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Estimation of Heterosis and Combining Ability in F_1 Hybrids of Upland Cotton for Yield and Fibre Traits

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Abstract. The experimental research was conducted so as to determine the general combining ability (GCA) and specific combining ability (SCA) estimates and heterotic effects for seed cotton yield and fibre traits in 5 × 5 half diallel crosses of upland cotton (*Gossypium hirsutum* L.). The parental genotypes studied were; CRIS-134, IR-3701, IR-1524, FH-113 and MG-6. The characters such as bolls/plant, sympodial branches/plant, boll weight (g), plant height (cm), fibre length (mm), seed cotton yield/plant (g), seed index (g) and ginning outturn percentage were studied. The experiment was laid-out in a randomized complete block design with four replications at experimental field of the Department of Plant Breeding & Genetics, Sindh Agriculture University Tandojam, Pakistan during 2013. The results revealed that, parents and hybrids differed significantly for their mean performance regarding all the traits studied. The importance of heterotic effects was evident from the significance of parents vs. hybrids performance. The variances due to GCA and SCA were significant for all the traits except that GCA was non-significant for boll weight only whereas, SCA was non-significant for boll weight, seed index and ginning outturn %. The significance of GCA indicated the importance of additive genes advocating the traits while, the involvement of non-additive genes was evident from the significance of SCA variances. The GCA variances were greater than SCA for bolls per plant, plant height, seed cotton yield and lint % while, SCA variances were higher than GCA for sympodial branches/plant and fibre length. Parents IR-3701, FH-113 and MG-6 displayed higher positive GCA effects for bolls/plant, sympodial branches/plant, fibre length, seed cotton yield, seed index and ginning outturn%. The *per se* performance of these three parents was exactly reflected in their GCA effects and such happenings are exceptional. Such results suggested that, all three parents were good general combiners covering most of the traits studied and may be preferred for hybridization and selection programmes. The crosses like CRIS-134 × MG-6, IR-3701 × FH-113 and IR-3701 × MG-6 with higher estimates of SCA for almost all the traits also expressed higher heterotic effects, thus these hybrids with dominant and over dominant genes could be potential hybrids for the exploitation of heterosis in cotton.

Keywords: general combining ability, specific combining ability, heterosis, upland cotton

Introduction

Estimation of genetic variation and combining ability are useful breeding tools being used in determining the breeding value of some populations or parents which guide cotton breeders to apply appropriate breeding procedures. The concept of combining ability is useful in testing procedures where, breeding objective focuses on comparing the performance of lines in hybrid combinations. Combining ability or productivity of hybrids is defined as the ability of parents or cultivars to combine amongst each other through hybridization so that favourable genes are transmitted to their progenies. Two types of combining ability, general and specific are well recognized in quantitative genetics. General combining ability (GCA) is defined as an average performance of a parent in a series of crosses whereas, specific combining ability (SCA) is the deviation in the performance of hybrids from the expected efficiency based upon the average performance of parents involved in the hybrid combination (Baloch *et al*., 2010). Thus, SCA is important for hybrid crop development whereas, GCA is useful for hybridization and selection programmes. Deshphande and Baig (2003) noted that, though GCA and SCA variances were important, yet the magnitude of SCA was higher than GCA indicating the preponderance of dominant genes controlling number of bolls, ginning outturn%, seed index, lint index and seed cotton yield. Similarly, combining ability analysis by El-Mansy *et al*. (2010), revealed significant GCA and SCA variances for most of the studied characters indicating that important role of both additive and non-additive genes. Contrary to such findings, Rokaya *et al*. (2005) and Jatoi *et al*. (2010) found significance of GCA and SCA suggesting the importance of additive

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as well as dominant genes, nevertheless the ratio of GCA/SCA was greater than the unity further indicating the preponderance of additive genes over the dominant ones in the inheritance of seed cotton yield, seed index and lint%.

Exploiting heterotic effects is one of the genetic parameters used to increase seed cotton yields that have reached to a plateau in recent years. In hybrid studies, large number of crosses and parental lines are used for assessing their heterotic effects and combining ability. On constantly observing the most potential crosses, attempts are also made to infer reasons of high heterosis. On the basis of genetic information available, heterotic groups have been developed (Patil *et al*., 2011). The term heterotic group refers to a group of related or unrelated genotypes from the same or different populations, which display similar combining ability and heterotic response when crossed with genotypes from other genetically distinct germplasm groups (Alkuddsi *et al*., 2013). The exercise of identifying diverse groups of parents is a continuous process because development of new breeding lines is a routine process. More recently, the concept of developing heterotic groups is put to investigate for predominantly self-pollinated crops like cotton. Segregating populations based on diverse pairs of genotypes can be the ideal base material required for implementing breeding procedures like reciprocal selection for improving combining ability (Patil *et al*., 2011; Patil and Patil, 2003). One of the problems in using heterosis in cotton involves defining a selection strategy of parents those ultimately will produce superior hybrids. Utilization of heterosis depends on genetic diversity existing between the parents, magnitude of dominance at the yield influencing loci and the genetic distance between the chosen parental genotypes. It is possible to maximise heterosis by enhancing genetic distance between two chosen parental lines or populations. Both, heterosis and heterobeltiosis in cotton have been observed by various workers such as; Nirania *et al*. (2004) obtained 36.55% heterosis for seed cotton yield; Kandhro *et al.* (2004) recorded 8.33% for bolls per plant; Ganapathy *et al*. (2005) noted 16.66% heterosis for ginning outturn%, 21.31% for seed index and 30.78% for lint index. While Basal *et al.* (2011) observed heterotic values of 79.8, 19.8, 35.2, and 5.7%, respectively, boll number, boll weight and lint %, yet, the heterosis values for fibre quality parameters were generally lower than that for yield components and 14.1% heterosis was noted for micronaire. The magnitude of heterosis varies from cross to cross and species-to-species. The present study evaluated the parents and hybrids produced from 5 × 5 diallel mating design with the objectives to estimate parental general and specific combining ability effects and heterosis of F_1 hybrids.

Materials and Methods

An experiment was conducted in the experimental field of the Department of Plant Breeding and Genetics, Sindh Agriculture University Tandojam, Sindh, Pakistan during Kharif crop season 2013. Total 5 parents *viz*. CRIS-134, IR-3701, IR-1524, FH-113 and MG-6 were crossed in a diallel mating fashion, thus 10 F_1 hybrids were developed so as to study the combining ability and heterotic effects of some quantitative traits in upland cotton (*Gossypium hirsutum* L.). The seeds of parents and 10 F_1 hybrids were sown in a randomised complete block design with 4 replications. The distance between row to row and plant to plant was kept at 75.0 to 30.0 cm, respectively. Sowing was done by hand dibbling method. Three seeds per hill were sown to ensure uniform plant stand. After 25 days of sowing, seedlings were thinned and only one vigorous plant was left to grow. Ten plants were tagged at random from central rows of each genotype per replication for recording the data. The observations were recorded for number of bolls/plant, sympodial branches/plant, boll weight (g), plant height (cm), fibre length (mm), seed cotton yield/plant (g), seed index (100 seeds weight, g), ginning outturn percentage (GOT %)/ lint %. The analysis of variance was carried according to Gomez and Gomez (1984) for determining the differences among the genotypes, whereas combining ability variances and their effects were determined through half diallel biometrical approach developed by Griffing's Model-1, Method-11 (1956) and adopted by Singh and Choudhary (1979) while heterosis was calculated with the following formulae developed by Fehr (1987).

$$\text{Mid-parent heterosis (\%)} = \frac{F1 - MP}{MP} \times 100$$

$$\text{Mid-parent heterosis (\%)} = \frac{F1 - HP}{HP} \times 100$$

where:

F_1 = performance of hybrid; MP = average performance of parents *per se* (parent 1 + parent 2)/2; HP = performance of best parent.

Results and Discussion

Mean performance of parents and their F_1 hybrids. The mean performance of parents and their hybrids have been summarized in Table 1, which indicates that among the parents, FH-113 formed maximum bolls/plant, produced highest number of sympodial branches/plant and gave maximum seed cotton yield/plant, highest seed index and ginned maximum lint%; the dwarfed plant with heavier bolls were recorded by the parent IR-1524. On an average, hybrids performed better than the parents for almost all the traits studied, however among the hybrids, at least two crosses IR-3701 × FH-113 and IR-3701 × MG-6 were at par in performance, yet set higher number of bolls, formed more number of sympodial branches, measured longer fibre, produced maximum seed cotton yield/plant, gave higher seed index and ginned higher lint%, hence ranked superior over the other eight hybrids evaluated. It is very interesting to note that parental performance like IR-3701 and FH-113 is well reflected in hybrid performance which is rarely expected. By and large hybrids performed better against the parents which are expected due to hybrid vigour expressed by the F_1s. Similar to present findings, several previous researchers like Baloch *et al*. (2014); Khan (2013), Alkuddsi *et al*. (2013b) and Jatoi *et al.* (2010) also reported significant differences among parents and their F_1 hybrids performance for yield and fibre traits in cotton.

Mean squares for general and specific combining ability analysis. The mean squares from analysis of variance revealed significant differences among the parents, crosses and parents vs. crosses for almost all the traits. These results suggested that parents and F_1 hybrids differed in the mean performance for various yield and fibre traits. The significance of parents vs. crosses revealed the scope of heterosis breeding. The variances due to general combining ability (GCA) and specific combining ability (SCA) presented in Table 2 were also significant for bolls/plant, sympodial branches/plant, fibre length, plant height and seed cotton yield/plant and lint% except that GCA was non-significant for boll weight and seed index whereas, SCA was

Table 1. Mean performance of parents and their F_1 hybrids for seed cotton yield, its components and fibre traits

Genotypes	Bolls/ plant	Sympodial branches/	Boll weight plant	Plant height (g)	Fibre length (cm)	Seed cotton yield/plant (mm)	Seed index (g)	Ginning outturn (g)(%)
					F_1 hybrids			
CRIS-134 × IR-3701	79.25	30.00	3.17	117.25	28.22	251.04	4.51	41.89
CRIS-134 × IR-1524	53.06	27.75	3.48	101.75	28.1	184.46	4.4	38.68
CRIS-134 × FH-113	78.06	29.55	3.22	108.5	28.58	251.55	4.95	41.57
CRIS-134 × MG-6	88.06	29.75	3.23	139.5	28.8	284.49	4.83	40.57
IR-3701 × IR-1524	78.16	28.73	3.21	121.00	27.49	251.10	4.91	41.24
IR-3701 × FH-113	105.44	33.00	3.29	129.5	30.05	347.41	5.39	42.91
IR-3701 × MG-6	102.36	31.5	3.83	138.5	28.72	392.78	4.92	41.88
IR-1524 × FH-113	67.12	29.25	3.49	101.25	27.38	235.75	4.59	38.15
IR-1524 × MG-6	60.75	28.14	3.18	98.25	27.7	193.06	4.76	39.73
FH-113 × MG-6	75.82	29.75	3.49	111.5	29.1	264.70	5.04	41.38
Average	78.8	29.74	3.35	116.7	28.14	265.63	4.83	40.80
LSD (5%)	2.90	1.07	0.14	5.89	0.38	17.77	0.16	0.38
					Parents			
CRIS-134	50.12	19.81	3.23	125	26.76	162.24	4.86	39.64
IR-3701	55.94	24.06	3.52	124	28.02	212.25	5.05	41.82
IR-1524	60.12	23.01	2.85	117	27.91	159.81	4.49	38.84
FH-113	66.5	24.8	3.15	99.93	28.36	209.86	4.68	40.12
MG-6	59.31	24.75	3.18	130.43	27.12	188.95	4.41	40.65
Average	58.39	23.28	3.18	119.27	27.63	186.62	4.69	40.21
LSD (5%)	1.11	0.40	0.06	2.58	0.14	6.92	0.06	0.28

Table 2. Mean squares for general and specific combining ability for various yield and fibre traits in upland cotton

Source of variation	Degrees of freedom	Mean squares							
		Sympodial branches/ plant	Plant height	Bolls/plant	Boll weight	Seed cotton yield/plant	Ginning outturn (%)	Fibre length	Seed index
Replication	3	4.13	59.81	36.45	0.35	199.3	0.14	0.096	0.044
Genotype	14	50.73**	758.72**	1148.5**	0.76**	17116.4**	7.66**	2.81**	0.308**
Parents (P)	4	16.59**	558.81**	143.95**	0.26 **	2515.5**	4.99**	1.79**	0.08
Crosses (C)	9	9.62**	922.04**	1105.51**	0.18**	16259.6**	9.18**	2.67**	0.224**
P vs. C	1	557.33**	88.40	5550.8**	0.41 **	83231.24**	4.53**	8.08 **	0.240**
GCA	4	6.62**	350.20**	268.28 **	0.04	5329.1**	4.78**	0.18*	0.12**
SCA	9	16.80**	139.41**	212.35**	0.06	4287.8**	0.84	0.76 **	0.07
Error	42	1.49	44.84	10.91	0.03	411.8	0.79	0.23	0.04

**, * = significant at 1 and 5% probability levels, respectively.

non-significant for boll weight, seed index and lint%. The significance of GCA mean squares indicated the importance of additive genes advocating the traits while the significance of SCA variances suggested that the traits were controlled by non-additive genes.

However, the GCA variances were greater than SCA for bolls/plant, plant height, seed cotton yield/plant and lint index while it was *vice versa* for sympodial branches per plant and fibre length. Madhuri *et al.* (2015) and Alkuddsi *et al*. (2013b), evaluated intra-hirsutum hybrids developed through line × tester mating design using 6 non-Bt hirsutum lines crossed with 8 Bt hirsutum genotypes. From combining ability estimates, though both additive and dominance variances were significant, yet dominance was prevailing for seed cotton yield/plant, plant height, bolls/plant and 2.5% span length. Similar to our results, Hamound (2014) found significant effects of GCA and SCA, yet none of the parents was good general combiner for all the studied traits. The magnitude of GCA and SCA variances revealed pre-dominance of additive as well as non-additive gene action in the inheritance of seed cotton yield and its yield attributes (Baloch *et al*., 2014; Swamy *et al*., 2013). Singh *et al.* (2010) attempted 8 × 8 half diallel for combining ability analysis and revealed significant general and specific combining ability variances for all traits measured except lint index and seed index. Yet, pre-dominance of non-additive gene action was observed for ginning outturn and 2.5% span length, while preponderance of additive gene action was obtained in seed cotton yield, boll weight and fibre elongation.

Combining ability and heterotic effects. For formulating sound breeding strategy for any crop species, it is important to know the genetic constitution of genotype/varieties and their quantitative traits. Yadav *et al*. (2009) presented the relationship between general combining ability of parents and the expression of heterosis. They stated that if the heterosis is manifested by the parents with high × high, low × high and low × low general combining ability, it indicated the involvement of additive, additive genes with complementary effects, over-dominant and epistasis gene interactions, respectively. With respect to GCA effects, parents IR-3701 and FH-113 displayed higher positive effects for bolls/plant, sympodial branches/plant, fibre length, seed cotton yield/plant, seed index and ginning outturn%, yet MG-6 also performed well for bolls/plant, sympodial branches, seed cotton yield and lint% (Table 3). The *per se* performance of these three parents particularly, exactly reflected in general combining ability effects. These results suggested that, all 3 parents were good general combiners covering most of the traits studied; however, their additive genes indicated that these parents can greatly be relied upon for hybridisation and selection programmes. Jatoi *et al*. (2010) found that GCA and SCA estimates anticipated that both additive and non addi-tive genes were controlling sympodia/plant, yet GCA variance being higher than SCA variances indicated greater influence of additive genes over the non-additive ones. The SCA effects of hybrids suggested that, crosses CRIS-134 × MG-6 and IR-3701 × FH-113 were good specific combiners for number of bolls/plant, sympodial branches/plant, fibre length, seed cotton yield/plant,

Table 3. General combining ability effects for various yield and fibre traits in upland cotton

Parents	Sympodial branches/plant	Plant height	Bolls/plant	Boll weight	Seed cotton yield	Ginning outturn (%)	Fibre length	Seed index
CRIS-134	-1.26	1.66	-3.88	-0.03	-19.96	-0.23	-0.24	-0.04
IR-3701	0.83	6.98	6.02	0.10	33.00	1.13	0.22	0.16
IR-1524	-0.80	-7.01	-7.91	-0.10	-35.97	-1.16	-0.34	-0.15
FH-113	0.80	-7.81	5.50	-0.001	11.91	0.09	0.42	0.08
MG-6	0.44	6.18	0.34	0.04	11.02	0.17	-0.06	-0.04
S.E. (gi.)	0.20	1.28	0.55	0.03	3.43	0.14	0.07	0.03

seed index and ginning outturn% (Table 4). Besides, hybrid IR-3701 × MG-6 expressed the highest SCA effects for seed cotton yield. From present results it could be inferred that the hybrids which manifested maximum SCA effects possess dominant and over dominant genes and such crosses are desirable for hybrid crop development to improve the traits under breeding objectives. Present results are in conformity with those of Solangi *et al*. (2002), who observed significant variances due to both additive and non-additive gene actions for number of sympodia/plant; Jatoi *et al*. (2011) for boll weight; Basal *et al*. (2009) and Kalpande *et al.* (2008) for plant height; Karademir and Gencer (2010) for fibre length; Alkuddsi *et al*. (2013b) for seed cotton yield/plant and bolls/plant and Baloch *et al*. (2010) for ginning outturn percentage.

It is generally presumed that hybrid performance by itself is reflected in SCA effects and heterotic effects. But in reality that assumption did not always hold true. In present investigation, the above assumptions to a large extent hold true in that the hybrids like CRIS-134 × MG-6, IR-3701 × FH-113 and IR-3701 × MG-6 higher estimates of SCA for almost all the traits also expressed higher heterotic effects for bolls/plant, sympodial branches/plant, fibre length, seed cotton yield/plant and ginning outturn % (Table 5).

These hybrids with dominant and over dominant genes could be potential hybrids for the exploitation heterosis in cotton. Similar to present findings; Nidagundi *et al*. (2012) observed high heterosis of 46.14% for bolls/plant, Patil *et al*. (2011) estimated high heterosis over better parent and standard check in boll formation which was associated with higher seed cotton yield; positive heterotic values for fibre length, fibre elongation, seed cotton yield and ginning percentage were noted by Karademir and Gencer (2010). Appreciable amount of heterosis for plant height, sympodia/plant, bolls/plant, boll weight, seed index, ginning % and 2.5% span length was observed by Saravanan and Koodalingam (2011).

Table 4. Specific combining ability effects for various yield and fibre traits in upland cotton

F_1 hybrids	Sympodial branches/plant	Plant height	Bolls/plant	Boll weight	Seed cotton yield	Ginning outturn (%)	Fibre length	Seed index
CRIS-134 × IR-3701	2.84	-8.96	6.97	-0.2	-13	0.39	0.09	-0.4
CRIS-134 × IR-1524	2.23	-10.45	-10.78	0.32	1.10	-0.53	0.54	0.19
CRIS-134 × FH-113	2.42	-2.91	6.29	-0.05	20.31	1.11	0.25	0.12
CRIS-134 × MG-6	2.98	14.09	21.45	-0.08	54.31	0.02	0.95	0.13
IR-3701 × IR-1524	1.11	3.46	9.91	-0.09	14.7	0.67	-0.54	0.11
IR-3701 × FH-113	3.78	12.77	23.76	-0.12	63.2	1.08	1.26	0.35
IR-3701 × MG-6	2.63	7.77	3.41	0.38	109.45	-0.03	0.39	0.02
IR-1524 × FH-113	1.66	-1.48	-0.61	0.29	20.51	-1.38	0.84	-0.13
IR-1524 × MG-6	0.55	-18.48	-18.25	-0.06	-21.29	0.11	-0.05	0.17
FH-113 × MG-6	0.91	-4.42	-0.18	0.15	2.47	0.51	0.59	0.21
S.E. (si.)	0.53	2.92	1.44	0.07	8.8	0.38	0.19	0.08

Table 5. Heterotic and heterobeltiotic effects in F_1 hybrids for morph-yield traits in upland cotton

F_1 hybrids	Sympodial branches/plant		Plant/height		Bolls/plant		Boll weight		Seed cotton yield		Ginning outtun (%)		Fibre length		Seed index	
	Ht	Hb	Ht	Hb	Ht	Hb	Ht	Hb	Ht	Hb	Ht	Hb	Ht	Hb	Ht	Hb
CRIS-134 × IR-3701	36.7	24.7	-0.5	-6.2	43.8	31.7	-6.2	-9.9	84.5	18.3	84.5	18.3	2.8	0.5	2.8	0.5
CRIS-134 × IR-1524	29.6	20.6	-15.9	-18.8	0.1	-5.1	15.2	7.7	25.4	13.7	25.4	13.7	2.8	0.7	2.8	0.7
CRIS-134 × FH-113	32.5	19.2	-3.5	-13.2	33.9	17.4	0.9	-0.3	53.1	19.9	53.1	19.9	3.6	0.7	3.6	0.7
CRIS-134 × MG-6	33.5	20.2	9.2	6.9	60.9	48.5	0.9	0.0	82.8	50.6	82.8	50.6	6.9	6.2	6.9	6.2
IR-3701 × IR-1524	22.1	19.4	0.4	-2.4	34.7	30.0	1.6	-8.8	67.3	18.3	67.3	18.3	-1.7	-1.9	-1.7	-1.9
IR-3701 × FH-113	35.1	33.1	15.7	4.4	66.5	58.5	1.2	-6.5	107.7	63.7	107.7	63.7	-1.7	5.9	-1.7	5.9
IR-3701 × MG-6	29.1	27.3	8.9	6.2	71.4	70.2	14.3	8.8	147.7	85.1	147.7	85.1	4.2	2.5	4.2	2.5
IR-1524 × FH-113	22.4	17.9	-6.6	-13.5	9.6	0.9	17.1	10.8	37.7	12.3	37.7	12.3	-2.7	-3.4	-2.7	-3.4
IR-1524 × MG-6	17.8	13.6	-20.6	-24.6	5.4	2.4	6.0	0.0	10.7	2.6	10.7	2.6	0.7	-0.7	0.7	-0.7
FH-113 × MG-6	20.1	19.9	-3.2	-14.5	20.5	14.0	10.4	9.7	47.4	26.1	47.4	26.1	4.9	2.6	4.9	2.6

Ht = heterosis; Hb = heterobeltiosis.

Conclusion

The variances due to GCA and SCA were significant for all the traits except that GCA was non-significant for boll weight only whereas, SCA was non-significant for boll weight, seed index and ginning outturn%. The significance of GCA indicated the importance of additive genes advocating the traits while, the involvement of non-additive genes was evident from the significance of SCA variances. The GCA variances were greater than SCA for bolls/plant, plant height, and seed cotton yield and lint%, nonetheless SCA mean squares were higher than GCA for sympodial branches/plant and fibre length. Parents IR-3701 and FH-113 displayed higher positive GCA effects for bolls/plant, sympodial branches/plant, fibre length, seed cotton yield, seed index and ginning outturn%, yet MG-6 also performed well for bolls/plant, sympodial branches, seed cotton yield and lint%. The *per se* performance of these three parents were perfectly reflected in general combining ability effects and such happenings are exceptional. These results suggested that all three parents were good general combiners covering most of the traits studied. The SCA effects of hybrids suggested that the crosses CRIS-134 × MG-6 and IR-3701 × FH-113 were considered as good specific combiners for majority of the traits, thus such crosses are desirable for hybrid crop development to improve the traits studied.

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