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Genetic variability study for fiber quality traits in some F1 hybrids of Cotton (*Gossypium hirsuitum* L.)

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ABSTRACT
The present experiment was planned to study the genetic basis of some agronomic traits contributing to yield of upland cotton. In this experiment, four genotypes viz PB-896, PB-76, AGC-2 and VH-282 were used as parents, which were crossed in all possible combinations. The F_1 along with four parents was evaluated in field conditions. These progenies were planted in three replications following RCBD. At the time of maturity, data were recorded on plant height, no. of bolls plant^{-1}, boll weight, seed cotton yield and ginning out turn. The data were used for analysis of variance to test the variation among genotypes for these traits. All the genotypes were highly significant for the parameters under studied. The same data set were analyzed for combining ability effects. The results were also highly significant for general combining ability, specific combining ability and reciprocal combining ability. Further combining ability effects and means showed that among the parents AGC-2 was found to be good general combiner for plant height and number of bolls per plant. The parent VH-282 was proved to be a good general combiner for boll weight and ginning out turn while PB-76 was good general combiner for seed cotton yield per plant. The hybrid of PB-896 × PB-76 exhibited good specific combining ability for plant height, number of bolls per plant, boll weight and seed cotton yield per plant. The cross of VH-282 × AGC-2 was found to be good specific combination for number of bolls per plant and PB-76 × AGC-2 was identified as good specific combination for boll weight and seed cotton yield per plant. The hybrid PB-76 × VH-282 was good cross combination for ginning out turn. In case of reciprocal combinations AGC-2 × PB-896 was found to be good combination for plant height, boll weight and seed cotton yield per plant while AGC-2 × PB-76 for number of bolls per plant. The parents and crosses which have good combining abilities for certain traits could be used in breeding programs for the improvement of these traits in cotton.
Key words: Cotton, combining ability effects, agronomic traits

INTRODUCTION

The cultivation of cotton in tropical and subtropical areas of the world is mainly for the fibre and oil purpose. Cotton (*Gossypium hirsutum* L.) belongs to family Malvaceae and genus *Gossypium*. *Gossypium* genus contain more than 50 species, about 46 are wild and 4 are cultivated. Among cultivated species *G. herbaceum* and *G. arboreum* are diploid (2n=2x=26) while *G. barbadense* and *G. hirsutum* are tetraploid (2n=2x=52). *G. hirsutum* is also known as upland cotton which is cultivated worldwide (Poehlman and Sleeper, 1995). With respect to ranking in the world China, USA, India and Pakistan are largest producer of cotton respectively (Hanif and Jafri, 2008), and it provide working sources to 1.5 million farming families (Hussain *et al*., 2010).

Cotton seed also provides edible oil (Ali and Awan, 2009), and low-quality oil used in soap industry and lubricants. Although marvelous achievements for the enhancement of cotton yield in terms of fiber, seed, and oil are made by Pakistani scientist in past but there is a need of high yielding varieties to meet the increasing demand of fiber and oil sectors in the country. The average yield of existing varieties is low as compare to existing genetic potential available in the germplasm. For improving the genetic architecture and crop production the genetic information of different quantitative traits is helpful for cotton breeders (Abbas *et al*., 2008). The existence of genetic variation within a species is a pre-requisite to start a breeding program for the development of new genotypes (Bajracharya *et al*., 2006). The success of breeding program primarily depends on promising parental lines. The parents are selected due to the presence of favorable genes and their pattern of inheritance (Ali *et al*., 2008). Genetic variability could be induced by using breeding methods like polyploidy, hybridization and introduction of exotic germplasm (Esmail *et al*., 2008). Likewise, several biometrical approaches are available to investigate various mechanism or gene action for the control of important plant parameters. One of them is diallel analysis which is also used to check the nature of inheritance of genetic variation in different plant characters (Griffing, 1956). Full diallel mating design is also used to estimate the general and specific combining abilities of parental lines (Gilbert, 1958). The present research was conducted for the evaluation of combining abilities and gene action for yield, its components and fibre quality traits of cotton lines. In this research four cotton genotypes and their F_1 hybrids were analysed by Griffing's approach, to check the performance of four parents of cotton and their F_1 hybrids for fiber and agronomic parameters. This performance is evaluated on the basis of general combining ability (GCA), specific combining ability (SCA) and type of gene action involved for selected traits.

Materials and methods

The presented research work was conducted for the determination of combining ability effects of cotton lines for some agronomic traits at the experimental area of the Department of Plant Breeding and Genetics, University of Agriculture, Faisalabad. Four lines of cotton namely PB-896, PB-76, VH-282 and AGC-2 were collected from cotton research group, which were planted in earthen pots placed in green house. At the time of flowering these varieties were crossed in complete diallel mating design and some of buds were self-pollinated. All of precautionary measures were taken to avoid alien pollens or contamination.

The list of parents and their crosses is given below.

Parents	Direct Crosses	Indirect Crosses
PB-896	PB-896 × PB-76	PB-76 × PB-896
PB-76	PB-896 × VH-282	VH-282 × PB-896
VH-282	PB-896 × AGC-2	AGC-2 × PB-896
AGC-2	PB-76 × VH-282	VH-282 × PB-76
	PB-76 × AGC-2	AGC-2 × PB-76
	VH-282 × AGC-2	AGC-2 × VH-282

The F_0 cotton seeds from 12 hybrids and their 4 parents were sown in field conditions in three replications under randomized complete block design. Ten plants of each family were planted in each row and plant to plant and row to row distance was maintained 30cm and 75cm respectively. All of agronomic practices were followed uniformly to have good crop. The data was collected from five guarded plants from each row. These guarded plants were tagged separately and data were collected at the time of maturity on individual plant.

Statistical analysis

Analysis of variance of collected data was carried out for the determination of varietal differences for desired traits (Steel *et al*.,1997). The data set showing significant differences was analyzed for combining ability (general and specific) by using Griffing's approach (1956).

The present research work was conducted to investigate the combining abilities (general and specific) of four parents and their 12 F_1 hybrids for 11 agronomic parameters by using 4 × 4 full diallel analysis. Following results were obtained for all the characters under investigation of combining abilities.

Results and discussion

Plant height (cm)

Average value for plant height of four parents and their 12 F_1 hybrids were subjected to the analysis of variance (ANOVA). Highly significant differences ($p<0.01$) were found among the 16 genotypes (four parents, six direct crosses and six indirect crosses) for plant height while in replication non-significant differences were found (Table 1). Due to presence of variation the same data set were further analyzed for combining ability. Results from combining ability analysis showed that general combining ability (GCA), specific combining ability (SCA) and reciprocal combining ability (RCA) values are highly significant ($p<0.01$) as indicated by (Table 2).

The selection of desired parent for plant height among four parents were done by testing general combining abilities. The parent AGC-2 was found best general combiner for the plant height because the value of general combining ability for AGC-2 is positive (2.47) and highly significant. PB-896 (-0.71), PB-76 (-0.64) and VH-282 (-1.11) were found poor general combiners due to negative GCA effects (Table 3).

Specific combining abilities of 12 F_1 hybrids were tested for the selection of best combination for plant height. The hybrid PB-896 × PB-76 was found best specific combination which showed highly significant and positive SCA effects (1.38) and originated from poor general combiners as shown in Table 3. The hybrids of PB-76 × VH-282 (-0.18), PB-76 × AGC-2 (-0.42) and VH-282 × AGC-2 (-0.34) were poor specific combinations due to non-significant and negative SCA effects and were yielded by a parent having good general combining ability. The crosses PB-896 × VH-282 (-6.23) and PB-896 × AGC-2 (-3.96) were highly significant but poor specific combinations due to negative value of SCA effects as indicated in Table 3. Our results are accordance with the findings of Islam *et al*. (2001) who revealed that parents with high GCA effects does not essentially produced hybrids with high SCA effects, both the GCA and SCA effects were not dependent on each other.

Results presented in Table 3 showed Highly significant, positive and high for reciprocal effects of indirect cross AGC-2 × PB-896 (4.28) followed by AGC-2 × VH-282 (2.86) revealed as best combinations while rest of crosses were highly significant but poor due to negative RCA effects. Performance of parent AGC-2 was found good in reciprocal combinations because maternal effects are important for this trait and poor in some specific combinations (Table 3). The genotype AGC-2 has higher value of GCA effects so it can be used as desirable parent for plant height for next generation. These results were similar with the findings of Islam *et al*. (2001) who found higher SCA effects as compared to RCA values. Kempthorne (1957) reported two classes of genetic variability i.e. general and specific combining abilities which are useful to study genetic control of traits. Neelima *et al*. (2004) exhibited that parameters such as plant height, number of bolls per plant, number of sympodial branches, fiber strength, seed index, fibre length and lint percentage were under the influence of non-additive gene action but Khan, (2003); Iqbal and Nadeem (2003) and Neelima *et al*. (2004) revealed that both additive and non-additive gene action were important for plant height.

Table 1 Analysis of variance for plant height in parents and crosses of upland cotton

Source of variation	D.F.	Sum of squares	Means of squares

Replication	2	3.64	1.19^{ns}
Genotype	15	1540.47	102.69**
Error	30	28.06	0.93
Total	47	1575.19	

Table 2. Analysis of variance of combining abilities for plant height in *Gossypium hirsutum* L.

Source of variation	D.F.	Sum of square	Means of squares
GCA	3	66.53	22.17**
SCA	6	259.83	43.30**
Reciprocal	6	187.12	31.18**
Error	30		0.31

Where ** <0.01 Highly significant, *<0.05 Significant, NS>0.05 Non Significant

Table 3. GCA, SCA and reciprocal estimation for four parents for plant height in upland cotton.

Parents	**GCA effects**
PB-896	-0.7135 **
PB-76	-0.6469 **
VH-282	-1.1177 **
AGC-2	2.4781 **
S.E. (gi - gj)	0.1710
Direct crosses	**SCA effects**
PB-896 × PB-76	1.3802 **
PB-896 × VH-282	-6.2323 **

PB-896 × AGC-2	-3.9615 **
PB-76 × VH-282	-0.1823 [ns]
PB-76 × AGC-2	-0.4281 [ns]
VH-282 × AGC-2	-0.3406 [ns]
S.E. (sij – sik)	0.3122
Indirect crosses	**Reciprocal effects**
PB-76 × PB-896	-5.1667 **
VH-282 × PB-896	-4.5833 **
AGC-2 × PB-896	4.2833 **
VH-282 × PB-76	-1.5333 **
AGC-2 × PB-76	-4.1167 **
AGC-2 × VH-282	2.8667 **
S.E. (rij – rki)	0.3949

Number of bolls per plant

Results from analysis of variance exhibited highly significant differences ($p<0.01$) among 16 genotypes (four parents, six direct crosses and six indirect crosses) for number of bolls per plant while replication was non-significant as presented in table 4. Same data set was further analyzed for combining ability due to presence of variation in the data set. Results from combining ability analysis showed that general combining ability, specific combining ability and reciprocal combining ability values were highly significant ($p<0.01$) as indicated by table 5.

General combining ability was estimated to study the performance of four parents for number of bolls per plant. The parent AGC-2 was found best general combiner for the number of bolls per plant due to highly significant and positive value of general combining ability for AGC-2 i.e. 0.62 while PB-76 (0.33) was positive but showed significant GCA effects and was second general combiner after AGC-2. The parent PB-896 (-0.33) and VH-282 (-0.62) were found poor general combiners exhibited negative value for GCA effects as indicated by table 6. In our findings, number of bolls per plant was found significant for mean squares due to GCA. Similarly, Hassan *et al*. (2000) showed significant mean squares for number of bolls per plant. Specific combining abilities of 12 F_1 hybrids were studied for the selection of best combination for number of bolls per plant. The hybrids PB-896 × PB-76 (1.91) followed by VH-282 × AGC-2 (1.08) were found excellent combinations due to highly significant and positive SCA effects as indicated in table 6 and were in support of Khan *et al.* (2009) who revealed that parents with high GCA produced good combinations when used as male parent. The hybrid PB-76 × VH-282 (0.04) was non-significant but showed positive SCA effects. The crosses PB-896 × AGC-2 (-0.20), PB-76 × AGC-2 (-0.37) were non-significant and PB-896 × VH-282 (-2.12) was highly significant but these all were poor specific combinations due to negative SCA effects (Table 6). In case of number of bolls per plant it was also noticed that parents with good GCA showed poor performance in hybrid development. Such contradiction might be due to genetic makeup of *G. hirsutum* lines and the environment where the crop was grown Khan *et al*. (2015).

In case of reciprocal effects, the combination AGC-2 × PB-76 exhibited highly significant and positive value (1.50) for number of bolls per plant and revealed as good combination. The crosses AGC-2 × PB-896 (0.66), AGC-2 × VH-282 (0.33) and VH-282 × PB-76 (0.33) were non-significant but showed positive RCA effects while rest of crosses were poor combinations due to negative RCA effects (Table 6). The genotype AGC-2 has higher GCA effects so it can be used as desirable parent for number of bolls per plant for next generation. These results were similar with the findings of Deosarkar *et al*. (2009). The parent AGC-2 was found best general combiner for number of bolls per plant. Non-additive effects are more important for number of bolls per plant because our findings are similar to the findings of Neelima *et al.* (2004) and Rauf *et al.* (2006).

Table 4. Analysis of variance for number of bolls per plant in parents and crosses of upland cotton

Source of variation	D.F.	Sum of squares	Means of squares
Replication	2	0.87	0.43^{ns}
Genotype	15	123.00	8.20**
Error	30	23.12	0.77
Total	47	147.00	

Table 5. Analysis of variance of combining abilities for number of bolls per plant in *Gossypium hirsutum* L.

Source of variation	D.F.	Sum of square	Means of square
GCA	3	8.02	2.67**
SCA	6	23.02	3.83**
Reciprocal	6	9.94	1.65**
Error	30		0.25

Where ** <0.01 Highly significant, *<0.05 Significant, NS>0.05 Non Significant

Table 6. GCA, SCA and reciprocal estimation for four parents for number of bolls per plant in upland cotton.

Parents	**GCA effects**
PB-896	-0.3333 *
PB-76	0.3333 *
VH-282	-0.6250 **
AGC-2	0.6250 **
S.E. (gi - gj)	0.1552
Direct crosses	**SCA effects**
PB-896 × PB-76	1.9167 **
PB-896 × VH-282	-2.1250 **
PB-896 × AGC-2	-0.2083 ^{ns}
PB-76 × VH-282	0.0417 ^{ns}
PB-76 × AGC-2	-0.3750 ^{ns}
VH-282 × AGC-2	1.0833 **
S.E. (sij – sik)	0.2834
Indirect crosses	**Reciprocal effects**
PB-76 × PB-896	-0.8333 *
VH-282 × PB-896	-1.1667 **
AGC-2 × PB-896	0.6667 ^{ns}
VH-282 × PB-76	0.3333 ^{ns}
AGC-2 × PB-76	1.5000 **
AGC-2 × VH-282	0.3333 ^{ns}
S.E. (rij – rki)	0.3584

Boll weight (g)

Average values for boll weight of four parents and their 12 F_1 hybrids were subjected to the analysis of variance (ANOVA). Highly significant differences (p<0.01) were found among the 16 genotypes (four parents, six direct crosses and six indirect crosses) for boll weight while replication was non-significant as shown by the table 7. The data set of boll weight was further analyzed for combining ability due to presence of variation. Results from combining ability analysis showed that GCA was significant ($p<0.05$), SCA was non-significant ($p>0.05$) and RCA values was highly significant ($p<0.01$) as presented by table 8.

The selection of desired parent for the increment of boll weight among four parents were carried out by testing general combining abilities. The genotype VH-282 was found best parent for the boll weight because the value of general combining ability effects for VH-282 was positive (0.06) and significant while PB-76 (0.03) was also positive but showed non-significant GCA effects. The parent PB-896 (-0.03) and AGC-2 (-0.06) were found poor general combiners due to negative values for GCA effects (Table 9).

The hybrids PB-76 × AGC-2 (0.07) followed by PB-896 × PB-76 (0.04) were showed positive SCA effects but non-significant as indicated in table 4.4.3. The hybrids PB-76 × VH-282 (-0.08), PB-896 × VH-282 (-0.004) and VH-282 × AGC-2 (-0.02) were non-significant and negative for SCA effects which revealed them poor specific combinations for boll weight. The cross PB-896 × AGC-2 (-0.12) was significant but poor specific combination for boll weight due to negative SCA effects as shown by table 9. The parent VH-282 was found good general combiner but showed poor performance in hybrid production so the selection of superior combination should not rely on general and specific combining abilities only but should also base on mean performance Basal *et al*. (2011).

Results presented in table 9 showed highly significant and positive reciprocal effects for combination AGC-2 × PB-896 (0.33) and was revealed as good combination for boll weight but in SCA effects it was poor specific combination due to negative value while rest of reciprocal crosses were poor combinations because of negative RCA effects (Table 9). In case of direct and indirect crosses our results are not in accordance with the findings of (Khan *et al*. (2009; 2011) who revealed that high GCA parents exhibited high yielding combinations in *G. hirsutum*. Our results are accordance with the findings of Islam *et al*. (2001) who revealed that parents with high GCA effects does not essentially produced hybrids with high SCA effects, both the GCA and SCA effects were not dependent on each other. The genotype VH-282 has higher value of GCA effects so it can be used as desirable parent for the improvement of boll weight for next generation. These results were similar with the findings of Sarwar *et al*. (2011) who found significant results for boll weight.

Table 7. Analysis of variance for boll weight in parents and crosses of upland cotton

Source of variation	D.F.	Sum of squares	Means of squares
Replication	2	0.06	0.03^{ns}
Genotype	15	2.44	0.16**
Error	30	0.66	0.02
Total	47	3.16	

Table 8. Analysis of variance of combining abilities for boll weight in *Gossypium hirsutum* L.

Source of variation	D.F.	Sum of square	Means of square
GCA	3	0.08	0.02*
SCA	6	0.08	0.01^{ns}
Reciprocal	6	0.64	0.10**
Error	30		0.007

Where ** <0.01 Highly significant, *<0.05 Significant, NS>0.05 Non Significant

Table 9. GCA, SCA and reciprocal estimation for four parents for boll weight in upland cotton.

Parents	**GCA effects**
PB-896	-0.0350^{ns}
PB-76	0.0375^{ns}
VH-282	0.0625 *
AGC-2	-0.0650 *
S.E. (gi - gj)	0.0263
Direct crosses	**SCA effects**
PB-896 × PB-76	0.0421^{ns}
PB-896 × VH-282	-0.0046^{ns}
PB-896 × AGC-2	-0.1204 *
PB-76 × VH-282	-0.0871^{ns}
PB-76 × AGC-2	0.0704^{ns}
VH-282 × AGC-2	-0.0229^{ns}
S.E. (sij – sik)	0.0479
Indirect crosses	**Reciprocal effects**
PB-76 × PB-896	-0.4350 **

VH-282 × PB-896	-0.0533 ^{ns}
AGC-2 × PB-896	0.3367 **
VH-282 × PB-76	-0.0533 ^{ns}
AGC-2 × PB-76	-0.0867 ^{ns}
AGC-2 × VH-282	-0.0750 ^{ns}
S.E. (rij – rki)	0.0606

Seed cotton yield per plant (g)

Analysis of variance (ANOVA) for seed cotton yield per plant of four parents and their 12 F_1 hybrids exhibited highly significant differences ($p<0.01$) among the 16 genotypes (four parents, six direct crosses and six indirect crosses) while in replication non-significant differences were found as presented in the table 10. Due to presence of variation, the same data set was further analyzed for combining ability. Results from combining ability analysis revealed that GCA, SCA and RCA values were highly significant ($p<0.01$) as indicated by table 11.

General combining abilities of four parents were studied for the selection of desired parent for seed cotton yield per plant. Results showed that parent PB-76 was best general combiner for the seed cotton yield per plant because the value of general combining ability for PB-76 was positive (0.57) and highly significant while rest of the parents were found non-significant and poor general combiner for seed cotton yield due to negative value of GCA effects as indicated by table 4.5.3. In our findings, seed cotton yield per plant was found significant for mean squares due to GCA. Similarly, Hassan *et al*. (2000) showed significant mean squares for seed cotton yield per plant.

Specific combining abilities of 12 F_1 hybrids were studied for the selection of best combination for seed cotton yield per plant. The hybrids PB-76 × AGC-2 (1.40) followed by PB-896 × PB-76 (0.82) were found good specific combinations due to highly significant and positive SCA effects for seed cotton yield while VH-282 × AGC-2 (0.46) was non-significant but showed positive SCA effects (Table 12). The performance of parent PB-76 in both specific combinations was good, in first cross it contributes maternal effects and in second cross used as pollen parent. The crosses PB-76 × VH-282 (-0.73), PB-896 × AGC-2 (-1.69) were found poor specific combinations for seed cotton yield due to negative value of SCA effects. The cross PB-896 × VH-282 (-0.20) was non-significant and poor specific combination for seed cotton yield due to negative value for SCA effects (Table 12). Our findings are also similar with the results of Ali *et al*. (2008) revealed significant mean squares due to SCA for seed cotton yield per plant.

Results presented in table 12 showed highly significant and positive reciprocal effects for combination AGC-2 × PB-896 (1.52) and shown best combination for seed cotton yield per plant while rest of crosses were poor combinations due to negative RCA effects. The genotype PB-76 has higher GCA effects so it can be used as desirable parent for the improvement of seed cotton yield per plant for next generation. These results were similar with the findings of Cicek and Kanyak (2008). *G. hirsutum* genotypes exhibited best performance for different yield contributing parameters and were used in selection of desired parents for crop improvement Khan *et al*. (2009). High GCA effects showed presence of genetic variability for seed cotton yield and effect of environment on parameters and results are accordance with findings of Ganensan & Reveendran (2007).

Table 10. Analysis of variance for seed cotton yield per plant in parents and crosses of upland cotton

Source of variation	D.F.	Sum of squares	Means of squares
Replication	2	0.11	0.05^{ns}
Genotype	15	125.94	8.39**
Error	30	16.62	0.55
Total	47	142.68	

Table 11. Analysis of variance of combining abilities for seed cotton yield per plant in *Gossypium hirsutum* L.

Source of variation	D.F.	Sum of squares	Means of squares
GCA	3	3.58	1.19**
SCA	6	16.27	2.71**
Reciprocal	6	22.12	3.68**
Error	30		0.18

Where ** <0.01 Highly significant *<0.05 Significant NS>0.05 Non Significant

Table 12. GCA, SCA and reciprocal estimation for four parents for seed cotton yield per plant in upland cotton.

Parents	**GCA effects**
PB-896	-0.1777^{ns}
PB-76	0.5748 **
VH-282	-0.1427^{ns}
AGC-2	-0.2544^{ns}
S.E. (gi - gj)	0.1316
Direct crosses	**SCA effects**

PB-896 × PB-76	0.8265 **
PB-896 × VH-282	-0.2060 ^{ns}
PB-896 × AGC-2	-1.6944 **
PB-76 × VH-282	-0.7385 **
PB-76 × AGC-2	1.4031 **
VH-282 × AGC-2	0.4606 ^{ns}
S.E. (sij – sik)	0.2403
Indirect crosses	**Reciprocal effects**
PB-76 × PB-896	-2.7417 **
VH-282 × PB-896	-0.2417 ^{ns}
AGC-2 × PB-896	1.5250 **
VH-282 × PB-76	-0.0883 ^{ns}
AGC-2 × PB-76	-1.0083 **
AGC-2 × VH-282	-0.3683 ^{ns}
S.E. (rij – rki)	0.3039

Lint percentage (GOT %)

Average values for ginning out turn of 4 parents and their 12 F_1 hybrids were subjected to the analysis of variance (ANOVA). Highly significant differences ($p<0.01$) were found among the 16 genotypes (four parents, six direct crosses and six indirect crosses) for ginning out turn (GOT) while in replication non-significant differences were found as shown by table 13. Due to presence of variation, the data were further analyzed for combining ability. Results from combining ability analysis showed that general combining ability, specific combining ability and reciprocal combining ability values were highly significant ($p<0.01$) as indicated by table 14.

General combining abilities among four parents were studied for ginning out turn. Results exhibited that parent VH-282 was best general combiner for the lint percentage because the value of general combining ability for VH-282 was positive (1.03) and highly significant while parent AGC-2 (0.04) was non-significant but showed positive GCA effects and rest of the parents were found poor general combiners for lint percentage showed negative values for GCA effects as indicated by table 15.

Specific combining abilities of 12 F_1 hybrids were studied for the selection of best hybrid for lint percentage of the cotton plant. The hybrid PB-76 × VH-282 (1.36) was found good specific combiner showing positive value of SCA effects and was highly significant for lint percentage while the crosses PB-896 × AGC-2 (0.44) and PB-896 × VH-282 (0.41) were found non-significant but showed positive SCA effects as shown by table 15. The crosses PB-76 × AGC-2 (-1.10), VH-282 × AGC-2 (-1.88) and PB-896 × PB-76 (-0.13) were found poor specific combiners for lint percentage due to negative SCA effects as presented by table 15. SCA effects of these combinations were associated with GCA effects of their parents as these combinations intricate at least one parent with high or average general combining ability effects for certain characters. Similar findings have been revealed by Ahuja and Dhayal (2007).

Results from table 15 showed highly significant and positive value for combination AGC-2 × PB-896 (1.32) revealed as best combiner for lint percentage while the hybrid VH-282 × PB-896 (0.11) was non-significant but showed positive RCA effects and rest of crosses were poor combiners exhibited negative RCA effects. The cross AGC-2 × PB-896 for ginning out turn was found superior which was produced from parents with poor GCA. The genotype VH-282 has higher value of GCA effects so it can be used as desirable parent for ginning out turn for next generation. These results were similar with the findings of Kaleem *et al*. (2016) who found highest SCA effects as compared to RCA effects. Ginning out turn was influenced by non-additive gene action which relates to the results of Sayal and Sulemani (1996).

Table 13. Analysis of variance for lint percentage in parents and crosses of upland cotton

Source of variation	D.F.	Sum of squares	Means of squares
Replication	2	0.35	0.17^ns
Genotype	15	143.26	9.55**
Error	30	14.99	0.49
Total	47	158.61	

Table 14. Analysis of variance of combining abilities for lint percentage in *Gossypium hirsutum* L.

Source of variation	D.F.	Sum of squares	Means of squares
GCA	3	17.22	5.74**
SCA	6	21.04	3.50**
Reciprocal	6	9.47	1.57**
Error	30		0.16

Where ** <0.01 Highly significant, *<0.05 Significant, NS>0.05 Non Significant

Table 15. GCA, SCA and reciprocal estimation for four parents for lint percentage in upland cotton.

Parents	**GCA effects**
PB-896	-1.0358 **
PB-76	-0.0467 ^{ns}
VH-282	1.0375 **
AGC-2	0.0450 ^{ns}
S.E. (gi - gj)	0.1250
Direct crosses	**SCA effects**
PB-896 × PB-76	-0.1350 ^{ns}
PB-896 × VH-282	0.4125 ^{ns}
PB-896 × AGC-2	0.4400 ^{ns}
PB-76 × VH-282	1.3633 **
PB-76 × AGC-2	-1.1025 **
VH-282 × AGC-2	-1.8850 **
S.E. (sij – sik)	0.2282
Indirect crosses	**Reciprocal effects**
PB-76 × PB-896	-0.8550 **
VH-282 × PB-896	0.1100 ^{ns}
AGC-2 × PB-896	1.3283 **
VH-282 × PB-76	-0.8067 **
AGC-2 × PB-76	-1.1383 **
AGC-2 × VH-282	-0.5333 ^{ns}
S.E. (rij – rki)	0.2886

Conclusions

Among the parents AGC-2 was revealed to be a good general combiner for plant height, number of bolls per plant, fiber length, fiber strength and fiber fineness. The parent VH-282 was proved to be a good general combiner for boll weight, ginning out turn and lint index while PB-76 was good general combiner for the seed cotton yield per plant and seed index.

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