plant under both the conditions except RSG-895 x RSG-888 and CSJD-901x RSG-931 under rainfed and all of them were showing heterobeltiosis in positive direction, which is desirable. The highest heterobeltiosis for biological yield per plant was observed in IPC-94-94 x RSG-888 followed by RSG-888 x ICC-4958 and BG-362 x RSG-931 under irrigated and in RSG-888 x ICC-4958 followed by IPC-94-94 x RSG-888 and RSG-895 x RSG-888 under rainfed condition.

Seed yield per plant is the ultimate and most important trait. Significant and positive heterosis over better parent for seed yield per plant was observed in all the five crosses under both the conditions except for cross CSJD-901 x RSG-931 under rainfed. This heterosis was desirable as it indicated superiority of hybrid over better parent and may throw some transgressive segregants in the succeeding generations. Heterobeltiosis for harvest index was found significant and positive in all the crosses except for CSJD-901 x RSG-931 under rainfed condition, which is desirable. The higher magnitude of positive heterobeltiosis was observed in BG-362 x RSG-931, RSG-888 x ICC-4958 and CSJD-901 x RSG-931 under irrigated, whereas under rainfed it was observed in BG-362 x RSG-931, RSG-888 x ICC-4958 and RSG-895 x RSG-888. Seed weight is one of the component characters directly influencing the seed yield. All the crosses exhibited non significant heterobeltiosis for 100-seed weight except RSG-888 x ICC-4958 and IPC-94-94 x RSG-888 under pooled, having significant and negative heterobeltiosis. Maximum heterobeltiosis for this trait was observed in BG-362 x RSG-931 under pooled and in RSG-895 x RSG-888 and CSJD-901 x RSG-931 under rainfed. For protein content all the crosses also exhibited significant heterobeltiosis under both the conditions as well as in pooled analysis over environments except BG-362 x RSG-931 (-1.69 %) under rainfed condition. Among them, desirable significant and positive heterobeltiosis for this trait was observed only in RSG-888 x ICC-4958 under pooled over environments, as it showing superiority of F_1 over better parent. Maximum heterobeltiosis was recorded by cross RSG-888 x ICC-4958, followed by BG-362 x RSG-931 and RSG-895 x RSG-888 across both the conditions including pooled. Significant and negative heterosis over better parent was observed for days to 50 per cent flowering under rainfed and for protein content under pooled in cross RSG-895 x RSG-888; for plant height under irrigated and for seeds per pod and 100-seed weight under pooled in RSG-888 x ICC-4958; for plant height under irrigated, for protein content under both irrigated and rainfed and for 100-seed weight under pooled in cross IPC-94-94 x RSG-RSG-888; for seeds per pod under irrigated and for protein content under both irrigated and rainfed in CSJD-901 x RSG-931, whereas in the cross BG-362 x RSG-931 significant and negative heterobeltiosis was recorded only for plant height under rainfed and for protein content under irrigated condition. Negative heterosis for yield and related traits is undesirable and may appear due to dominance of unfavorable gene or inhibitory gene action. Absence of heterosis in certain other cases could be explained on the basis of internal cancellation of components of heterosis, which depends on the material under study. This study confirms the findings of Salimath and Bahl (1985), Salimath *et al.* (1988), Pandey and Tiwari (1989), Patil *et al.* (1998), Jeena and Arora (2000), Sharif *et al.* (2001), Bakhsh *et al.* (2007), Hegde *et al.* (2007), Farshadfar *et al*. (2008) and Parameshwarappa *et al.* (2012). It is also revealed that the magnitude of heterobeltiosis was maximum for seed yield per plant followed by fruiting branches per plant, pods per plant and biological yield per plant under irrigated, whereas under rainfed it was maximum for seed yield per plant followed by pods per plant, biological yield per plant and harvest index.

The inbreeding depression is indirectly a manifestation of non-additive gene action controlling the character, which may require complicated breeding methodology for their exploitation or will demand exploitation of heterosis through hybrid varieties. Significant inbreeding depression was observed for seed yield and its attributes in this study but the degree of inbreeding depression as well as direction also differed. Significant and positive inbreeding depression was observed for days to 50% flowering under irrigated and for days to maturity and seed yield per plant under rainfed in the cross RSG-895 x RSG-888; for days to 50% flowering, days to maturity under rainfed and for protein content under pooled in cross RSG-888 x ICC-4958; for days to 50 % flowering, days to maturity, pods per plant, and harvest index under rainfed in cross IPC-94-94 x RSG-888; for days to maturity and harvest index under rainfed and for fruiting branches per plant, biological yield per plant and seed yield per plant under irrigated in cross CSJD-901 x RSG-931; for days to maturity under rainfed and for protein content under irrigated in cross BG-362 x RSG-931. Positive inbreeding depression for days to 50% flowering and days to maturity showed possibility of selection of early flowering and early maturing new genotypes in subsequent generations. Tewari and Pandey (1987), Singh *et al.* (2002) and Bhaduoria and Chaturvedi (2003) were also observed the positive inbreeding depression for yield and associated traits in chickpea.

Negative inbreeding depression was observed for some of the characters like days to 50% flowering under rainfed in crosses RSG-895 x RSG-888; days to maturity under irrigated in cross RSG-888 x ICC-4958; days to maturity and pods per plant under rainfed in cross CSJD-901 x RSG-931 and days to 50 % flowering under both irrigated and rainfed in cross BG-362 x RSG-931. It may appear due to the favorable gene recombinations and may be useful in self-pollinated crops like chickpea for selection in advanced generations. Pandey and Tiwari (1989) and Singh *et al.* (2002) also reported negative inbreeding depression for days to flowering, days to maturity, fruiting branches, seed yield and 100-seed weight in chickpea. On the basis of *per se* performance, heterosis and inbreeding depression it was concluded that the crosses RSG-888 x ICC-4958, BG-362 x RSG-RSG-931 and IPC-94-94 x RSG-888 involving bold seeded parents (ICC-4958, BG-362 and IPC-94-94) had high mean value, heterobeltiosis with least inbreeding depression from F_1 to F_2 generation for most of the yield contributing characters *viz.*, plant height, fruiting branches per plant, pods per plant, seeds per pod biological yield per plant, harvest index and 100-seed weight even in rainfed condition, thus, could be utilized in future breeding programme. This supports the findings of Singh (1997).

The components of heterosis revealed that (l) followed by (h) and (i) contributed maximum towards heterosis in most of the characters under both the conditions, indicating role of non-additive gene action. The opposite signs of (h) and (l) components indicated duplicate type of epistasis in all the crosses for all the characters could reduce the heterotic effect. Furthermore, the presence of duplicate type of epistasis in present study suggested that selection intensity should be mild in early and intense in the later generations with increased homozygosity. Such dynamic breeding approaches for handling all the five crosses used in the present investigation are expected to end up in some homozygous lines with appreciable yield levels in rainfed areas.

Conclusion

On the basis of the findings of the present investigation it has been concluded that there were significant differences among crosses, generations and environments. Generation x Environment interaction showed differential response of irrigated and rainfed conditions. Significant heterobeltiosis was observed for most of the characters in almost all the crosses under both the conditions except for fruiting branches per plant under rainfed condition. Inbreeding depression was also common in all the crosses for most of the characters under both the conditions, varied from -17.94 % to 18.42 %. The components of heterosis revealed that (l) followed by (h) and (i) contributed maximum towards heterosis in most of the characters under both the conditions, indicating role of non-additive gene action. It is also concluded that the crosses involving bold seeded cultivars *i.e*. ICC-4958, BG-362 and IPC-94-94 as one of the parent performed better in the cross combination. The crosses RSG-888 x ICC-4958, BG-362 x RSG-RSG-931 and IPC-94-94 x RSG-888 had high per se performance and significant positive heterobeltiosis with low inbreeding depression from F_1 to F_2 generation in one or more of the yield components even in rainfed condition. Therefore, these crosses may produce transgressive segregants, could be utilized in future breeding programme. The higher magnitude of non-additive gene action *viz*., dominance (h) and dominance x dominance (l) in controlling of most of the characters suggests the use of recurrent selection by way of intermating the desirable segregants or the use of biparental intermating of desirable segregants in early segregating generation followed by selection, which may be handled through pedigree method of breeding. Furthermore, the presence of duplicate type of epistasis in present study suggested that selection intensity should be mild in early and intense in the later generations with increased homozygosity.

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Table 1. Analysis of variance (mean squares) for different characters in chickpea crosses under irrigated (IRG) and rainfed (RF) conditions

Characters/ Source of variation	D. F.	Days to 50% flowering	Days to maturity	Plant height (cm)	Fruiting branches per plant	Pods per plant	Seeds per pod	Biological yield per plant (g)	Seed yield per plant (g)	Harvest index (%)	100-seed weight (g)	Protein content (%)
Irrigated												
Replications	2	0.070	0.174	0.058	0.258	0.578	0.002	0.365	0.131	0.248	0.098	0.016
Crosses	4	51.708**	88.793**	55.084**	1.455**	24.465**	0.045**	19.267**	7.788**	7.848**	35.574**	0.622**
Error	8	0.096	0.316	0.449	0.172	1.405	0.001	0.318	0.130	0.603	0.086	0.023
Rainfed												
Replications	2	0.037	0.167	0.148	0.043	1.281	0.003	0.478	0.089	0.251	0.030	0.005
Crosses	4	198.05**	147.186**	19.633**	6.927**	52.503**	0.019**	22.987**	18.029**	51.117**	29.679**	0.689**
Error	8	0.081	0.033	0.231	0.106	0.499	0.001	0.271	0.219	0.205	0.165	0.008

*, ** Significant at 5 per cent and 1 per cent level, respectively

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Table 2. Individual and pooled analysis of variance (mean squares) of generation means for different characters in five crosses of chickpea under irrigated (IRG) and rainfed (RF) conditions

Characters	IRG			RF			Pooled analysis of variance				
	Rep. (2 d.f.)	Gener. (4 d.f.)	Error (8 d.f.)	Rep. (2 d.f.)	Gener. (4 d.f.)	Error (8 d.f.)	Env. (E) (1d.f.)	Rep./ Env. (4 d.f.)	Gener. (G) (4 d.f.)	G x E (4 d.f.)	Error (16 d.f.)
Days to 50% flowering											
RSG-895 x RSG-888	1.445	18.681**	2.090	0.002	7.390**	0.916	412.799**	0.722	9.586**	16.483**	1.504
RSG-888 x ICC-4958	0.048	12.398**	1.176	0.269	12.164**	1.016	208.086**	0.159	20.624**	3.938*	1.096
IPC-94-94 x RSG-888	0.064	319.744**	3.233	0.868	242.273**	3.534	1320.254**	0.466	428.814**	133.202**	3.384
CSJD-901 x RSG-931	0.452	4.144*	0.850	0.200	7.599**	0.783	265.083**	0.326	7.858**	3.885*	0.816
BG-362 x RSG-931	0.266	8.126**	0.850	0.464	22.468**	0.633	40.756**	0.366	26.680**	3.913**	0.741
Days to maturity											
RSG-895 x RSG-888	1.364	11.592*	1.947	0.171	16.669**	0.640	418.133**	0.766	20.391**	7.868**	1.294
RSG-888 x ICC-4958	2.561	24.823**	0.779	0.061	17.013**	0.907	172.400**	1.312	30.251**	11.586**	0.843
IPC-94-94 x RSG-888	2.399	250.044**	13.900	0.198	277.193**	3.117	580.800**	1.300	494.347**	32.892*	8.508
CSJD-901 x RSG-931	0.598	12.766**	0.766	0.468	15.235**	0.968	224.079**	0.533	22.371**	5.630**	0.867
BG-362 x RSG-931	0.268	33.388**	1.682	0.599	18.073**	1.684	73.299**	0.434	32.991**	18.471**	1.683
Plant height (cm)											
RSG-895 x RSG-888	0.001	40.021**	1.637	0.242	13.272*	2.379	337.234**	0.121	41.525**	11.768**	2.008
RSG-888 x ICC-4958	1.081	37.791**	4.305	2.539	15.087**	2.051	250.377**	1.812	24.789**	28.089**	3.178
IPC-94-94 x RSG-888	0.839	54.150**	5.200	1.032	53.350**	3.422	43.056**	0.936	86.982**	20.519*	4.311
CSJD-901 x RSG-931	5.069	40.133**	3.348	0.945	18.129**	1.731	121.874**	3.006	36.605**	21.657**	2.540
BG-362 x RSG-931	2.281	28.138**	3.591	0.611	55.511**	6.429	318.220**	1.446	59.894**	23.755*	5.010
Fruiting branches per plant											
RSG-895 x RSG-888	0.132	16.421**	0.788	0.997	7.565**	0.765	137.217**	0.565	17.083**	6.903**	0.776
RSG-888 x ICC-4958	1.391	18.542**	1.623	0.572	6.489**	0.524	27.950**	0.983	18.536**	6.496**	1.073
IPC-94-94 x RSG-888	0.640	25.117**	1.067	0.500	12.694**	0.915	24.300**	0.570	24.441**	13.369**	0.991
CSJD-901 x RSG-931	2.464	20.678**	0.730	0.162	5.592**	0.745	19.976**	1.311	22.873**	3.395*	0.738
BG-362 x RSG-931	0.098	17.179**	0.628	0.098	6.805**	0.254	11.371**	0.099	19.045**	4.941**	0.441
Pods per plant											
RSG-895 x RSG-888	13.089	331.556**	16.37	1.237	173.984**	3.208	973.674**	7.163	419.413**	86.127**	9.789
RSG-888 x ICC-4958	1.798	142.749**	12.227	4.862	263.506**	3.416	650.164**	3.330	341.484**	64.771**	7.821
IPC-94-94 x RSG-888	3.174	151.826**	9.067	1.335	152.074**	6.353	635.904**	2.256	251.215**	52.686**	7.710
CSJD-901 x RSG-931	9.204	115.315**	14.863	7.074	177.750**	6.860	1152.828**	8.139	224.393**	68.672**	10.861
BG-362 x RSG-931	3.725	127.541**	10.562	1.866	147.495**	7.105	555.212**	2.795	231.613**	43.422**	8.834
Seeds per pod											
RSG-895 x RSG-888	0.016	0.041*	0.008	0.006	0.034**	0.004	0.033*	0.011	0.071**	0.004	0.006
RSG-888 x ICC-4958	0.002	0.078**	0.011	0.007	0.076**	0.004	0.033	0.004	0.150**	0.003	0.007
IPC-94-94 x RSG-888	0.003	0.043*	0.008	0.003	0.045**	0.001	0.039*	0.001	0.069**	0.016*	0.005

*, ** Significant at 5 and 1 per cent level, respectively

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Table 2. Contd.,

Characters	IRG			RF			Pooled analysis of variance				
	Rep. (2 d.f.)	Gener. (4 d.f.)	Error (8 d.f.)	Rep. (2 d.f.)	Gener. (4 d.f.)	Error (8 d.f.)	Env. (E) (1d.f.)	Rep./ Env. (4 d.f.)	Gener. (G) (4 d.f.)	G x E (4 d.f.)	Error (16 d.f.)
Seeds per pod											
CSJD-901 x RSG-931	0.011	0.064**	0.009	0.001	0.019**	0.001	0.035*	0.006	0.066**	0.015*	0.005
BG-362 x RSG-931	0.003	0.024**	0.003	0.003	0.039**	0.003	0.017	0.001	0.057**	0.004	0.004
Biological yield per plant (g)											
RSG-895 x RSG-888	2.423	45.621**	2.995	1.991	31.965**	2.133	191.572**	2.206	60.081**	17.504**	2.564
RSG-888 x ICC-4958	0.992	68.477**	2.640	0.879	81.273**	1.912	385.137**	0.936	111.629**	38.121**	2.276
IPC-94-94 x RSG-888	0.084	50.796**	2.072	1.487	33.537**	2.784	140.078**	0.787	54.584**	29.749**	2.428
CSJD-901 x RSG-931	3.787	28.793*	4.187	0.917	30.259**	1.191	358.111**	2.351	30.553**	28.498**	2.689
BG-362 x RSG-931	0.904	76.659**	4.451	2.529	38.431**	2.148	68.675**	1.716	90.519**	24.570**	3.30
Seed yield per plant (g)											
RSG-895 x RSG-888	0.588	20.359**	1.200	1.666	15.436**	0.738	172.777**	1.125	25.269**	10.524**	0.970
RSG-888 x ICC-4958	0.117	27.273**	1.123	1.336	41.168**	0.885	23.870**	0.726	62.193**	6.248**	1.004
IPC-94-94 x RSG-888	0.722	12.402**	1.194	0.578	19.553**	0.762	9.509**	0.650	16.413**	15.542**	0.978
CSJD-901 x RSG-931	1.274	10.832**	0.867	0.989	6.320**	0.345	62.400**	1.132	14.272**	2.879*	0.606
BG-362 x RSG-931	0.566	25.112**	1.242	0.259	30.401**	1.415	19.018**	0.414	51.234**	4.280*	1.328
Harvest index (%)											
RSG-895 x RSG-888	10.479	67.467**	5.798	1.283	66.859**	3.276	231.778**	5.879	96.939**	37.386**	4.537
RSG-888 x ICC-4958	1.297	77.514**	1.359	1.807	71.264**	1.842	29.489**	1.553	123.058**	25.721**	1.600
IPC-94-94 x RSG-888	0.629	28.351**	1.514	0.591	62.157**	1.106	132.806**	0.609	48.440**	42.067**	1.310
CSJD-901 x RSG-931	0.200	16.665*	2.504	0.258	13.102**	1.384	30.724**	0.229	16.441**	13.326**	1.944
BG-362 x RSG-931	0.682	37.732**	1.614	1.428	91.035**	1.379	17.328**	1.054	107.491**	21.276**	1.497
100-seed weight (g)											
RSG-895 x RSG-888	0.061	2.157**	0.094	0.326	1.972**	0.060	1.152**	0.191	3.784**	0.344*	0.077
RSG-888 x ICC-4958	1.256	75.130**	4.095	0.083	57.462**	0.503	14.658*	0.669	131.818**	0.774	2.299
IPC-94-94 x RSG-888	0.310	39.523**	2.176	1.515	28.635**	1.011	8.175*	0.912	67.174**	0.984	1.593
CSJD-901 x RSG-931	0.127	2.588**	0.144	0.163	3.884*	0.643	4.074**	0.144	4.718**	1.753*	0.394
BG-362 x RSG-931	0.461	44.749**	0.939	1.362	34.737**	0.654	3.931*	0.913	78.924**	0.563	0.796
Protein content (%)											
RSG-895 x RSG-888	0.183	1.145*	0.202	0.064	0.946**	0.066	1.298**	0.125	1.947**	0.145	0.134
RSG-888 x ICC-4958	0.055	1.929**	0.049	0.018	1.258**	0.041	0.252*	0.035	3.075**	0.111	0.045
IPC-94-94 x RSG-888	0.059	4.952**	0.094	0.055	3.812**	0.061	0.666**	0.057	8.523**	0.241*	0.078
CSJD-901 x RSG-931	0.193	2.515**	0.192	0.033	0.917**	0.027	1.285**	0.113	2.610**	0.823**	0.109
BG-362 x RSG-931	0.052	1.659**	0.191	0.019	0.132**	0.017	2.191**	0.037	1.288**	0.505**	0.104

*, ** Significant at 5 per cent and 1 per cent level, respectively

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Table 3. Heterosis, inbreeding depression and components of heterosis for different characters in chickpea crosses under irrigated (IRG) and rainfed (RF) conditions

Phenological traits

Characters/ Crosses	Env.	Components of heterosis (-)				Per cent heterosis		Inbreeding depression (%)
		[h]	+[l]	-[-d]	-[i]	Over mid parent	Over better parent	
Days to 50% flowering								
RSG-895 x RSG-888	IRG	9.38	-12.09	-1.67	-1.38	5.19**±0.35	7.17**±0.37	1.76**±0.37
	RF	-3.45	4.79	-1.50	3.92	-2.97**±0.25	-1.23**±0.27	-0.64*±0.25
RSG-888 x ICC-4958	IRG	4.67	-8.00	-2.67	1.33	0.71**±0.19	3.66**±0.25	0.35±0.20
	RF	-5.77	14.21	-2.50	9.61	-1.31**±0.25	1.55**±0.27	0.76*±0.26
IPC-94-94 x RSG-888	IRG	-2.21	1.75	-12.67	36.21	11.06**±0.31	32.49**±0.40	-0.77±0.36
	RF	0.44	12.48	-11.17	16.40	-7.31**±0.25	8.86**±0.37	4.79**±0.31
CSJD-901 x RSG-931	IRG	3.57	-5.43	-1.00	0.43	2.21**±0.26	3.36**±0.31	0.47±0.25
	RF	3.88	-13.78	-1.83	-1.72	-1.75**±0.26	0.39±0.30	-1.78**±0.25
BG-362 x RSG-931	IRG	3.77	-11.54	2.17	-8.28	-0.17±0.20	2.17**±0.23	-1.06**±0.22
	RF	2.22	-7.12	3.34	-6.55	2.58**±0.24	6.49**±0.26	-0.72**±0.23
Days to maturity								
RSG-895 x RSG-888	IRG	8.44	-14.22	1.33	-7.77	2.45*±0.37	3.46**±0.43	0.48±0.51
	RF	8.45	-8.91	-1.83	-0.62	3.25**±0.35	4.74**±0.40	1.51**±0.36
RSG-888 x ICC-4958	IRG	3.78	-11.56	-3.83	2.38	-1.08**±0.39	1.73**±0.45	-0.73**±0.38
	RF	6.51	-6.45	-2.00	1.83	3.30**±0.35	4.90**±0.40	1.21**±0.36
IPC-94-94 x RSG-888	IRG	-7.79	11.57	-12.50	34.61	1.50**±0.63	13.07**±0.84	-0.81±0.70
	RF	6.68	-5.35	-13.17	18.17	-1.27**±0.45	11.19**±0.50	1.72**±0.50
CSJD-901 x RSG-931	IRG	4.89	-7.12	1.50	-4.06	2.91**±0.36	4.10**±0.42	0.49±0.35
	RF	5.57	-4.45	-1.17	1.60	3.84**±0.39	4.81**±0.43	1.28**±0.38
BG-362 x RSG-931	IRG	-4.90	7.12	4.52	-5.95	-1.35**±0.39	2.06**±0.46	-0.50±0.39
	RF	-1.77	8.91	1.50	3.27	3.48**±0.38	4.70**±0.50	1.00**±0.36

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Table 3. Contd.,

Yield and yield components:

Characters/ Crosses	Env.	Components of heterosis (+) [h]	+[l]	[-d]	-[i]	Per cent heterosis Over mid parent	Over better parent	Inbreeding depression (%)
Plant height (cm)								
RSG-895 x RSG-888	IRG	17.29	-30.05	-2.05	-15.18	11.11**±1.20	7.18**±1.40	1.82±1.33
	RF	10.16	-13.92	1.20	-4.36	6.73**±1.12	4.25±1.23	2.97±1.19
RSG-888 x ICC-4958	IRG	-6.39	5.47	4.47	15.13	-0.35±1.44	-7.52*±1.86	-3.19±1.38
	RF	-4.98	17.36	-1.13	6.64	7.75**±0.89	5.40**±1.01	3.38±1.01
IPC-94-94 x RSG-888	IRG	-5.69	3.95	5.57	16.86	0.07±1.17	-10.26**±1.32	-3.85±1.24
	RF	13.30	-18.00	4.90	0.03	7.56**±0.96	-2.66±1.10	4.28±1.10
CSJD-901 x RSG-931	IRG	15.22	-22.64	2.60	-3.75	12.02**±1.00	6.70**±1.07	3.34±1.31
	RF	-2.54	9.80	-0.93	5.28	9.68**±1.17	7.57*±1.64	2.26±1.00
BG-362 x RSG-931	IRG	-5.44	17.87	-2.05	6.32	8.71**±1.14	4.95*±1.30	2.81±1.20
	RF	10.67	-20.99	-5.57	-19.44	4.48*±1.01	-5.47**±1.07	0.16±1.10
Fruiting branches per plant								
RSG-895 x RSG-888	IRG	8.19	-13.79	1.25	-1.18	32.63**±0.73	21.63**±0.83	3.55±0.77
	RF	-4.23	10.27	1.72	8.88	11.57*±0.5	-4.09±0.59	3.84±0.50
RSG-888 x ICC-4958	IRG	-4.32	13.28	-1.53	5.29	29.20**±0.78	16.31*±1.04	6.51±0.73
	RF	-4.80	13.62	1.00	8.73	14.84*±0.77	6.70±0.98	6.69±0.75
IPC-94-94 x RSG-888	IRG	12.93	-18.85	2.07	-4.16	33.31**±0.89	16.03*±0.98	9.44±0.97
	RF	-5.05	12.29	1.45	10.60	23.00**±0.93	9.25±0.95	3.88±0.92
CSJD-901 x RSG-931	IRG	10.08	-11.35	1.97	-1.58	32.48**±0.85	16.24*±1.11	11.82*±0.87
	RF	6.06	-13.04	0.77	-2.32	17.31**±0.63	10.62±0.75	-1.54±0.73
BG-36 x RSG-931	IRG	-4.60	13.78	1.20	10.96	27.36**±0.79	17.62**±0.94	6.21±0.87
	RF	-4.38	13.68	-0.97	4.71	15.80**±0.80	8.50±1.09	7.41±0.90
Pods per plant								
RSG-895 x RSG-888	IRG	50.08	-88.48	7.15	-19.56	32.80**±2.72	16.02**±3.19	4.45±3.08
	RF	13.81	-34.03	2.30	4.65	39.41**±1.65	30.85**±1.86	-3.26±2.14
RSG-888 x ICC-4958	IRG	-15.63	39.87	-3.68	18.45	18.42**±1.84	11.02**±2.02	3.29±2.19
	RF	-17.49	40.91	4.99	41.28	31.84**±2.05	18.26**±2.32	2.59±2.66

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Table 3. Contd.,

Characters/ Crosses	Env.	Components of heterosis (+)				Per cent heterosis		Inbreeding depression (%)
		[h]	+[l]	[-d]	-[i]	Over mid parent	Over better parent	
Pods per plant								
IPC-94-94 x RSG-888	IRG	-12.05	37.55	4.97	33.18	21.39**±1.77	10.87**±2.19	5.29±2.34
	RF	-7.47	37.33	-3.20	15.14	33.08**±1.63	23.77**±1.73	9.89**±2.03
CSJD-901 x RSG-931	IRG	30.06	-42.00	2.53	-13.76	20.55**±2.05	15.21**±2.32	6.87±2.64
	RF	18.09	-70.05	3.17	-2.65	23.88**±2.13	14.37*±2.58	-17.94**±2.72
BG-362 x RSG-931	IRG	-14.04	40.96	3.47	31.40	19.19**±2.02	12.05**±2.30	4.97±2.70
	RF	-19.23	59.07	-4.04	22.07	23.83**±2.63	13.80*±2.97	9.09±3.76
Seeds per pod								
RSG-895 x RSG-888	Pooled	0.58	-1.12	-0.07	-0.71	0.44±0.07	-3.35±0.08	0.58±0.07
RSG-888 x ICC-4958	Pooled	0.51	-1.00	-0.19	-0.88	1.00±0.06	-10.36*±0.07	0.33±0.07
IPC-94-94 x RSG-888	IRG	-0.49	1.39	0.05	0.74	9.26±0.11	5.99±0.13	5.65±0.12
	RF	-0.41	0.43	0.12	0.59	-3.73±0.08	-10.40±0.09	-6.45±0.09
CSJD-901 x RSG-931	IRG	0.48	-1.28	-0.15	-0.89	-5.96±0.09	-13.20**±0.09	-4.68±0.10
	RF	0.48	-1.01	-0.03	-0.52	0.36±0.08	-1.09±0.11	-0.71±0.07
BG-362 x RSG-931	Pooled	0.35	-0.80	-0.07	-0.58	-5.43±0.07	-8.88±0.08	-1.43±0.07
Biological yield per plant (g)								
RSG-895 x RSG-888	IRG	19.11	-29.01	2.41	-8.21	16.29**±1.58	9.24*±1.72	5.30±1.74
	RF	15.23	-23.41	-2.32	-14.88	15.38**±1.54	7.68±1.67	4.70±1.66
RSG-888 x ICC-4958	IRG	21.76	-34.56	2.79	-7.82	19.81**±2.01	12.38*±2.23	4.43±2.05
	RF	-7.07	23.41	2.31	20.91	28.53**±1.77	19.98**±2.19	5.58±1.75
IPC-94-94 x RSG-888	IRG	19.12	-32.49	2.05	-7.67	19.72**±1.46	13.51**±1.76	3.22±1.52
	RF	-3.59	19.55	-2.02	6.05	20.00**±1.73	12.98*±1.77	7.94±1.77
CSJD-901 x RSG-931	IRG	-5.79	28.67	1.88	15.55	16.44**±1.42	10.71**±1.45	10.08*±1.71
	RF	16.89	-45.89	2.73	-10.76	2.11±1.48	-5.96±1.72	-9.33±1.61
BG-362 x RSG-931	IRG	-9.20	13.60	2.19	20.01	17.51**±1.64	10.92*±1.92	-2.77±1.85
	RF	-10.61	31.81	-2.49	10.69	14.09±1.90	6.70*±2.19	6.48±2.24

Table 3. Contd.,

Characters/ Crosses	Env.	Components of heterosis (+)				Per cent heterosis		Inbreeding depression (%)
		[h]	+[l]	[-d]	-[i]	Over mid parent	Over better parent	
Seed yield per plant (g)								
RSG-895 x RSG-888	IRG	-3.79	13.63	1.64	11.56	28.57**±0.69	16.36**±0.78	7.50±0.85
	RF	10.82	-14.64	1.05	-4.67	32.93**±0.83	22.47**±0.94	10.70*±0.83
RSG-888 x ICC-4958	IRG	-3.39	13.63	-1.14	6.85	34.25**±0.78	25.71**±1.06	7.62±0.87
	RF	-5.00	16.80	1.60	14.82	46.39**±1.20	31.63**±1.13	8.14±1.08
IPC-94-94 x RSG-888	IRG	9.04	-13.44	1.28	-2.95	21.16**±0.71	12.57*±0.89	5.73±0.70
	RF	-4.75	17.49	-1.93	5.07	28.88**±1.06	13.74*±1.08	10.74±1.06
CSJD-901 x RSG-931	IRG	5.32	3.00	1.11	0.36	23.05**±0.71	14.62**±0.81	18.42**±0.89
	RF	7.61	-17.09	0.96	-3.90	14.95*±0.84	6.42±1.00	-3.42±0.93
BG-362 x RSG-931	IRG	-4.46	12.70	0.92	11.28	31.31**±0.75	24.18**±0.88	4.53±0.88
	RF	-5.09	16.27	-1.45	7.75	39.09**±0.94	26.23**±1.08	7.70±1.14
Harvest index (%)								
RSG-895 x RSG-888	IRG	-12.54	33.82	2.82	24.97	16.22**±1.64	8.88*±1.84	4.50±2.31
	RF	17.91	-24.67	3.61	-2.49	21.61**±1.70	11.05*±1.96	6.05±1.85
RSG-888 x ICC-4958	IRG	-11.47	28.52	-3.17	12.26	16.91**±1.34	8.74**±1.47	2.84±1.92
	RF	-6.04	22.56	2.50	19.84	20.04**±1.48	13.59**±2.07	4.97±1.45
IPC-94-94 x RSG-888	IRG	16.21	-30.03	1.39	-8.49	11.55**±1.29	8.02*±1.37	1.26±1.61
	RF	-7.39	25.63	-3.18	8.54	16.89**±1.36	9.08*±1.84	5.22*±1.04
CSJD-901 x RSG-931	IRG	10.73	-15.15	0.90	-4.37	11.05**±1.43	8.68*±1.72	3.45±1.21
	RF	-5.25	19.65	-1.61	5.35	8.51**±1.06	4.21±1.09	5.41*±1.03
BG-362 x RSG-931	IRG	-3.78	17.21	1.65	13.89	16.38**±1.66	11.96**±1.80	4.98±1.67
	RF	-5.47	18.29	-3.03	8.92	23.07**±1.26	14.65**±1.48	3.63±1.26
100 seed weight (g)								
RSG-895 x RSG-888	IRG	-3.07	6.93	-0.79	2.04	3.30±0.59	-1.38±0.72	1.16±0.67
	RF	-2.73	8.27	-0.26	3.49	7.99±0.79	6.27±0.79	4.05±0.80
RSG-888 x ICC-4958	Pooled	-2.27	6.52	6.09	17.78	15.21**±0.44	-9.89**±0.58	1.97±0.47
IPC-94-94 x RSG-888	Pooled	-0.02	2.16	-4.35	-5.97	13.36**±0.56	-6.70*±0.64	2.31±0.60

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Table 3. Contd.,

Characters/ Crosses	Env.	Components of heterosis (+)				Per cent heterosis		Inbreeding depression (%)
		[h]	+[l]	[-d]	-[i]	Over mid parent	Over better parent	
100 seed weight (g)								
CSJD-901 x RSG-931	IRG	-1.52	4.49	-0.69	1.54	8.70**±0.39	4.24±0.50	2.07±0.46
	RF	-2.40	5.60	0.80	5.50	9.85±0.76	4.32±0.85	1.20±0.68
BG-362 x RSG-931	Pooled	0.95	0.21	-3.78	-3.65	24.93**±0.46	4.67±0.58	2.17±0.41
Protein content (%)								
RSG-895 x RSG-888	Pooled	1.08	-1.19	-0.71	-2.53	-0.17±0.17	-3.97**±0.20	1.37±0.17
RSG-888 x ICC-4958	Pooled	0.28	2.44	0.71	2.38	6.88*±0.17	2.82*±0.20	3.90**±0.17
IPC-94-94 x RSG-888	IRG	2.21	-3.17	-1.57	-5.84	-2.65**±0.18	-10.03**±0.20	1.67±0.17
	RF	-0.16	1.44	-1.50	-3.37	-2.76**±0.18	-9.81**±0.21	1.50±0.18
CSJD-901 x RSG-931	IRG	-1.01	3.01	-1.25	-1.80	-1.65±0.17	-7.80**±0.20	1.36±0.20
	RF	-0.65	0.61	-0.32	-1.06	-5.49**±0.17	-7.01**±0.19	-0.92±0.17
BG-362 x RSG-931	IRG	1.41	-1.41	-0.97	-3.09	1.39±0.17	-3.61**±0.20	1.84*±0.17
	RF	0.80	-1.92	-0.20	-1.33	-0.65±0.17	-1.69±0.19	-0.42±0.17

*, ** Significant at 5 per cent and 1 per cent level, respectively