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HETEROSIS AND SPECIFIC COMBINING ABILITY ESTIMATES FOR ASSESSING POTENTIAL CROSSES TO DEVELOP F_1 HYBRIDS IN UPLAND COTTON

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ABSTRACT

Heterosis and combining ability estimates are very useful genetic parameters for identification of potential crosses to develop hybrid cotton. The crosses were attempted in a line x tester mating design, which involved five female and three tester parents, thus 15 F_1 hybrids were developed. The experiment was carriedout in a randomized complete block design with four replications. The mean squares due to general combining ability (GCA) of lines and testers and specific combining ability (SCA) of lines x tester interactions were significant. The significance of GCA and SCA variances suggested that both additive and dominant genes were controlling the characters. The high but parallel expression of SCA and heterosis determines the involvement of dominant genes and suitability of F_1 crosses for hybrid cotton development. At least five out of fifteen F_1 hybrids such as CIM-506 x BH-160, CRIS-134 x BH-160, CIM-496 x Bt-cotton, Sadori x Sindh-1 and Chandi x Bt-cotton manifested higher magnitude of SCA effects for bolls plant^{-1}, boll weight, seed cotton yield and lint%. Almost all the same hybrids demonstrated higher heterobeltiotic effects for bolls plant^{-1}, seed cotton yield plant^{-1} and lint%. The correlation coefficient between SCA and heterobeltiotic effects further determined the reliability of these two genetic parameters to identify potential F_1 hybrids. These correlations between SCA and heterobeltiosis were positive and significant for plant height (r=0.500*), bolls plant^{-1} (r=0.888**), seed cotton yield plant^{-1} (r=0.810**), lint% (r=0.550*) and fibre length (r=0.556*). The significant correlations between SCA and heterobeltiotic effects for majority of the traits obviously indicated that both estimates are equally good to predict the potential crosses for hybrid cotton development.

Keywords: Combining ability, heterosis, upland cotton, yield and fibre traits.

INTRODUCTION

For exploiting different types of gene action in plant population, the information regarding the relative magnitude of genetic variation and combining ability among important traits in cotton is very essential. The first step in the utilization of

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heterosis is the selection of parents from the available germplasm that could produce the best combinations or hybrids for most important characters. Thus, recent cotton improvement programmes primarily emphasize on development of hybrids which have contributed a lot in escalating the productivity of cotton (Christopher *et al*., 2003). Selection of parents on the basis of phenotypic performance alone is not an effective approach because phenotypically superior parents may perform poor in cross combinations. It is therefore imperative to choose the parents on the basis of combining ability, particularly specific combing ability of parents in hybrid combination. Hence combining ability analysis via mating designs is the most widely used biometrical technique for identifying prospective parents and helps in formulating effective breeding strategy. Generally, non-systemic approach is used to create genetic variability for combining ability. On the contrary to this approach, some hybrid breeding programmes are supplemented with regular breeding programmes aimed at improving combining ability due to which hybrid breeding programmes become more significant and purposeful than that when crosses are made at random without knowing their combining ability effects. Such guided mating schemes have led to development of lines with improved specific combining ability which resulted in isolation of potential hybrids (Baloch *et al.,* 2011). Baloch *et al.* (2010) examined the combining ability of eight upland cotton genotypes using F_1 hybrids. The SCA estimates suggested that hybrid FH-901 x CIM-506 expressed maximum effects for boll weight (0.77), NIBGE-2 x CIM-497 for bolls per plant (8.58) and seed cotton yield per plant (30.482) and NIBGE-2 x CIM-506 for monopodial branches per plant (2.29). Their results indicated that different hybrids may be exploited for hybrid crop development with improved traits.

Heterosis in any breeding programmes refers to the superiority of F_1 hybrids over the parental performance (Wu *et al*., 2004). Generally positive heterosis is considered desirable, yet in cotton some negative heterosis are useful such as plant height, days to first flower or maturity, node to first sympodia branch, micronaire and gossypol contents because hybrids with these traits are superior over the parental lines (Singh *et al*., 2012). For successful development of hybrid cotton, the magnitude of heterosis should be at acceptable level. In cotton, heterosis of 50% over the popular variety and 20% over the popular hybrid is considered useful for hybrid development (Singh *et al.*, 2012). Patil *et al*. (2011) reported that some hybrids exhibited significant heterosis in boll number and boll weight which were associated with increased seed cotton yield, thus suggested that such crosses could be considered for exploitation of hybrid vigour in cotton. Karademir and Gencer (2010) observed as high as 243.7% heterosis in seed cotton yield and 19.38% in fibre length. Very little is still known about relationship of F_1 hybrids about expressing heterosis and specific combining ability so that potential F_1 hybrids could reliably be isolated for hybrid seed production. The objectives of present investigation therefore are to estimate heterosis and specific combining ability of intra hirsutum F_1 hybrids for the exploitation of hybrid vigour in yield and fibre traits.

MATERIALS AND METHODS

An experiment was conducted at the experimental field of the Department of Plant Breeding and Genetics, Sindh Agriculture University Tandojam, during 2010. The breeding material consisted of 5 parental lines/females viz. CIM-506, CRIS-134, CIM-496, Sadori and Chandi and 3 testers/pollinators such as Bt-cotton, Sindh-1 and BH-160 and their 15 intrahirsutum F_1 hybrids. The seed of 15 F_1 hybrids was developed by line x tester mating design. The seed of parents and their F_1 hybrids was sown in a randomized complete block design with four replications. Distance between row to row and plant to plant was kept at 75.0 and 30 cm, respectively. Five rows of each parental line and F_1 hybrids were grown in a plot size of 12.5 $\times$ 45.0 feet. Sowing was done by dibbling three seeds per hill. After 25 days of sowing, seedlings were thinned and only one vigorous plant was allowed to grow. Ten plants were tagged from each genotype in each repeat at random from central row excluding border plants for recording the data. The cultural practices like dry hoeing, weeding and inter-culturing were carried out as and when required while the inputs like one bag of DAP ha^{-1} was applied with soaking irrigation and 2 bags ha^{-1} of urea were applied in three split doses; 1/3 with first irrigation, 2/3 with third irrigation and 3rd dose at peak flowering. The heterosis was calculated as percentage increase or decrease of F_1 hybrids over respective mid-parents and heterobeltiosis against better parents (Fehr, 1987). The specific combining ability analysis was carriedout according to procedures of Singh and Choudhry (1979).

RESULTS AND DISCUSSION

The parents and their F_1 hybrids were evaluated for analysis of variance, mean performance, general combining ability (GCA), specific combining ability (SCA) and heterotic effects. Significant differences among the genotypes and F_1 hybrids for plant height (cm), bolls $plant^{-1}$, boll weight (g), seed cotton yield $plant^{-1}$ (g), lint %, and fibre length (mm) were recorded (Table 1). The mean squares due genotypes were further partitioned into parental lines and their F_1 hybrids which also showed significant differences. These results added that the entire data is worth for estimating general combining ability (GCA), specific combining ability (SCA) and heterotic effects. The mean squares due to general combining ability (GCA) and specific combining ability (SCA) were highly significant for all the characters studied. Similar to present results, Baloch *et al*. (2003) estimated significant general and specific combining ability effects for seed cotton yield, bolls per plant, boll weight, lint percent and fibre length. The mean squares due to male and female parents both determined general combining ability (GCA) variances and males x females which pertained to specific combining ability (SCA) variances were significant for all the characters. The general combining ability of lines (female parents) were higher than the testers (male parents), except boll weight suggesting that lines possessed more additive variances and additive genes against the tester parents. While the SCA variances (line x tester interaction) were generally lower than both lines and testers indicating preponderance of the additive genes in the control of most of the characters.

Since the main emphasis of this research work was to determine the relationship of heterosis, specially high parent heterosis (heterobeltiosis) with SCA effects so as to identify potential crosses for hybrid crop development, hence other data set like mean performance of parents, hybrid performance *per se* and GCA effects were less important for this study.

The heterotic effects and specific combining ability estimates

Heterosis is the superiority of F_1 hybrids over their mid parents or better parents. Heterosis will to be useful when F_1 hybrid performance exceeds to that of better parent commonly known as heterobeltiosis (Patil *et al*., 2011). The occurrence of heterosis is common in plant species, but the level of expression is highly variable. It is generally believed that F_1 hybrids which express positive heterosis are those with dominant genes whereas the ones which exhibit negative heterosis possess recessive genes. Lot of researchers also found that extent of heterosis depends on the genetic distance of two parents upon their crosses. Ahmed *et al*. (2002) observed significantly positive heterobeltiotic in 55 hybrids for bolls per plant, 31 for seed cotton yield, 32 and 43 hybrids for staple length.

Table 1. Mean squares from line x tester analysis for various characters in upland cotton.

Source of variation	D.F.	Plant height	Bolls (plant^{-1})	Boll weight	Seed cotton yield (plant^{-1})	Lint %	Staple length
Replication	3	137.9	3.5	0.03	6.00	1.5	0.27
Genotypes	22	617.3**	236.1**	0.65**	4763.0**	10.1**	3.87**
F_1 hybrids	14	590.7**	3.8**	0.83**	3176.0**	12.0**	4.16**
Lines (L)	4	1045.0**	5.9**	0.79**	4279.0**	27.9**	8.22**
Testers (T)	2	952.3**	1.8**	2.07**	3611.0**	2.5**	0.02ns
L x T	8	273.2**	3.3**	0.53**	2515.0**	6.5**	3.16**
Error	42	12.1	0.43	0.01	67.9	0.41	0.58

** = significant at 1 % probability level.

Specific combining ability (SCA) is defined as the performance of two parents in the specific crosses. As such, the phenomenon of hybrid vigour is a result of the specific combining ability of two parents. Kumar *et al*. (2010) found greater portion of SCA variances over the GCA for yield and fibre traits in cotton, thus stated that such traits could be improved through heterosis breeding.

Medium-tall plants regarded as desirable cotton because of two reasons. First, the medium tall plants can produce fair number of sympodial branches, hence form more fruiting branches. Second, the medium tall plants could be fairly resistant to lodging and early maturing as compared to taller plants. Among fifteen F_1 hybrids, eight exhibited positive SCA effects while seven gave negative SCA effects for plant height (Table 4). The moderate negative but desirable SCA effects (-1.52) however were manifested by the hybrid Chandi x Sindh-1, followed by minimum but desirable SCA effects by Sadori x Bt-cotton (-1.35), hence these hybrids are preferable for plant height. The heterotic effects for plant height are summarized in Table 2 which revealed that seven F_1 hybrids expressed positive heterobeltiosis ranging from 4.09 to 30.02, while negative heterobeltiosis varied from -4.20 to -15.02. The moderate but either positive or negative heterobeltiosis may be desirable for plant height and the hybrids CRIS-134 x Bt-cotton (-5.52%), followed by Chandi x Sindh-1 (-4.12%) are regarded as suitable ones for this trait.

In cotton plant, as the number of bolls per plant increase, the yield also increases. Thus, there is close but positive association between bolls per plant and seed cotton yield. All the fifteen hybrids expressed positive SCA effects for bolls per plant (Table 4), nonetheless the highest SCA effect of 51.64 was manifested by Sadori x Sindh-1, followed by Chandi x Sindh-1 (51.14) and CIM-496 x BH-160 (51.07). Similarly, all the hybrids manifested positive relative heterotic and heterobeltiotic effects for bolls per plant (Table 2). The maximum heterosis of 38.54 and 34.34 % however were manifested by CIM-496 x BH-160 over its mid parent and better parents, respectively followed by the cross CRIS-134 x Sindh-1 which exhibited relative heterosis of 37.56% over mid parent and 29.36 % over better parent. These results suggested very close proximity between heterobeltiosis and SCA effects exists where some hybrids have changed a little bit rank order only (Table 4 and Fig. 1). For example, hybrid CIM-496 x BH-160 which ranked first in heterobeltiotic effects, still ranked third in SCA effects. Larik *et al*. (2000) also reported highest average heterosis (32.41%), heterobeltiosis (16.37%) and dominance estimates (4.93) for number of bolls per plant. The correlation between heterobeltiosis and SCA effects (r=0.888**) was also highly positive indicating that hybrids expressing high heterobeltiosis also displayed greater SCA effects (Table 3). It is assumed that as boll weight increases, the yield correspondingly increases if the number of bolls is kept constant. With respect to boll weight, from among fifteen crosses, only seven hybrids gave positive SCA effects (Table 4). However, top three rankers for SCA effects were; CIM-496 x Bt-cotton (0.43), CIM-506 x BH-160 (0.42) and Sadori x Sindh-1 (0.35). Very similar to SCA effects, seven F_1 hybrids exhibited positive heterobeltiosis ranging from 2.82% to 28.17% (Table-2). However, the highest relative heterosis of 30.0% was exhibited by cross CIM-496 x Bt-cotton which also gave highest (28.17%) heterobeltiosis. Though, the first ranking hybrid (CIM-496 x Bt-cotton) with maximum SCA effect also ranked similar for heterobeltiosis which indicated the supremacy of hybrid CIM-496 x Bt-cotton, yet non-significant correlations (r=0.111) between SCA and heterobeltiosis (Table 2) suggested that SCA effects of hybrids must not be taken as granted for expecting similar vigour in boll weight also.

Seed cotton yield per plant had a unique importance among many plant characters because it plays an important role in strengthening the economy of the growers and the country. The SCA results for seed cotton yield revealed that six F_1 hybrids manifested positive SCA effects, whereas remaining nine hybrids gave negative SCA effects (Table 4). However, hybrids CIM-506 x BH-160 (21.75), CIM-496 x Bt-cotton (16.92) and Sadori x sindh-1 (16.45) were the three top scorers in expressing SCA effects. Contrary to SCA results, all the fifteen F_1 hybrids showed positive heterobeltiosis for seed cotton yield per plant (Table 3 and Fig 2). The heterobeltiosis ranged between 5.69% to 46.08% and the top three scoring F_1 hybrids were; CIM-496 x Bt-cotton, Sadori x Sindh-1 and CRIS-134 x BH-160 and their Fig. 2. Relationship between heterosis and SCA effects for seed cotton yield increase over better parents were; 46.08, 36.76 and 34.68%, respectively. It is very interesting to note that atleast two out of three hybrids are same which exhibited high SCA effects also manifested greater heterobeltiosis for seed cotton yield. The high positive correlation between SCA effects and heterobeltiosis (r=0.810**) also support the idea that hybrids which are good specific combiners for seed cotton yield may be those which reliably exhibit high vigour in productivity also (Table 3).

Table 2. Heterosis and heterobeltiotic effects of intrahirsutum F_1 hybrids for seed cotton yield and fibre traits.

F_1 Hybrids	Plant height		Bolls plant^{-1}		Boll weight	
	RH	HB	RH	HB	RH	HB
CIM-506 × Bt-cotton	9.59	4.09	19.80	18.63	-8.82	-12.68
CIM-506 × Sindh-1	14.74	7.81	18.18	14.71	-7.09	-9.23
CIM-506 × BH-160	12.64	11.01	30.26	24.51	0.76	0.00
CRIS-134 × Bt-cotton	1.53	-5.52	25.36	20.18	8.96	2.82
CRIS-134 × Sindh-1	26.57	16.55	37.56	29.36	-2.40	-3.17
CRIS-134 × BH-160	10.22	9.43	31.68	22.02	6.98	4.55
CIM-496 × Bt-cotton	21.82	18.80	14.57	14.00	30.00	28.17
CIM-496 × Sindh-1	31.83	30.02	24.10	22.22	8.40	2.90
CIM-496 × BH-160	2.56	-6.14	38.54	34.34	-6.67	-8.70
Sadori × Bt-cotton	-6.92	-15.02	24.64	20.56	6.58	0.00
Sadori × Sindh-1	3.87	-6.14	34.98	28.04	7.69	-4.94
Sadori × BH-160	-6.14	-8.70	33.00	24.30	-18.37	-25.93
Chandi × Bt-cotton	-4.99	-11.29	29.76	26.67	7.35	2.82
Chandi × Sindh-1	3.78	-4.12	34.33	28.57	-2.36	-4.62
Chandi × BH-160	-8.27	-8.60	20.20	13.33	-5.34	-6.06
Correlation between HB and SCA estimates	-	0.50*	-	0.888**	-	0.111

RH = Relative heterosis, HB = Heterobeltiosis and SCA = Specific combining ability.

From line x tester crosses, seven hybrids demonstrated positive SCA effects, nonetheless eight crosses gave negative SCA effects (Table 4). However, highest three SCA scoring F_1 hybrids were; CIM-506 x BH-160 (1.75), Sadori x Sindh-1 (1.24) and Chandi x Bt-cotton (1.10) for lint%. Iqbal *et al.* (2005) while estimating GCA and SCA observed that hybrid LRA-5166 X CIM-499 exhibited reasonably high SCA effect for seed cotton yield and lint% which indicated that the progenies of this cross may be used for improving yield and yield components. The results of heterotic effects of F_1 hybrids revealed that relative positive heterosis ranged between 1.01 to 9.63% whereas positive heterobeltiosis varied from 1.32 to 9.27% in lint% (Table 3). The highest increase over mid parent (9.63%) was recorded by cross CRIS-134 x Sindh-1 and the same hybrid also exhibited maximum heterobeltiosis (9.27%), nevertheless CRIS-134 x BH-160 ranked next higher scoring for mid parent and better parent heterosis with an increase of 2.85 and 7.79%, respectively. The discrepancy of F_1 hybrids in SCA and heterobeltiosis estimates indicated that SCA effects of hybrids is not necessarily expected to be observed in hybrid vigour also, specially for lint%. Though three higher ranking hybrids did not perform similar for SCA and heterosis, yet significant positive correlation (r=0.550**) between two parameters suggested that majority of the hybrids performed in similar direction. Ten hybrids manifested positive SCA effects while five cross combinations recorded negative SCA effects for fibre length. Nonetheless, Sadori x BH-160 (0.88), followed by CIM-496 x Sindh-1 (0.85) and Sadori x Bt-cotton (0.82) scored maximum positive SCA effects (Table 4). Results depicted in Table 3 indicated that F_1 hybrids expressed low to medium positive mid parent heterosis (1.85 to 8.52%) and positive heterobeltiosis (0.88 to 6.36%). The highest positive heterobeltiosis of 6.36% was manifested by CIM-506 x Bt-cotton whereas hybrid CRIS-134 x Bt-cotton manifested next higher heterobeltiosis (6.14%) among the F_1 hybrids for fibre length. The discrepancy in the hybrid performance was observed in top three scoring for SCA and heterobeltiosis which suggested that if the objective of breeding is to develop potential hybrids for lint%, both SCA and heterosis may not necessarily favour the same hybrids. The significant and positive correlations (0.556**) further suggested that though top three hybrids may not performed similar, yet the trend of other hybrids could be in the same direction (Table 3), thus better hybrids may be selected to improve fibre length in cotton. Khan *et al*. (2009) found higher SCA than GCA suggesting that dominant genes controlling boll weight, boll number and seed cotton yield per plant. F_1 hybrids like CIM-1100 × CRIS-9, CIM-1100 × FH-682, CIM-1100 × BH-36 and CIM-109 × CIM-1100 performed well in SCA determination, outstanding mean performance *per se* and heterosis. They stated that higher SCA effects associated with useful heterosis were more pronounced for yield traits and above hybrids could prove useful for hybrid crop development. In another study, Khan *et al.* (2011) reported positive economic values as 80% in F_1 hybrids for plant height, 97% for sympodia, 60% for boll weight, 83% for bolls per plant, and 60% for seed cotton yield.

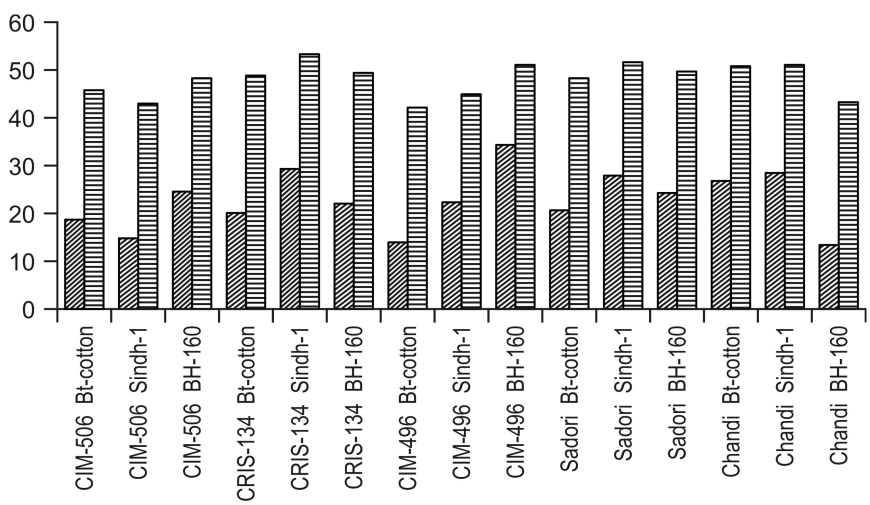

Figure 1. Relationship between heterobeltiosis and SCA effects for bolls plant^{-1}.

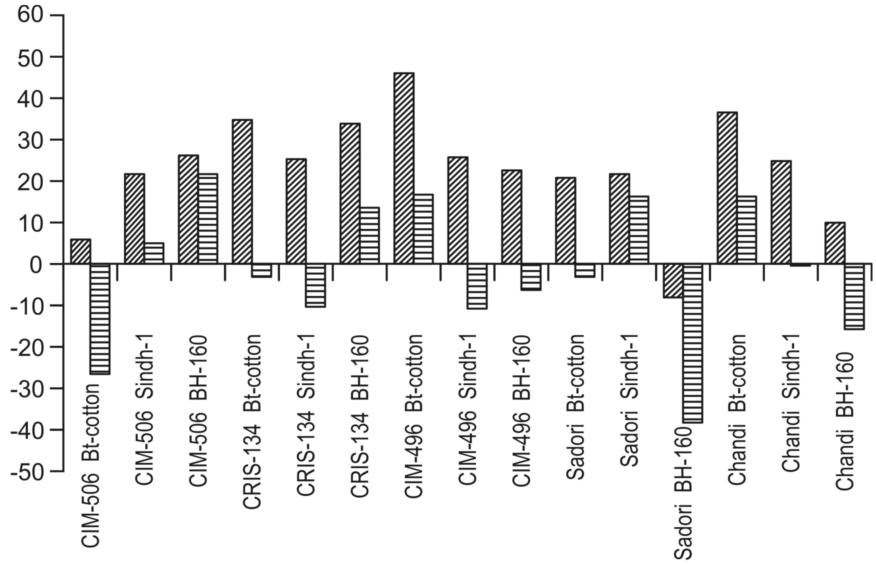

Figure 2. Relationship between heterosis and SCA effects for seed cotton yield plant^{-1}.

Table 3. Heterosis and heterobeltiotic effects of intrahirsutum F_1 hybrids for seed cotton yield and fibre traits.

F_1 Hybrids	Seed cotton yield plant^{-1}		Lint%		Fibre length	
	RH	HB	RH	HB	RH	HB
CIM-506 × Bt-cotton	9.29	5.69	3.38	1.32	6.85	6.36
CIM-506 × Sindh-1	28.45	21.86	-3.65	-3.97	2.24	0.88
CIM-506 × BH-160	31.19	26.33	3.61	2.60	7.41	5.45
CRIS-134 × Bt-cotton	36.91	34.68	8.78	6.62	8.52	6.14
CRIS-134 × Sindh-1	34.17	25.22	9.63	9.27	5.73	5.26
CRIS-134 × BH-160	41.11	33.63	8.85	7.79	3.64	0.00
CIM-496 × Bt-cotton	48.89	46.08	4.79	4.08	0.00	-1.77
CIM-496 × Sindh-1	34.42	25.76	1.01	0.00	4.42	4.42
CIM-496 × BH-160	29.20	22.66	-1.66	-3.90	5.02	1.77
Sadori × Bt-cotton	32.54	20.56	6.62	2.55	-0.90	-2.65
Sadori × Sindh-1	44.34	21.74	6.84	4.46	0.00	0.00
Sadori × BH-160	7.79	-7.92	-0.96	-1.91	6.85	3.54
Chandi × Bt-cotton	40.72	36.76	6.44	4.67	2.28	1.82
Chandi × Sindh-1	32.28	24.90	-0.67	-0.67	-4.93	-6.19
Chandi × BH-160	14.89	10.09	-3.95	-5.19	1.85	0.00
Correlation between HB and SCA estimates	-	0.810**	-	0.550**	-	0.556**

RH = Relative heterosis, HB = Heterobeltiosis and SCA = Specific combining ability.

Table 4. Specific combining ability (SCA) estimates from line x tester analysis for various characters in upland cotton.

F_1 hybrids	Plant height	Bolls plant^{-1}	Boll weight	Seed cotton yield plant^{-1}	Lint%	Fibre length
CIM-506 × Bt-cotton	0.61	45.63	-0.38	-26.62	-0.15	0.35
CIM-506 × Sindh-1	-8.19	43.06	-0.03	4.85	-1.60	-0.40
CIM-506 × BH-160	7.56	48.20	0.42	21.75	1.75	0.05
CRIS-134 × Bt-cotton	-10.47	48.96	-3.10	-3.30	-1.15	0.68
CRIS-134 × Sindh-1	6.73	53.39	-0.20	-10.33	0.40	0.43
CRIS-134 × BH-160	3.73	49.53	0.30	13.62	0.75	-1.12
CIM-496 × Bt-cotton	8.11	42.00	0.43	16.92	0.27	-0.90
CIM-496 × Sindh-1	4.31	44.93	-0.07	-10.56	0.07	0.85
CIM-496 × BH-160	-12.44	51.07	-0.37	-6.36	-0.33	0.05
Sadori × Bt-cotton	-0.55	48.21	0.05	-3.12	-0.06	0.82
Sadori × Sindh-1	-1.35	51.64	0.35	16.45	1.24	-0.07
Sadori × BH-160	1.90	49.78	-0.40	-38.30	-1.16	0.88
Chandi × Bt-cotton	2.28	50.71	0.00	16.12	1.10	0.68
Chandi × Sindh-1	-1.52	51.14	-0.05	-0.41	-0.10	-0.82
Chandi × BH-160	-0.77	43.28	0.05	-15.71	-1.00	0.13
S.E. (si.)	1.74	0.32	0.05	4.11	0.32	0.38

CONCLUSION

The variances due to general combining ability (GCA) and specific combining ability (SCA) were significant suggesting that both additive and dominant genes were advocating the traits under study. The high and parallel expression of SCA and heterosis effects of F_1 hybrids for important traits determine the suitability of F_1 crosses for hybrid cotton development. Five out of fifteen F_1 hybrids such as CIM-506 x BH-160, CRIS-134 x BH-160, CIM-496 x Bt-cotton, Sadori x Sindh-1 and Chandi x Bt-cotton manifested both higher SCA and heterobeltiotic effects indicating that bolls plant^{-1}, boll weight, seed cotton yield and lint% can be considered for hybrid cotton development either on the basis of their SCA or heterotic effects or both. The close and positive association between SCA and heterobeltiotic effects in F_1 hybrids was observed for plant height, bolls plant^{-1}, seed cotton yield plant^{-1}, lint% and fibre length. The significant correlations between SCA and heterobeltiotic effects for majority of the traits obviously indicated that both estimates are equally reliable to identify potential crosses for hybrid cotton development.

REFERENCES

Ahmed, R. D., A. J. Malik, M. A. Chang, G. Hassan and M. Subhan. 2002. Heterosis studies for yield and its components in various crosses of cotton (*Gossypium hirsutum* L.). Asian J. Pl. Sci., 1 (4): 432-435.

Baloch, M. J. and H. U. Bhutto. 2003. Design-II analysis for estimating general and specific combining ability effects of cotton leaf curl virus resistant inbred parents. Zagazig J. Agric. Res., 30 (3): 635-649.

Baloch, A. W., M. J. Baloch, W. A. Jatoi and N. F. Veesar. 2010. Production of superior F_1 hybrids: Genetic analysis for estimating combining ability in upland cotton (*Gossypium hirsutum* L.). J. Agric. Res., 48 (4): 419-428.

Baloch, M. J., I. A. Mallano, A. W. Baloch, W. A. Jatoi and N. F.Veesar. 2011. Efficient methods of choosing potential parents and hybrids: line x tester analysis of spring wheat (*Triticum aestivum* L.) cultivars. Pak. J. Sci. Ind. Res., 54 (3): 117-121.

Jatoi, W. A., M. J. Baloch, N. F. Veesar and S. A. Panhwar. 2011. Combining ability estimates from line x tester analysis for yield and yield components in upland cotton genotypes. J. Agric. Res., 49: 165-172.

Christopher. L., J. N., C. Jenkins, C. Jack, J. Mc-Carty, E. Clarence and J. Wu-Waston. 2003. Genetic variance and combining ability of crosses of American cultivars, Australian cultivars and wild cottons. J. Cotton Sci., 7: 16-22.

Fehr, W. R. 1987. Principles of cultivar development. Theory and Technique. Vol.1. Macmillan Publishing Company, New York, U.S.A. pp.115.

Iqbal, M., R. S. A. Khan, K. Hayat and N. Khan. 2005. Genetic variation and combining ability for yield and fiber traits among cotton F_1 hybrid population. J. Biol. Sci., 5 (6): 713-716.

Karademir, E and O. Gencer. 2010. Combining ability and heterosis for yield and fiber quality properties in cotton (*Gossypium hirsutum* L.) obtained by half diallel mating design. Not. Bot. Hort. Agrobot. Cluj., 38 (1): 222-227.

Khan, N. U., G. Hassan, M. B. Kumbhar, K. B. Marwat, M. A. Khan, A. Parveen, U. Aiman and M. Saeed. 2009. Combining ability analysis to identify suitable parents for heterosis in seed cotton yield, its components and lint % in upland cotton. Ind. Crops Prod., 29 (1): 108-115.

Khan, N. U. 2011. Economic heterosis for morpho-yield traits in F_1 and F_2 diallel crosses of upland cotton. SABRAO J. Breeding Genetics, 43: 144-164.

Kumar, A. K., R. Ravikesavan and K. S. J. Prince. 2010. Combining ability estimates for yield and fibre quality traits in line x tester crosses of upland cotton (*Gossypium hirsutum* L.). Int. J. Bio., 2 (1): 179-189.

Larik, A. S., B. A. Shabrarri, A. R. Baretch., G. M. Kakar and A. A. Kakar. 2000. Expression of hybrid vigour and dominance in intervarietal crosses of cotton. Pak. J. Agric. Sci., 37 (1-2): 65-69.

Patil, S. A., M. R. Naik, A. B. Patil and G. R. Chaugule. 2011. Heterosis for seed cotton yield and its contributing characters in cotton (*Gossypium hirsutum* L.). Plant Archives, 11 (1): 461-465.

Singh, P., M. S. Kairon and S. B. Singh. 2012. Breeding Hybrid Cotton. Cicr Technical Bulletin No: 14. Breeding Hybrid Cotton [www.cicr.org.in].

Singh, R. K. and B. D. Choudhry. 1979. Biometrical methods in quantitative genetic analysis. (1st ed.). Kalyani Publishers, New Delhi, India.

Wu, Y. T., J. M. Yin, W. Z. Guo, X. P. Zhu and T. Z. Zhang. 2004. Heterosis performance of yield and fibre quality in F_1 and F_2 hybrids in upland cotton. Plant Breed., 123: 285-289.

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