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

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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 days to 50% flowering, days to maturity, 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 in chickpea (*Cicer arietinum* L.) through generation mean analysis under irrigated and rainfed conditions. Five generations (P1, P2, F1, F2 and F3) 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 heterosis over mid parent was observed for all the characters under both the conditions except for seeds per pod. Similarly, significant heterobeltiosis was also 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,* Irrigated, Rainfed

**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 Durga *et al.* (2003), Kumar *et al.* (2004), Dhiman *et al.* (2006) and Meena *et al.* (2006).

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 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.,* P1, P2, F1, F2 and F3of 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, India. The average precipitation was 241.6 mm and average temperature was 32.260C. 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, F1s in one row and F2s and F3s were sown in four rows. Among the eleven studied characters 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 P1, P2 and F1 and on 20 randomly selected plants from each of the F2 and F3 generations. The observations for days to 50% flowering and days to maturity were recorded on the plot basis.

**Statistical analysis**

***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:

 ‾F1 – 

 Per cent heterosis over mid parent = ----------- x 100

 

Where, ‾F1 = Mean value of the F1 generation

 = Mean value of the two parental mean values

 ‾F1 – 

Per cent heterosis over better parent = ----------- x 100

 

Where, ‾F1 = Mean value of the F1 generation

 = Mean value of the better parent

 ‾F1 –‾F2

Per cent inbreeding depression = ----------- x 100

 ‾F1

Where, ‾F1= Mean value of the F1 generation

 ‾F2= Mean value of the F2 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 (+) = ‾F1 –‾P1= ([h] + [l]) – ([d] + [i])

 and for negative heterosis,

 Heterosis (–) = ‾F1 –‾P2= ([h] + [l]) –([–d] + [i])

 Where, P1 corresponds to the parent with the greater mean value and P2 to the parent with the smaller mean value, but for the present purpose, either P1 or P2 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).

**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

**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 |
| 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

***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 character wise as under:

***Days to 50% flowering*:**Early flowering is desirable to achieve higher yield in rainfed condition (Calcagno and Gallo, 1993 and Singh, 1997). Significant values of mid parent and better parent heterosis for this trait were found in most of the crosses under both the conditions (Table 3). The desirable significant and negative heterobeltiosis 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. Inbreeding depression was significant in all the crosses except RSG-888 x ICC-4958, IPC-94-94 x RSG-888 and CSJD-901 x RSG-931 under irrigated condition. Inbreeding depression for the F1 to the F2 ranged from -1.06 to 1.76% in irrigated and from -1.78 to 4.79% in rainfed condition. Significant and positive inbreeding depression was observed in RSG-895 x RSG-888 under irrigated and in RSG-888 x ICC-4958 and IPC-94-94 x RSG-888 under rainfed condition, indicated that flowering in F2 occurred earlier than F1.  Significant and negative inbreeding depression was observed in RSG-895 x RSG-888 and CSJD-901 x RSG-931 under rainfed and in BG-362 x RSG-931 under both the conditions, indicated that F2 was comparatively late in flowering than F1. This study is in accordance with the work of Salimath and Bahl (1985) and Parameshwarappa *et al.* (2012) who have also observed high heterotic effect with significant negative better parent heterosis for earliness. Moreover, Deshmukh and Bhapkar (1982) reported that most of the F2’s were significantly late in blooming than the corresponding F1 hybrids. Evaluation of components of heterosis revealed that (l) followed by (h) and (i) under irrigated and (l) followed (i) under rainfed condition contributed more towards better parent heterosis in most of the crosses, indicate the role of non-additive gene action in control of this character. The opposite signs of (h) and (l) components indicating duplicate type of epistasis.

***Days to maturity*:** Chickpea is usually grown under rainfed conditions. Therefore, early maturity is desired. Under both the conditions, all the five crosses exhibited significant mid parent and better parent heterosis (Table 3). Better parent heterosis was significant and positive in all the crosses, indicated inferiority (late maturity) of F1 to the better parent. Inbreeding depression ranged from -0.81 to 0.49% under irrigated and from 1.00 to 1.72% under rainfed condition for this trait. It was found non-significant in all the crosses under irrigated condition except RSG-888 x ICC-4958, which exhibiting significant and negative

**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 xRSG-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 xICC-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 xRSG-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 xRSG-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 xRSG-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 xRSG-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 xICC-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 xRSG-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 xRSG-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 xRSG-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 |
| **Yield and yield components:** |
| Characters/Crosses | Env. | Components of heterosis (+) | Per cent heterosis | Inbreeding depression(%) |
| [h] | +[l] | [-d] | -[i] | Over mid parent | Over better parent |
| **Plant height (cm)** |
| RSG-895 xRSG-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 xICC-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 xRSG-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 xRSG-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 xRSG-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 xRSG-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 xICC-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 xRSG-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 xRSG-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-362 xRSG-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 xRSG-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 xICC-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 |
| IPC-94-94 xRSG-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 xRSG-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 xRSG-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 xRSG-888 | Pooled | 0.58 | -1.12 | -0.07 | -0.71 | 0.44±0.07 | -3.35±0.08 | 0.58±0.07 |
| RSG-888 xICC-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 xRSG-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 xRSG-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 xRSG-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 xRSG-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 xICC-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 xRSG-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 xRSG-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 xRSG-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 |
| **Seed yield per plant (g)** |
| RSG-895 xRSG-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 xICC-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 xRSG-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 xRSG-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 xRSG-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 xRSG-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 xICC-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 xRSG-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 xRSG-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 xRSG-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 xRSG-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 xICC-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 xRSG-888 | Pooled | -0.02 | 2.16 | -4.35 | -5.97 | 13.36\*\*±0.56 | -6.70\*±0.64 | 2.31±0.60 |
| CSJD-901 xRSG-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 xRSG-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 xRSG-888 | Pooled | 1.08 | -1.19 | -0.71 | -2.53 | -0.17±0.17 | -3.97\*\*±0.20 | 1.37±0.17 |
| RSG-888 xICC-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 xRSG-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 xRSG-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 xRSG-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

inbreeding depression. Under rainfed condition all the five crosses exhibited significant and positive inbreeding depression, indicated that F2 was early in maturity as compared to F1, which is desirable for this trait. These results are in line with findings of Deshmukh and Bhapkar (1982). Study of components of heterosis revealed that dominance x dominance (l) with duplicate epistasis in most of the crosses showed consistency over environments and therefore, selection for early maturity in this population might be difficult.

***Plant height (cm)*:** Plant height is important growth parameter from productivity point of view. Heterobeltiosis was found significant in all the crosses except in RSG-895 x RSG-888 and IPC-94-94 x RSG-888 under rainfed condition ranging from -10.26% to 7.18% under irrigated and from -5.47% to 7.57% under rainfed condition. The highest desirable significant positive heterobeltiosis 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 CSJD-901 x RSG-931 followed by RSG-888 x ICC-4958 and RSG-895 x RSG-888 under rainfed. Inbreeding depression was found non-significant in all the five crosses under both the conditions, indicated non-significant reduction in F2 as compared to F1. Least inbreeding depression of 1.82% was observed for RSG-895 x RSG-888 under irrigated and of 0.16% for BG-362 x RSG-931 under rainfed. The negative values of inbreeding depression for RSG-888 x ICC-4958 and IPC-94-94 x RSG-888 irrigated condition indicated increase plant height of these crosses in F2 population than their respective F1hybrids. These results are in agreement with the findings of Pandey and Tiwari (1989) and Bhaduoria and Chaturvedi (2003). Deshmukh and Bhapkar (1982) have noted non significant inbreeding depression for plant height in their all studied crosses. Components of heterosis revealed that (l) followed by (h) and (i) under irrigated and (l) followed (i) and (h) under rainfed condition contributed more towards the better parent heterosis. This is in agreement with Girase and Deshmukh (2000). The opposite signs of (h) and (l) components, indicating duplicate type of epistasis.

***Fruiting branches per plant*:** Fruiting branches per plant is another growth parameter expected contributes to productivity. All the five crosses exhibited significant heterobeltiosis under irrigated, whereas under rainfed it was non-significant. Absence of heterobeltiosis under rainfed condition might be due to internal cancellation of heterosis components. 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. Inbreeding depression was found non-significant in all the five crosses except in CSJD-901 x RSG-931 under irrigated, indicating non-significant reduction in F2 as compared to F1. The cross CSJD-901 x RSG-931exhibited significant heterobeltiosis with significant inbreeding depression under irrigated condition. Further, RSG-895 x RSG-888, BG-362 x RSG-931, RSG-888 x ICC-4958 and IPC-94-94 x RSG-888 exhibited significant heterobeltiosis with non-significant inbreeding depression *i.e*. inbreeding depression in these crosses was comparatively low, which may be attributed to epistatic gene action. Similar results were also reported by Pandey and Tiwari (1989) and Sharif *et al*. (2001). Components of heterosis study showed that (l) followed by (h) and (i) under irrigated and (l) followed (i) and (h) under rainfed condition contributed more towards the better parent heterosis. This is in agreement with Patil *et al.* (1987) who have also found the involvement of epistatic gene in control of this trait. The opposite signs of (h) and (l) components, indicating duplicate type epistasis in all the crosses under both the conditions.

***Pods per plant*:** Higher value of pods per plant has positive effect on seed yield; hence, positive heterosis for this trait is desirable. As for as heterobeltiosis was concerned all the crosses exhibited significant and positive heterobeltiosis under both the conditions ranging from 10.87% to 16.02% under irrigated and from 13.80% to 30.85% under rainfed condition. Inbreeding depression for the F1 to the F2 ranged from 3.29 to 6.87% under irrigated and from -17.94 to 9.89 % under rainfed condition and found non-significant in all the crosses except IPC-94-94 x RSG-888 and CSJD-901x RSG-931 under rainfed condition. The negative value of inbreeding depression was noted in CSJD-901 x RSG-931 (-17.94%), indicated increase in number of pods per plant in F2 as compared to F1 and can be attributed to epistatic gene action. This is in accordance with the findings of Tewari and Pandey (1987). The significant inbreeding depression with significant heterosis suggests the importance of non-additive gene in chickpea (Deshmukh and Bhapkar, 1982). The present study is also supported by the work of Bhaduoria and Chaturvedi (2003) and Farshadfar *et al*. (2008). The highest heterosis over better parent along with non-significant inbreeding depression 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. Components of heterosis revealed that (l) followed by (i) and (h) under irrigated and (l) followed by (h) and (i) under rainfed contributed more towards the better parent heterosis in most of the crosses, indicated importance of epistatic gene action in controlling of this character. Further, the opposite signs of (h) and (l) components, indicating duplicate type epistasis.

***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. This is well in agreement with the findings of Tewari and Pandey (1987). Inbreeding depression for this character was also found non-significant in all the crosses under both the conditions as well as in pooled analysis over environments. Components of heterosis revealed that (l) followed by (i) and (h) contributed more towards the better parent heterosis in most of the crosses, indicated importance of epistatic gene action in controlling of this character. Pandey and Tiwari (1989) have also revealed role of dominance x dominance (l) gene effect in controlling of this character.

***Biological yield per plant (g)*:** Biological yield considered to be an important trait for enhancing chickpea productivity under a drought prone rainfed short duration environment. All the crosses exhibited significant heterobeltiosis 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. Hegde *et al.* (2007) also revealed positive better parent heterosis in large number of crosses with average better parent heterosis (12.65%) for this tarit. 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. Inbreeding depression was found non-significant in all the crosses under both the conditions except CSJD-901 x RSG-931 under irrigated condition. Similar results were also reported by Deshmukh and Bhapkar (1982) for this trait in chickpea. The higher positive heterobeltiosis with non-significant inbreeding depression was observed in RSG-888 x ICC-4958 and IPC-94-94 x RSG-888 under both the conditions. Components of heterosis revealed that (l) followed by (h) and (i) contributed more towards the better parent heterosis. Further, the opposite signs of (h) and (l) components, indicating duplicate type epistasis.

***Seed yield per plant (g)*:** Seed yield per plant is the ultimate and most important trait. In the present investigation, the degree of heterosis for seed yield varied considerably. The estimates of mid parent heterosis ranged from 21.16% to 34.25% under irrigated and from 14.95% to 46.39% under rainfed condition. Heterobeltiosis estimates ranged from 12.57% to 25.71% under irrigated and from 6.42% to 31.63% under rainfed condition. Both mid parent heterosis and heterobeltiosis were found significant positive in all the crosses under both the conditions except for heterobeltiosis in CSJD-901 x RSG-931 under rainfed, which exhibited non-significant positive heterobeltiosis. Inbreeding depression for this seed yield ranged from 4.53 to 18.43% under irrigated and from -3.42 to 10.745 under rainfed condition. All the crosses except RSG-895 x RSG-888 under rainfed and CSJD-901 x RSG-931 under irrigated condition showed non-significant inbreeding depression. The crosses RSG-895 x RSG-888 under rainfed and CSJD-901 x RSG-931 under irrigated showed significant positive heterobeltiosis with significant inbreeding depression, indicating the importance of non-additive genes. The highest positive heterobeltiosis with low inbreeding depression was observed in RSG-888 x ICC-4958 followed by BG-362 x RSG-931 and RSG-895 x RSG-888 under both the conditions, could be utilized in future breeding programme to get segregates superior to better parent. Similar results with regard to heterosis and inbreeding depression for seed yield in chickpea have also been reported by Deshmukh and Bhapkar (1982), Bakhsh *et al*. (2007) and Farshadfar *et al.* (2008). Evaluation of components of heterosis revealed that (l) followed by (i) and (h) under irrigated and (l) followed by (h) and (i) under rainfed contributed more towards the better parent heterosis in most of the crosses, indicated importance of epistatic gene action in controlling of this character. Further, the opposite signs of (h) and (l) components, indicating duplicate type epistasis in all the crosses under both the conditions. Pandey and Tiwari (1989) have also reported the importance of epistatic gene action with predominant of duplicate epistasis in controlling of this character.

***Harvest index (%)*:** For this traitheterobeltiosis was found significant and positive in all the crosses except for CSJD-901 x RSG-931 under rainfed condition, which is desirable. These results are similar with the findings of Deshmukh and Bhapkar (1982) and Hedge *et al.* (2007), who have also observed heterotic effects for this trait in chickpea crosses. Inbreeding depression was found non-significant in all the crosses except for IPC-94-94 x RSG-888 and CSJD-901 x RSG-931 under rainfed condition. The higher magnitude of positive heterobeltiosis along with low inbreeding depression 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. Evaluation of components of heterosis revealed that (l) followed by (h) and (i) contributed more towards the better parent heterosis. The opposite signs of (h) and (l) components, indicating duplicate type epistasis.

***100- Seed weight (g)*:** Seed weight is one of the component characters directly influencing the seed yield. All the crosses exhibited non significant heterobeltiosis except RSG-888 x ICC-4958 and IPC-94-94 x RSG-888 under pooled, having significant and negative hetrobeltiosis. Maximum hetrobeltiosis 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. Inbreeding depression was observed non-significant in all the crosses and it ranged from 1.16 to 4.05% across both the conditions including pooled analysis over environments. No negative value of inbreeding depression was observed showing the superiority in weight of seeds of all F1 hybrids compared to their F2 combinations. A range of significant negative heterotic effect and non-significant inbreeding depression for this trait have been also reported by Tewari and Pandey (1987) and Farshadfar *et al*. (2008). For this trait (i) followed by (d) and (l) contributed more towards the better parent heterosis in most of the crosses, indicating role of additive gene effect with substantial contribution of non-allelic interaction in controlling of this character. Further, the opposite signs of (h) and (l) components, indicating duplicate type epistasis.

***Protein content (%)*:** For this trait all the crosses 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 F1 over better parent. This is in accordance with Salimath *et al*. (1988) who have also observed significant and positive heterosis over mid parent and over better parent for protein content in different chickpea crosses. 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. Inbreeding depression was found non-significant in all the crosses except in RSG-888 x ICC-4958 under pooled and in BG-362 x RSG-931 under irrigated, which had significant and positive inbreeding depression. The maximum heterobeltiosis 2.82% and-3.61% with maximum inbreeding depression 3.90% and 1.84% was recorded in the crosses RSG-888 x ICC-4958 and BG-362 x RSG-931 respectively, suggests the importance of non-additive gene action in controlling of this trait. Negative value of inbreeding depression was observed in CSJD-901 x RSG-931 and BG-362 x RSG-931 under rainfed, indicating superiority of F2 over F1. Evaluation of components of heterosis revealed that (l) followed by (i) and (h) contributed more towards the better parent heterosis in most of the crosses, indicating role of epistatic gene action in control of this trait. This is in agreement with Patil *et al.* (1987). The opposite signs of (h) and (l) components, indicating duplicate type epistasis in all the crosses

**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 and varied from -13.20 to 32.49 % in different characters across both the conditions. 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. 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. 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 F1 to F2 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. 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.

**ACKNOWLEDGEMENT**

The authors are greatly acknowledging the Officer Incharge, Agricultural Research Sub Station, Hanumangarh (SKRAU, Bikaner) for providing facilities & financial assistance to conduct this study.

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