Estimating Combining Ability of Yield and its Components in Upland Cotton Through Line × Tester Analysis

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Abstract. Combining ability estimates are very important genetic attributes to cotton breeders in predicting improvement that could be envisaged from hybridisation and selection programmes. The crosses were attempted in a line × tester mating design, which involved five female and three testers, hence 15 F_1 hybrids were developed. The experiment was carried out in a randomised 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 × testers interactions were significant, for all the characters studied. The significance of GCA and SCA variances suggests that both additive and non-additive genes were controlling the characters, yet additive genes of female lines were predominant because their variances were generally, higher than GCA of testers and SCA of lines × testers. Among the lines, parents CIM-506, CRIS-134 and Sadori and from testers, Bt-cotton and Sindh-1 exhibited higher GCA effects hence proved to be the best general combiners for most of the traits studied. Results further suggested that these potential parents can reliably be used in hybridisation and selection programmes for extracting desirable plants from segregating populations. The F_1 hybrids like Sadori × Sindh-1, Chandi × Bt-cotton and Sadori × BH-160 were best specific combiners for earliness (bolls formation and opening at 90 and 120 days after planting), bolls per plant, boll weight, seed cotton yield per plant, lint % and staple length. The performance of F_1 hybrids *per se* was very well reflected in SCA effects, conferring the potentiality of F_1 hybrids.

Keywords: combining ability, hybridisation, genetic variability, upland cotton

Introduction

For the improvement of any plant character, plant breeders heavily rely upon the availability of genetic variability determined by various mating designs. Cotton breeders are well aware of the phenomenon that in a hybridisation programme, certain crosses pass-on more favourable genes towards the progeny than the others. Thus, some cross combinations may be superior as compared to their parents for improving economic traits in cotton breeding programmes.

Cotton breeders are looking for desirable genes and gene complexes, thus identification of promising parents/ individuals is very important task in all breeding programmes (Baloch *et al.,* 2010). Mating designs are one of the biometrical breeding tools which help the breeders to recognise the potential parents and the promising recombinants/hybrids. For these purposes, diallel analysis has been extensively used but line × tester analysis is still superior mating design against diallel in that, it

uses more and different sets of parents as males and females with relatively small number of crosses. Thus, it provides more reliable estimates of genetic variances among males and females as compared to diallel analysis. In a diallel mating, the parents are crossed in all possible combinations to identify parents as best or /poor general combiners through general and specific cross combinations. It involves both direct as well as reciprocal crosses through which maternal effects can also be ascertained. To exploit different types of gene action in plant population, information regarding the relative magnitude of genetic variation and combining ability for important traits in cotton is essential. The first step in the utilisation of heterosis is a selection from the available germplasm that could produce the best combinations of important characters. The entire genetic variability in the analysis of each trait is partitioned into general and specific combining ability as defined by Sprague and Tatum (1942), and reciprocal effects as sketched by Griffing (1956). They stated that GCA effects administer the additive type of gene action,

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whereas, SCA effects are due to genes which are non-additive (dominant or epistatic) in nature. Batool and Khan (2012), Hassan *et al*. (1999), and Sayal *et al*. (1997), reported the importance of non-additive type of gene action for different cotton traits. However, Khan (2010), Bhutto *et al*. (2001), Baloch *et al*. (2000), and Khan *et al*. (1991), stressed upon the appreciable degree of variance due to GCA for morpho-yield traits. Makhdoom (2011), Khan *et al*. (2009; 2005), and Khan (2003), observed that mean squares due to GCA and SCA were highly significant; however, the genetic variances due to SCA were greater than GCA for yield related traits, showing the predominance of non-additive gene action. High × low and low × high GCA parents performed well in SCA determination (Makhdoom, 2011). Many commercial cotton cultivars despite their high or low agronomic performance combine in a better or poor way when used as a parental cultivars in cross combinations (Batool *et al*., 2010, Makhdoom *et al*., 2010). Therefore, the present research work was conducted to evaluate the performance of some new but important commercial upland cotton genotypes and 15 F_1 hybrids were developed through line × tester analysis so as to ascertain their genetic potential, genetic variability and combining ability for seed cotton yield and yield related traits.

Materials and Methods

An experiment was conducted at the experimental field of the Department of Plant Breeding and Genetics, Sindh Agriculture University Tandojam, Pakistan, during 2010. The experimental material was consisted of 5 parental female lines (CIM-506, CRIS-134, CIM-496, Sadori and Chandi) and 3 testers/pollinators (Bt-cotton, Sindh-1 and BH-160) and their 15 F_1 hybrids belonging to upland cotton (*Gossypium hirsutum* L.). The seed of 15 F_1 hybrids was developed by attempting crosses in line × tester mating fashion during 2009. The seed of parents and their F_1 hybrids was sown in a randomised complete block design with four replications. Distance between row to row and plant to plant was kept at 75.0 and 30 cm, respectively. Three rows of each genotype were grown in a plot size of 7.5 × 45.0 feet. Sowing was done by dibbling method. Three seeds per hill were sown to ensure uniform stand. After 25 days of sowing, seedlings were thinned and only one vigorous plant was allowed to grow. The inorganic fertiliser like one bag (50 kg) of DAP per hectare was applied at the time of sowing, whereas, two bags of urea, one with third irrigation and second dose was applied at the time of grain formation. To reduce the intensity of harmful weeds, weedicide like Buctrol Super at the rate of 1000 cc was applied after first irrigation. Five plants from each replication per genotype were tagged at random from central rows excluding border plants for recording the data.

The characters studied were; node number to set first sympodial branch, bolls formed at 90 days after planting, bolls opened at 120 days after planting, plant height (cm), bolls per plant, boll weight (g), seed cotton yield per plant (g) ginning outturn percentage (GOT%) and staple length (mm). The analysis of variance was carried-out according to Gomez and Gomez (1984) for determining differences among the genotypes whereas, combining ability variances and effects were calculated according to statistical methods developed by Kempthorne (1957) and adopted by Singh and Choudhry (1985).

Results and Discussion

The mean squares from analysis of variance (Table 1) revealed significant differences for GCA of lines, GCA of testers and SCA of lines × testers indicating predominance of additive as well as non-additive genes controlling node number to first sympodial branch, bolls formed at 90 days after planting (DAP), bolls opened at 120 (DAP), plant height (cm), bolls per plant, boll weight (g), seed cotton yield per plant (g) ginning outturn percentage (GOT%) and staple length (mm). The mean performance of hybrids *per se* summarised in Table 2 indicates that CRIS-134 × Sindh-1 produced maximum bolls per plant, gave tallest plants, yet ranked next in GOT% and staple length. While, hybrid Sadori × Bt-cotton formed maximum bolls at 90 days after planting (DAP), yet ranked next good performing in bolls opened at 120 (DAP), boll weight and seed cotton yield per plant. The hybrid Chandi × Bt-cotton opened maximum bolls at 120 (DAP); CIM-496 × Bt-cotton recorded heavier bolls; Sadori × Sindh-1 produced maximum seed cotton yield per plant and scored next in bolls per plant; CRIS-134 × BH-160 ginned maximum GOT% and CRIS-134 × Bt-cotton measured longest staple. Among the parents, Chandi formed lowest node to 1st sympodial branch, opened maximum bolls after 120 (DAP), whereas, Sadori formed maximum bolls at 90 (DAP) and measured tallest plants, weighed bigger bolls, produced maximum seed cotton yield and ginned highest GOT% and ranked second in bolls per plant and staple length, while, CRIS-134 produced maximum bolls per plant and measured longest staple length.

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

Source of variation	DF	Node number to 1st sympodia	Earliness (bolls formed at 90 DAP*)	Earliness (bolls opened at 120 DAP)	Plant height	No. of bolls per plant	Boll weight	Seed cotton yield per plant	GOT %	Staple length
Replications	3	0.36	0.77	0.90	137.90	3.49	0.03	6.00	1.59	0.27
Genotypes	22	4.63**	61.63**	43.05**	617.30**	236.10**	0.65**	4763.00**	10.12**	3.87**
Crosses	14	5.59**	50.07**	37.20**	590.70**	3.81**	0.83**	3176.00**	12.03**	4.16**
Lines (GCA)	4	3.00**	70.15**	41.85**	1045.00**	5.91**	0.79**	4279.00**	27.89**	8.22**
Testers (GCA)	2	10.22**	12.22**	11.48**	952.30**	1.79**	2.07**	3611.00**	2.45**	0.02ns
Lines × tester (SCA)	8	5.73**	49.49**	41.30**	273.20**	3.26**	0.53**	2515.00**	6.49**	3.16**
Error	42	0.76	0.62	0.56	12.14	0.43	0.01	67.86	0.41	0.58

** = significant at 1 % probability level, DAP * = days after planting.

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

Parents (lines and testers)	Node to 1st sympodia	Bolls formed at 90 DAP*	Bolls opened at 120 DAP	Plant height (cm)	Bolls per plant	Boll weight (g)	Seed cotton yield per plant (g)	GOT (%)	Staple length (mm)
CIM-506	6.50	7.50	6.25	134.50	51.00	3.25	165.80	37.75	27.50
CRIS-134	5.75	6.25	5.00	140.50	54.50	3.15	171.70	37.75	28.50
CIM-496	7.50	8.50	7.50	115.00	49.50	3.45	170.80	36.75	28.25
Sadori	5.50	9.75	6.75	146.50	53.50	4.05	216.65	39.25	28.25
Chandi	5.50	4.50	9.75	139.50	52.50	3.25	167.50	37.50	27.50
Bt-cotton	7.50	7.75	6.50	121.00	50.00	3.55	177.50	36.25	27.25
Sindh-1	5.50	6.50	4.50	118.25	48.00	3.10	148.80	37.50	28.25
BH-160	7.00	6.50	6.25	138.50	46.50	3.30	153.50	38.50	26.50
F_1 hybrids									
CIM-506 × Bt-cotton	7.50	9.50	7.75	140.00	60.50	3.10	187.60	38.25	29.25
CIM-506 × Sindh-1	5.25	11.50	9.75	145.00	58.50	2.95	202.05	36.25	28.50
CIM-506 × BH-160	4.50	12.00	11.00	153.75	63.50	3.30	209.45	39.50	29.00
CRIS-134 × Bt-cotton	6.75	7.75	5.75	132.75	65.50	3.65	239.05	40.25	30.25
CRIS-134 × Sindh-1	8.50	12.50	9.00	163.75	70.50	3.05	215.00	41.25	30.00
CRIS-134 × BH-160	5.75	9.50	7.75	153.75	66.50	3.45	229.45	41.50	28.50
CIM-496 × Bt-cotton	6.50	9.50	7.25	143.75	57.00	4.55	259.30	38.25	27.75
CIM-496 × Sindh-1	7.50	11.75	9.75	153.75	60.50	3.55	214.80	37.50	29.50
CIM-496 × BH-160	5.50	14.75	11.50	130.00	66.50	3.15	209.50	37.00	28.75
Sadori × Bt-cotton	7.75	16.25	12.50	124.50	64.50	4.05	261.20	40.25	27.50
Sadori × Sindh-1	7.00	15.00	11.00	137.50	68.50	3.85	263.75	41.00	28.25
Sadori × BH-160	5.75	16.00	12.50	133.75	66.50	3.00	199.50	38.50	29.25
Chandi × Bt-cotton	5.25	11.00	15.50	123.75	66.50	3.65	242.75	39.25	28.00
Chandi × Sindh-1	7.75	10.20	11.50	133.75	67.50	3.10	209.20	3725	26.50
Chandi × BH-160	7.50	10.00	7.50	127.50	59.50	3.10	184.40	36.50	27.50
LSD/ (5%)	2.16	9.50	1.84	8.73	1.63	0.24	20.66	1.59	2.16

DAP* = days after planting.

The mean squares due to GCA of lines were highly significant for all the characters (Table 1), whereas, GCA effects among the lines revealed that CRIS-134 displayed maximum GCA for number of bolls per plant, plant height, GOT % and staple length (1.02) and Sadori exhibited maximum GCA effects for bolls formed at 90 days, bolls opened at 120 days and seed cotton yield per plant; CIM-496 recorded higher GCA effects for boll weight and moderately desirable for plant height, yet CIM-506 expressed negative but desirable GCA effect for 1st sympodial node number (Table 3).

From the tester parents, Sindh-1 demonstrated higher GCA effects for node number to set first sympodial branch, bolls formed at 90 days of planting, bolls opened at 120 days after planting and total number of bolls formed. While, tester Bt-cotton recorded maximum GCA effects for boll weight, seed cotton yield per plant and GOT% (Table 3).

Whereas, BH-160 exhibited maximum GCA for staple length, yet it expressed maximum but negatively desirable GCA for node number to 1st sympodial branch (Table 3).

With respect to SCA effects, hybrid Sadori × Sindh-1 recorded maximum SCA estimates for bolls per plant, boll weight, seed cotton yield per plant and GOT %. Hybrid Chandi × Bt-cotton exhibited maximum SCA for bolls formed at 90 days after planting and bolls opened at 120 days after planting; Sadori × BH-160 measured longer staple length and also gave negatively desirable SCA effect for 1ˢᵗ sympodial node number (Table 4).

The analysis of variance showed highly significant differences among the genotypes (eight parents and fifteen F₁ hybrids) for all the traits (Table 1). The partition of crosses mean squares into GCA for lines, GCA for testers and SVA for lines × tester interaction also revealed significant differences for all traits except that the staple length in tester was non-significant. These results indicate that both additive and non-additive genes were operating for the studied traits. While, comparing the mean squares of lines and testers, the results indicated that lines showed greater GCA variances for majority of the traits against the testers (Lu and Myers, 2011; Khanzada *et al.*, 2008; Panhwar *et al.*, 2008). When the SCA of lines × testers interaction was compared with GCA of lines or testers, it was noted that GCAs of lines specially were higher

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

Parents	Node number to 1ˢᵗ sympodia	Earliness (bolls formed at 90 DAP*)	Earliness (bolls opened at 120 DAP)	Plant height	No. of bolls per plant	Boll weight	Seed cotton yield per plant	GOT %	Staple length
Lines (females)									
CIM-506	-0.83	-1.54	-0.68	6.44	-0.83	-0.32	-23.76	-0.85	0.35
CRIS-134	0.42	-2.21	-1.93	10.27	0.84	-0.05	4.37	2.15	1.02
CIM-496	-0.08	-1.21	-1.18	2.69	-0.70	0.32	4.40	-1.27	0.10
Sadori	0.25	3.54	2.65	-7.90	0.59	0.20	26.34	1.06	-1.23
Chandi	0.25	1.45	1.15	-11.48	0.09	-0.15	-11.35	-1.10	-0.01
S.E.(gi.)	0.25	0.22	0.21	1.00	0.18	0.02	2.37	0.18	0.21
Testers (pollinators/males)									
Bt-cotton	0.17	-0.71	-0.53	-6.86	-0.33	0.37	14.52	0.40	-0.01
Sindh-1	0.62	0.84	0.87	6.94	0.24	-0.13	-2.50	-0.15	-0.01
BH-160	-0.78	-0.11	-0.33	-0.06	0.10	-0.23	-12.00	-0.25	0.04
S.E. (gi.)	0.19	0.17	0.16	0.77	0.14	0.02	1.84	0.14	0.17

DAP* = days after planting.

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

F₁ Hybrids	Node number to 1ˢᵗ sympodia	Earliness (bolls formed at 90 DAP*)	Earliness (bolls opened at 120 DAP)	Plant height	No. of bolls per plant	Boll weight	Seed cotton yield per plant	GOT %	Staple length
CIM-506 × Bt-cotton	1.58	-1.46	-1.72	0.61	45.63	-0.38	-26.62	-0.15	0.35
CIM-506 × Sindh-1	-1.12	-1.01	-1.12	-8.19	43.06	-0.03	4.85	-1.60	-0.40
CIM-506 × BH-160	-0.47	2.44	2.83	7.56	48.20	0.42	21.75	1.75	0.05
CRIS-134 × Bt-cotton	-0.42	-2.54	-2.47	-10.47	48.96	-3.10	-3.30	-1.15	0.68
CRIS-134 × Sindh-1	0.88	3.91	3.13	6.73	53.39	-0.20	-10.33	0.40	0.43
CRIS-134 × BH-160	-0.47	-1.39	-0.67	3.73	49.53	0.30	13.62	0.75	-1.12
CIM-496 × Bt-cotton	-0.17	-1.79	-1.72	8.11	42.00	0.43	16.92	0.27	-0.90
CIM-496 × Sindh-1	0.38	-1.09	-0.62	4.31	44.93	-0.07	-10.56	0.07	0.85
CIM-496 × BH-160	-0.22	2.86	2.33	-12.44	51.07	-0.37	-6.36	-0.33	0.05
Sadori × Bt-cotton	0.75	0.21	0.70	-0.55	48.21	0.05	-3.12	-0.06	0.82
Sadori × Sindh-1	-0.45	-0.84	-0.20	-1.35	51.64	0.35	16.45	1.24	-0.07
Sadori × BH-160	-0.30	0.61	-0.50	1.90	49.78	-0.40	-38.30	-1.16	0.88
Chandi × Bt-cotton	-1.75	5.55	5.20	2.28	50.71	0.00	16.12	1.10	0.68
Chandi × Sindh-1	0.30	-1.00	-1.20	-1.52	51.14	-0.05	-0.41	-0.10	-0.82
Chandi × BH-160	1.45	4.55	-4.00	-0.77	43.28	0.05	-15.71	-1.00	0.13
S.E. (si.)	0.43	0.39	0.37	1.74	0.32	0.05	4.11	0.32	0.38

DAP* = days after planting.

for almost all the traits indicating preponderance of additive genes controlling the traits. Jatoi *et al.* (2011) reported greater GCA than the SCA suggesting greater importance of additive against non-additive genes particularly dominant genes. It is generally believed that hybrid performance *per se* is most of the times but not always reflected in SCA effects (Baloch, 2004). However, in present studies, the results did not confirm it which indicates that, hybrid performance *per se* may not be trusted for their higher SCA effects (Jatoi *et al.*, 2010). The mean performance of F_1 hybrids *per se* is summarised in Table 2, indicat that CRIS-134 × Sindh-1 produced maximum bolls per plant, gave tallest plants, yet ranked next in GOT% and staple length. While hybrid Sadori × Bt-cotton formed maximum bolls at 90 days after planting (DAP), yet ranked next good performing in bolls opened at 120 DAP, boll weight and seed cotton yield per plant. The hybrid Chandi × Bt-cotton opened maximum bolls at 120 DAP; CIM-496 × BT-cotton recorded bigger bolls; Sadori × Sindh-1 produced maximum seed cotton yield per plant and scored next in bolls per plant; CRIS-134 × BH-160 ginned maximum lint% and CRIS-134 × Bt-cotton measured longest staple. From these results it can be inferred that none of the F_1 hybrids was good performing for majority of the traits.

Among the female lines, Chandi formed lowest node to 1st sympodial branch, opened maximum bolls at 120 DAP, whereas, Sadori formed maximum bolls at 90 DAP and measured tallest plants, weighed bigger bolls, produced maximum seed cotton yield and ginned highest GOT % and ranked second in bolls per plant and staple length; yet CRIS-134 set maximum bolls per plant and measured longest fibre length. These results suggested that earlier maturing variety may also form more number of total bolls hence, produce higher seed cotton yield (Jatoi *et al.,* 2012).

Earliness is very important character in cotton because late maturing crop suffers from many losses like low market value, requires additional inputs, delays wheat sowing and favours late season insect-pest attacks (Jatoi *et al.,* 2012). As far as GCA effects of lines are concerned, CRIS-134 displayed maximum GCA for number of bolls per plant, plant height, GOT % and staple length; Sadori exhibited maximum GCA effects for bolls formed at 90 DAP, bolls opened at 120 (DAP) and seed cotton yield per plant; CIM-496 recorded higher GCA effects for boll weight and moderately desirable for plant height, yet CIM-506 expressed negative but desirable GCA effect for 1st sympodial

node number (Table 3). Parental lines CRIS-134 and Sadori, which exhibited higher GCA effects for seed cotton yield, its components and earliness characters may best be in hybridisation and selection programmes due to having additive genes. Khan *et al.* (2009), Mueen *et al.* (2008), Wu *et al.* (2008), and Zhu *et al.* (2007), noted significant GCA effects, which were due to additive genes for yield and earliness traits. Lu and Myers (2011) stated that, influential cotton lines are those, which contribute a larger proportion of genes to modern cotton cultivars than any other germplasm. From the tester parents, Sindh-1 demonstrated higher GCA effects for node number to set first sympodial branch, bolls formed at 90 DAP, bolls opened at 120 DAP and total bolls formed; Bt-cotton recorded maximum GCA effects for boll weight, seed cotton yield per plant and GOT %, whereas, BH-160 for staple length, yet maximum negative but desirable GCA for node number to 1st sympodial branch. Since the Pakistani breeders are very much interested in developing varieties, which are earlier in maturing and fit very well in wheat-cotton rotation (Jatoi *et al.*, 2012). In this context, parent Sindh-1 and Bt-cotton with additive genes may be potential parents for hybridisation and selection pro-grammes so as to improve yield and earliness parameters simultaneously.

For hybrid crop to be feasible in cotton, it is very impor-tant to identify parents, which express high SCA effects. With respect to SCA effects, hybrid Sadori × Sindh-1 recorded maximum SCA for bolls per plant, boll weight, seed cotton yield per plant and GOT%, whereas, Chandi × Bt-cotton exhibited maximum SCA for bolls formed at 90 DAP and bolls opened at 120 DAP, yet Sadori × BH-160 measured longer staple length and also gave negatively desirable SCA effects for 1st sympodial node number. The hybrids, which manifested higher SCA effects are considered as having more dominant genes therefore can be potential crosses for hybrid cotton development. Yet for their commercial use, these hybrids could be evaluated for several years over multiple locations so as to confirm their superiority. Similar to present results, Patil *et al.* (2011) noted significant, SCA effects for seed cotton yield and fibre quality traits in cotton.

Conclusion

Combining ability estimates help plant breeders to select potential parents for hybridisation and selection programmes. The mean squares due to general combining ability (GCA) of lines and testers and specific

combining ability (SCA) of lines × testers interactions were significant, indicating that both additive and non-additive genes were advocating the characters. Among the lines, parents CIM-506, CRIS-134 and Sadori and from testers, Bt-cotton and Sindh-1 expressed higher GCA effects hence proved to be the best general combiners for most of the traits and are suitable parents for hybridisation and selection programmes. The F_1 hybrids like Sadori × Sindh-1, Chandi × Bt-cotton and Sadori × BH-160 were best specific combiners for earliness (bolls formation and opening at 90 and 120 days after planting), bolls per plant, boll weight, seed cotton yield per plant, lint % and staple length. The performance of F_1 hybrids *per se* was very much reflected in SCA effects, conferring the potentiality of F_1 hybrids.

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