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Research Article

Combining ability and heterosis studies for seed cotton yield and fibre quality traits in *hirsutum* cotton

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Abstract
To study the combining ability, gene action and heterosis, eighteen intra-hirsutum cotton hybrids were developed by crossing three lines (females) and six testers (mlaes) in line × tester design during *Kharif* 2021 at Regional Agricultural Research Station, ANGRAU, Lam, Guntur. The analysis of variance revealed significant variability among the experimental material for seed cotton yield, lint yield, and fibre quality traits. The non-additive gene action was observed for traits namely, ginning out turn, seed cotton yield, lint yield, and fibre quality traits while the upper half mean length and uniformity index exhibited preponderance of additive gene action. Among the parents, TCH 1837 (Line) and Lam GPC 274 (Tester) were identified as the best general combiners for the traits, bundle strength and elongation while the lines, SCS 1207, GISV 298, and tester Lam GPC 235 were identified as the best combiner for ginning out turn, seed cotton yield, and lint yield. The F_1 hybrids *viz.,* TCH 1837 / Lam GPC 117, GISV 298 / Lam GPC 274, and GISV 298 / Lam GPC 51 were identified as the best hybrids and these could be used for exploitation through heterosis breeding as these hybrids exhibited significant *per se* performance, high positive SCA effects and better parental heterosis for the said characters. The cross combinations namely, GISV 298 / Lam GPC 235 and SCS 1207 / Lam GPC 355 possessed significantly high GCA effects for the parents and non-significant SCA effects for the corresponding hybrids for important yield components and fibre quality traits. Hence, these could be exploited in recombination breeding for improvement of yield and other fibre quality traits in cotton.

Keywords : Cotton, GCA,SCA, Heterosis

INTRODUCTION

In India, cotton commonly known as White Gold and the King of Fibres, plays a vital role in the Indian economy in terms of raw cotton and its by-products. India's total cotton production during 2021-22 was 315.43 lakh bales. In cotton acreage, India ranked 1st place in the world with 120.69 Lakh hectares area under cotton cultivation *i.e*. around 36% of the world area of 333 Lakh hectares. Around 67% of India's cotton is grown in rain-fed areas and 33% irrigated in areas. In terms of productivity, India secured 38th rank with yield of 510 kg/ha (https://cottoncorp.org.in). At this juncture, there is an immense need to improve the seed cotton productivity as well as quality parameters which in turn fetches the farmers good remunerative prices. The choice and selection of superior genotypes are important for the development of better hybrid combinations and in turn useful in the success of the breeding program. The seed cotton yield as well as the fibre quality traits are polygenic and largely influenced by the environment. Thorough information on the genetic architecture of parents is needed to develop the good cross combinations. In recent years, yields of cotton are stagnated, hence there is an immense need to keep efforts in line development with improved combining ability to use them for the further use in hybrid development program. Plant breeders with their concentrated efforts in fetching new allelic combinations and subsequent selection of transgressive segregants improved fibre traits in cotton. The initial phase of any effective breeding program is to select desirable parents. Line × Tester analysis, one of the combing ability analysis techniques, is commonly used to test the parent's genetic makeup. It helps in detecting the parents with high general combining ability (GCA) and hybrid combinations with high specific combining ability (SCA) effects. With this objective, the current experiment was planned and carried out at the Regional Agricultural Research Station, Lam, Guntur for finding out the combining ability of parents for seed cotton yield and fibre-related traits in cotton.

MATERIALS AND METHODS

An experiment was conducted during *Kharif* 2021-22 at Regional Agricultural Research Station, Lam, Guntur with three lines (females) *viz*., TCH 1837, GISV 298, SCS 1207 and six testers namely, Lam GPC 51, Lam GPC 274, Lam GPC 501, Lam GPC 235, Lam GPC 355 and Lam GPC 117 and eighteen intra-specific cross combinations developed by crossing the above parents in L × T fashion. Each entry was planted in two rows of 6 m in length by following 120 x 60 cm spacing in two replications. The necessary package of practices was implemented. Data were recorded on a plot basis from each genotype from each replication for the characters seed cotton yield (kg) and lint yield (kg) and converted to kg/ha. The other parameters ginning out turn (%), Upper half mean length (mm), micronaire value (µg/inch), bundle bundle strength (g/tex), uniformity ratio, and elongation (%) were recorded on a plot basis. Lint samples were analyzed for fibre quality traits at the Central Institute for Research on Cotton Technology (CIRCOT), RARS, Lam, Guntur, Andhra Pradesh with help of using HVT Expert 1201 high-volume fibre tester instrument. The mean data of 18 F_1 hybrids along with their (six) parents for all eight parameters were analyzed for analysis of variance as proposed by Panse and Sukhatme (1985). The combining ability using Line × Tester analysis was used to estimate the GCA of parents and SCA of the F_1 hybrids as suggested by Kempthorne (1957). Estimation of heterosis was calculated for F_1 hybrids against its mid parent and better parent value as referred by Fehr (1987).

RESULTS AND DISCUSSION

Mean squares of the line × tester analysis showed significant differences (P<0.01) among the treatments and crosses for all the traits under study except for micronaire (**Table 1)** which represented the significant variability for these traits in the material under study. Hence, the data was further subjected to combining ability analysis to identify the best parents and appropriate hybrids.

It was noticed that the proportional contribution of crosses was more for all the traits under study except for micronaire and elongation percent (**Fig. 1**) depicting

Table 1. Analysis of variance for combining ability for various yield and fibre quality traits in *Gossypium hirsutum* L.

Source of Variation	df	GOT (%)	SCY (kg/ ha)	Lint yield (kg/ha)	UHML (mm)	UI (%)	Mic. (µg/inch)	Bundle strength (g/tex)	Elongation (%)
Treatments	26	55.10**	216558**	72367.74**	51118.23**	5.67**	0.32	8.69**	0.81**
Parents	8	9.35	86971	15972.72	9.39	0.51	0.38	5.93**	0.89**
Crosses	17	74.31**	282364**	98804.44**	76936.16**	6.84**	0.31	10.31**	0.50**
Parent vs Crosses	1	94.45**	134550	74104.09**	21084.08**	27.00**	0.04	3.34	5.33**
Lines	2	4.17	271424*	43450.17**	16.17	0.67	0.17	18.17**	0.67**
Testers	5	13.20	21708	7076.15	4.20	0.53	0.33	2.13	0.48**
Line effect	2	259.00*	624410	292045.40	76088.11	30.78*	0.78*	28.58	0.44
Tester effect	5	42.78	114908	47865.96	77086.43	2.64	0.38	6.52	0.38
Line * Tester effect	10	53.13**	297682**	85625.48**	77030.64**	4.14**	0.18	8.55**	0.58**
Error	26	5.98	49259	7680.57	119.84	1.12	0.17	1.28	0.02
Total	53	30.02	130729	39464.48	25136.60	3.34	0.24	4.99	0.41
δ^2 GCA		15.98	35384.95	18052.74	0.495	1.714	0.045	1.779	0.046
δ^2 SCA		23.01	123243.90	39072.21	2.58	1.428	0.004	3.506	0.289
δ^2GCA/ δ^2 SCA		0.69	0.29	0.46	0.19	1.20	11.25	0.51	0.16

*Significant 5% level **Significant at 1% level
GOT: Ginning Out Turn; SCY: Seed Cotton Yield; LY: Lint Yield; UHML: Upper Half Mean Length; UI: Uniformity Index

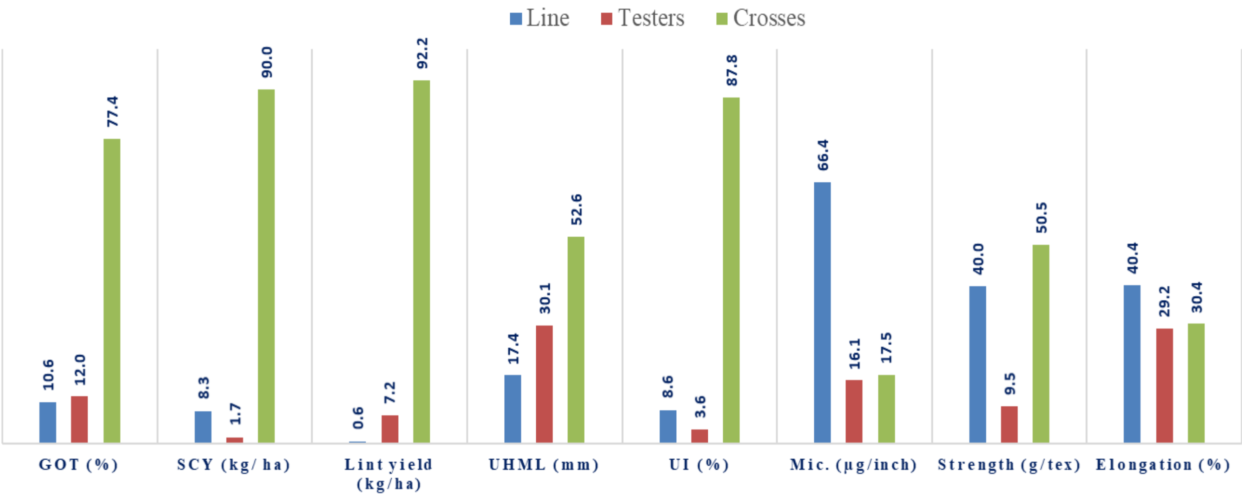

Fig. 1. Contribution of lines, testers and crosses to combining ability

GOT: Ginning Out Turn; SCY: Seed Cotton Yield; LY: Lint Yield; UHML: Upper Half Mean Length; UI: Uniformity Index

the importance of the non-additive type of gene action for investigated traits while the line's contribution was more for micronaire and elongation percent. The lines showed significant differences for the characters like micronaire, bundle strength, and elongation while the testers showed significant differences for the traits upper half mean length and elongation (%). The line x tester interaction is more significant for most of the characters except for micronaire while line effects were more for the traits, ginning out turn (%), seed cotton yield, lint yield, uniformity index, micronaire, and bundle strength (**Fig. 2**). Madhuri *et al.* (2015) and Chapara *et al.* (2020) in their study reported the significant line x tester interaction for upper half mean length, elongation per cent, fibre strength and ginning out turn.

The ratio of additive (δ^2 GCA) to dominance (δ^2 SCA) variance is less than unity for all the characters studied *i.e* ginning out turn (%), seed cotton yield, lint yield, upper half mean length, bundle strength, and elongation except for the uniformity index and micronaire indicating a preponderance of non-additive gene action (dominance and epistasis), which is an essential feature in the manipulation of heterosis breeding. These results were in agreement with the reports of Pushpam and Raveendran, (2005), Usharani *et al.* 2016, Monicashree *et al.* (2017), and Aziz *et al*. (2019).

The selection of parents is one of the important steps in the cotton breeding program to improve the seed cotton yield and fibre quality as well. Based on the average mean performance along with the high general combining ability the parents are to be selected to develop the hybrids. Therefore, the information on *per se* performance and GCA effects are much essential. In the current investigation, nine parents were evaluated individually as well as in combinations. Superior significant genotypes were chosen for all the traits under study except for micronaire (**Table 2**).

Often it is expected that the high-yielding parents with high *per se* performance resulting the best recombinants in the segregating generations and yield the best hybrids in the offspring. The parents with high mean yield are preferred for all the traits except for micronaire. The *per se* performance of the parents is presented in **Table 2**. The testers *viz*., Lam GPC 235 followed by Lam GPC 501 recorded the higher *per se* performance for all the traits understudy. The lines, SCS 1207 and TCH 1837 while the testers Lam GPC 235, Lam GPC 117, and Lam GPC 501 exhibited high ginning out turn percent. The information on the selection and choice of the parents in terms of the predictable performance of their offspring depends upon the general combining ability effects (GCA) of parents.

The estimates of general combining ability revealed that significant positive effects were observed for all the traits except for micronaire. Similar results were reported by Chapara *et al.* (2020).

The GCA of parents for seed cotton yield and fibre quality traits were represented in **Table 3**. Based on the mean value and GCA effects, line GISV 298 excelled with higher mean and GCA effects for five characters *viz*., ginning out turn, seed cotton yield, lint yield, uniformity index, micronaire and bundle strength followed by the line SCS 1207 which exhibited the significantly high mean value and significantly superior GCA effects for the characters *viz*., ginning out turn, seed cotton yield, lint yield and micronaire. Among the testers, Lam GPC 235 exhibited high mean couple with significant positive GCA

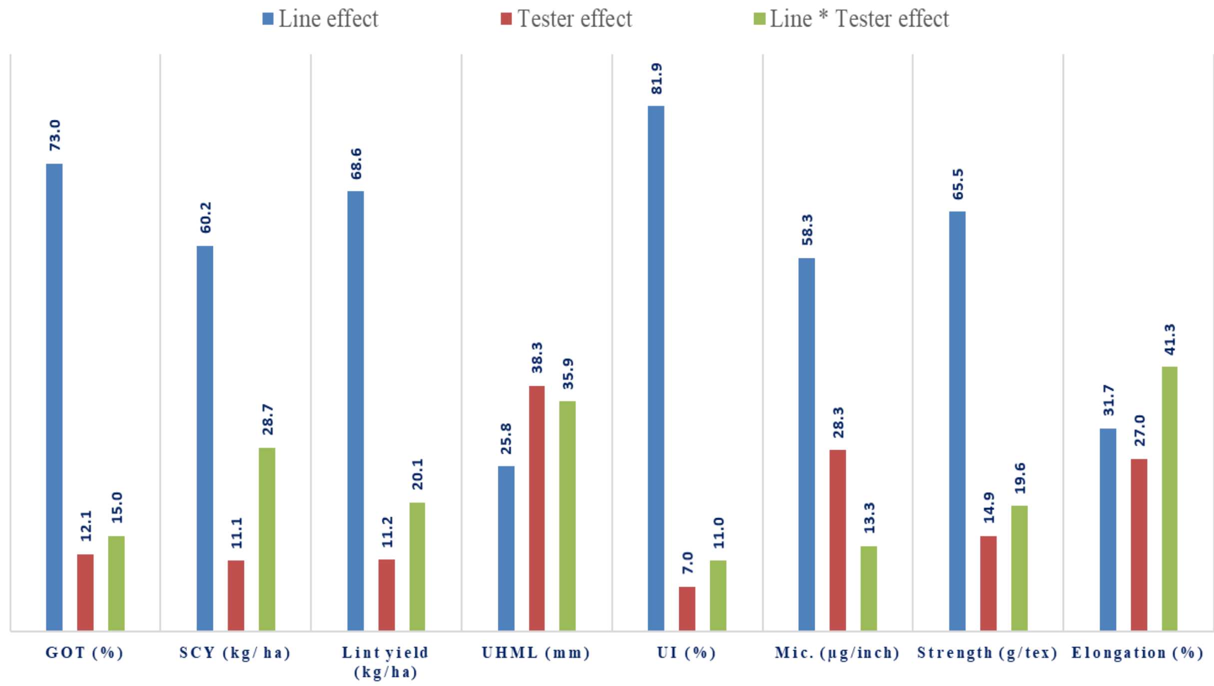

Fig. 2. Contribution of line effect, tester effect and L× T effect

GOT: Ginning Out Turn; SCY: Seed Cotton Yield; LY: Lint Yield; UHML: Upper Half Mean Length; UI: Uniformity Index

Table 2. Mean performance of parents for seed cotton yield components and fibre quality traits in *Gossypium hirsutum* L.

	GOT (%)	SCY (kg/ha)	LY (kg/ha)	UHML (mm)	UI (%)	Mic. (µg/inch)	Bundle strength (g/tex)	Elongation (%)
Lines								
TCH1837	35.7	1983.0	709.3	27.0	83.5	4.0	28.3	5.8
GISV298	32.6	2188.5	715.0	28.9	83.5	3.4	31.8	6.2
SCS1207	37.2	1999.0	743.4	26.7	84.5	4.7	27.8	6.7
Testers								
Lam GPC 51	30.4	2170.0	657.8	29.4	83.5	3.7	30.5	6.2
Lam GPC 235	36.1	2261.0	815.2	30.5	84.0	4.0	29.1	6.5
Lam GPC 117	36.1	2166.5	780.2	27.2	83.5	4.4	28.3	6.0
Lam GPC 501	35.7	2296.5	817.9	28.1	83.0	4.5	28.2	6.7
Lam GPC 355	33.8	2215.0	747.7	29.2	83.5	3.9	27.4	6.8
Lam GPC 274	32.6	2202.5	715.4	31.0	83.0	3.5	28.8	6.0

GOT: Ginning Out Turn; SCY: Seed Cotton Yield; LY: Lint Yield; UHML: Upper Half Mean Length; UI: Uniformity Index

effects for ginning out turn, lint yield, and uniformity index. The tester Lam GPC 235 recorded high positive mean performance and GCA effects for ginning out turn, seed cotton yield, lint yield and bundle strength. The parents exhibiting a significant positive relationship between mean performance and GCA effects might be due to more number of additive genes and may contribute to the accumulation of favourable genes in varietal improvement and development programmes.

The lack of association between *per se* performance and the GCA effects of parents, signifies that the particular trait was probably under the influence of non-additive gene action. In the present study, considering GCA effects and *per se* performance together, the line GISV 298 and the testers Lam GPC 235 were identified as desirable parents for developing hybrids with improved yield and fibre quality traits. Hence, it could be concluded that these parents can be utilized in hybridization programmes to

Table 3. Estimates of the GCA effects of the parents for different traits in *Gossypium hirsutum* L.

Parents	GOT (%)	SCY (kg/ ha)	Lint yield (kg/ha)	UHML (mm)	UI (%)	Mic. (µg/inch)	Bundle strength (g/tex)	Elongation (%)
Lines								
TCH1837	-5.33**	-261.97**	-180.11**	0.72	0.28	-0.22	1.50**	0.22**
GISV298	2.17*	154.69*	87.39**	-0.44	1.44**	-0.06	0.08	-0.11**
SCS1207	3.17**	107.28	92.72**	-0.28	-1.72**	0.28*	-1.58**	-0.11**
Testers								
Lam GPC 51	-2.25	66.94	-18.19	0.81	-0.06	0.11	-2.08**	-0.28**
Lam GPC 274	-3.25**	-222.22*	-142.36**	1.14*	0.78	-0.22	0.58	0.06**
Lam GPC 501	0.42	-10.72	4.31	0.47	-0.39	-0.06	0.58	0.39**
Lam GPC 235	4.42**	118.11	117.14**	-0.03	0.78	-0.06	0.58	0.06**
Lam GPC 355	0.58	139.44	68.47	-1.86**	-0.22	-0.22	0.08	-0.28**
Lam GPC 117	0.08	-91.56	-29.36	-0.53	-0.89	0.44*	0.25	0.06**
CD 95% GCA(Line)	1.62	137.81	52.68	0.74	0.69	0.25	0.76	
CD 95% GCA(Tester)	2.30	194.89	74.50	1.05	0.98	0.36	1.07	
δ^2 Line	20.99	47767.96	23713.70	0.27	2.46	0.05	2.25	0.04
δ^2 Tester	5.95	10618.92	6730.82	0.94	0.23	0.04	0.83	0.06
δ^2 GCA	15.98**	35384.95**	18052.74**	0.50**	1.71**	0.05**	1.78**	0.05**
δ^2 (SCA)	23.01**	123243.90**	39072.21**	2.58**	1.43**	0.00**	3.51**	0.29**
Heritability (NS) %	54.60	32.23	45.75	22.94	62.32	50.49	45.43	24.03
Genetic Advance 5 %	8.60	311.09	264.76	0.98	3.01	0.44	2.62	0.31

*Significant 5% level **Significant at 1% level
GOT: Ginning Out Turn; SCY: Seed Cotton Yield; LY: Lint Yield; UHML: Upper Half Mean Length UI: Uniformity Index

identify superior segregants with high yield and good fibre quality traits. An attempt could be made for selecting desirable hybrids through multiple crosses for yield and fibre quality traits in the segregating generations, as no parent was found to be a good combiner for all the traits. Ranking of parents based on GCA effects is furnished in **Table 4**. The parents, Lam GPC 235 followed by SCS 1207 for ginning out turn, the lines, GISV 298 and Lam GPC 355, Lam GPC 274 followed by Lam GPC 51 for upper half mean length, GISV 298 followed by Lam GPC 274 for micronaire and bundle strength were found to be superior with significant positive GCA values. In GCA estimates Lam GPC 501 followed by TCH 1837 stood first and second places and were identified as the best parents for the respective traits (**Table 4**).

The SCA of hybrids for yield and fibre quality-related traits are represented in **Table 4**. The hybrid TCH1837 / Lam GPC 117 excelled with superior SCA effect for the characters *viz*., ginning out turn, seed cotton yield, lint yield and uniformity index. The hybrid, GISV298 / Lam GPC 274 recorded a significantly superior SCA effect for seed cotton yield, lint yield and upper half mean length. For fibre related traits, the F_1 hybrid, TCH1837 / Lam GPC 355 for upper half mean length, TCH1837 / Lam GPC 117 for uniformity index, SCS1207 / Lam GPC 235 for bundle strength and GISV298 / Lam GPC 51 for elongation ranked first with positive SCA effects (**Table 5 and 6**). For the trait, micronaire seven cross combinations exhibited negative SCA effects in the desirable direction. Ten cross combinations showed significant positive SCA effects for elongation percent. The female parent GISV 298 was identified as the best parent as it yielded the top combinations in F_1 hybrids for all the traits. It was followed by TCH 1837 for seven traits and SCS 1207 for five traits. Similarly, among the testers, Lam GPC 117 (for six traits) followed by Lam GPC 51 and Lam GPC 355, for five traits, were found to the best male parents. Madhuri *et al*. (2015), Reddy *et al*. (2017), Chattha *et al*. (2018), and Chinchane, *et al*. (2018) reported significant SCA effects in their findings for fibre related traits. In general, the cross combinations involving high × high general combiners produce crosses with significant SCA effect indicating the role of additive and additive × additive genetic component of variance which could be easily improved through simple selection procedures. The crosses between high x low or low x high general combiners resulted in superior cross combinations due to the complementary gene action which had arisen out of both additive and nonadditive gene action. These crosses may likely provide superior transgressive segregants. These components may be exploited by adopting breeding procedures like cyclic hybridization, biparental mating and diallel selective mating system.

Table 4. Ranking of parents based on the GCA effects for different traits in *Gossypium hirsutum* L. genotypes

Parents	GOT (%)	Rank	Parents	SCY (kg/ ha)	Rank	Parents	Lint yield (kg/ha)	Rank	Parents	UHML (mm)	Rank
Lam GPC 235	4.417**	1	GISV298	154.694*	1	Lam GPC 235	117.139**	1	Lam GPC 274	1.139*	1
SCS1207	3.167**	2	Lam GPC 355	139.444	2	SCS1207	92.722**	2	Lam GPC 51	0.806	2
GISV298	2.167*	3	Lam GPC 235	118.111	3	GISV298	87.389**	3	TCH1837	0.722	3
Lam GPC 355	0.583	4	SCS1207	107.278	4	Lam GPC 355	68.472	4	Lam GPC 501	0.472	4
Lam GPC 501	0.417	5	Lam GPC 51	66.944	5	Lam GPC 501	4.306	5	Lam GPC 235	-0.028	5
Lam GPC 117	0.083	6	Lam GPC 501	-10.722	6	Lam GPC 51	-18.194	6	SCS1207	-0.278	6
Lam GPC 51	-2.25	7	Lam GPC 117	-91.556	7	Lam GPC 117	-29.361	7	GISV298	-0.444	7
Lam GPC 274	-3.25**	8	Lam GPC 274	-222.222*	8	Lam GPC 274	-142.361**	8	Lam GPC 117	-0.528	8
TCH1837	-5.333 **	9	TCH1837	-261.972**	9	TCH1837	-180.111**	9	Lam GPC 355	-1.861**	9

Parents	UI (%)	Rank	Parents	Mic. (µg/inch)	Rank	Parents	Bundle strength (g/tex)	Rank	Parents	Elongation (%)	Rank
GISV298	1.444**	1	TCH1837	-0.222	1	TCH1837	1.500**	1	Lam GPC 501	0.389**	1
Lam GPC 274	0.778	2	Lam GPC 274	-0.222	2	Lam GPC 274	0.583	2	TCH1837	0.222**	2
Lam GPC 235	0.778	3	Lam GPC 355	-0.222	3	Lam GPC 501	0.583	3	Lam GPC 274	0.056**	3
TCH1837	0.278	4	GISV298	-0.056	4	Lam GPC 235	0.583	4	Lam GPC 235	0.056**	4
Lam GPC 51	-0.056	5	Lam GPC 501	-0.056	5	Lam GPC 117	0.25	5	Lam GPC 117	0.056**	5
Lam GPC 355	-0.222	6	Lam GPC 235	-0.056	6	GISV298	0.083	6	GISV298	-0.111**	6
Lam GPC 501	-0.389	7	Lam GPC 51	0.111	7	Lam GPC 355	0.083	7	SCS1207	-0.111**	7
Lam GPC 117	-0.889	8	SCS1207	0.278*	8	SCS1207	-1.583**	8	Lam GPC 51	-0.278**	8
SCS1207	-1.722**	9	Lam GPC 117	0.444*	9	Lam GPC 51	-2.083**	9	Lam GPC 355	-0.278**	9

*Significant 5% level **Significant at 1% level

Table 5. Estimates of SCA effects of 18 F_1 hybrids for various traits in *Gossypium hirsutum* L.

F_1 Hybrid	GOT (%)	SCY (kg/ ha)	LY (kg/ha)	UHML (mm)	UI (%)	Mic. (µg/inch)	Bundle strength (g/tex)	Elongation (%)
TCH1837 / Lam GPC 51	-3.00	-370.86*	-167.72*	-0.56	-0.94	-0.11	-1.00	-0.56**
TCH1837 / Lam GPC 235	-2.00	76.81	-7.06	0.11	-0.28	0.22	0.33	0.11**
TCH1837 / Lam GPC 117	8.33**	539.81**	325.78**	-2.22*	2.39**	0.06	-0.67	-0.22**
TCH1837 / Lam GPC 501	3.83	212.47	133.44*	-0.22	0.72	0.06	-0.17	0.11**
TCH1837 / Lam GPC 355	-3.83	-324.86	-183.39**	2.11*	-0.78	-0.28	0.33	0.44**
TCH1837 / Lam GPC 274	-3.33	-133.36	-101.06	0.78	-1.11	0.06	1.17	0.11**
GISV298 / Lam GPC 51	4.0*	5.47	80.78	-0.89	0.89	-0.28	2.42*	0.78**
GISV298 / Lam GPC 235	5.0*	176.14	149.44*	-0.72	0.06	0.06	-3.25**	-0.56**
GISV298 / Lam GPC 117	-8.17	-591.36**	-340.22**	0.44	-2.78**	0.39	-0.25	0.11**
GISV298 / Lam GPC 501	-2.67	-5.69	-54.06	-0.56	-0.44	-0.11	-0.75	-0.56**
GISV298 / Lam GPC 355	0.67	52.47	19.11	-0.22	1.06	0.06	0.25	-0.22**
GISV298 / Lam GPC 274	1.17	362.97*	144.94*	1.94*	1.22	-0.11	1.58	0.44**
SCS1207 / Lam GPC 51	-1.00	365.39*	86.94	1.44	0.06	0.39	-1.42	-0.22**
SCS1207 / Lam GPC 235	-3.00	-252.94	-142.39*	0.61	0.22	-0.28	2.92**	0.44**
SCS1207 / Lam GPC 117	-0.17	51.56	14.44	1.78	0.39	-0.44	0.92	0.11**
SCS1207 / Lam GPC 501	-1.17	-206.78	-79.39	0.78	-0.28	0.06	0.92	0.44**
SCS1207 / Lam GPC 355	3.17	272.39	164.28*	-1.89*	-0.28	0.22	-0.58	-0.22**
SCS1207 / Lam GPC 274	2.17	-229.61	-43.89	-2.72**	-0.11	0.06	-2.75**	-0.56**
CD 95% SCA	3.98	337.55	129.04	1.82	1.69	0.62	1.85	

*Significant 5% level **Significant at 1% level
GOT: Ginning Out Turn; SCY: Seed Cotton Yield; LY: Lint Yield; UHML: Upper Half Mean Length; UI: Uniformity Index

For the character seed cotton yield, the crosses that were having the parents with low × low, high × high, and high × low GCA effects exhibited significant positive SCA effects. For lint yield, the parents with low × high, high × high exhibited superior yield. For ginning out turn, the parents with low × high, high × high, and high × low GCA effects yielded significant positive SCA effects.

For the fibre traits, *viz*., upper half mean length, significant positive SCA effects were exhibited by the crosses that were having high × low and low × high GCA effects parents; Similarly, the cross combinations that involved with the parents with high × low GCA effects for uniformity index; low × high, and high × low GCA effects for bundle strength; low × low and high × low GCA effects for elongation exhibited significant positive SCA effects. These significant positive SCA effects denoted the complementary gene action which may be due to both additive and non-additive gene action. These cross-combinations may likely yield superior transgressive segregants in further segregating generations hence, these components may be improved by adopting breeding procedures like recurrent hybridization, diallel selective mating system, and biparental mating.

Table 6. Estimation of heterosis and hetrobeltiosis (%) for 18 hybrids for various plant traits in upland cotton

F_1 Hybrid	GOT (%)			SCY (kg/ha)			LY (kg/ha)			UHML (mm)		
	Mean	MP	BP	Mean	MP	BP	Mean	MP	BP	Mean	MP	BP
TCH1837 / Lam GPC 51	21.50	-34.85 **	-39.44 **	1548.00	-25.45 *	-28.66 *	328.00	-52.01 **	-53.77 **	24.50	-13.27 **	-16.95 **
TCH1837 / Lam GPC 235	21.50	-39.86 **	-40.28 **	1706.50	-19.58 *	-24.52 *	364.50	-52.18 **	-55.28 **	25.50	-11.30 **	-16.39 **
TCH1837 / Lam GPC 117	35.50	-1.39	-2.74	2381.00	14.76	9.90	844.00	13.29	8.14	22.50	-17.43 **	-18.18 **
TCH1837 / Lam GPC 501	35.00	-2.10	-2.78	2182.50	2.00	-4.96	764.50	0.13	-6.48	24.00	-12.73 **	-14.29 **
TCH1837 / Lam GPC 355	23.50	-31.88 **	-33.80 **	1666.50	-20.61 *	-24.76 *	399.00	-45.25 **	-46.66 **	24.50	-12.50 **	-15.52 **
TCH1837 / Lam GPC 274	23.50	-30.88 **	-33.80 **	1627.00	-22.26 *	-26.13 *	383.50	-46.18 **	-46.40 **	24.50	-15.52 **	-20.97 **
GISV298 / Lam GPC 51	36.00	13.39	9.09	2341.00	7.42	6.97	844.00	22.99	18.04	23.00	-20.69 **	-22.03 **
GISV298 / Lam GPC 235	36.00	4.35	0.00	2222.50	-0.10	-1.70	788.50	3.07	-3.25	23.50	-20.34 **	-22.95 **
GISV298 / Lam GPC 117	26.50	-23.74 **	-27.40 **	1666.50	-23.47 *	-23.85 *	445.50	-40.42 **	-42.92 **	24.00	-14.29 **	-15.79 **
GISV298 / Lam GPC 501	36.00	4.35	0.00	2381.00	6.18	3.68	844.50	10.21	3.30	22.50	-20.35 **	-21.05 **
GISV298 / Lam GPC 355	35.50	6.77	5.97	2460.50	11.75	11.08	869.00	18.80	16.18	21.00	-26.96 **	-27.59 **
GISV298 / Lam GPC 274	35.50	8.40	7.58	2540.00	15.69	15.32	897.00	25.41 *	25.37	24.50	-17.65 **	-20.97 **
SCS1207 / Lam GPC 51	32.00	-5.88	-14.67	2653.50	27.30 **	22.28 *	855.50	22.17	15.14	25.50	-8.93 *	-13.56 **
SCS1207 / Lam GPC 235	29.00	-21.09 **	-22.67 **	1746.00	-18.03	-22.78 *	502.00	-35.56 **	-38.40 **	25.00	-12.28 **	-18.03 **
SCS1207 / Lam GPC 117	35.50	-4.05	-5.33	2262.00	8.61	4.41	805.50	5.74	3.20	25.50	-5.56	-7.27
SCS1207 / Lam GPC 501	38.50	4.76	2.67	2132.50	-0.71	-7.14	824.50	5.67	0.86	24.00	-11.93 **	-14.29 **
SCS1207 / Lam GPC 355	39.00	9.86	4.00	2633.00	24.96 *	18.87	1019.50	36.75 **	36.30 **	19.50	-29.73 **	-32.76 **
SCS1207 / Lam GPC 274	37.50	7.14	0.00	1900.00	-9.56	-13.73	713.50	-2.16	-3.97	20.00	-30.43 **	-35.48 **

*Significant 5% level **Significant at 1% level

GOT: Ginning Out Turn; SCY: Seed Cotton Yield; LY: Lint Yield; UHML: Upper Half Mean Length

Table 6. Conti…

F_1 Hybrid	UI (%)			Mic (µg/inch)			Bundle strength (g/tex)			Elongation (%)		
	Mean	MP	BP	Mean	MP	BP	Mean	MP	BP	Mean	MP	BP
TCH1837 / Lam GPC 51	81.50	-2.40	-2.40	4.00	0.00	0.00	27.50	-5.98	-9.84 *	5.00	-16.67 **	-16.67 **
TCH1837 / Lam GPC 235	83.00	-0.90	-1.19	4.00	0.00	0.00	31.50	10.53 *	8.62	6.00	-4.00 **	-7.69 **
TCH1837 / Lam GPC 117	84.50	1.20	1.20	4.00	-5.88	-11.11	30.50	7.96	7.02	6.00	0.00	0.00
TCH1837 / Lam GPC 501	84.00	0.90	0.60	4.00	-5.88	-11.11	31.00	9.73 *	8.77	6.00	-7.69 **	-14.29 **
TCH1837 / Lam GPC 355	81.50	-2.40	-2.40	3.50	-12.50	-12.50	31.00	11.71 **	10.71 *	6.00	-7.69 **	-14.29 **
TCH1837 / Lam GPC 274	80.50	-3.30 *	-3.59 *	4.50	20.00	12.50	32.00	12.28 **	10.34 *	6.00	0.00	0.00
GISV298 / Lam GPC 51	84.50	1.20	1.20	4.00	6.67	0.00	29.50	-4.84	-6.35	6.00	0.00	0.00
GISV298 / Lam GPC 235	84.50	0.90	0.60	4.00	6.67	0.00	26.50	-12.40 **	-15.87 **	5.00	-20.00 **	-23.08 **
GISV298 / Lam GPC 117	80.50	-3.59 **	-3.59 *	4.50	12.50	0.00	29.50	-1.67	-6.35	6.00	0.00	0.00
GISV298 / Lam GPC 501	84.00	0.90	0.60	4.00	0.00	-11.11	29.00	-3.33	-7.94	5.00	-23.08 **	-28.57 **
GISV298 / Lam GPC 355	84.50	1.20	1.20	4.00	6.67	0.00	29.50	0.00	-6.35	5.00	-23.08 **	-28.57 **
GISV298 / Lam GPC 274	84.00	0.90	0.60	4.50	28.57 *	28.57 *	31.00	2.48	-1.59	6.00	0.00	0.00
SCS1207 / Lam GPC 51	80.50	-4.17 **	-4.73 **	5.00	11.11	0.00	24.00	-17.95 **	-21.31 **	5.00	-23.08 **	-28.57 **
SCS1207 / Lam GPC 235	81.50	-3.26 *	-3.55 *	4.00	-11.11	-20.00 *	31.00	8.77 *	6.90	6.00	-11.11 **	-14.29 **
SCS1207 / Lam GPC 117	80.50	-4.17 **	-4.73 **	4.00	-15.79	-20.00 *	29.00	2.65	1.75	6.00	-7.69 **	-14.29 **
SCS1207 / Lam GPC 501	81.00	-3.28 *	-4.14 **	4.50	-5.26	-10.00	29.00	2.65	1.75	6.00	-14.29 **	-14.29 **
SCS1207 / Lam GPC 355	80.00	-4.76 **	-5.33 **	4.50	0.00	-10.00	27.00	-2.70	-3.57	5.00	-28.57 **	-28.57 **
SCS1207 / Lam GPC 274	79.50	-5.07 **	-5.92 **	5.00	17.65	0.00	25.00	-12.28 **	-13.79 **	5.00	-23.08 **	-28.57 **

*Significant 5% level **Significant at 1% level
UI: Uniformity Index; MIC: Micronaire

Karademir *et al*. 2016, Chinchane *et al.* 2018 and Gnanasekaran *et al.* (2019) in their reports observed similar results in their investigation of cotton.

For the trait micronaire, the parents with high × high and low × low GCA effects yielded the top two hybrids namely SCS1207 / Lam GPC 117 and TCH1837 / Lam GPC 355 indicating the presence of additive gene action for this trait which can be improved by simple selection. From the above results on the combining ability using line × tester fashion, it is concluded that the choice of the parents for the crossing program should not only be based on the per se performance and GCA effects of the parents but also the SCA effects of the cross combinations.

Positive and significant hetrobeltiosis was recorded in the cross combinations namely, SCS1207 / Lam GPC 51 for seed cotton yield, SCS1207 / Lam GPC 355 followed by GISV298 / Lam GPC 274 for lint yield, SCS1207 / Lam GPC 274 followed by SCS1207 / Lam GPC 355 for upper half mean length, TCH1837 / Lam GPC 355 followed by TCH1837 / Lam GPC 274 for uniformity index. High positive SCA values in the desirable direction were observed in GISV298 / Lam GPC 51 and GISV298 / Lam GPC 274 for ginning out turn, TCH1837 / Lam GPC 117, GISV298 / Lam GPC 51 and GISV298 / Lam GPC 355 for uniformity index. The F_1 hybrids, TCH1837 / Lam GPC 117, TCH1837 / Lam GPC 274, GISV298 / Lam GPC 51, GISV298 / Lam GPC 117, and GISV298 / Lam GPC 274 were on par with the better parents for the trait elongation.

High positive better parental values were observed in the cross combinations, TCH1837 / Lam GPC 117, GISV298 / Lam GPC 51, and GISV298 / Lam GPC 355 concerning the trait uniformity index. For the trait, upper half mean length none of the hybrids were superior to the parent and showed significant negative values in the unintended direction. Significant negative values were observed in the cross combinations, SCS1207 / Lam GPC 235 and SCS1207 / Lam GPC 117 which is desirable. Abdul *et al.* (2016) and Monicashree *et al.* (2017) reported similar results in upland cotton.

Based on the per se performance, SCA effects, and better parental heterosis for important yield and fibre quality traits, the cross combinations *viz*., TCH 1837 / Lam GPC 117, GISV 298 / Lam GPC 274 and GISV 298 / Lam GPC 51 were chosen for heterosis breeding as these hybrids showed high mean SCA effects and better parental heterosis. Besides, these F_1 hybrids GISV 298 / Lam GPC 235 and SCS 1207 / Lam GPC 355 could be recommended for recombination breeding as these hybrids possessed significantly high GCA effects of the parents and non-significant SCA effects of the corresponding hybrids for important yield components and fibre quality traits.

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REFERENCES

Abdul Wahab Soomro, Faiz Hussain Panhwar, Abdul Razzaque Channa, Muhammad Zahir Ahsan, Muhammad Saffar Majidano and Karim Bukhsh Sial. 2016. Study of heterosis and heterobeltiosis in upland cotton. *International Journal of Biology and Biotech*nology, **13** (1): 111-114.

Aziz Ullah, Amir Shakeel, Tanwir Ahmad Malik and Muhammad Farrukh Saleem. 2019. Combining ability analysis of various fibre quality traits under normal and water deficit condition In Cotton. *Pakistan Journal of Agricultural Sciences*, **56**(2): 359-366.

Chapara, R., Sudha Rani, M. and Satish, Y. 2020. Combining ability studies in cotton (*Gossypium hirsutum* L.) for yield and fibre quality parameters. *International Journal of Chemical Studies,* **8**(2): 523-527. [Cross Ref]

Chattha, W. S., Shakeel, A., Malik T. A., Saleem M. F., Akram H. M., Yaseen M. and Naeem M. 2018. Combining ability analysis of yield and fiber quality traits under normal and water deficit condition in *G. hirsutum* L. *The Journal of Animal and Plant Sciences,* **28** (4): 1062- 1067.

Chinchane, V.N., Patil, V.S. and Ingole, D.G. 2018.Combining ability studies for yield and its components in desi cotton (*Gossypium arboreum* L.). *International Journal of Current Microbiology and Applied Sciences*, **6**:1368-1372.

Fehr, W.R. 1987. Principles of cultivar development. Theory and Technique. Macmillan Pub. Comp. Inc., New York. 115-119.

Karademir, E., Karademir, C. and Basal, H. 2016. Combining ability and line × tester analysis on heat tolerance in cotton (*Gossypium hirsutum* L.). *Indian Journal of Natural Sciences*, **6** (34):10515-10525.

Kempthorne, O. 1957. An Introduction to Genetical Statistics. The Iowa State University Press, Ames, Iowa, pp.545.

Gnanasekaran, M., Thiyagu K. and Gunasekaran, M. 2019. Combining ability and heterosis studies for seed cotton yield and fibre quality traits in *hirsutum* cotton. *Electronic Journal of Plant Breeding,* **10** (4): 1519-1531. [Cross Ref]

Madhuri, S., Solanke A., Mhasal G.S. and Deshmukh S.B. 2015. Combining ability and heterosis for seed cotton yield, its components and quality traits in *Gossypium hirsutum* L. *Indian Journal of Agricultural Research*, **49** (2): 154-159. [Cross Ref]

Monicashree, C., Amala Balu P. and Gunasekaran, M. 2017. Combining ability and heterosis studies on yield and fibre quality traits in upland cotton (*Gossypium hirsutum* L.). *International Journal of Current Microbiology and Applied Sciences*, **6** (8): 912-927. [Cross Ref]

Panse, V.G. and Sukhatme, P.V. 1985. Statistical methods for agricultural workers. 2nd Ed., ICAR, New Delhi, pp:1-361.

Pushpam, R. and Raveendran, T.S. 2005. Heterosis and combining ability studies in upland cotton for fibre characters. *Tropical Agricultural Research and Extension,* **8**:65-70.

Reddy, K. B., Reddy V. C., Ahmed M. L., Naidu T. C. M. and Srinivasarao V. 2017. Combining ability analysis for seed cotton yield and quality traits in upland cotton (*G. hirsutum* L.). *Electronic Journal of Plant Breeding*, **8**: 142-152. [Cross Ref]

Usharani, C.V., Manjula S.M. and Patil S.S. 2016. Estimating combining ability through Line × tester analysis in upland cotton. *Research in Environment and Life Sciences,* **9**: 628-633.