Research Article

Studying Combining Ability and Heterosis in Different Cotton (*Gossypium hirsutum* L.) Genotypes for Yield and Yield Contributing Traits

Ehtisham Shakeel Khokhar*[1], Amir Shakeel[1], Muhammad Amir Maqbool[1], Muhammad Khubaib Abuzar[2], Sumaira Zareen[3], Syeda Sana Aamir[4] and Muhammad Asadullah[4]

[1]Department of Plant Breeding and Genetics, University of Agriculture, Faisalabad, Pakistan; [2]Environmental Science Department, Bahria University, Islamabad, Pakistan; [3]Department of Bioinformatics and Biotechnology, International Islamic University, Islamabad; [4]National Agricultural Research Center (NARC), Islamabad, Pakistan.

Abstract | Combining ability and heterosis analysis was done to identify the potential parents and best performing hybrids for seed cotton yield, yield contributing traits and fiber quality parameters. Six lines, viz., VH-259, IUB-222, CRS-456, AA-703, KZ-191, PB-39 and four testers PB-39, CIM-608, BH-163 and PB-900 were crossed in line × tester crossing fashion to develop 20 F_1 hybrids. Analysis of variance displayed significant differences among parents and hybrids indicating the presence of genetic variability except fiber fineness. δ^2GCA/δ^2SCA ratio depicted the predominance of non-additive types of gene action for plant height, number of monopodial branches, number of sympodial branches, numbers of bolls, boll weight, seed cotton yield, lint percentage, fiber length and fiber strength. The parents VH-259, CRS-456 and AA-703 among lines and PB-39 among testers displayed significant GCA effects for most of the traits. VH-259 × PB-39, CRS-456 × CIM-608 and AA-703 × PB-900 registered significant SCA effects and positive heterosis and hetrobeltiosis for most of the trait investigated.

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***Correspondence** | Ehtisham Shakeel Khokhar, University of Agriculture, Faisalabad, Pakistan; **Email:** ehtishamshakeel@hotmail.com
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Introduction

Cotton is the major fiber crop and life line of Pakistan's economy. It is important agricultural commodity which provides the livelihood to farmers in Pakistan and raw material to the textile industry. Cotton contribeutes 7% value added to agriculture and 1.5% to the GDP of Pakistan. However, 2012-13 is not the productive year for cotton growers of Pakistan. White fly and thrips inflicted the maximum damaged to the cotton in cotton belts of Punjab and Sindh (Shahid et al., 2013). Cotton is the most important source of raw fiber. Improvement of the fiber quality and enhancement of the seed cotton yield is the demand of farmers and textile industry. Prolong and frequent occurrence of Cotton Leaf Curl Virus Disease badly damaged the cotton crop. Due to prevalence of sucking insect pests and high CLCuD pressure cotton production was reduced up to 4.2% in 2013 as compared to previous year. However

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the area under cultivation was 2879 hectares in 2013 which is 1.6% more as compared the previous year. Despite of increase in cultivated area, cotton production is restricted to 13 million bales which is 10.3% lower as compared to set target of 14.5 million bales (Economic Survey of Pakistan, 2012-13).

Keeping in view the low trend of yield and increasing demand of the textile industry there is need to design the breeding programs as a breeder which can boost the cotton production in the country. Pakistan has potential to become key producer of cotton around the globe. National agricultural research system must devise the plan to combat the high pressure of sucking pest and frequent occurrence of CLCuD. For this very purpose cotton breeders put their efforts to enhance the quality and yield of cotton through identification and use of genotypes with higher genetics potential. Different developmental (plant height, number of sympodial branches and number of monopodial branches) and economic (number of bolls and seed cotton yield) characters of cotton genotype determine its yield (Seoudy et al., 2014). In breeding program information about the inheritance mechanism, heterosis and combining ability of various characters are important.

Selection of parent is important for any breeding program. Combining ability analysis provides opportunity to cotton breeder for selection of better parent as it disclose the mode of inheritance for various plant traits. It also helps the plant breeder to study parental combination and can devise the breeding program for development of superior cotton cultivars. One of the most important biometrical tool which provides the information regarding the combining ability variances and effects of the genotypes is line × tester analysis (Sajjad et al., 2016). This analysis provides information to identify and select the appropriate parents and superior crosses. Thus, line × tester is widely used by the plant researchers for selection in early generations. Ashokkumar et al. (2010), Shakeel et al. (2012), Seoudy et al. (2014), Sawarkar et al. (2015), Usharani et al. (2016), Ali et al. (2016) and Sivia et al. (2017) conduct combining ability analysis by deploying line × tester design for identification of appropriate parents and better crosses and reported the non-additive type of gene action for yield contributing and fiber quality traits.

Heterosis studies exploit the crosses with better genetic potential when compared to their better parents for different traits under study. However, heterosis is only useful when performance of new combinations is better from its parents or commercial standard (Adsare et al., 2017). Thus, seed cotton yield and yield contributing traits with desired fiber quality traits can be improved through heterosis breeding. Gohil et al. (2017) and Monicashree et al. (2017) also exploited the heterosis breeding for the genetic improvement of economic and fiber traits in cotton cultivars.

Keeping in view the due importance of economical and fiber quality traits of cotton, present study was planned to evaluate the general combining ability effects (GCA) of parents, specific combining ability (SCA) effects of different cross combinations. Evaluation of heterosis potential of the different economic yield contributing and fiber quality traits was also the one of the key objective to conduct the present study.

Materials and Methods

Plant material

The material used in present study was developed by crossing nine lines *viz:* VH-259, IUB-222, CRS-456, AA-703, KZ-191, PB-39, CIM-608, BH-163 and PB-900 according to line × tester method in glass house. Temperature, humidity and light availability was ensured according to recommended levels in glass house. At flowering stage five genotypes *i.e.* VH-259, IUB-222, CRS-456, AA-703 and KZ-191 were used as seed parents (lines), and these were pollinated by PB-39, CIM-608, BH-163 and PB-900 (testers) by following the line × tester design. Extreme precautionary measures were taken to avoid the pollen contamination of the genetic material during crossing.

Field evaluation of single cross F1 hybrids

The seeds of 20 hybrids and their 9 parents were field planted during Kharif 2012-2013 at experimental area of department of Plant Breeding and Genetics (PBG), University of Agriculture, Faisalabad (UAF) under Randomized Complete Block Design (RCBD) with three replications. Two rows of four meters were planted for each genotype. Row to row and plant to plant distance was maintained as 75 and 25 cm respectively. Standard agronomic practices and plant protection measures were followed throughout the cropping season of cotton crop.

Data analysis

At maturity, data were recorded for yield and fib-

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er quality traits under study *viz*., plant height (cm), number of monopodial branches , number of sympodial branches, number of bolls, boll weight (g), lint percentage (%), seed cotton yield (g), fiber fineness (µg/Inch), fiber strength (g/tex) and fiber length (mm). Lint samples were analyzed for quantification of quality traits fiber strength (g/tex), fiber length (mm) and fiber fineness (micro gram/inch) in Fiber Testing Laboratory, Department of Fiber and Textile Technology, University of Agriculture, Faisalabad.

Statistical analysis

The data on the above mentioned parameters were statistically analyzed following the analysis of variance technique (Steel et al., 1997). Combining ability analysis was performed by using line × tester fallowing Kempthrone (1957) combining ability analysis. Heterosis was calculated in term of percent increase (+) and decrease (-) of the F_1 hybrids against its mid parent and better parent value as suggested by Fehr (1987).

Results

Mean squares of the line × tester analysis showed significant differences (P<0.01) among the genotypes, parents, crosses, parent vs cross, lines, testers and line × tester for plant height number of monopodia, number of sympodia, seed cotton yield, lint percentage, number of bolls, boll weight, fiber strength, fiber length and fiber fineness (Table 1). It showed that there is significant variability for the traits under study. Data is further subjected to combining ability analysis to identify the potential parents and appropriate hybrids.

Data showed that contribution of lines were lower to male contributions for plant height, lint percentage, boll weight, fiber strength and fiber length while male contributions were lower for number of monopodia, number of sympodia, seed cotton yield and boll numbers. Contribution of line × tester interaction was higher, when compared to lines or tester for all investigated traits except number of monopodia and plant height. However, line × tester interaction for number of monopodia was lower to lines and testers contributions, whereas line × tester interaction for plant height was higher than female's contribution and lower than male's contributions. Present study revealed that relatively line × tester contributions were greater as compared to lines and testers contributions for most of the trait depicting the importance of non-additive type of gene action for investigated traits (Figure 1).

General combining ability effects

Positive estimates of the general combining ability were desirable for the plant height. Among lines, IUB-222 (6.647) showed maximum and significant positive GCA effects, so declared as best general combiner followed by CRS-456 (6.488), whereas VH-259 (-7.620) had maximum negative undesirable GCA effects which revealed that it is poor general combining for the trait under study. Among the testers, maximum significant GCA effects were displayed by CIM-608 (18.713) considered as best general combiner followed by PB-39 (1.96) while BH-163 (-14.107) showed maximum negative values for GCA effects and declared as poor general combiner for plant height (Table 2 and 4).

Table 1: *Analysis of variance showing mean squares for various plant traits in upland cotton*

Source of Variation	Degrees of freedom	Plant height (cm)	No. of monopodia	No. of sympodia	Seed cotton yield (g)	Lint (%)	Boll weight (g)	Boll number	Fiber fineness (µg/inch)	Fiber strength (g/tex)	Fiber length (mm)
Replication	2	31.09	0.04	8.52	64.299	0.17	0.004	0.752	0.007	0.162	0.003
Treatment	28	639.87**	0.60**	52.69**	1507.20**	48.09**	0.45**	61.29**	0.011	2.97**	0.71**
Parent	8	204.66**	0.50**	64.90**	1124.68**	39.14**	0.47**	78.74**	0.007	4.32**	0.53**
Crosses	19	846.43**	0.56**	45.84**	1459.81**	41.80**	0.47**	41.91**	0.012	2.45**	0.77**
Parent vs cross	1	197.08**	2.25**	85.17**	5467.83**	239.1**	0.00**	289.8**	0.005	1.88**	0.98**
Female	4	490.05**	0.93**	40.15**	1313.78**	26.74**	0.17**	65.91**	0.017	1.81**	0.46**
Male	3	2981.3**	1.17**	6.84**	815.98**	73.85**	0.29**	36.44**	0.022*	2.63**	1.40**
F vs M	1	5177.9**	3.52**	689.9**	20033.3**	465.6**	7.40**	423.5**	0.106**	31.49**	8.59**
Line ×Tester	12	431.49**	0.29**	57.49**	1669.44**	38.80**	0.61**	35.28**	0.009	2.62**	0.71**
Error	56	13.32	0.019	3.01	127.56	1.717	0.04	2.85	0.008	0.517	0.10
Total	86										

**= significant at 5% probability level; **= highly significant at 1% probability level*

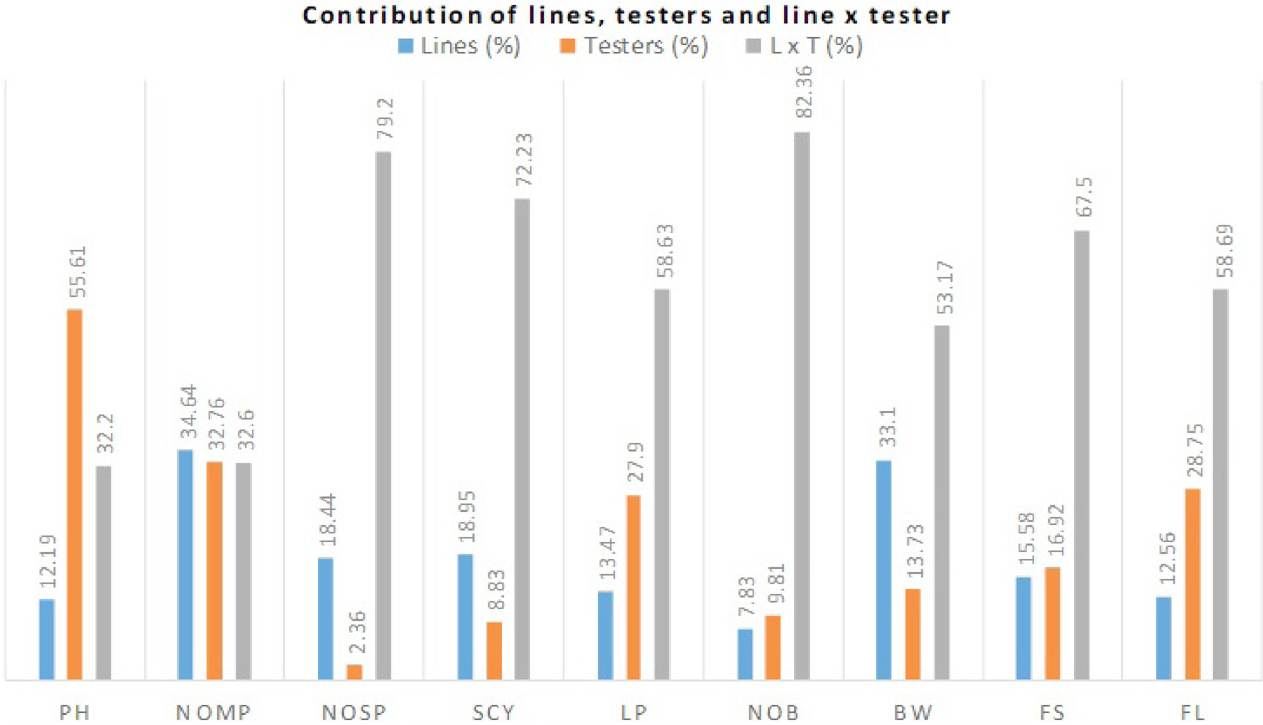

Figure 1: *Contribution of lines, testers and line × tester interactions in the performance of F_1 progeny for different traits.*

PH: Plant height (cm), NOMP: Number of monopodial branches, NOSP: Number of sympodial branches, SCY: Seed cotton yield (g); Lint percentage (%), NOB: Number of bolls, BW: Boll weight, FS: Fiber strength (g/tex), FL: Fiber Length (mm).

Table 2: *General combining ability effects (GCA) of line and tester for various pant traits in upland cotton.*

Parents	Plant height (cm)	Number of Monopodia	Number of sympo-dia	Seed cotton yield (g)	Lint per-centage (%)	Number of bolls	Boll weight (g)	Fiber strength (g/tex)	Fiber length (mm)
Lines									
VH-259	-7.620**	-0.273**	0.932	6.022	1.927**	1.420**	0.071	-0.654**	-0.186
IUB-222	6.647**	0.391**	-1.393**	-12.170**	-1.208**	-2.638**	-0.025	-0.064	0.149
CRS-456	6.488**	-0.198**	2.440**	8.688**	0.540	0.903	0.170**	0.219	0.027
AA-703	-4.137**	-0.106**	0.165	8.080	0.523	2.620**	-0.122	0.280	0.224
KZ-191	-1.378	0.186**	-2.143**	-10.620**	-1.782**	-2.305**	-0.095	0.220	-0.214
S.E	1.053	0.040	0.500	3.260	0.378	0.478	0.058	0.207	0.095
Testers									
PB-39	1.967ns	-0.234**	0.532ns	10.33*	0.883ns	1.410**	0.203*	0.051**	0.434**
CIM-608	18.713**	0.396**	-0.655ns	-6.287ns	-1.019	-1.463**	-0.117ns	0.060ns	-0.043
BH-163	-14.107	-0.154**	0.632ns	0.007ns	2.612**	1.283**	-0.040ns	0.452**	-28.33**
PB-900	-6.573**	0.008ns	-0.508ns	-3.95ns	-2.4612**	-1.230**	-0.045ns	-0.562*	-0.280**
S.E	0.945	0.035	0.448	2.916	0.338	0.435	0.052	0.185	0.085

Monopodial branches has indirect role in overall yield of cotton but more monopodial branches, with high disease pressure such as cotton leaf curl disease (CLCuD) and high infestation of sucking along with chewing pest decrease the yield and create hindrance to perform the cultural practices with utmost ease. Cotton breeders therefore, prefer less monopodial branches. Negative and significant GCA effects were required for trait under study. Among lines, VH-259 (-0.273) showed maximum negative GCA effects followed by CRS-456 (-0.198) and AA-703 (-0.106) for monopodia and declare as good general combiner while IUB-222 (0.391) exhibited maximum positive effects and revealed as poor general combiner followed by KZ-191 (1.86). Among testers, PB-39 (-0.234) displayed maximum negative GCA effects while CIM-608 (0.396) showed maximum positive effects for said trait and declared as poor general combiner. Maximum positive GCA effects were required to ensure the maximum number of sympodial branches. Among lines, CRS-456 (2.440) showed maximum and positive GCA effects followed by VH-259 (0.932) and AA-703 (0.186), which showed that these are good general combiner. Among testers, BH 163 (0.632) showed maximum positive GCA effects followed by PB-39 (0.532) and declared as good general combiner. Among lines, KZ-191 (-2.143) and in testers CIM-608 (-0.655) displayed maximum negative GCA effects, which revealed that these are poor general combiner for the monopodial branches (Table 2 and 4).

Maximum and positive GCA effects were preferred by plant researcher to increase the number of bolls. Among parents, AA703 (2.620) and VH-259 (1.420) displayed maximum positive and significant GCA effects, which showed that these lines were good general combiner while IUB-222 (-2.638) and KZ-191 (-2.305) showed maximum negative, undesirable GCA effects and declared as poor general combiner for investigated trait. The testers, CIM-608 (1.463) and PB-39 (1.410) displayed maximum positive and significant GCA effects and revealed as good while undesirable negative GCA effects were displayed by CIM-608 (-1.463) followed by PB-900 (-1.230) and declared as poor general combiner. Significant and positive GCA effects for boll weight were required, CRS-456 (0.170) followed by VH-259 (0.071) showed maximum and significant GCA effects and declared as good general combiner while AA-703 (-0.122) followed by KZ-191 (-0.095) and IUB-222 (-0.025) displayed undesirable negative GCA effects, which revealed that these lines were poor general combiner. Among testers, CIM-608 (-0.117) followed by BH-163 (-0.040) and PB-900 (-0.045) displayed negative GCA effects, However, PB-39 (0.203) showed maximum and significant GCA effects and revealed as the only and best general combiner among four testers (Table 2 and 4).

Effects of general combining ability (GCA) on controlling seed cotton yield were variable for parents. Among lines, CRS-456 (8.688) followed by AA-703(8.080) and VH-259 (6.022) displayed maximum positive GCA effects and declared as good general combiner while maximum negative GCA effects were exhibited by IUB-222 (-12.170) followed by KZ-191 (-10.620) which proved that these lines were poor general combiner for the said trait. The testers, PB-39 (10.33) followed by BH-163 (0.007) showed maximum positive and significant GCA effects and reported as best general combiner for the plant trait under study. The lines VH-259 (1.927) followed by CRS-456 (0.540) and AA-703 (0.523) showed maximum and positive GCA effects and reported as good general combiner for lint percentage. However, the tester BH-163 (2.162) displayed maximum positive and significant GCA effects and reported as best general combiner followed by PB-39 (0.883) (Table 2 and 4).

Among the parents, the line AA-703 (0.224), IUB-222 (0.149) and CRS-456 (0.027) displayed maximum positive GCA effect which showed that it is best general combiner for fiber length while among testers, PB-39 (0.043) showed maximum positive and significant GCA effects and declared as best general combiner. For fiber strength, Among parents, the lines AA-703 (0.28), followed by KZ-191(0.220) and CRS-456 (0.219) showed maximum positive GCA effects and declared as best general combiner while VH-259 (-0.186) showed maximum negative GCA effects which revealed that it is poor general combiner for plant trait under study. The testers, AA-703 (-28.33) followed by KZ-191 (-0.280) and CIM-608 (-0.043) displayed negative GCA effects depicting these testers as poor general combiner while BH-163 (0.452) showed maximum positive GCA effects and declared as single and best general combiner for the plant character under study (Table 2 and 4).

Specific combining ability effects

The crosses, VH-259 × CIM-608 (21.37), CRS-456 × BH-163 (20.373) and KZ-191 × CIM-608 (7.498) displayed maximum positive combining ability effects for plant height table 3. VH-259 × PB-39 (-17.133) and CRS-456 × PB-900 (-10.927) showed maximum negative values for SCA effects. Which is not desirable for this trait and declared as poor specific combiner for plant height (Table 3). SCA variances is greater than GCA variance indicating the importance of non-additive type of gene action for the trait under study (Table 8).

For monopodial branches, hybrid IUB-222 × CIM-608 (-0.405) showed maximum negative and significant GCA effects which showed that it is best specific combiner followed by IUB-222 × PB-39 (-0.346) and AA-703 × BH-163 (-0.246) whereas, IUB-222 × BH-163 (0.419) showed maximum positive undesirable SCA effects, which showed that it is poor specific combiner for trait under study followed by KZ-191 × PB-900 (0.408) and AA-703 × PB-39 (0.271) for investigated plant character. The crosses, AA-703 × PB-900 (5.942), CRS-456 × CIM-608 (5.097) and KZ-191 × PB-39 (4.00) showed maximum positive and significant SCA effects, which revealed that these new combinations were best good general combiner for the number of sympodial branches. VH-259 × PB-39 (-7.132) and KZ-191 × PB-900 (-5.137) displayed maximum negative SCA effects, which showed that these hybrids were poor specific combiner (Table 3 and 5). Greater SCA variance indicates the presence of non-additive type of gene action for the said trait (Table 8).

Table 3: *Specific combining ability effects (SCA) for 20 hybrids of various plant traits in upland cotton*

Crosses	Plant height (cm)	Number of monopodia	Number of sympodia	Seed cotton yield (g)	Lint percentage (%)	Number of bolls	Boll weight (g)	Fiber strength (g/tex)	Fiber length (mm)
VH-259 x PB-39	-17.133**	0.326**	-7.132**	3.525	3.969**	-1.927	0.107	0.399	-0.226
VH-259 x CIM-608	21.367**	-0.171	2.027	-4.817	-0.490	1.432	-0.123	0.676	0.359
VH-259 x BH-163	-5.242	0.084	2.260	9.992	2.302**	1.923	-0.055	0.366	-0.159
VH-259 x PB-900	-6.883**	-0.074	1.102	2.067	-4.435**	-1.360	0.154	-0.551	-0.256
IUB-222 x PB-39	7.892**	-0.166	1.743	-10.767	-1.346	-0.068	-0.083	-0.891	0.282
IUB-222 x CIM-608	-0.580	-0.405**	2.522	1.078	-2.109**	0.613	0.032	-0.026	0.020
IUB-222 x BH-163	-5.813**	0.419**	-4.853**	10.837	5.386**	3.305**	0.113	0.564	-0.055
IUB-222 x PB-900	4.745	-0.346**	-2.087	18.512**	-0.609	0.797	0.586**	0.471	-0.182
CRS-456 x PB-39	7.970**	0.329**	-0.678	-19.747**	-1.699	-2.487	-0.389**	-0.060	0.570**
CRS-456 x CIM-608	-6.322**	0.004	5.097**	-10.680	-0.967	-2.228	-0.342**	-0.950	-0.352
CRS 456 x BH-163	20.373**	0.213**	-1.332	-37.582**	-2.620**	-3.033**	-0.796**	-0.518	-0.612**
CRS-456 x PB-900	-10.927**	-0.084	-1.173	-7.823	-4.972**	-4.142**	0.117	-0.848	0.163
AA-703 x PB-39	-7.002**	0.271**	1.560	9.352	0.240	2.250	-0.007	-1.011	0.035
AA-703 x CIM-608	0.257	-0.154	2.468	3.727	3.257**	0.733	0.088	1.548**	0.388
AA-703 x BH-163	-2.702	-0.246**	-1.523	32.327**	4.096**	4.192**	0.598**	0.828	0.026
AA-703 x PB-900	-2.660	-0.134	5.942**	32.978**	0.761	4.347**	0.657**	0.146	0.818**
KZ-191 x PB-39	-4.627	-0.164	4.000**	1.803	0.076	-0.595	-0.107	-0.393	-0.467
KZ-191 x CIM-608	7.498**	-0.009	-1.733	-37.855*	-1.932	-4.970**	-0.524**	0.173	0.305
KZ-191 x BH-163	-1.343	-0.101	-2.892**	13.953	2.878**	3.113**	0.148	-0.938	-0.702**
KZ-191 x PB-900	1.132	0.408**	-5.317**	-10.880	-1.783	-1.895	-0.173	1.012	0.046
S.E	2.107	0.080	1.001	6.520	0.756	0.979	0.116	0.145	0.190

Table 4: *Above average and poor general combing parents for different traits*

Characters	Lines			Testers
	Above average combiners		Poor combiners	Above average combiner
	1st	2nd		
Plant height	CRS-456 (6.647**)	IUB-222 (6.488**)	VH-259 (7.620**)	CIM-608 (18.73)
No. of monopods	VH-259 (-0.273**)	CRS-456 (-0.198**)	IUB-222 (0.321**)	PB-39 (-0.234)
No. of sympods	CRS-456 (2.440**)	VH-259 (0.932)	KZ-191 (2.143**)	BH-163 (06.23)
Boll weight (g)	CRS-456 (0.170**)	VH-259 (0.071)	AA-703 (-0.122)	PB-39 (0.203)
No. of bolls	AA-703 (2.620**)	VH-259 (1.420**)	IUB-222 (-2.638)	PB-39 (1.410)
Seed cotton yield (g)	CRS-456 (8.688**)	AA-703 (8.080)	IUB-222 (-12.170)	PB-39 (10.33**)
Lint percentage (%)	VH-259 (-0.273**)	CRS-456 (-0.198**)	KZ-191 (-1.782**)	BH-163 (2.162**)
Fiber length (μ/Inch)	AA-703 (0.224)	IUB-222 (0.149)	KZ-191 (-0.214)	PB-39 (0.434**)
Fiber strength (mm)	AA-703 (0.280)	KZ-191 (0.220)	VH-259 (-0.654**)	BH-163 (0.452**)

For number of bolls, AA-703 × PB-900 (4.347) displayed maximum positive and significant SCA effects followed by AA-703 × BH-163 (4.192) and IUB-222 × BH-163 (3.305) which revealed that these hybrids were good specific combiner. However, KZ-191 × CIM608 (-4.970) and CRS-456 × PB-900 (-4.142) displayed maximum negative SCA effects, which showed that these hybrids have not good specific combining ability effects. The new cross combinations, AA-730 × PB-900 (0.657), AA-703 × BH-163 (0.598) and IUB-222 × PB-900 (0.586) showed maximum positive and significant SCA effects for boll weight, which revealed that these hybrids were good specific combiner while CRS-456 × BH-163 (-0.796) and KZ-191 × PB-900 (-0.524) displayed maximum negative SCA effects and reported as poor specific combiner for the plant character under study (Table 3). SCA variances is greater than GCA variance indicating the importance of non-additive type of gene action for number of bolls per plant and boll weight (Table 8).

Among 20 hybrids, AA-703 × PB-39 (32.978) proved to be best specific combiner with maximum positive and significant SCA effects followed by AA-703 × PB-900 (32.327) and IUB-222 × PB-900 (18.512) for seed cotton yield while KZ191 × CIM-608 (-37.855) showed maximum negative SCA effects and reported as poor specific combiner followed by CRS-456 × BH-163 (-37.582). The hybrid IUB-222 × BH-163 (5.386) displayed maximum positive and significant SCA effects and declared as best specific combiner for lint percentage followed by AA-703 × BH-163 (4.096) and VH-259 × PB-39 (3.969). However, CRS-456 × PB-39 (-4.972) showed maximum negative and significant SCA effects, which showed that it is poor specific combiner for the investigated trait (Table 3 and 5). Higher SCA variance suggested the presence of non-additive type of gene action for seed cotton yield and lint percentage (Table 8).

Among 20 new cross combinations, AA-703 × CIM-608 (1.548) showed maximum positives SCA effects and marked as best specific combiner for fiber strength followed by KZ-191 × PB-900 (1.012) and KZ-191 × BH-163 (0.828). However, AA-703 × PB-39 (-1.011) displayed maximum negative SCA effects which showed that it is poor specific combiner followed by KZ-191 × BH-163 (-0.938) for the trait under study. For fiber length, hybrid AA-703 × PB-900 (0.818) showed maximum positive and significant SCA effects followed by CRS-456 × PB-39 (0.570) and AA-703 × CIM-608 (0.388) while KZ-191 × BH-163 (-0.702) showed maximum negative SCA effects which revealed that it is poor specific combiner for the character under study (Table 3-5). Lower GCA variance compared to SCA variance indicated the predominance of non-additive type of gene action for fiber strength and fiber length (Table 8).

Heterosis and Hetrobeltiosis

Positive and significant heterosis and hetrobeltiosis was found for plant height. The crosses, IUB-222 × PB-39 (34.80) showed maximum positive heterosis followed by CRS-456 × PB-39 (27.22) and VH-259 × CIM-608 (21.35) while the same cross IUB-222 × PB-39 (32.66), exhibited maximum hetrobeltiosis followed by CRS-456 × PB-39 (25.68) and VH-259 × CIM-608 (17.83). Out of 20 hybrids, half of them suppressed their mid parent and seven suppressed their better parent. The percent increase in plant height over mid parent and better parent ranged from 2.58% (VH-259 × BH-163) to 34.80% (IUB-222 × PB-39) and 9.60% (CRS-456 × BH-163) to 32.66% (IUB-222 × PB-39) respectively (Table 6).

Table 5: *Above average and poor specific cross combination of various plant traits.*

Characters	Above average cross combinations		Poor cross combinations
	1st	2nd	
Plant height	VH-259 × CIM-608 (21.37)	CRS-456 × BH-163 (20.373)	VH-259 x PB-39 (-17.133)
No. of monopods	IUB-222 × CIM-608 (-0.405)	IUB-222 × PB-39 (-0.346)	KZ-191 x PB-900 (0.408)
No. of sympods	VH-259 × PB-39 (-7.132)	KZ-191 × PB-900 (-5.137)	VH-259 x PB-39 (-7.132)
Boll weight (g)	AA-730 × PB-900 (0.657)	AA-703 × BH-163 (0.598)	KZ-191 x CIM-608 (-0.524)
No. of bolls	AA-703 × PB-900 (4.347)	AA-703 × BH-163 (4.192)	CRS-456 x PB-900 (-4.142)
Seed cotton yield (g)	AA-703 × PB-39 (32.978)	AA-703 × PB-900 (32.327)	CRS 456 x BH-163 (-37.582)
Lint percentage (%)	AA-703 × BH-163 (4.096)	VH-259 × PB-39 (3.969)	CRS-456 x PB-900 (-4.972)
Fiber length (µ/Inch)	AA-703 × PB-900 (0.818)	CRS-456 × PB-39 (0.570)	AA-703 x PB-39 (-1.011)
Fiber strength (mm)	AA-703 × CIM-608 (1.548)	KZ-191 × PB-900 (1.012)	KZ-191 x BH-163 (-0.702)

Table 6: *Estimation of heterosis and hetrobeltiosis (%) for 20 hybrids for various plant traits in upland cotton*

	Plant height (cm)		No. of Monopodia		No. of Sympodia		Boll Numbers		Boll weight (g)	
	Heterosis over Mid & better parent		Heterosis over Mid & better parent		Heterosis over Mid & better parent		Heterosis over Mid & better parent		Heterosis over Mid & better parent	
Crosses	MPH	BPH	MPH	BPH	MPH	BPH	MPH	BPH	MPH	BPH
VH-259 x PB-39	-19.8**	-26.40**	-24.59**	-35.21**	-19.5NS	-32.73**	18.29**	11.21NS	8.58NS	5.42NS
VH-259xCIM-608	21.35**	17.83**	-12.7NS	-22.61**	15.3NS	-8.41NS	9.34NS	-2.05NS	4.77NS	2.49NS
VH-259 x BH-163	2.58	-4.61	-25.45**	-30.51**	50.81**	25.72**	18.54**	3.51NS	1.48NS	-5.9NS
VH-259 x PB-900	-8.80**	-14.89**	-38.10**	-48.00**	32.44**	12.67NS	20.11**	9.58NS	-1.8NS	-9.74NS
IUB-222 x PB-39	6.03	-0.20	4.65NS	-11.7NS	4.60NS	-18.87**	8.42NS	-0.72NS	7.18NS	1.64NS
IUB-222xCIM-608	17.80**	14.32**	-37.68**	-39.44**	36.53**	13.20NS	20.76**	10.12NS	3.1NS	-5.3NS
IUB-222 x BH-163	19.22**	15.81**	31.83**	30.75**	-32.6**	-46.83**	9.16NS	-4.99NS	8.5NS	4.58NS
IUB-222 x PB-900	34.80**	32.66**	-25.40**	-29.85**	15.8NS	-4.14NS	8.85NS	-7.56NS	16.07*	2.03NS
CRS-456 x PB-39	27.22**	25.68**	-1.41NS	-6.67NS	13.5NS	-4.16NS	9.90NS	-2.65NS	-20.5**	-30.70**
CRS-456xCIM-608	15.13**	14.79**	35.29**	2.99**	17.8NS	-9.21NS	-5.78**	-16.2NS	-4.8NS	-5.3NS
CRS 456 x BH-163	11.01**	9.60**	-33.28**	-36.62**	23.5NS	-0.72**	22.97**	7.18NS	-23.7**	-25.84**
CRS-456 x PB-900	-11.9**	-17.95**	-13.71**	-15.02**	0.21**	-23.17**	-2.6NS	-18.79**	4.4NS	1.98NS
AA-703 x PB-39	-3.89	-6.43	-20.26**	-23.32**	52.69**	22.48NS	27.67**	4.06NS	-3.9NS	-10.7NS
AA-703xCIM-608	-7.63**	-10.42**	-43.84**	-48.00**	47.9NS	20.98**	36.30**	15.60**	-10.1**	-17.25**
AA-703 x BH-163	-8.71**	-12.25**	-9NS**	-29.6NS	-10.60**	-32.99**	31.64**	12.02**	20.26**	13.85**
AA-703 x PB-900	-14.8**	-22.13**	-44.29**	-45.07**	74.11**	32.55NS	43.16**	23.07**	23.52**	13.64**
KZ-191 x PB-39	-8.88**	-11.91**	-14.01**	-15.94**	31.66**	-3.97NS	2.32NS	-15.75**	3.60NS	0.10NS
KZ-191 xCIM-608	5.86	-1.97	-29.69**	-34.78**	29.70**	-1.44NS	-4.1NS	-22.88**	-13.4**	-23.7NS
KZ-191 x BH-163	-11.9**	-18.14**	-37.50**	-40.0**	8.80NS	-15.9NS	37.64**	15.19**	-3.78**	-15.92**
KZ-191 x PB-900	-8.04**	-13.79**	32.69**	0.00**	-37.01**	-54.98**	1.84NS	-14.49**	2.69NS	2.41NS

MPH: *mid parent heterosis*, **BPH**: *better parent heterosis*

Among crosses, AA-703 × PB-900 (-44.29) showed maximum negative and significant heterosis followed by AA-703 × CIM-608 (-43.84), VH-259 × PB-900 (-38.10) for monopodia. AA-703 × BH-163 (-48.00) and VH-259 × PB-900 (-48.00) displayed maximum and significant hetrobeltiosis followed by AA-703 × PB-900 (-45.07) and KZ-191 × BH-163 (-40.00) for the said trait. Out of 20 hybrids, sixteen hybrids exceed its mid parent and seventeen hybrids suppressed their better parent. The percent increase for heterosis and hetrobeltiosis have ranged of -1.10% to -44.29% and -6.67% to -48.00% for monopodial branches respectively. The new cross combinations, maximum and positive heterosis were displayed by AA-703 × PB-900 (74.11) followed by AA-703 × PB-39 (52.39) and VH-259 × PB-39 (50.81) for sympodial branches. AA-703 × PB-900 (35.55) showed maximum positive hetrobeltiosis followed by VH-259 × BH-163 (25.72). Among 20 hybrids, 15 hybrids suppressed their better parent and 5 hybrids suppressed their batter parent. The percent increase for heterosis and hetrobeltiosis ranged from 0.21% to 30.75% and 12.67% to 32.55% respectively for plant character understudy (Table 6).

For number of bolls, the crosses, AA-703 × PB-900 (43.16) and KZ-191 × BH-163 (37.64) showed maximum positive and significant heterosis while AA-703 × PB-900 (23.07) and AA-703 × CIM-608 (15.60) displayed maximum and significant hetrobeltiosis. Out of 20 hybrids, 17 hybrids showed heterosis over their mid parent and 10 hybrids displayed hetrobeltiosis over better parent. The percent increase for heterosis and hetrobeltiosis ranged from 1.84% to 43.16% and 3.51% to 23.07 respectively. Heterosis analysis revealed that 11 hybrids suppressed their mid parent and 10 hybrids suppressed their better parent for boll weight. The crosses, AA-703× PB-900 (23.52) and AA-703 × BH-163 (20.26) showed maximum heterosis over mid parent. However, the same hybrids AA-703 × BH-163 (18.85) and PB-900 (13.64) displayed hetrobeltiosis over their better parent (Table 6).

Table 7: *Estimation of Heterosis and hetrobeltiosis for 20 hybrids for various plant traits in upland cotton*

	Seed cotton yield (g)		Lint percentage %		Fiber strength		Fiber length	
	Heterosis over Mid & better parent		Heterosis over Mid & better parent		Heterosis over Mid & better parent		Heterosis over Mid & better parent	
Crosses	MPH (%)	BPH (%)	MPH (%)	BPH (%)	MPH (%)	BPH (%)	MPH (%)	BPH (%)
VH-259 x PB-39	45.07**	44.74**	28.97**	28.17**	1.21NS	-1.16NS	1.76NS	1.26NS
VH-259 x CIM-608	1.28NS	-10.42NS	-0.73NS	-6.70NS	3.28NS	2.62NS	5.48**	5.34**
VH-259 x BH-163	37.42**	23.76**	24.29**	20.24**	5.52NS	2.50NS	3.00**	2.72**
VH-259 x PB-900	28.64**	15.35NS	-4.36NS	-7.62NS	2.27NS	-1.24NS	1.97NS	0.35NS
IUB-222 x PB-39	3.22NS	-4.15NS	-0.85NS	-3.18NS	-2.05NS	-2.98NS	1.96NS	0.00NS
IUB-222 x CIM-608	25.11**	24.91NS	13.36**	3.56NS	-5.91**	-12.52**	1.24NS	0.43NS
IUB-222 x BH-163	0.63NS	-11.30NS	20.02**	4.21NS	-2.52**	-7.88**	2.55**	2.11NS
IUB-222 x PB-900	30.10**	16.77NS	18.73**	12.54**	0.40**	-7.13**	1.49NS	0.91NS
CRS-456 x PB-39	-7.34NS	-17.19NS	6.51NS	-5.20NS	-1.05**	-8.98**	3.54**	1.59NS
CRS-456 x CIM-608	-12.82NS	-19.33NS	2.65NS	-7.72NS	-7.37**	-12.71**	-1.70NS	-3.89**
CRS 456 x BH-163	1.02NS	-9.60NS	27.60**	13.18**	1.02NS	0.71NS	-2.50**	-2.90**
CRS-456 x PB-900	-1.95NS	-21.34**	1.50NS	-14.27**	0.42NS	-1.02NS	1.86NS	1.07NS
AA-703 x PB-39	40.39**	14.41NS	38.72**	27.51**	3.32NS	2.44NS	0.81NS	0.18NS
AA-703 x CIM-608	33.06**	8.03NS	38.47**	19.79**	16.02**	14.35**	1.42NS	0.71NS
AA-703 x BH-163	50.24**	25.75**	35.28**	18.15**	9.54**	8.31**	-1.77NS	-2.8**
AA-703 x PB-900	86.37**	61.62**	11.97**	7.92NS	-2.01NS	-3.68NS	2.03NS	1.61NS
KZ-191 x PB-39	6.65NS	-16.70NS	-6.23NS	-14.38**	-3.48NS	-3.49NS	-1.03NS	-1.79NS
KZ-191 x CIM-608	-10.75NS	-29.24**	3.01NS	2.77NS	2.59NS	0.29NS	1.17NS	0.54NS
KZ-191 x BH-163	43.45**	13.33NS	10.80**	3.88NS	-1.58NS	-4.34NS	-3.06**	-3.74**
KZ-191 x PB-900	1.69NS	-17.29NS	-9.75**	-14.48**	4.31NS	4.01NS	-2.30**	-3.33**

MPH: *mid parent heterosis*, **BPH:** *better parent heterosis*

Table 8: *Estimation of variance due to GCA and SCA for various plant traits in G. hirsutum L.*

Genetic Component	Plant height (cm)	No. of monopodia	No. of sympodia	Seed cotton yield (g)	Lint percentage (%)	Boll weight (g)	Boll number	Fiber strength (g/tex)	Fiber length (mm)
δ2 GCA	96.6066	0.05659	2.518	44.782	0.85158	0.0283	1.17706	0.0296	0.01594
δ2 SCA	427.057	0.28696	56.4877	1626.92	38.2316	0.60311	34.3384	2.45194	0.67991
δ2 GCA/δ2 SCA	0.22621	0.19719	0.0446	0.0275	0.02227	0.0469	0.03428	0.0121	0.023450

δ^2 GCA: *variance of general combining ability*, **δ^2 SCA:** *variance of specific combining ability*, **δ^2 GCA/δ^2 SCA**: *ratio of GCA to SCA variance*

The hybrid, AA-703 × PB-900 (86.37) showed positive heterosis over mid parent followed by and AA-703 × BH-183 (50.24) and VH-259 × PB-39 (45.07) for seed cotton yield. However, AA-703 × PB-900 (61.62) displayed maximum positive hetrobeltiosis over better parent followed by VH-259 × PB-39 (44.74) and IUB-222 × CIM-608 (24.91). Among 20 hybrids, 13 hybrids suppressed their mid parent while 10 hybrids suppressed their better parent. The percent increase for heterosis and hetrobeltiosis ranged from 1.69% to 86.37% over mid parent while 8.03% to 61.62% over better parent respectively. Heterosis and hetrobeltiosis revealed that among 20 hybrids, 15 hybrids suppressed their mid parent while 12 hybrids suppressed their better parent for lint percentage. Among crosses, AA-703 × PB-39 (38.72) showed maximum positive and significant heterosis over their mid parent followed by AA-703 × CIM-608 (38.47) and AA-703 × BH-163 (35.28). However, AA-703 × PB-39 (27.51) showed maximum positive and significant hetrobeltiosis over their better parent followed by VH-259 × PB-39 (28.17). The percent increase and decrease for heterosis and hetrobeltiosis ranged from 1.50% to 38.72% and 3.56% to 38.87% respectively (Table 7).

Heterosis and hetrobeltiosis revealed that among crosses, 12 hybrids suppressed mid parent while 8 hybrids suppressed better parent for fiber strength. The crosses, AA-703 × CIM-608 (16.02) showed maximum heterosis over mid parent followed by AA-703 × BH-163 (8.31). However, the same hybrids AA-703 × CIM-608 (14.35) AA-703 × BH-163 (8.31) showed maximum hetrobeltiosis over better parent for the trait investigated. The percent increase and decrease for heterosis and hetrobeltiosis ranged from 0.40% to 16.02% and 0.29% to 14.35% respectively for the trait under study. The crosses, VH-259 × CIM-608 (5.48) showed maximum positive and significant heterosis over mid parents followed by VH-259 × BH-163 (3.00) while the same hybrids VH-259 × CIM-608 (5.34) and VH-259 × BH-163 (2.72) showed maximum positive and significant hetrobeltiosis for the fiber length. The percent increase and decrease for heterosis and hetrobeltiosis ranged from 1.17 to 5.48% and 0.54% to 5.34% respectively (Table 7).

Discussion

Genetic improvement of economical and developmental plant characters, depends upon the availability and magnitude of variability. Therefore, plant breeder must have information on the genetic component of variation for that particular trait. Genetics components reveal appropriate magnitude of variability with mode of inheritance, which help cotton breeders to devise selection procedures for breeding population. Biometrical analysis of data revealed that variation for plant height, monopodial branches, sympodial branches, boll numbers, boll weight, seed cotton yield, lint percentage, fiber strength and fiber length were genetically manifested. The genetic component for each trait is further differentiated in two components *i.e.* general combining ability and specific combining ability as outlined by Kempthorne (1957) and practice by Maqbool et al. (2017) and Aslam et al. (2015).

Combining ability effects relatively provides appropriate understanding on the genetic control of various plant characters. GCA to SCA ratio revealed, predominance of non-additive type of gene action for plant height, monopodial branches, sympodial branches, boll numbers, boll weight, seed cotton yield, lint percentage, fiber strength and fiber length. Present findings are in accordance with Neelima et al. (2004), Rauf et al. (2005), Shakeel et al. (2012) and Usharani et al. (2016). Contrary to the findings of present study, Lukonge et al. (2008) and Khan et al. (2015) reported additive type of gene action while Jatoi et al. (2010) and Patel et al. (2014) reported both additive and non-additive type of gene action for traits under study.

For sympodial and monopodial branches, non-additive genetics effects were appeared to be dominant this confirms the findings of Ahmed et al. (2005) and Rauf et al. (2005) whereas Ali and Khan (2007) reported dominance of additive type of gene action for said traits. For boll numbers per plant and boll weight, non-additive type of gene action was reported by Imran et al. (2012) and Monicashree et al. (2017) while Natera et al. (2012) showed that additive genetic effects were more important. Seed cotton yield and lint percentage were governed by non-additive genetic effects. The results were in accordance with Yanal et al. (2013) whereas Jatoi et al. (2010) reported predominance of additive type of gene action for the plant trait under study. For fiber quality traits, fiber strength and fiber length, non-additive genetic effects were more important this confirm the findings of Preetha and Raveendran (2008) and Saravanan et al. (2010). However, Rauf et al. (2006) reported both additive and non-additive type of gene action for the investigated traits. The present findings enables cotton breeder to handle the breeding material. Low heritability had been reported by plant researcher for non-additive genetic effects suggesting to postpone the selection in early generations (Falconer and Macky, 1996). Thus, selection must be delayed till the genes are established in segregating populations.

The combining ability effects (GCA and SCA) provide information which is useful to classify the parental lines, tester and new cross combination. Both lines, VH-259 and CRS-456 proved to be a good general combiner for number of monopodia and lint percentage. IUB-222 and CRS-456 proved to be good general combiner for plant height. CRS-456 proved to be a good general combiner for number of sympodia and boll weight. CRS-456 and AA-703 proved to be a good general combiner for seed cotton yield while AA-703 also proved to be good general combiner for numbers of bolls, fiber strength and fiber length. Among testers, PB-39 proved to be a good general combiner for number of monopodia, number of bolls, boll weight, seed cotton yield and fiber length.

CIM-608 proved to good general combiner for plant height. BH-163 proved to good general combiner for number of sympodia, lint percentage and fiber strength. Parental lines, with higher GCA effects in cross combination with different testers, were expected to yield better hybrids for that particular trait. The plant researchers had been reported, new cross combination under line × tester analysis with at least one parental line, which displayed higher GCA effects. For plant height, CRS-456 and IUB-222 were good combiner and produced good hybrids i.e. CRS-456 × BH-163 and IUB-222 × PB-39. Parental line, VH-259 declared as good general combiner for number of monopodia and lint percentage and developed appropriate hybrid i.e. VH-259 × PB-39. CRS-456 with higher GCA effects produce appropriate hybrids for number of sympodia and lint percentage i.e. CRS-456 × CIM-608 and CRS-456 × PB-900. AA-703 proved its worth as best general combiner and produced best cross combinations for seed cotton yield (AA-703 × PB-900), number of bolls (AA-703 × PB-900) fiber strength (AA-703 × PB-39) and fiber length (AA-703× PB-900). By contrast, VH-259 was poor general combiner for plant height but produce best cross combination i.e. VH-259 × CIM-608. Despite of poor GCA effects, IUB-222 produce the best hybrid (IUB-222 × CIM-608) for number of monopodia. AA-703 × PB-900 displayed as best cross combination for boll weight but the cross was originated from the parental line with poor GCA effects. Thus, present study clarified that it is possible for parental lines with poor GCA effects to produce good new cross combination. Comparable findings were given by Sajjad et al. (2016), Maqbool et al. (2017), Aslam et al. (2015). Results for parental contribution in hybrids, confirmed the finding of Saleh and Ali (2012), Samreen et al. (2008), Khokhar et al. (2017).

Heterosis and hetrobeltiosis were calculated using the value suggested by Fehr (1987). Present study showed significant heterosis and hetrobeltiosis for yield and yield contributing traits. All hybrids, displayed range of heterosis and hetrobeltiosis for various plant characters. For plant height, heterosis and hetrobeltiosis were ranged from 2.58 to 34.80% and 9.60 to 32.66% respectively. High heterosis (34.80) and hetrobeltiosis (32.66) were displayed by IUB-222 × PB-39. However, cotton breeders for plant height prefer moderate heterosis. CRS-456 × PB-39 (27.22) and VH-259 × CIM-608 (17.83) displayed moderate heterosis and hetrobeltiosis respectively and considered for further selection. Present findings are in accordance with Patil et al. (2011) who had reported moderate heterosis and hetrobeltiosis for plant height.

For number of monopodial branches, among hybrids, 14 hybrids depicted significant and positive heterosis while 15 hybrids displayed positive and significant hetrobeltiosis. AA-703 × PB-900 (-44.29) and AA-703 × BH-163 (-48.00) proved their worth with maximum heterosis and hetrobeltiosis. The heterosis and hetrobeltiosis ranged from -1.10 to -44.29% and -6.67 to -48.00% respectively. Khan et al. (2009) also reported negative and significant heterotic effects for monopodial branches.

Among 20 hybrids, eight displayed positive and significant heterosis while two hybrids showed positive and significant hetrobeltiosis for number of sympodia. The heterosis and hetrobeltiosis ranged from 0.21 to 30.75% and 12.67 to 32.55% respectively. AA-703 × PB-900 (74.11) displayed maximum positive heterosis and however, maximum positive hetrobeltiosis was showed by AA-703 × PB-900 (35.55). Present study confirm the findings of Abro et al. (2014) who revealed positive heterosis and hetrobeltiosis for the trait investigated.

The present study revealed the presence of positive and significant heterosis and hetrobeltiosis for number of bolls. Ten hybrids displayed positive and significant heterosis while only two hybrids were entitled with positive and significant hetrobeltiosis. The crosses, AA-703 × PB-900 (43.16) and AA-703 × PB-900 (23.07) topped the twenty hybrids with maximum positive heterosis and hetrobeltiosis. The percent increase remained 1.84 to 43.16% for heterosis and 3.51 to 23.07% for hetrobeltiosis. Similar findings were reported by Vineela et al. (2013) for F_1 cotton hybrids.

For boll weight, among twenty hybrids, AA-703× PB-900 proved it worth as best combination with maximum positive values for heterosis (23.52%) and hetrobeltiosis (18.85%). Three hybrids, suppressed their mid parent with positive and significant heterosis while only two cross combinations suppressed their better parent with positive and significant hetrobeltiosis. The heterosis and hetrobeltiosis were ranged from 2.69 to 23.52% and 0.10 to 13.64% respectively. Seoudy et al. (2014) findings are in accordance with present study for trait investigated.

The F_1 hybrid, AA-703 × PB-900 declared as best new cross combination with its maximum positive heterosis (86.37) and hetrobeltiosis (61.62) for seed cotton yield. This hybrid can be utilized for commercial cultivation after multi location trails in the cotton belts of Pakistan. Among twenty hybrids, ten displayed positive and significant heterosis while four hybrids showed positive and significant hetrobeltiosis for the trait under study. The heterosis and hetrobeltiosis ranged from 1.69 to 86.37% and 8.03 to 61.62% for seed cotton yield. Present finding were in accordance with Tyagi et al. (2014).

Heterosis and hetrobeltiosis results for lint percentage suggested that eleven hybrids displayed significant and positive heterosis while seven hybrids showed positive and significant hetrobeltiosis. AA-703 × PB-39 proved its worth as best new cross combination with maximum positive heterosis (38.72%) and hetrobeltiosis (27.51%). The percent increase ranged from 1.50 to 38.72% for heterosis and 3.56 to 38.87% for hetrobeltiosis for the plant character investigated. Solanki et al. (2014) reported fair amount of heterosis and hetrobeltiosis for lint percentage.

Results regarding heterosis and hetrobeltiosis for fiber length suggested that four F_1 hybrids displayed positive and significant heterosis while only two hybrids showed positive and significant hetrobeltiosis for trait under study. The heterosis and hetrobeltiosis ranged from 0.40 to 1.17 to 5.48% and 0.54% to 5.34% respectively. The hybrid, VH-259 × CIM-608 topped among all hybrids with maximum heterosis (5.48) and hetrobeltiosis (5.34) values. Present findings are in accordance with Baloch et al. (2014).

As regarding fiber strength, cross AA-703 × CIM-608 proved to be a best new cross combination with maximum positive heterosis (16.02%) and hetrobeltiosis (14.35%). Among hybrids, three displayed positive and significant heterosis and two hybrids showed positive and significant hetrobeltiosis. The heterosis and hetrobeltiosis ranged from 0.40 to 16.02% and 0.29 to 14.35% respectively for the plant character investigated. Rauf et al. (2005) also reported fair amount of hybrids vigor for fiber strength.

Conclusions

It was concluded that VH-259, CRS-456 and AA-703 among lines and PB-39 among testers were good general combiner for most of the yield and fiber quality plant characters under study. Single cross F_1 hybrids VH-259 × PB-39, CRS-456 × CIM-608 and AA-703 × PB-900 displayed their superiority for yield and yield contributing traits.

Author's Contribution

Ehtisham Shakeel Khokhar: Planned and executed the research experiment. Also acquired the data from field and prepared the manuscript.
Amir Shakeel: Supervised the research experiment by helping in the planning, execution, analyzing, writing and proofreading of manuscript.
Muhammad Amir Maqbool: Contributed in data analysis, results explanations and manuscript preparation.
Muhammad Khubaib Abuzar: Assisted in data acquisition from the field and performing the lab quality analysis.
Sumaira Zareen: Assisted in manuscript preparation and technical inputs
Syeda Sana Aamir: Data compilation, data formatting
Muhammad Asadullah: Assisted in compilation of results, preparation of tables and figures.

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