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

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ABSTRACT

Breeders are aware of the phenomenon that in a hybridization programmes, certain crosses pass-on more favorable genes towards the progenies than others. Thus, identification of potential parents and hybrids remained main concern to cotton breeders for improving various yield and fibre traits in cotton breeding programmes. The present studies were carried-out to estimate the general and specific combining ability estimates and heterotic effects for different characters from line x tester crosses developed from six lines viz., Sindh-1, Sadori, CRIS-134, Chandi-95, Haridost and IR-1524 crossed with three testers i.e. NIA-ufaq, Sohni and Shahbaz. The experiment was laid-out in a Randomized Complete Block Design with four replications during 2016. The degrees of freedom for hybrids were split into lines, testers and line x tester interaction. The mean squares owing to lines and testers were significant for majority of the traits, however the general combining ability of lines for 1st sympodial node number while general combining ability of testers only boll weight was non-significant. Similarly, the mean square for line x tester interaction which designate specific combining ability were also significant for all traits except staple length, G.O.T. % and seed index. Among the lines, Chandi-95, IR-1524 and from testers Shahbaz expressed higher GCA effects especially for seed cotton yield, thus, proved as good general combiners and suitable parents for hybridization and selection of desirable plants from segregating populations. For SCA effects, F_1 hybrids like Sadori x Shahbaz, Haridost x NIA-ufaq and Sindh-1 x Shahbaz demonstrated as best specific combiners, therefore' these proved promising hybrids. The high heterotic effects were expressed by the hybrids Sadori x Shahbaz for bolls per plant, boll weight and seed cotton yield plant^{-1} and IR-1524 x NIA-ufaq for staple length thus, these hybrids with dominant and over dominant genes could be potential hybrids for the exploitation of heterosis breeding in cotton.

Key words: Heterosis, combining ability, line x tester analysis, upland cotton.

INTRODUCTION

One of the best breeding approaches to increase seed cotton yield is heterosis breeding. Heterosis is the performance of F_1 hybrids in relation to mid and better parents. This breeding approach is useful in determining the most appropriate parents to be used in crossing programme for improving specific traits (Khan *et al*., 2010). Heterosis is obtained via allelic or non-allelic interaction of genes expressed under particular environment. This phenomenon has been observed in many crop species hence remained the objective of considerable importance for increasing productivity of crop plants.

Heterosis has been accomplished in cotton breeding, however to be prospective, a hybrid should be more advantageous than best existing commercial cultivar or check hybrid. This refers that the hybrid should have greater yield potential and superior fiber quality traits over the pure varieties. Adopting heterosis breeding to improve yield and fiber quality traits of cotton have long been remained major objectives of cotton researchers (Baloch *et al*., 2015). Several researches have observed significant amount of heterosis for various traits like Ashok Kumar and Ravikesavan (2013) recorded positive heterotic effects for fiber elongation. While Baloch *et al*. (2014a) demonstrated substantial heterobeltiotic effects for bolls plant^{-1}, seed cotton yield plant^{-1} and lint%, yet Abro *et al*. (2014) noticed considerable heterosis for sympodia, number of bolls and yield. Basal *et al*. (2011) suggested that the identification and selection of best new F_1 hybrids should be based on their specific combining ability and heterotic estimates. Both positive and negative heterosis can be desirable depending on the characters associated (Singh *et al*., 2012). Negative heterosis for plant height was reported by (Khan *et al*., 2009). Patil *et al*. (2011) observed considerable heterosis for number of bolls and boll size and these traits were related to enhanced yield and such potential cross combinations can be explored for hybrid breeding.

Combining ability analysis provides information for the selection of parents as well as the nature and magnitude of gene action involved in the expression of different traits. The variance of general combining ability (GCA) includes additive and additive x additive gene interactions while specific combining ability (SCA) denotes non-additive genetic portion. Hence combining ability is important in the development of crop varieties and its notable use in crop hybridization either to exploit heterosis or to combine the fixable favorable genes (Sarwarkar *et al*., 2015). Information on GCA and SCA for yield and its components has proved very useful in selection of appropriate parents for the development of cotton hybrids (Kumar *et al*., 2014). The combining ability study is very important for the selection of parents and crosses which give maximum improvement for the character under consideration and also provides information on the nature of genetic variation present in material under study. It is most widely used biometrical approach in plant breeding. Success in the development of high yielding and widely adapted hybrids however depends on the specific combining ability of parental crosses (Baloch *et al*., 2014b). For hybrid cotton, different female parents are evaluated via combining ability analysis. Quite a number of profitable cotton cultivars may combine their potential genes in a particular cross permutation (Khan *et al*., 2015). Nisar *et al*. (2018) observed that additive gene action was advocating the characters like bolls plant^{-1}, sympodia plant^{-1}, staple strength, and seed cotton yield plant^{-1} which were influenced by non-additive gene action. The combining ability and heterosis are important genetic parameters for determining breeding value of parents. Line x tester analysis provides a systematic technique for the identification of suitable parents and cross combination suitable either for hybridization and selection or hybrid cotton development (Sarwarkar *et al*., 2015). The main aim of current studies hence was to isolate the superior combiner parents in terms of GCA and hybrids in terms of SCA and to determine the pattern of gene action for various plant traits so as to develop the high yielding cotton cultivars with better fiber traits.

MATERIALS AND METHODS

An experiment was carried out in the field of the Department of Plant Breeding and Genetics, Sindh Agriculture University Tandojam, during 2016. Six female lines viz. Sindh-1, Sadori, CRIS-134, Chandi-95, Haridost and IR-1524 and 3 testers/pollinators viz., NIA-Ufaq, Sohni and Shahbaz were crossed in a line x tester mating fashion, hence 18 cross combinations were formed. The seed of 18 F_1s was obtained by mating 6 females with 3 males. The parental and their F_1 hybrid seed were grown in RCBD with four repeats. The space between rows and plants were maintained at 75 and 45 cm, respectively. Planting was carried-out with hand dibble and after fifteen days, thinning was carried-out to maintain uniform plant population. Observations were taken on ten randomly tagged plants from each repeat. Recommended cultural practices were adopted for cotton crop. On ha^{-1} basis, one and half bags of di-ammonium phosphate and two bags of urea were applied. The observations were recorded for plant height (cm), sympodial branches plant^{-1}, 1st effective boll node number, 1st sympodial node number, bolls plant^{-1}, bolls weight (g), staple length, ginning outturn percentage, seed cotton yield plant^{-1} (g) and seed index (100-seed wt. in g). The analysis of variance was carried-out as suggested by Gomez and Gomez (1984); while general and specific combining ability were estimated according to Kempthorne (1957) and adopted by Singh and Choudhry (1979). The heritability (narrow sense) and heterosis were estimated according to Hallauer and Miranda (1987) and Fehr (1987), respectively.

RESULTS AND DISCUSSION

Analysis of variance and mean performance of parental varieties and F_1 hybrids: For the improvement of any character, plant breeders heavily rely upon the combining ability of parents determined by various mating designs. Cotton breeders are also well known of the phenomenon that in a hybridization programs, certain crosses transfer more favorable genes towards the offspring than others. Thus, some cross combinations may be superior as compared to their parents for some economic traits. The analysis of variance revealed that parents and F_1 hybrids were statistically different for plant height, sympodial branches plant^{-1}, 1st effective boll node number, 1st sympodial node number, bolls plant^{-1}, boll weight, staple length, G.O.T, seed cotton yield plant^{-1} and seed index (Table1)

The average performance of eighteen F_1 hybrids and nine parents was assessed for 10 characters summarized in Table 2. Generally, F_1 hybrids expressed greater averages over their parents for almost all the characters. However, among the parents, Haridost gave maximum plant height (160.9cm), sympodial branches plant^{-1} (25.66), but produced next maximum bolls (53.06), boll weight (3.12g) and yield (148.58g). While CRIS-134 recorded maximum bolls plant^{-1} (54.51) and yield (174.42g), yet genotypes Sindh-1 gave maximum boll weight (3.25g). The parent Sadori ginned maximum G.O.T (42.80%). Among the F_1 hybrids, Haridost x NIA-ufaq recorded tallest plants (140.9cm) and longer fibre (29.85mm), while Haridost x Shahbaz recorded maximum sympodial branches plant^{-1} (29.57), bolls plant^{-1} (89.22). The hybrid IR-1524 x Sohni gave maximum boll weight (3.78g) and IR-1524 x Shahbaz ginned maximum G.O.T (41.85%). While maximum seed index (8.52g) was recorded by the hybrid CRIS-134 x Sohni. The degrees of freedom for hybrids were split into lines, testers and line x tester interaction.

The mean squares concerning to lines and testers both determine the general combining ability (GCA) were important for most of the characters, nonetheless the GCA of lines for 1st sympodial node number while GCA of testers for boll weight were different (Table 3). Likewise, mean squares due to line x tester interaction which designate SCA were also significant for all traits (Table 4). Such outcome indicated that additive and non-additive genes were essential for the determination of characters studied. Such results revealed the existence of significant differences in the average value of parents and F_1 hybrids as well. Results further indicated that data is suitable for estimating GCA and SCA and heterosis estimates.

Plant height: Medium taller plants are considered as enviable in cotton breeding due to motive that medium taller plants may produce greater number of sympodia, thus bear additional fruiting branches. Secondly, medium taller plants are reasonably tolerant to lodging. The average performance of hybrids *per se* indicated that cross CRIS-134 x NIA-ufaq, CRIS-134 x Shahbaz and IR-1524 x NIA-ufaq produced medium taller plants among the F_1 hybrids (Table 2). From the parents, Sindh-1 and Sadori manifested desirable negative GCA effects for plant height (Table 3). Whereas for SCA effects, several F_1 hybrids exhibited moderately negative but desirable SCA effects being potential hybrids for plant height. Nonetheless, hybrids like Haridost x Sohni, Haridost x NIA-ufaq and Chandi-95 x Sohni expressed desirable negative SCA effects being highly desirable hybrids for lodging resistance and for earlier maturity (Table 4). These finding are in conformity to that of Baloch *et al*. (2012) and Alkuddsi *et al*. (2013) who also reported that some hybrids expressed moderate positive or negative GCA and SCA effects. However present results suggested that parents Sindh-1, Sadori and Sohni being good general combiners are suitable parents for hybridization and selection programs so as to develop breeding material with medium taller plant height.

The heterotic effects of eighteen F_1 hybrids regarding plant height are depicted in Table 5. The results revealed that out of eighteen, thirteen hybrids manifested undesirable positive relative heterosis in the range of 3.98% to 25.76% and positive better parent heterosis from 0.43% to 10.60%. The maximum positive relative heterosis was recorded by Sindh-1 x NIA-ufaq whereas heterobeltiosis was manifested by Sindh-1 x Sohni. Five out of eighteen hybrids manifested desirable negative relative heterosis ranging from -0.55% to -13.94% whereas seven out of eighteen crosses, expressed negative desirable heterobeltiosis from -7.48% to -28.71%.

Sympodial branches plant^{-1}: Formation of more sympodial branches increases the opportunity for more number of bolls produced by the individual plant. Among the parents, Haridost, Sadori, Chandi and IR-1524 formed relatively higher number of branches plant^{-1} (Table 2). The mean performance of hybrids *per se* showed that crosses Haridost x Shahbaz, Haridost x NIA-ufaq and Chandi-95 x NIA-ufaq recorded higher number of sympodial branches plant^{-1}. From parents Haridost, IR-1524 and Shahbaz exhibited maximum GCA effects (Table 3). The SCA effects revealed that out of eighteen F_1 hybrids, ten exhibited positive effects while remaining eight hybrids expressed negative SCA being undesirable ones for sympodial branches (Table 4). Similar to our results, Jatoi *et al*. (2010) found that GCA and SCA estimates with additive and non- additive genes were controlling sympodia per plant. Yet, GCA mean squares being higher than SCA exhibited greater influence of additive genes.

The percent increase or decrease of F_1 hybrids over mid and better parents for the number of sympodial branches plant^{-1} is presented in Table 5 which indicated that all the eighteen crosses displayed positive mid parent heterosis ranging from 1.74% to 24.42% whereas in case of better parent heterosis out of eighteen crosses, seventeen exhibited positive heterosis except one. While positive heterobeltiosis ranged from 2.93% to 22.05%. From eighteen hybrids, the top three high scoring hybrids were; IR-1524 x Shahbaz, IR-1524 x Sohni and Haridost x Shahbaz (Table 5). These three high scoring hybrids showed that dominant and over dominant genes were responsible for the manifestation of high heterotic effects. The results are accordance to Arain *et al*. (2015) who also stated that hybrids with dominant and over dominant genes would be potential hybrids for the exploitation of heterosis in cotton.

1st effective boll node number: 1st effective boll node number is the early maturing trait, hence could reliably be considered as good indicator to measure earliness in upland cotton. From six female lines, four expressed undesirable positive GCA estimates viz., CRIS-134, Sadori, Chandi-95 and IR-1524, while only two lines like Sindh-1 (-0.16) and Haridost (-0.24) manifested desirable negative effects for 1st effective boll node number (Table 3). Only one i.e., Sohni (-0.23) out of three male testers recorded desirable negative effect for 1st effective boll node number, yet other two males i.e., NIA-ufaq (0.20) and Shahbaz (0.03) manifested undesirable positive GCA effects. Regarding SCA estimates, ten out of eighteen hybrids displayed desirable negative SCA effects, yet other eight crosses expressed undesirable positive SCA estimates (Table 4). However, the best three crosses were; IR-1524 x NIA-ufaq (-18.53) Sindh-1 x NIA-ufaq (-0.53) and Sadori x NIA-ufaq (-0.50).

The heterotic effects of eighteen hybrids regarding 1st effective boll node number are presented in Table 5. Three hybrids expressing undesirable high mid and better parent heterosis respectively were; Sadori x Shahbaz (16.87, 10.21%), Sindh-1 x Shahbaz (13.35, 6.56%) and CRIS-134 x NIA-ufaq (10.58, 5.84%).

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

Source of variation	D.F.	Plant height	Sympodial branches plant	1st effective boll node number	1st sympodial node number	Bolls plant-1	Boll weight	Staple length	G.O.T%	Seed cotton yield plant-1	Seed index
Replications	3	80423.28	13.20	2.85	1.75	1.52	0.06	2.06	2.53	60.87	2.06
Genotypes	26	520.67**	18.26**	1.03**	0.84**	1089.388**	0.19 *	0.32*	9.56**	11393.78**	0.32**
Parents (P)	8	1299.22**	9.10**	1.76**	1.09*	187.85**	0.02**	0.36 **	16.26**	1256.33**	0.36**
Crosses (C)	17	172.54**	12.28**	0.75**	0.77*	417.00**	0.25**	0.32**	3.82**	2791.41**	0.32**
P vs. C	1	210.57**	193.23**	0.11 ns	0.00 ns	19732.03**	0.58**	0.05**	53.51**	238733.67**	0.05ns
Lines (GCA)	5	256.49**	25.03**	0.36**	0.60**	541.20*	0.32**	0.13**	4.18**	6055.51**	0.13**
Testers (GCA)	2	482.51**	11.93**	1.17**	0.75**	1054.44**	0.15**	0.17**	9.30**	2240.38**	0.17**
Line x Tester (SCA)	10	68.57**	5.97**	0.86**	11.42**	227.41**	0.23**	0.45**	2.55**	1269.57**	0.03ns
Error	78	35.12	0.11	0.09	0.02	0.03	0.00	0.03	0.03	150.70	0.03

**, * = Significant at 1 and 5% probability levels, respectively, ns= non-significant, GCA=general combining ability, SCA= specific combining ability

Table 2. Average performance of nine parents and their eighteen F_1 hybrids for various characters in upland cotton.

Parents/ F_1 hybrids	Plant height (cm)	Sympodial branches plant-1	1st effective boll node number	1st sympodial node number	Bolls plant-1	Boll weight (g)	Staple length (mm)	G.O.T (%)	Seed cotton yield plant-1 (g)	Seed index (g)
Lines										
Sindh-1	82.0	22.29	6.04	4.35	34.51	3.25	28.78	37.83	112.36	7.67
Sadori	99.7	24.55	6.07	4.70	39.96	3.17	28.51	42.80	126.87	7.93
CRIS-134	112.7	23.76	7.04	5.27	54.51	3.20	28.70	40.37	174.42	7.81
Chandi-95	130.9	24.61	6.36	4.27	45.78	3.14	29.30	38.78	143.99	8.64
Haridost	160.9	25.66	7.42	4.32	53.06	3.12	29.33	36.03	165.82	8.27
IR-1524	143.5	24.12	7.57	5.50	49.20	3.02	28.65	39.43	148.58	7.95
Testers										
NIA-ufaq	110.1	22.34	7.70	5.67	49.33	3.12	29.12	36.84	152.55	8.27
Sohni	101.9	20.70	7.57	5.05	38.62	3.15	29.45	38.22	121.67	8.27
Shahbaz	115.9	23.20	6.85	4.85	42.22	3.23	29.12	39.81	135.78	7.88
Average	117.5	23.47	6.95	4.88	45.24	3.15	29.00	38.9	142.4	8.07
F_1 hybrids										
Sindh-1 x NIA -ufaq	120.8	24.06	6.55	4.30	64.54	3.37	28.85	40.14	217.51	7.78
Sindh-1 x Sohni	112.8	24.05	6.77	4.80	58.58	3.52	29.80	40.59	206.86	7.69
Sindh-1 x Shahbaz	122.3	25.80	7.30	5.55	72.88	3.52	29.36	40.70	257.09	8.18
Sadori x NIA-ufaq	111.7	23.85	6.75	4.55	53.07	3.26	28.98	41.84	173.27	7.56

Sadori x Sohni	108.6	25.27	6.85	4.30	61.62	3.44	29.42	40.60	212.46	8.12
Sadori x Shahbaz	116.4	25.93	7.55	5.70	81.20	3.57	29.53	38.80	289.90	8.23
CRIS-134 x NIA-ufaq	123.1	25.25	8.15	5.47	69.21	3.37	29.60	41.29	233.60	7.70
CRIS-134 x Sohni	115.2	26.86	6.85	4.90	83.64	3.15	28.87	38.93	263.89	8.52
CRIS-134 x Shahbaz	125.3	25.13	6.82	4.55	77.71	3.04	29.64	40.28	237.22	7.64
Chandi-95 x NIA-ufaq	135.0	27.75	7.65	5.30	68.70	3.75	28.70	41.69	257.97	7.98
Chandi-95 x Sohni	121.1	25.12	6.90	4.65	80.45	3.32	29.62	39.93	267.30	7.98
Chandi-95 x Shahbaz	135.9	26.87	6.65	4.80	86.36	3.27	29.74	38.42	282.40	8.18
Haridost x NIA-ufaq	140.9	28.82	6.77	5.30	76.59	2.99	29.85	40.45	229.41	8.04
Haridost x Sohni	114.7	26.51	6.70	4.82	72.74	3.17	29.56	40.71	230.60	7.66
Haridost x Shahbaz	119.1	29.57	6.90	4.57	89.22	3.03	29.54	39.84	270.36	8.24
IR-1524 x NIA-ufaq	126.1	26.00	7.52	5.30	84.43	3.03	29.65	40.30	256.46	8.49
IR-1524 x Sohni	116.3	27.29	6.70	4.68	67.73	3.78	29.39	40.75	256.04	7.96
IR-1524 x Shahbaz	120.1	29.44	7.15	4.45	81.79	3.01	29.50	41.85	246.62	8.10
Average	121.4	26.30	7.02	4.88	73.91	3.31	29.42	40.39	243.83	8.00
LSD (5%)	0.559	0.464	0.426	0.173	0.252	0.042	0.146	0.258	12.903	0.254

While the hybrid IR-1524 x Sohni (-11.49%) showed minimum but desirable negative mid parent heterosis. Whereas minimum (-12.33) but desirable better parent heterosis was given by the hybrid Sadori x NIA-ufaq for 1st effective boll node number. Similar tour results, Baloch *et al*. (2014c) observed that two cotton genotypes like CRIS-134 and Sadori were significantly better for 1st flower, formed sympodial branches at relatively lower node and 1st effective boll on lower sympodia.

1st sympodial node number: Regarding appearance of 1st sympodia on plant, among six lines, three parents viz., Sindh-1 (-0.01), Sadori (-0.04) and IR-1524 (-0.08) expressed desirable negative GCA effects (Table 3). Similarly, from three tester parents, only Sohni (-0.20) displayed desirable negative GCA estimates and the reminder two males were undesirable by expressing positive effects for 1st sympodia. Among the hybrids, nine crosses manifested desirable negative SCA estimates while, other nine crosses which displayed positive SCA estimates were considered as undesirable. The best cross however was Sindh-1 x NIA-Ufaq (Table 4).

The heterotic effects of F_1 hybrids for 1st sympodial node number are accessible in Table 5. The minimum but desirable negative mid parent heterosis as well as better parent heterosis was manifested by the hybrid Sindh-1 x NIA-ufaq (-14.17, -24.16) respectively for 1st sympodial node number. Analogous results were also reported by Baloch *et al*. (2014c).

Bolls plant^{-1}: As bolls plant^{-1} increase, the yield is also expected to increase simultaneously. Therefore, high affirmative relationship between bolls and yield is usually observed between these two traits. On an average, maximum number of bolls plant^{-1}were set by crosses Haridost x Shahbaz, Chandi-95 x Shahbaz and IR-1524 x NIA-ufaq as *per se* hybrid performance. While from the parents, CRIS-134 produced maximum bolls plant^{-1} followed by Haridost (Table 2). The line Haridost recorded higher GCA effects whereas from testers, Shahbaz exhibited more desirable GCA effects indicating that these parents retain more additive genes, thus may be utilized in hybridization programs so as to improve the bolls per plant from segregating populations (Table 3). The results further revealed that crosses IR-1524 x NIA-ufaq, CRIS-134 x Sohni and Sadori x Shahbaz recorded higher SCA effects due to dominant and over dominant genes, hence may prove suitable crosses for hybrid cotton development (Table 4). The present results are in conformity with those of Jatoi *et al*. (2011).

Results presented in Table 6 revealed that all eighteen crosses expressed positive mid parent heterosis ranging from 18.88% to 97.61%. While heterobeltiosis varied from 7.58% to 92.32%. At least three hybrids were identified as manifesting high mid and better parent heterosis and such crosses were; Sadori x Shahbaz, Chandi-95 x Shahbaz and Chandi-95 x Sohni. The higher heterotic effects in general and in particular for these three crosses suggested that dominant and over dominant genes were controlling bolls plant^{-1} and hybrid cotton development with increased yield via more number of bolls plant^{-1} would be meaningful. Similar to our results, Abro *et al*. (2009) succeeded in identifying some hybrids which exhibited high positive relative heterosis and better parent heterosis for number of bolls plant^{-1}.

Boll weight: It may be assumed that as the size of boll becomes bigger, the yield consecutively increases. When we compared the average performance of parents *per se*, Sindh-1 weighed bigger bolls followed by Shahbaz. Similarly, *per se* performance of F_1 hybrids indicated that IR-1524 x Sohni weighed bigger bolls, while hybrid Chandi-95 x NIA-ufaq produced next heavier bolls (Table 2). The GCA and SCA variances denoted from lines, testers and line x tester interactions were highly significant indicating that both additive and non-additive genes were equally important for boll weight. However, the variances due to lines and testers being greater than their interactions revealed that GCA was predominant against the SCA. Among the parents, Sindh-1 revealed maximum GCA effects followed by Sohni (Table 3). Among the crosses, IR-1524 x Sohni expressed highest SCA effects and next higher SCA effects were recorded by the cross Chandi-95 x NIA-ufaq (Table 4). The present results are also in consonance with those observed by Alkuddsi *et al*. (2013) and Baloch *et al*. (2014a) who also reported that additive as well as dominant genes were advocating boll weight. Thus, our results suggested that parents Sindh-1 and Sohni are the best general combiners hence may be used for hybridization and selection programs. While crosses IR-1524 x Sohni and Chandi-95 x NIA-ufaq are best specific combiners and may be exploited for hybrid vigour to improve the boll weight.

The heterotic performance of F_1 hybrids for boll weight is depicted in Table 6. The highest relative heterosis and the highest heterobeltiosis were recorded by the cross Chnadi-95 x NIA-ufaq. Other hybrid combinations such as Sadori x Shahbaz, Sadori x Sohni and Sindh-1 x Sohni also gave significant increase over mid and better parents, however positive relative heterosis ranged from 1.27% to 19.80%, whereas better parent heterosis varied from 0.33% to 20%. Baloch *et al*. (2015) evaluated F_1 hybrids and maximum heterosis and heterobeltiosis were achieved in some hybrids for sympodia, number of bolls, boll weight, lint% and yield.

Staple length: Amongst the fiber properties, staple length is one of the most important fiber properties being considered from economic point of view, however, fiber length is more useful in yarn manufacturing. Mean performance indicated that among F_1 hybrids, Haridost x NIA-ufaq measured longer fiber whereas Sindh-1 x Sohni measured next ranking in producing long fiber.

Nonetheless, other hybrids also measured medium to medium long staple length (Table 2). Among the females, Haridost and from testers, Shahbaz expressed positive GCA effects (Table 3). For SCA effects, most of the F_1 hybrids exhibited positive SCA effects were; Sindh-1 x Sohni, CRIS-134 x NIA-ufaq and Haridost x NIA-ufaq (Table 4). These hybrids were noted as good specific combiners for hybridization and selection programmes so as to select desirable plants for staple length from later segregating populations or they may be considered for hybrid cotton development. to improve staple length. Present findings are in accordance with those reported by Arain *et al*. (2015) and Ashokkumar and Ravikesavan (2013).

The heterotic performance of crosses regarding the staple length is presented in Table 6. The hybrid IR-1524 x NIA-ufaq displayed maximum relative and better parent heterosis. The range of positive heterotic effects varied from 0.5 % to 2.66%. Whereas positive heterobeltiosis ranged from 0.37% to 1.82%. With consonance to our findings, significant and positive heterotic values were observed for fiber length, fiber elongation, seed cotton yield and ginning percentage by Karademir and Gencer (2010).

Ginning outturn percentage (G.O.T %): It is a complex character and polygenic in nature controlled by many genes. While comparing the mean performance of F_1 hybrids, IR-1524 x Shahbaz and Sindh-1 x Sohni exhibited first and next maximum ginners respectively. From the parents, Sadori ginned the highest lint percentage, yet next maximum lint % was ginned from CRIS-134 (Table 2). Among the lines, Haridost and from the tester NIA-ufaq exhibited positive GCA effects for this trait (Table 3). The top three higher SCA scoring hybrids however were; IR-1524 x Shahbaz, Chandi-95 x NIA-ufaq and Sadori x NIA-ufaq for ginning outturn percentage (Table 4). The present result are in consonance with those of Karademir and Gencer (2010) and Baloch *et al*. (2014a) who also reported that GCA and SCA variances suggested that both additive and dominant genes were controlling the lint character: From F_1 hybrids, crosses IR-1524 x Shahbaz and Chandi-95 x NIA-ufaq which were best specific combiners and retained more non-additive genes, may be utilized for hybrid crop development or selection for desirable plants may be exercised in later segregating generations.

With respect to the character ginning outturn percent, heterotic performance of various crosses are presented in Table 6. Results revealed that cross Haridost x NIA-ufaq showed maximum positive relative and better parent heterosis. The positive mid parent heterotic effects varied from 0.22% to 11.03% whereas positive better parent heterosis varied from 0.07% to 9.79%. Other researchers like Baloch *et al*. (2015) also succeeded in developing some F_1 hybrids which exhibited relative and better parent heterosis for sympodia, bolls plant^{-1}, boll weight, G.O.T% and yield plant^{-1}.

Seed cotton yield plant^{-1}: Yield per plant possess an exceptional importance for cotton breeders because it plays major role in boosting the finance of farmers and the country. Regarding *per se* mean performance hybrids Sadori x Shahbaz recorded highest yield whereas cross Chandi-95 x Shahbaz produced next higher seed cotton yield per plant (Table 2). While comparing *per se* mean performance of parents, CRIS-134 gave highest seed cotton yield whereas, Haridost gave next maximum seed cotton yield. The GCA and SCA effects were significant for seed cotton yield plant^{-1} due to significance of lines, testers and line x tester interaction. These results indicated that additive and non-additive genes were governing this character. However, the highest GCA effects were recorded by the line Chandi-95 and tester Shahbaz (Table 3) implied that both the parents are good general combiners, hence can reliably be used in hybridization and selection programmes to improve the yield. Maximum SCA effects were recorded by the cross Sadori x Shahbaz and Haridost x NIA-ufaq (Table 4). Present results are in conformity with those of Patil *et al*. (2014) and Swamy *et al*. (2013) who also reported significant GCA and SCA variances stating pre-dominance of additive as well as non-additive gene action involved in the inheritance of seed cotton yield.

The heterotic effects of all the eighteen F_1 hybrids regarding the seed cotton yield plant^{-1} are presented in Table 7. The results indicated that all the F_1 hybrids manifested positive mid parent and better parent heterosis. The positive mid parent heterosis ranged from 24.02% to 120.75% whereas, better parent heterosis varied from 13.58% to 113.50%. The outstanding mid parent and better parent heterosis were recorded by Sadori x Shahbaz. Tuteja and Agrawal (2013) noted that some hybrids gave significantly higher heterotic effects over the check hybrid CSHH for seed cotton yield.

Seed index: Seed index and seed cotton yield are usually positively correlated, that means increase in seed index will simultaneously increase the seed cotton yield. However, it is true that bolder seeds may produce higher seed cotton yield on the cost of lint%. The mean performance of hybrids *per se* showed that cross CRIS-134 x Sohni, and IR-1524 x NIA-ufaq gave maximum seed index (Table 2). Among the parents, line IR-1524 and tester Shahbaz expressed positive GCA effects (Table 3). Quite a number of hybrids expressed greater SCA estimates, yet highest positive SCA effects were recorded by cross CRIS-134 x Sohni and next higher ranker was IR-1524 x NIA-ufaq (Table 4). The present

Table 3. General combining ability (GCA) effects of lines and testers for various characters in upland cotton

Parents	Plant height	Sympodial branches plant^{-1}	1st effective boll node number	1st sympodial node number	Bolls plant^{-1}	Boll weight	Staple length	G.O.T%	Seed cotton yield plant^{-1}	Seed index
					Lines (females)					
Sindh-1	-2.07	-1.67**	-0.16*	-0.01	-8.58**	0.16**	-0.09**	0.02	-34.35**	-0.12**
Sadori	-6.88*	-1.29**	0.02	-0.04	-8.62**	0.11**	-0.11**	-0.23**	-20.95**	-0.03
CRIS-134	-0.15	-0.56**	0.24**	0.09*	2.94**	-0.12**	-0.05*	-0.38**	13.27*	-0.05
Chandi-95	9.96**	0.27**	0.04	0.03	4.59**	0.13**	-0.07*	-0.06	21.01**	0.04
Haridost	2.57	1.99**	-0.24**	0.01	5.60**	-0.25**	0.23**	0.57**	4.78	-0.02
IR-1524	-0.43	1.27**	0.09	-0.08*	4.07**	-0.04**	0.09**	0.02	16.24*	0.18**
S.E. (gi.)	4.75	0.13	0.12	0.05	0.07	0.00	0.04	0.07	9.14	0.07
					Testers (male pollinators)					
NIA-ufaq	3.62**	-0.35**	0.20**	0.15**	-4.49**	-0.01**	-0.15**	0.56**	-4.55	-0.08*
Sohni	-5.01*	-0.46**	-0.23**	-0.20**	-3.12**	0.09**	0.02	-0.14**	-6.54*	-0.01
Shahbaz	1.39	0.81**	0.03	0.05	7.61**	-0.07**	0.13**	0.41**	11.10*	0.09*
S.E. (gi.)	3.36	0.10	0.09	0.04	0.05	0.00	0.04	0.05	6.46	0.05

*=Declared significant when SCA values are equal or greater than S.E., **=Declared significant when the SCA values are equal or twice greater than S.E.

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

F_1 hybrids	Plant height	Sympodial branches plant^{-1}	1st effective boll node number	1st sympodial node number	Bolls plant^{-1}	Boll weight	Staple length	G.O.T (%)	Seed cotton yield plant^{-1}	Seed index
Sindh-1 x NIA –ufaq	-2.00	-0.22	-0.53**	-0.73**	3.70**	-0.09**	-0.34**	-0.89**	-26.93*	-0.02
Sindh-1 x Sohni	0.56	0.13	0.13	0.11*	-3.63**	-0.03*	0.44**	0.26*	12.96	-0.18*
Sindh-1 x Shahbaz	1.44	0.35*	0.39*	0.62**	-0.07	0.12**	-0.11**	0.63**	13.97	0.20*
Sadori x NIA-ufaq	-4.10	-0.82**	-0.50**	-0.45**	-7.73**	-0.15**	-0.18**	0.87**	0.31	-0.33*
Sadori x Sohni	2.24	0.71**	0.03	-0.35**	-0.56**	-0.07**	0.09*	0.33**	-20.62*	0.16*
Sadori x Shahbaz	1.86	0.10	0.47**	0.80**	8.29**	0.21**	0.09*	-1.20**	20.30*	0.17*
CRIS-134 x NIA-ufaq	-2.30	-0.14	0.67**	0.35**	-3.15**	0.20**	0.38**	0.56**	10.48	-0.18*
CRIS-134 x Sohni	0.52	1.57**	-0.19	0.12**	9.91**	-0.12**	-0.52**	-1.09**	3.29	0.58**
CRIS-134 x Shahbaz	1.78	-1.43**	-0.048	-0.47**	-6.75**	-0.07**	0.14**	0.53**	-13.76	-0.40**
Chandi-95 x NIA-ufaq	-0.42	1.53**	0.38*	0.24**	-5.31**	0.32**	-0.50**	1.12**	-9.58	0.01
Chandi-95 x Sohni	-2.27	-1.00**	0.07	-0.07	5.07**	-0.21**	0.25**	0.06	6.98	-0.05
Chandi-95 x Shahbaz	2.69	-0.53**	-0.45**	-0.16**	0.25*	-0.11**	0.26**	-1.18**	2.60	0.04
Haridost x NIA-ufaq	8.44*	0.88**	-0.22*	0.25**	1.57**	-0.06**	0.35**	-0.44**	14.98	0.14*
Haridost x Sohni	-7.72	-1.79**	-0.09	-0.07	-3.66**	0.02*	-0.09*	0.38**	-15.55	-0.32**

Haridost x Shahbaz	-5.74	0.46*	0.08	-0.37**	2.09**	0.04**	-0.24**	-0.08	-5.97	0.17*
IR-1524 x NIA-ufaq	0.39	-1.23**	-18.53**	0.34**	10.94**	-0.23**	0.29**	-1.22**	10.74	0.39**
IR-1524 x Sohni	1.65	0.17	-0.19	0.07	-7.13**	0.42**	-0.15**	-0.07	6.40	-0.21*
IR-1524 x Shahbaz	-2.04	1.05**	-0.01	-0.41**	-3.80**	-0.19**	-0.14**	1.29**	-17.14*	-0.18*
S.E. (si.)	8.22	0.23	0.21	0.09	0.13	0.01	0.07	0.13	15.82	0.13

*=Declared significant when SCA values are equal or greater than S.E., **=Declared significant when the SCA values are equal or twice greater than S.E.

Table 5. Heterotic effects of F_1 hybrids over their mid and better parents for plant height, sympodial branches, 1st effective boll node number and 1st sympodial node number

F_1 hybrids	Plant height		Sympodial branches		1st effective boll node number		1st sympodial node number	
	MP (%)	BP (%)	MP (%)	BP (%)	MP (%)	BP (%)	MP (%)	BP (%)
Sindh-1 x NIA -ufaq	25.76	9.71	10.26	7.69	-4.69	-115	-14.17	-24.16
Sindh-1 x Sohni	22.67	10.69	11.91	9.91	-0.44	-10.56	2.12	-4.95
Sindh-1 x Shahbaz	23.59	5.52	13.45	11.20	13.35	6.56	20.65	14.43
Sadori x NIA-ufaq	6.48	1.45	1.74	-2.85	-1.88	-12.33	-12.16	-19.75
Sadori x Sohni	7.73	6.57	11.71	2.93	0.43	-9.51	-11.70	-14.85
Sadori x Shahbaz	7.97	0.43	8.63	5.62	16.87	10.21	19.49	17.52
CRIS-134 x NIA-ufaq	10.50	9.22	9.54	6.27	10.58	5.84		-3.52
CRIS-134 x Sohni	7.36	2.21	20.82	13.04	-6.16	-9.51	-5.03	-2.97
CRIS-134 x Shahbaz	9.62	8.11	7.02	5.76	-1.20	-3.12	-10.07	-13.66
Chandi-95 x NIA-ufaq	12.03	3.13	18.23	12.75	8.81	-0.64	6.63	-6.52
Chandi-95 x Sohni	4.03	-7.48	10.90	2.07	-0.86	-8.85	-0.21	-7.92
Chandi-95 x Shahbaz	10.12	3.81	12.42	9.18	0.75	-2.91	5.26	-1.03
Haridost x NIA-ufaq	3.98	-12.43	20.08	12.31	-10.44	-12.07	6.21	-6.52
Haridost x Sohni	-12.70	-28.71	14.36	3.31	-10.54	-11.49	2.99	-4.55
Haridost x Shahbaz	-13.94	-25.97	21.03	15.23	-3.22	-8.85	-0.21	-5.77
IR-1524 x NIA-ufaq	-0.55	-12.12	11.92	7.79	-1.44	-2.33	-5.01	-6.52
IR-1524 x Sohni	-5.21	-18.95	21.77	13.14	-11.49	-11.49	-11.19	-7.32
IR-1524 x Shahbaz	-7.40	-16.30	24.42	22.05	-0.83	-5.54	-13.92	-19.09

MP=Mid parent heterosis, BP=Better parent heterosis.

Table 6. Heterotic effects of F_1 hybrids over their mid and better parents for bolls plant^{-1}, boll weight, staple length and ginning outturn percentage.

F_1 hybrids	Bolls plant^{-1}		Boll weight		Staple length		Ginning outturn (%)	
	MP (%)	BP (%)	MP (%)	BP (%)	MP (%)	BP (%)	MP (%)	BP (%)
Sindh-1 x NIA -ufaq	53.92	30.83	5.97	3.69	-0.34	-0.92	7.52	6.10
Sindh-1 x Sohni	60.22	51.68	10	8.30	2.37	1.18	6.75	6.20
Sindh-1 x Shahbaz	89.98	72.61	3.52	8.30	1.41	0.82	4.84	2.23
Sadori x NIA-ufaq	18.88	7.58	3.82	2.83	0.59	-0.48	5.07	-2.24
Sadori x Sohni	56.83	54.20	8.86	8.51	1.79	1.03	0.22	-5.14

Sadori x Shahbaz	97.61	92.32	11.56	10.52	2.49	1.40	-6.05	-9.34
CRIS-134 x NIA-ufaq	33.30	26.96	6.64	5.31	2.38	1.64	6.96	2.27
CRIS-134 x Sohni	79.63	53.43	-0.63	-1.56	-0.67	-0.85	-0.91	-3.56
CRIS-134 x Shahbaz	60.69	42.56	-5.29	-5.88	2.52	1.78	0.47	-0.22
Chandi-95 x NIA-ufaq	44.47	39.26	19.80	19.42	-1.74	-2.04	10.26	7.50
Chandi-95 x Sohni	90.63	75.73	5.73	5.39	0.85	0.57	3.71	2.96
Chandi-95 x Shahbaz	96.27	88.64	2.83	1.23	1.81	1.50	-2.21	-3.49
Haridost x NIA-ufaq	49.61	44.34	-4.16	-4.16	2.15	1.77	11.03	9.79
Haridost x Sohni	58.68	37.09	1.27	0.63	1.09	0.37	9.67	6.51
Haridost x Shahbaz	87.27	68.14	-4.41	-6.19	1.47	0.71	5.06	0.07
IR-1524 x NIA-ufaq	71.39	71.15	-1.30	0.33	2.66	1.82	5.69	2.20
IR-1524 x Sohni	56.83	37.66	-0.64	25.16	1.17	-0.20	4.97	3.34
IR-1524 x Shahbaz	78.93	66.23	-3.52	-6.81	1.54	1.30	5.62	5.12

MP=Mid parent heterosis, BP=Better parent heterosis.

Table 7. Heterotic effects of F_1 hybrids over their mid and better parents for seed cotton yield plant^{-1} and seed index

F_1 hybrids	Seed cotton yield plant^{-1}		Seed index	
	MP (%)	BP (%)	MP (%)	BP (%)
Sindh-1 x NIA –ufaq	64.22	42.58	-2.38	-5.92
Sindh-1 x Sohni	76.78	70.01	-3.51	-7.01
Sindh-1 x Shahbaz	107.21	89.34	5.27	3.80
Sadori x NIA-ufaq	24.02	13.58	-6.66	-8.58
Sadori x Sohni	70.96	67.46	0.24	-1.81
Sadori x Shahbaz	120.75	113.50	4.17	3.78
CRIS-134 x NIA-ufaq	42.89	33.92	-4.22	-6.89
CRIS-134 x Sohni	78.25	51.29	5.97	3.02
CRIS-134 x Shahbaz	52.94	36.00	-2.55	-3.04
Chandi-95 x NIA-ufaq	73.98	69.10	-5.56	-7.63
Chandi-95 x Sohni	101.23	85.63	-5.56	-7.63
Chandi-95 x Shahbaz	101.88	96.12	-0.96	-5.32
Haridost x NIA-ufaq	44.11	38.34	-2.78	-2.78
Haridost x Sohni	60.42	39.06	-7.37	-7.37
Haridost x Shahbaz	79.28	63.04	2.10	-0.36
IR-1524 x NIA-ufaq	70.33	68.11	4.68	2.66
IR-1524 x Sohni	89.49	72.32	-1.84	-3.74
IR-1524 x Shahbaz	73.45	65.98	2.40	1.88

MP=Mid parent heterosis, BP=Better parent heterosis.

results are in consonance with those obtained by Kumar *et al*. (2014) and Yanal *et al*. (2013) who also demonstrated significant GCA and SCA variances and effects for seed index. Based on present results, parent IR-1524 and Shahbaz proved to be the best general combiners for hybridization and selection programmes to improve seed index in cotton crop.

Relative heterosis and heterobeltiosis for seed index are presented in Table 7. In case of heterobeltiosis five, out of eighteen crosses exhibited positive better parent heterosis that varied from 1.88% to 3.80%. Cross Sindh-1 x Shahbaz expressed high positive better parent heterotic effect. Gohil *et al*. (2017) stated that six hybrids manifested significant positive heterotic effects with maximum estimates for its contributing characters like bolls per plant, average boll weight, lint%, yield per plant and seed index.

Conclusion: The significant mean squares for genotypes, parents, hybrids and parents vs. hybrids for almost all the traits indicated that the data is worth for determining parental performance, hybrid evaluation, and heterosis estimates. Significance of lines and testers indicated the importance of general combining ability (GCA) variances and effects, especially additive type of genes advocating different traits. The significant mean squares of line x tester interactions indicated the importance of specific combining ability (SCA) of the hybrids and important role of dominant or non-additive type of variances and effects. Among the lines, Chandi-95, IR-1524 and from testers Shahbaz expressed higher GCA effects for majority of the traits specially for seed cotton yield and ranked as the best general combiner hence they are suitable parents for hybridization and selection programmes so as to select desirable plants from segregating populations. For SCA effects, F_1 hybrids like CRIS-134 x Sohni, Sadori x Shahbaz , Haridost x NIA-ufaq and IR-1524 x NIA-ufaq demonstrated to be the best specific combiners for sympodial branches plant^{-1}, seed index, plant height, seed cotton yield plant^{-1}, and number of bolls plant^{-1}, therefore, these promising hybrids may be exploited for hybrid cotton development. High heterotic effects were expressed by the hybrids Sadori x Shahbaz for bolls per plant, boll weight and seed cotton yield; IR-1524 x NIA-ufaq for staple length and Chandi-95 x NIA-ufaq for G.O.T%.

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