Validation of Biometrical Principles for Genetic Enhancement of Chickpea (*Cicer arietinum* L.)

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In the present investigation, the degree of heterosis for seed yield varied considerably. Parent such as ICC 7315, ICC 13124, ICC 15697 and ICC 6877 were good general combiners and could be of use in breeding for improved productivity in chickpea. The top three crosses *viz*., ICC 11944 x ICC 13124 (16.95), ICC 9137 x ICC 13124 (16.63) and ICC 2507 x ICC 2072 (13.10) exhibited highly significant positive (specific combining ability) effect with high *per se* performance for seed yield/ plant. This indicated that the heterotic performance of these hybrids were mainly due to additive gene action. Further, these crosses are having parents with good x good general combiners. The high Holics effects in these crosses was mainly through additive x additive type of interaction causing heterosis. Hence, direct selection for higher values of seed yield can be made in the advanced generations of the heterotic crosses involving such parents, as a large portion of the total variation is a result of additive gene effects. Considering F_2 performance of these hybrids, three of the six highly heterotic F_1's in high diversity group and high mean (ICC 6877 x ICC 7315, ICC 6877 x ICC 2072 and ICC 6877 x ICC 10755) followed by high coefficient of variation and range. The mean F_2 values of these hybrids range from 25.6 to 37g, from 32.2 to 39.0% coefficient of variation and the higher value of range from 41.2 to 43 g/ plant. While in case of medium diversity group, three hybrids (ICC 15697 x ICC 7315, ICC 3776 x ICC 7315 and ICC 3776 x ICC 10755) showed relatively high mean values and higher coefficient of variation with reasonably high range of expression but these figures were lower than those of the hybrids in high diversity group. These facts indicate that parents with high diversity have a better chance of showing high heterosis and better performance.

Key Words: Chickpea, Combining ability, Heterosis, Heterotic crosses

Introduction

Chickpea (*Cicer arietinum* L.) is the world's third largest legume crop with a total annual production of 8.8 million tonnes. The cultivated area is over 10 million hectare. Major chickpea production worldwide is predominantly under rainfed conditions, grown on residual, progressively declining soil moisture. Chickpea is a self pollinated crop and it needs intensive studies to investigate and exploit the existing variability. Realizing the importance of diversity, the breeders are now looking for more diverse forms from various sources to augment the yield potential. Selection of parent is very crucial step in breeding programmes for generating potential breeding populations with high variability. This will ensure success of the breeding programme by employing proper and meticulous selection scheme in such population. Selection of parent can be done in different ways. It is suggested that parental diversity is important to generate productive breeding population. It is often suggested that the extent of diversity between the parents involved in hybridization programme assume greater importance in developing potential breeding populations. Though it was suggested that the extent of diversity should be high for realizing high heterosis and potential cross combination, Arunachalam *et al*., (1984) based on their experimentation in groundnut reported that the level of diversity between parents should be medium. To verify such concept minicore will provide an excellent opportunity to identify parents with varying levels of diversity. Similarly concept of combining ability, though highly used, in practical crop improvement programmes of cross pollinated species, its use in self pollinated crops is very minimal. It is also known that combining ability of the parent is important. But unfortunately information on either diversity or combining ability are hardly used for planning and developing breeding population in self pollinated crops. Although these quantitative genetic principles are routinely used in cross pollinated crops such as maize. It is important that such quantitative genetic principles should also be used in self pollinated

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crops, not only to make the exercise more scientific but also to increase the probability of success of breeding programmes. It is often reported that high diversity is pre requisite in generating highly heteriotic and potential population. But very often the reports are based on the studies conducted in limited number of accessions, consequently represent the traunkated information on diversity. Therefore, if at all any generalization is to be made to provide a guideline then it is essential that the hypothesis relating to desired level of diversity has to be made on the basis of the studies on the entire spectrum of variability of the species concerned. It is however a very difficult task to conduct the studies on thousands and lakhs of germplasm accessions. Hence, the present study aims at generating information on the usefulness of biometrical principles for genetic enhancement of chickpea.

Materials and Methods

The experimental material for this study was constituted by a set of lines and testers selected based on diversity analysis. Twelve genotypes selected as lines which are having high *per se* and to some extent higher seed weight belong to high, medium and low diversity groups from different inter and intra clusters and four genotypes selected as testers having high *per se* productivity. Each of these lines were crossed to four testers used as male in a line x tester mating design to produce 48 F_1 hybrids. The experimental material consisting of 48 F_1 hybrids and 17 (12 lines+ 4 testers + A1 check) parents was grown in a Randomized Block design with two replications at the Genetics and Plant Breeding garden, College of Agriculture, Dharwad during *rabi* 2007-08. Each entry was represented by a single two meter long row with a spacing of 60 cm between rows and 10 cm between plants within a row. Both parents and F_1s were randomized completely among themselves but grown in a continuous block. The experiments were laid out in medium black soils. The soils are rich in available nitrogen, potash and poor in available phosphorous. The soil pH is 7.6 and contains high amount of clay, silt and sand with a bulk density of 1.33 g/cc. The field experiments were carried out in a Randomized Complete Block Design with two replications.The following observations were recorded on each of the five plants selected at random per treatment or genotype in each replication and averaged separately in all the experiments. 1. Days to 50% flowering (DFF), 2. Plant height (PLHT) (cms), 3. Primary branches/ plant (PB), 4. Secondary branches/plant (SB), 5. Tertiary branches/plant (TB), 6. Pods/plant (PPP), 7. 100-seed weight (SDWT) (g), 8. Yield/plant (YPP) (g).

The magnitude of heterosis was estimated in relation to mid parental, better parental and standard check values. They were thus, calculated as percentage increase or decrease of F_1,s over the mid-parent (MP), better parent (BP) and standard check (SC) using the methods of Turner (1953) and Hayes *et al.* (1955).The variation among the hybrids was further partitioned into genetic components attributed to general combining ability (gca) and specific combining ability (sca) following the method suggested by Kempthorne (1957).

Parents and crosses were scored for gca and sca effects, respectively. A parent showing positive or negative (significant or non significant) gca effect for a character was multiplied with their genotypic correlation value and put the value as positive or negative to that character. A total of the values obtained by a parent for all the characters under study was obtained by adding these values. Mean of the total values of the parents was worked out and used as a norm for classifying parents into high and low combiners. Similar procedure was followed to score and categorize the crosses with respect to their sca effects. The F_1s so generated were evaluated and the gca, sca and heterosis were all computed. The criteria of advancing the crosses showing yield performance of above mean $\pm$ 2 SD. Totally 16 crosses were evaluated during *rabi* 2007-08. The observation on 50 plants in each F_2's were studied. The performance of F_2 populations giving mean, range and coefficient of variation were computed.

Results and Discussion

With 203 accessions all possible (203×202/2 D^2 values) pair wise D^2 values were obtained. Taking the minimum D^2 value and maximum D^2 value, the mean D^2 value was computed. This provided the base for classifying the F_1s either as highly diverse or as low depending upon the D^2 value being more than or less than the mean, respectively. Further taking productivity of popular check cultivar A-1 and it's seed size as the criteria parents were chosen in such a way that pair wise they would represent high, medium and low diversity. They were then crossed following L×T design so that their combining ability status could also been estimated. In the present investigation, the degree of heterosis for seed yield varied considerably. Parent such as ICC 7315, ICC 13124, ICC 15697 and ICC 6877 were good general combiners and could be of use in breeding for improved productivity in chickpea. The superiority of the hybrids in crosses was estimated over mid parent (MP), better parent (BP) and standard check (SC) for all the eight characters studied. The range of heterosis over mid parent, better parent and standard check and top three desirable hybrids in respect of each of the character studied are presented (Table 1-4).

The over all gca status of parents studied across the characters (Table 5).The parent having high gca effects for productivity and productivity related traits was determined. On the basis of this, parents ICC 15697, ICC 5878, ICC 11944, ICC 6877, ICC 3776, ICC 2507, ICC 13124 and ICC 7315 had high gca effects for yield/ plant, number of pods/ plant, seed weight and days to 50 per cent flowering. This suggests that, parent such as ICC 7315, ICC 13124, ICC 15697 and ICC 6877 were good general combiners and could be of use in breeding for improved productivity in chickpea.

Table 1. ***Per se*** **performance and heterosis of top three potential hybrids in respect of eight quantitative characters in chickpea**

Characters	Potential hybrids	Mean	MP (%)	BP (%)	SC (%)
DFF	ICC 6279 × ICC 13124	37.50	-3.23	-3.85	-8.54
	ICC 6877 × ICC 7315	39.50	-25.47	-24.76	-3.66
	ICC 6877 × ICC 10755	39.50	-22.55	-18.56	-3.66
PLHT (cm)	ICC 6877 × ICC 10755	67.30	20.77	2.44	63.15
	ICC 6877 × ICC 13124	67.10	38.55	31.83	62.67
	ICC 9137 × ICC 7315	66.15	20.38	5.08	60.36
PB	ICC 15697 × ICC 7315	9.15	150.68	131.65	200.00
	ICC 1180 × ICC 2072	8.95	167.16	184.13	193.44
	ICC 6877 × ICC 10755	8.80	121.38	120.00	188.52
SB	ICC 1180 × ICC 2072	18.95	67.70	59.24	69.20
	ICC 11944 × ICC 2072	18.90	83.05	76.64	68.75
	ICC 9137 × ICC 13124	18.80	51.00	17.50	67.86
TB	ICC 2969 × ICC 7315	37.10	123.83	112.61	136.31
	ICC 2969 × ICC 2072	30.35	106.81	122.34	93.31
	ICC 15697 × ICC 7315	28.55	78.72	63.61	81.85
PPP	ICC 5878 × ICC 7315	195.40	106.77	117.77	133.37
	ICC 11944 × ICC 13124	187.85	94.61	50.58	124.30
	ICC 11944 × ICC 7315	173.55	119.61	93.37	107.22
SDWT (g)	ICC 15697 × ICC 7315	38.40	29.84	12.78	144.59
	ICC 2507 × ICC 2072	37.00	124.58	127.69	135.67
	ICC 15697 × ICC 2072	36.90	78.48	127.08	135.07
YPP (g)	ICC 6877 × ICC 2072	64.40	136.76	100.62	152.05
	ICC 2507 × ICC 2072	61.00	83.05	90.03	138.75
	ICC 6877 × ICC 7315	60.55	90.86	47.14	136.99

Productivity is the ultimate trait of interest to the breeder. In the present study, the top three crosses *viz.*, ICC 11944xICC 13124 (16.95), ICC 9137xICC 13124 (16.63) and ICC 2507xICC 2072 (13.10) exhibited highly significant positive sca effect with high *per se* performance for seed yield/ plant. This indicated that the heterotic performance of these hybrids were mainly due to additive gene action. Further these crosses are having parents with good × good general combiners. The high sca effects in these crosses was mainly through additive × additive type of interaction causing heterosis. Hence, direct selection for higher values of seed yield can be made in the advanced generations of the heterotic crosses involving such parents, as a large portion of the total variation is a result of additive gene effects. For this trait, similar results have been reported by Sarode *et al.,* (2000), Jeena and Arora (2000) and Mali *et al.* (2006). The over all sca status of hybrids studied across the characters (Table 6).

Table 7 gives the mean, seed yield, heterosis over mid parent and standard check, combining ability status of parents and hybrids, parental GCA status, SCA status of hybrids and the performance of respective F_2 populations giving mean, range and coefficient of variation. The number of hybrids with high as well as low heterosis occurring in the high, medium and low diversity groups have been listed. It may be seen from the table that there were as many as six highly heterotic crosses under high diversity class while their was none with low heterosis. In medium diversity group there were five hybrids showing high heterosis while two hybrids were with

Table 2. Percent heterosis in respect of seed yield of heterotic hybrids with different parental diversity in chickpea

S. No.	Hybrids	Per se performance			D^2 value	Percent heterosis over		
High diversity groups		Female	Male	F_1		MP	BP	SC
1	ICC 6877 × ICC 2072	57.05	39.88	54.65	695.04	136.76	100.62	152.05
2	ICC 6877 × ICC 7315	57.05	36.38	64.40	695.04	115.16	91.75	113.89
3	ICC 6877 × ICC 10755	57.05	38.17	60.55	695.04	90.86	47.14	136.99
4	ICC 5878 × ICC 7315	45.93	39.88	37.00	868.60	46.25	29.82	44.81
5	ICC 5878 × ICC 13124	45.93	40.60	50.30	868.60	57.68	20.62	96.87
6	ICC 5878 × ICC 10755	45.93	38.17	57.95	868.60	83.24	40.83	126.91
7	ICC 506 × ICC 7315	37.81	39.88	47.30	566.99	72.47	65.96	85.13
8	ICC 506 × ICC 13124	37.81	40.60	43.20	566.99	26.97	3.6	69.08
9	ICC 2507 × ICC 7315	50.28	39.88	47.25	968.70	49.88	65.79	84.93
10	ICC 2507 × ICC 2072	50.28	36.38	61.00	968.70	83.05	90.03	138.75
Medium diversity groups								
1	ICC 3776 × ICC 7315	45.10	39.88	57.10	488.90	99.83	100.35	123.48
2	ICC 3776 × ICC 10755	45.10	38.17	55.85	488.90	60.03	35.72	118.59
3	ICC 15697 × ICC 7315	40.39	39.88	52.90	292.28	110.55	85.61	107.05
4	ICC 15697 × ICC 2072	40.39	36.38	42.55	292.28	58.03	32.55	66.54
5	ICC11944 × ICC 13124	38.85	40.60	57.65	232.80	69.43	38.25	125.64
6	ICC 11944 × ICC 7315	38.85	39.88	39.95	232.80	45.67	40.18	56.36
Low diversity groups								
1	ICC 1431 × ICC 13124	31.94	40.60	35.15	10.62	12.84	-15.71	37.57
2	ICC 1431 × ICC 7315	31.94	39.88	36.30	10.62	47.88	27.37	42.07
3	ICC 1431 × ICC 2072	31.94	36.38	32.25	10.62	22.39	0.47	26.22
4	ICC 2969 × ICC 2072	28.03	36.38	29.80	3.16	3.38	-7.17	16.63

Table 3. Heterosis index of heterotic hybrids in chickpea

S. No.	Hybrids	Heterosis index									
		DFF	PLHT	PB	SB	TB	PPP	SDWT	YPP	Total score	Class
	High diversity groups										
1	ICC 6877 × ICC 2072	0.01	0.006	0.02	0.0004	-0.01	0.14	0.11	1.37	1.65	High
2	ICC 6877 × ICC 7315	0.01	-0.004	0.12	0.007	-0.002	0.15	0.01	1.15	1.44	High
3	ICC 6877 × ICC 10755	0.01	0.03	0.15	0.01	0.17	0.15	0.02	0.91	1.45	High
4	ICC 5878 × ICC 7315	0.006	-0.002	0.15	0.01	0.16	0.35	-0.06	0.46	1.07	High
5	ICC 5878 × ICC 13124	0.003	0.000	0.02	0.002	0.002	0.07	-0.08	0.58	0.60	High
6	ICC 5878 × ICC 10755	-0.005	-0.000	0.15	0.006	0.05	0.02	-0.02	0.83	1.04	High
7	ICC 506 × ICC 7315	-0.002	0.01	0.03	-0.001	0.06	0.17	0.02	0.72	1.07	High
8	ICC 506 × ICC 13124	-0.005	-0.00	0.15	0.006	0.05	0.02	-0.02	0.83	1.04	High
9	ICC 2507 × ICC 7315	0.01	-0.002	0.01	0.003	0.04	0.09	-0.008	0.50	0.64	High
10	ICC 2507 × ICC 2072	0.01	0.02	0.09	0.002	=0.02	0.06	0.31	0.83	1.30	High
	Medium diversity groups										
1	ICC 3776 × ICC 7315	-0.003	0.008	0.180	0.010	0.20	0.17	0.08	1.11	1.75	High
2	ICC 3776 × ICC 10755	-0.010	0.020	0.110	0.008	0.16	0.02	0.19	0.58	1.08	High
3	ICC 15697 × ICC 7315	0.008	0.006	0.020	0.010	0.09	0.13	-0.06	0.99	1.19	High
4	ICC 15697 × ICC 2072	0.010	-0.030	0.020	-0.009	0.14	0.08	-0.04	0.60	0.77	High
5	ICC 11944 × ICC 13124	0.006	0.010	0.004	-0.004	0.06	0.17	-0.09	0.69	0.84	High
6	ICC 11944 × ICC 7315	0.001	0.005	0.000	-0.004	0.00	0.22	-0.06	0.46	0.62	High
	Low diversity groups										
1	ICC 1431 × ICC 13124	0.005	0.020	0.100	-0.001	-0.01	0.10	-0.05	0.13	0.29	Low
2	ICC 1431 × ICC 7315	0.009	0.007	0.140	0.006	0.03	0.14	-0.08	0.48	0.73	High
3	ICC 1431 × ICC 2072	0.004	0.002	0.040	0.003	0.03	0.03	0.04	0.22	0.37	Low
4	ICC 2969 × ICC 2072	0.000	0.006	0.186	0.006	0.27	0.06	0.06	0.034	0.62	High

Table 4. Heterosis index for eight characters in chickpea

S. No.	Hybrids	Heterosis index score									
		DFF	PLHT	PB	SB	TB	PPP	SDWT	YPP	Total score	Class
1	ICC 2969 × ICC 13124	-0.01	0.01	0.02	-0.01	0.16	-0.08	0.08	-0.03	0.14	Low
2	ICC 2969 × ICC 7315	-0.00	0.05	0.05	0.04	0.31	-0.01	0.01	-0.06	0.39	High
3	ICC 2969 × ICC 2072	0.00	0.01	0.19	0.01	0.27	0.06	0.06	0.03	0.62	High
4	ICC 2969 × ICC 10755	-0.00	0.01	0.07	0.00	0.15	0.04	-0.03	-0.27	-0.05	Low
5	ICC 9137 × ICC 13124	-0.00	0.01	0.10	0.01	0.19	0.09	0.02	0.47	0.88	High
6	ICC 9137 × ICC 7315	0.01	0.02	0.05	0.01	0.13	0.02	0.01	-0.03	0.22	Low
7	ICC 9137 × ICC 2072	0.01	-0.01	0.03	0.02	0.12	-0.05	-0.04	-0.14	-0.06	Low
8	ICC 9137 × ICC 10755	0.01	-0.01	0.00	-0.00	0.08	-0.09	0.01	-0.22	-0.23	Low
9	ICC 6279 × ICC 13124	0.00	0.03	0.01	0.00	0.07	-0.07	-0.03	-0.25	-0.24	Low
10	ICC 6279 × ICC 7315	-0.00	0.03	0.03	0.02	0.12	0.03	-0.05	-0.06	0.12	Low
11	ICC 6279 × ICC 2072	0.00	0.00	0.07	0.02	0.26	0.07	0.12	-0.29	0.25	Low
12	ICC 6279 × ICC 10755	0.01	0.02	0.01	0.01	0.17	-0.02	0.02	-0.08	0.13	Low
13	ICC15697 × ICC 13124	0.01	0.01	0.11	0.00	0.01	0.06	-0.05	-0.08	0.07	Low
14	ICC15697 × ICC 7315	-0.00	0.01	0.18	0.01	0.20	0.17	0.08	1.11	1.75	High
15	ICC15697 × ICC 2072	-0.01	0.02	0.11	0.01	0.16	0.02	0.19	0.58	1.08	High
16	ICC15697 × ICC 10755	0.01	-0.01	0.13	0.01	0.09	-0.04	0.06	0.18	0.43	Low
17	ICC 506 × ICC 13124	-0.01	0.01	0.00	-0.01	0.04	0.03	-0.07	0.27	0.26	Low
18	ICC 506 × ICC 7315	-0.00	0.01	0.03	-0.00	0.06	0.17	0.02	0.72	1.01	High
19	ICC 506 × ICC 2072	0.00	-0.02	0.03	0.00	0.13	-0.02	0.01	0.24	0.38	Low
20	ICC 506 × ICC 10755	-0.00	0.00	0.03	0.01	0.08	-0.03	0.05	-0.27	-0.14	Low
21	ICC 5878 × ICC 13124	0.00	0.00	0.02	0.00	0.00	0.07	-0.08	0.58	0.60	High
22	ICC 5878 × ICC 7315	0.01	-0.00	0.15	0.01	0.16	0.35	-0.06	0.46	1.07	High
23	ICC 5878 × ICC 2072	0.01	0.00	0.09	0.01	0.16	0.13	0.01	0.42	0.82	High
24	ICC 5878 × ICC 10755	0.01	-0.00	0.15	0.01	0.05	0.02	-0.02	0.83	1.04	High
25	ICC11944 × ICC 13124	0.01	0.01	0.00	-0.00	0.06	0.17	-0.09	0.69	0.84	High
26	ICC11944 × ICC 7315	0.00	0.01	0.00	-0.00	0.00	0.22	-0.06	0.46	0.62	High
27	ICC11944 × ICC 2072	0.01	-0.00	0.17	0.02	0.16	0.08	0.01	-0.18	0.26	Low
28	ICC11944 × ICC 10755	0.03	-0.00	0.09	0.01	0.08	-0.02	0.08	0.00	0.24	Low
29	ICC 1180 × ICC 13124	0.01	-0.00	0.01	-0.01	0.01	0.00	0.07	-0.00	0.08	Low
30	ICC 1180 × ICC 7315	0.01	0.02	0.14	0.01	0.05	0.00	-0.09	-0.13	0.01	Low
31	ICC 1180 × ICC 2072	0.01	0.01	0.20	0.01	0.21	0.02	-0.01	-0.18	0.27	Low
32	ICC 1180 × ICC 10755	0.01	-0.02	0.16	0.01	0.18	-0.01	0.01	-0.12	0.21	Low
33	ICC 6877 × ICC 13124	0.01	0.05	0.04	-0.00	-0.01	0.04	0.04	0.52	0.69	High
34	ICC 6877 × ICC 7315	0.01	-0.00	0.12	0.01	-0.00	0.15	0.01	1.15	1.44	High
35	ICC 6877 × ICC 2072	0.01	0.01	0.02	0.00	-0.01	0.14	0.11	1.37	1.65	High
36	ICC 6877 × ICC 10755	0.01	0.03	0.15	0.01	0.17	0.15	0.02	0.91	1.45	High
37	ICC 3776 × ICC 13124	0.01	0.01	0.03	0.01	0.05	0.06	-0.05	-0.05	0.06	Low
38	ICC 3776 × ICC 7315	0.01	0.01	0.02	0.01	0.09	0.13	-0.06	0.99	1.19	High
39	ICC 3776 × ICC 2072	0.01	0.02	0.03	0.00	0.05	0.01	-0.02	0.13	0.23	Low
40	ICC 3776 × ICC 10755	0.01	-0.03	0.02	-0.01	0.14	0.08	-0.04	0.60	0.77	High
41	ICC 1431 × ICC 13124	0.01	0.02	0.10	-0.00	-0.01	0.10	-0.05	0.13	0.29	Low
42	ICC 1431 × ICC 7315	0.01	0.01	0.14	0.01	0.03	0.14	-0.08	0.48	0.73	High
43	ICC 1431 × ICC 2072	0.00	0.00	0.04	0.00	0.03	0.03	0.04	0.22	0.37	Low
44	ICC 1431 × ICC 10755	0.01	-0.03	0.03	0.00	0.04	0.02	-0.09	-0.22	-0.24	Low
45	ICC 2507 × ICC 13124	0.01	0.01	-0.03	-0.01	-0.04	-0.06	-0.04	0.16	-0.002	Low
46	ICC 2507 × ICC 7315	0.01	-0.00	0.01	0.00	0.04	0.09	-0.00	0.50	0.64	High
47	ICC 2507 × ICC 2072	0.01	0.02	0.09	0.00	-0.02	0.06	0.31	0.83	1.30	High
48	ICC 2507 × ICC 10755	0.01	-0.01	0.09	-0.00	-0.02	-0.05	-0.03	0.28	0.27	Low
										Mean	0.50

Table 5. Overall gca status of lines and testers evaluated in Line × Tester experiment in chickpea

S. No.	Lines/ Testers	Combining ability effects									
		DFF	PLHT	PB	SB	TB	PPP	SDWT	YPP	Total score	class
Lines											
1	ICC 2969	-0.28	-0.008	-0.03	-0.04	2.23	-4.55	0.08	-10.73	-13.32	Low
2	ICC 9137	-0.08	0.04	-0.11	-0.001	0.32	-6.70	1.16	-5.83	-11.20	Low
3	ICC 6279	0.10	-0.04	0.18	0.03	0.59	-2.68	-0.37	-10.72	-12.91	Low
4	ICC 15697	-0.006	0.04	0.19	0.01	0.24	-2.42	2.24	1.63	1.93	High
5	ICC 506	-0.23	-0.12	-0.15	0.04	-0.18	-1.41	-0.26	-0.95	-3.26	Low
6	ICC 5878	0.12	-0.52	0.11	0.03	0.04	7.98	-1.67	7.12	13.20	High
7	ICC 11944	0.10	-0.34	-0.009	-0.02	-0.57	4.40	-0.49	0.09	3.16	High
8	ICC 1180	-0.07	0.07	0.19	0.03	0.18	-1.96	-0.56	-9.99	-12.07	Low
9	ICC 6877	0.24	0.11	0.07	-0.009	-0.42	8.06	-2.13	18.29	24.21	High
10	ICC 3776	0.01	0.18	-0.19	0.01	-0.53	0.27	-1.34	6.34	4.75	High
11	ICC 1431	-0.11	-0.04	0.12	0.01	-0.72	2.74	-1.50	-6.82	-6.32	Low
12	ICC 2507	0.15	0.66	-0.008	0.002	-1.17	-1.99	-0.35	11.52	1351	High
									Mean	**0.14**	
Testers											
1	ICC 13124	0.11	-0.15	-0.11	-0.03	-0.47	-0.49	0.03	1.85	0.74	High
2	ICC 7315	-0.11	0.33	0.05	0.002	0.23	3.47	-0.09	1.12	5.00	High
3	ICC 2072	-0.08	0.01	-0.005	0.006	-0.13	0.48	-0.64	-2.38	-2.74	Low
4	ICC 10755	0.07	-0.20	0.06	0.02	0.37	-3.46	0.700	-0.57	-3.01	Low
									Mean	**-0.003**	

Table 6. Overall sca status of hybrids evaluated in Line × tester experiment in chickpea

S. No.	Hybrids	Combining ability effects									
		DFF	PLHT	PB	SB	TB	PPP	SDWT	YPP	Total score	Class
1	ICC 2969 × ICC 13124	-0.06	-0.19	-0.11	-0.06	-0.21	-5.81	1.93	2.68	-1.83	Low
2	ICC 2969 × ICC 7315	0.04	-0.22	-0.13	0.02	0.11	-5.83	0.27	-3.84	-9.58	Low
3	ICC 2969 × ICC 2072	0.08	-0.14	0.27	0.03	0.04	5.80	-0.80	4.15	9.43	High
4	ICC 2969 × ICC 10755	-0.05	0.54	-0.04	0.02	-1.20	5.85	-1.39	-2.19	0.74	High
5	ICC 9137 × ICC 13124	-0.11	0.23	0.34	0.12	1.74	10.53	1.24	16.63	30.72	High
6	ICC 9137 × ICC 7315	0.02	1.13	-0.00	0.01	-0.18	-3.31	0.66	-6.69	-8.36	Low
7	ICC 9137 × ICC 2072	0.06	-0.76	-0.11	-0.01	-0.69	-3.88	-2.17	-4.70	-12.26	Low
8	ICC 9137 × ICC 10755	0.02	-0.13	-0.22	-0.13	-0.87	-3.33	0.27	-5.24	-9.63	Low
9	ICC 6279 × ICC 13124	0.22	-0.14	0.07	-0.01	-0.41	-6.17	-0.28	-2.33	-9.05	Low
10	ICC 6279 × ICC 7315	-0.22	0.33	-0.03	0.03	-0.60	-1.87	-0.81	-0.86	-4.03	Low
11	ICC 6279 × ICC 2072	-0.10	-0.78	0.09	0.03	0.91	6.45	0.74	-2.81	4.53	High
12	ICC 6279 × ICC 10755	0.11	0.59	-0.13	-0.05	0.10	1.59	0.23	6.00	8.44	High
13	ICC15697 × ICC 13124	0.26	-0.28	0.05	0.02	-0.86	-5.86	-2.59	-13.18	-22.42	Low
14	ICC15697 × ICC 7315	-0.51	0.02	0.15	-0.01	1.21	7.69	1.13	11.39	21.07	High
15	ICC15697 × ICC 2072	0.13	0.69	-0.16	-0.04	0.18	-0.19	1.30	4.54	6.45	High
16	ICC15697 × ICC 10755	0.12	-0.43	-0.04	0.03	0.53	1.63	0.16	-2.75	-4.01	Low
17	ICC 506 × ICC 13124	0.11	-0.10	0.04	-0.05	-0.08	1.42	-1.41	3.54	3.47	High
18	ICC 506 × ICC 7315	0.02	0.48	-0.02	-0.05	0.33	6.10	1.03	8.37	16.26	High
19	ICC 506 × ICC 2072	0.17	-0.91	-0.02	0.03	-0.41	-5.46	-0.97	0.77	-7.57	Low
20	ICC 506 × ICC 10755	0.07	0.53	-0.00	0.06	0.16	-2.06	1.35	-12.68	-12.57	Low
21	ICC 5878 × ICC 13124	0.05	-0.35	-0.17	0.01	-0.62	-0.60	-0.41	2.53	0.44	High
22	ICC 5878 × ICC 7315	0.06	-0.24	0.13	0.03	-1.20	2.45	-0.01	-10.04	-8.82	Low
23	ICC 5878 × ICC 2072	-0.02	0.03	-0.11	0.03	0.15	2.24	-0.01	-5.09	-2.78	Low
24	ICC 5878 × ICC 10755	-0.09	0.57	0.16	-0.01	0.72	-4.09	0.42	12.61	10.29	High
25	ICC11944 × ICC 13124	-0.02	0.22	-0.11	-0.03	-0.57	-8.62	-1.61	16.95	6.21	High
26	ICC11944 × ICC 7315	0.14	-0.20	-0.27	-0.11	1.24	2.09	0.11	-0.02	2.98	High

Contd……

S. No.	Hybrids	Combining ability effects									
		DFF	PLHT	PB	SB	TB	PPP	SDWT	YPP	Total score	Class
27	ICC11944 × ICC 2072	0.03	-0.06	0.30	0.11	-0.75	-2.77	-0.80	-12.32	-16.26	Low
28	ICC11944 × ICC 10755	-0.16	0.31	0.08	0.03	-0.08	-7.95	2.30	-4.41	-9.88	Low
29	ICC 1180 × ICC 13124	0.08	-0.16	-0.31	-0.07	-0.78	1.82	2.54	3.39	6.51	High
30	ICC 1180 × ICC 7315	-0.03	0.06	0.02	-0.01	-1.13	-5.07	-1.54	-4.78	-12.48	Low
31	ICC 1180 × ICC 2072	-0.11	0.22	0.17	0.06	0.90	1.04	-1.20	-1.23	0.15	High
32	ICC 1180 × ICC 10755	0.06	-0.12	0.12	0.03	1.01	2.20	0.19	2.62	6.11	High
33	ICC 6877 × ICC 13124	-0.22	0.44	-0.05	0.00	-0.08	-5.39	0.67	-10.30	-14.93	Low
34	ICC 6877 × ICC 7315	0.18	-0.36	0.14	0.01	-0.91	-3.65	-0.30	-3.52	-8.11	Low
35	ICC 6877 × ICC 2072	0.04	-0.08	-0.30	-0.07	-1.13	1.86	0.11	9.73	10.16	High
36	ICC 6877 × ICC 10755	0.00	-0.01	0.21	0.06	2.12	7.18	-0.48	4.09	13.10	High
37	ICC 3776 × ICC 13124	0.00	-0.01	0.15	0.05	0.25	1.93	0.44	-13.60	-10.77	Low
38	ICC 3776 × ICC 7315	0.02	-0.03	-0.05	0.03	-0.04	-1.37	0.04	10.88	9.46	High
39	ICC 3776 × ICC 2072	-0.07	0.13	-0.04	-0.10	-0.91	-5.68	-0.33	-8.62	-15.62	Low
40	ICC 3776 × ICC 10755	0.04	-0.09	-0.06	0.02	0.70	5.12	-0.15	11.34	16.92	High
41	ICC 1431 × ICC 13124	0.03	-0.07	0.24	0.02	0.14	5.06	0.61	1.37	7.40	High
42	ICC 1431 × ICC 7315	0.14	-0.27	0.23	0.03	0.01	0.14	-0.14	3.25	3.39	High
43	ICC 1431 × ICC 2072	-0.22	0.43	-0.21	-0.02	-0.22	-4.43	0.89	2.69	-1.09	Low
44	ICC 1431 × ICC 10755	0.05	-0.09	-0.26	-0.02	0.07	-0.76	-1.36	-7.30	-9.65	Low
45	ICC 2507 × ICC 13124	-0.13	0.26	-0.17	-0.00	0.18	-5.56	-1.15	-7.65	-14.22	Low
46	ICC 2507 × ICC 7315	0.15	-0.30	-0.15	0.03	0.65	2.64	-0.45	-4.14	-1.57	Low
47	ICC 2507 × ICC 2072	0.00	-0.02	0.13	0.01	-0.40	5.03	3.22	13.10	21.07	High
48	ICC 2507 × ICC 10755	-0.03	0.06	0.19	-0.04	-0.44	-2.12	-1.62	-1.29	-5.29	Low
	Total										-17.86
	Mean										-0.37

Table 7. Mean, heterosis, combining ability of F_1 hybrids, their F_2 performance of combinations with representing different diversity levels in chickpea

Diversity class and heterotic status	F_1 performance			Parental combining ability status	SCA status	F_2 performance		
	Mean yield (g)	Heterosis (%)				Mean (g)	Range	CV (%)
		MP	SC					
I High diversity and high heterosis								
1. ICC 5878 × ICC 10755	57.9	83.2	126.8	H X L	H	13.2	11-17	21.5
2. ICC 6877 × ICC 13124	48.6	51.9	90.2	H X H	L	11.8	11-14	17.9
3. ICC 6877 × ICC 7315	54.6	115.2	113.9	H X H	L	27.4	12-43	39.3
4. ICC 6877 × ICC 2072	64.4	136.8	152.0	HXL	L	30.7	25-41	34.5
5. ICC 6877 × ICC 10755	60.6	90.9	136.9	HXL	H	25.6	19-42	33.2
6. ICC 2507 × ICC 2072	61.0	48.4	89.4	HXL	H	9.6	7-14	21.7
II High diversity and low heterosis	No cross showed heterosis in this class							
III Medium diversity and high heterosis								
1. ICC 11944 × ICC 13124	57.6	89.4	125.6	HXH	H	7.0	6-8	16.0
2. ICC 15697 × ICC 7315	52.9	110.6	107.0	HXH	H	27.4	18-32	27.8
3. ICC 15697 × ICC 2072	42.6	58.0	66.5	HXL	H	9.7	6-16	23.4
4. ICC 3776 × ICC 7315	57.1	99.8	123.5	HXH	H	16.4	12-21	25.7
5. ICC 3776 × ICC 10755	55.8	60.0	118.6	HXL	L	19.8	10-32	32.1
IV Medium diversity and low heterosis								
1. ICC 11944 × ICC 10755	33.8	0.30	32.5	HXL	L	9.5	7-13	19.9
2. ICC 1180 × ICC 13124	34.0	-3.75	33.1	HXL	L	8.4	6-10	18.3
V Low diversity and high heterosis	No crosses showed heterosis in this class							
VI Low diversity and low heterosis								
1. ICC 9133 × ICC 10755	27.1	-21.7	6.07	LXL	L	7.8	5-14	19.7

H-high L-low SCA- specific combining ability CV- coefficient of variation low heterosis. In low diversity group no hybrid showed high heterosis while there was only one hybrid with low heterosis. This indicates that the probability of getting heterotic hybrids is high with high diversity. The mean performance of heterotic hybrid as well as the extent of mid parent heterosis and standard heterosis are slightly better with the hybrids in high diversity group. Further looking to the combining ability status of these heterotic crosses they were mostly of H x H type followed closely by H x L type. Considering F_2 performance of these hybrids, three of the six highly heterotic F_1's in high diversity group and high mean (ICC 6877 x ICC 7315, ICC 6877 x ICC 2072 and ICC 6877 x ICC 10755) followed by high coefficient of variation and range. The mean F_2 values of these hybrids range from 25.6 to 37 g, from 32.2 to 39.0% coefficient of variation and the higher value of range from 41.2 to 43 g/ plant. While in case of medium diversity group, three hybrids (ICC 15697 x ICC 7315, ICC 3776 x CC 7315 and ICC 3776 x ICC 10755) showed relatively high mean values and higher coefficient of variation with reasonably high range of expression but these figures were lower than those of the hybrids in high diversity group. These facts indicate that parents with high diversity have a better chance of showing high heterosis and better F_2 performance.

References

Arunachalam V, A Bandoypadhyay, SN Nigam and RW Gibbons (1984) Heterosis in relation to genetic divergence and specific combining ability in groundnut (*Arachis hypogaea* L.). *Euphytica* **3:** 33-39.

Turner JH (1953) A study of heterosis in upland cotton, *Agron*. *J*. **45:** 484-486.

Hayes HK, FR Immer and DC Smith (1955) *Methods of Plant Breeding*. McGraw Hill Book Co., India, pp 551.

Kempthorne O (1957) *An introduction to genetic statistics.* John Wiley and Sons. Inc., New York.

Sarode ND, RB Deshmukh, JV Patil, MR Manjare and LB Mhase (2000) Heterosis and combining ability in chickpea (*Cicer arietinum* L.). *Legume Res.* **23:** 206-209.

Jeena AS and PP Arora (2000) Heterosis in chickpea (*Cicer arietinum* L.). *Agric*. *Sci*. *Dig*. **20:** 71-74.

Mali CT, NB Sable, KB Wanjari and Vandana Kalamkar (2006) Combining ability analysis in chickpea (*Cicer arietinum* L.). *J. Phytol*. *Res*. **19:** 323-326.