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Estimation of Combining Ability and Heterosis on Seed Cotton Yield and its Attributing traits in American Cotton *Gossypium hirsutum* L. Genotypes

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ABSTRACT

An experiment was executed during *Kharif* 2021 at Regional Agricultural Research Station, Lam, Guntur in randomized block design (RBD) in two replications for estimation of combining ability of the parents and gene effects and also the extent of heterosis using line × tester fashion design. Statistical data were collected on the biometrical observations *viz*., days to 50% flowering, plant height (cm), number of monopodia/plant, number of sympodia/plant, number of bolls per plant, boll weight (g), seed index (g), lint index (g), Ginning Out Turn (GOT %), seed cotton yield (kg/ha) and lint yield (kg/ha). The lines GISV298 and SCS1207; the testers, Lam GPC 501 and Lam GPC 355 exhibited positive General Combining Ability (GCA) effects for the traits Ginning Out Turn (GOT%), Seed Cotton Yield (SCY) and Lint Yield (LY) signifying that these were good general combiners. The cross combinations *viz*., TCH1837/GP117, GISV298/GP274, and SCS1207 / GP117 expressed significant specific combining ability (SCA) effects for Seed Cotton Yield (SCY) and Lint Yield (LY). The cross combination, SCS1207/ Lam GPC 355 was identified as the best hybrid combination with high GCA and SCA for important traits like GOT, seed cotton yield, and lint yield coupled with significant positive heterosis which can be further tested in multi-location testing at the station and all India level.

Key words: *Cotton, Line × Tester Analysis, General Combining Ability (GCA), Specific Combining Ability (SCA), and Heterosis.*

Introduction

Cotton is one of the important natural fibre crops widely used in the textile industry, a source of edible oil and planted in more than 80 countries/regions of the world. The main aim of the cotton breeder is to develop high-yielding cotton varieties, through heterosis breeding using selection and hybridization methods in the available germplasm. The association between genetic and non-genetic components has complex nature. The selection of plants with desirable traits depends on the objectives of the breeder. At this juncture, for the development of promising genotypes, it is essential to study the genetic material for nature and the degree of correlation between the seed cotton yield and other attributing traits. The study of the magnitude of variation in a particular trait in each plant and its inheritance to the next generation is of utmost importance for the effective screening of the breeding population.

The combination of ability or productivity is the combination of cross-line potential concerning the

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transfer of desirable genes to their progeny. The ability of combination between two parents has been classified into general combining ability, defined as the average performance of a line in a series of crosses, and specific combining ability is known as performance in specific combination consanguineous parents (Sprague and Tatum, 1942).

Hybrid cotton is growing in many countries like China, India, Vietnam, and Myanmar (Ansari, 2011). In India, Rajasthan, Haryana and Punjab, and Western Uttar Pradesh of the North Zone, Gujarat, Madhya Pradesh, and Maharashtra of the Central Zone, Karnataka, Andhra Pradesh, and Tamil Nadu of the South zone cover about 95% of the cotton area and also contribute about 95% to the total cotton production. Commercial cultivation of cotton hybrids has brought about substantial change in cotton production in India in terms of quality and quantity. Seed cotton yield is a complex polygenic trait governed by many genes whose individual effect is very minor and greatly influenced by the environment. Hence, the utmost importance should be given to increasing the productivity of better-quality raw cotton.

The evidence on combining ability for seed cotton yield and its attributing traits guides to select of suitable parents and promising cross combination in a breeding program. Based on combining ability and gene action, parents and cross combinations can be selected to get the best phenotypic performance. Usharani *et al.* 2016 stated that the line x tester analysis is one of the most important statistic-genetic methods that offer existing information about the general combing ability of parents (GCA) and the specific combining abilities of their crosses (SCA).

Materials and Methods

The current investigation was executed at Regional Agricultural Research Station (RARS), Lam, Guntur during *Kharif* 2021 by using the experimental material of three lines and six testers along with 18 F_1 hybrids in Randomized Block Design (RBD) in two replications to estimate general combining ability of parents and specific combing ability of the F_1 hybrids. Each parent and F_1 hybrid were sown in two rows of 6m in length each with a spacing of 105 x 60 cm. The necessary package of practices was implemented to raise a healthy crop. Statistical data were recorded on five randomly selected plants in all the replications for the traits viz., days to 50% flowering, plant height (cm), number of monopodia/ plant, number of sympodia/plant, number of bolls/plant, boll weight (g), seed index (g), lint index (g), Ginning Out Turn (GOT) (%), Seed Cotton Yield (SCY) (kg/ha) and Lint Yield (LY) (kg/ha).

Statistical analysis: The collected data were subjected to statistical analysis for ANOVA as proposed by Gomez and Gomez (1984), heterosis and heterobeltiosis according to Falconer (1989), and the line x tester as recommended by Kempthorne (1957) as implemented by Singh and Chaudhary (1979). The significance of Heterosis was determined using the least significant difference value (L.S.D) at 0.05 and 0.01 levels of probability according to Steel and Torrie (1980).

Results and Discussion

The average performance of the hybrids and their parents was presented in Table 1. The F_1hybrids, SCS1207 / GP51, SCS1207 / GP355, GISV298 / GP274, GISV298 / GP355, GISV298 / GP501 and TCH1837 / GP117 were identified as top performers for seed cotton yield, while the F_1hybrids, SCS1207 / GP355 followed by GISV298 / GP274, GISV298 / GP355 exhibited high lint yield. The F_1hybrids, GISV298 / GP355, SCS1207 / GP501, SCS1207 / GP274 and SCS1207 manifested high ginning out turn per cent. The tester Lam GPC 355 showed notable average performance by crossing with females SCS 1207 and GISV 298 for seed cotton and lint yield.

The lines and testers that have high GCA estimates are considered the best general combiners for that particular character while the F_1 hybrids that are having high SCA effects are viewed as the specified best hybrid combination for the said trait.

To know the stake of each component; the relative role of females (lines), males (testers), and their interaction (L × T) to whole genetic variance for different traits studied. The mean sum of squares for combining ability for different traits was presented in Table 2. Significant differences were observed due to genotypes from the analysis of variance for all the traits representing the existence of adequate variability in the experimental material. The parents showed a significant mean sum of squares for the traits, days to 50% flowering, plant height, number of monopodia/plant, number of bolls/plant, boll weight, seed index, and lint index whereas the F_1 hybrids exhibited significant differences for all the

Table 1. Mean performance values of F_1crosses and their parents concerning seed cotton yield and its components in *Gossypium hirsutum* L.

S. No	F_1Hybrid/Parent	DFF	Plant height (cm)	Number of Monopodia/ plant	Number of Sympodia/ plant	No of bolls/ plant	Boll weight (g)	Seed index (g)	Lint Index (g)	GOT (%)	SCY (kg/ha)	LY (kg/ha)
F_1 Hybrid												
1	TCH1837 / Lam GPC 51	62	130	2	20	48	2	7.4	4.6	21.1	1547.6	327.6
2	TCH1837 / Lam GPC 235	64	154	3	22	51	4	8.6	4.4	21.4	1706.3	364.5
3	TCH1837 / Lam GPC 117	65	152	2	27	66	5	10.2	6.9	35.4	2381.0	844.1
4	TCH1837 / Lam GPC 501	63	140	2	27	65	5	9.5	6.6	35.2	2182.5	764.8
5	TCH1837 / Lam GPC 355	65	130	2	21	58	4	7.7	5.0	23.8	1666.7	399.0
6	TCH1837 / Lam GPC 274	64	111	1	19	43	3	9.7	4.7	23.8	1627.0	383.5
7	GISV298 / Lam GPC 51	63	149	2	26	68	5	6.7	7.2	35.9	2341.3	844.1
8	GISV298 / Lam GPC 235	62	115	3	26	68	5	8.8	6.4	35.6	2222.2	788.7
9	GISV298 / Lam GPC 117	64	132	1	16	35	4	9.7	4.5	26.6	1666.7	445.3
10	GISV298 / Lam GPC 501	63	133	2	24	69	5	9.6	6.5	35.6	2381.0	844.4
11	GISV298 / Lam GPC 355	65	135	2	14	67	5	10.5	7.4	35.4	2460.3	869.2
12	GISV298 / Lam GPC 274	63	132	1	27	67	5	10.4	7.0	35.4	2539.7	897.1
13	SCS1207 / Lam GPC 51	59	96	2	15	53	5	10.9	5.1	32.3	2653.8	855.1
14	SCS1207 / Lam GPC 235	63	143	2	17	33	4	9.7	4.8	28.9	1746.0	501.7
15	SCS1207 / Lam GPC 117	63	145	1	26	68	5	13.9	6.8	35.7	2261.9	805.4
16	SCS1207 / Lam GPC 501	62	128	2	14	51	4	8.9	5.6	38.6	2132.5	824.4
17	SCS1207 / Lam GPC 355	60	115	1	14	48	5	9.2	5.8	38.7	2632.9	1019.6
18	SCS1207 / Lam GPC 274	61	112	1	14	49	4	9.4	5.7	37.6	1899.8	713.8
Parents												
19	TCH1837	63	119	2	18	52	3	13.8	4.4	35.7	1983.0	709.3
20	GISV298	61	111	2	16	24	4	13.4	4.1	32.6	2188.5	715.0
21	SCS1207	62	108	1	18	36	4	11.4	3.7	37.2	1999.0	743.4
22	Lam GPC 51	60	117	1	16	40	4	15.7	5.1	30.4	2170.0	657.8
23	Lam GPC 235	62	99	1	16	41	3	15.3	4.9	36.1	2261.0	815.2
24	Lam GPC 117	63	138	2	20	51	4	13.9	4.9	36.1	2166.5	780.2
25	Lam GPC 501	62	139	2	22	48	4	10.7	4.2	35.7	2296.5	817.9
26	Lam GPC 355	63	116	1	18	46	3	9.2	3.2	33.8	2215.0	747.7
27	Lam GPC 274	62	166	1	23	40	4	13.3	4.9	32.6	2202.5	715.4

traits except for seed index. The crosses (F_1 hybrids) showed great significant variation for all the traits under study except for the seed index. The lines (L) exhibited highly significant mean squares for the traits days to 50% flowering, plant height, number of sympodia/plant, number of bolls/plant, boll weight, lint index, GOT % seed cotton yield, and lint yield while non-significant values were observed for the number of monopodia/plant and seed index. In testers, highly significant variances were observed for days to 50% flowering, plant height, the number of monopodia/plant, boll weight, seed index, and lint index whereas non-significant variances were recorded for the number of sympodia/plant, the number of bolls/plant, GOT, seed cotton yield and lint yield. The relative impact of L × T interactions contributed maximum and significance to the total sum of squares for the characters except for the seed index These results were in agreement with the findings of Sivia *et al*. (2017). Significant differences were observed among parents, crosses, and parents vs crosses. This implied adequate genetic variability among the lines (L), testers (T), and their crosses (F_1 hybrids), and hence general combining ability for lines and testers was estimated and partitioned from the sum of squares as general comingling ability (mean squares of lines/females) and Specific Combining Ability (SCA) (mean squares of testers/males). The non-significance of mean squares of GCA for lines as well as testers and significance of line × tester effect for most of the traits indicate the predominance of both additive and non-additive gene actions (Chattha *et al.*, 2018; Prakash *et al.*, 2018 and Chapara *et al.,* 2020). The traits, days to 50% flowering, number of monopodia/plant, and seed index exhibited high GCA variances than SCA variances, and GCA to SCA ratio more than unity suggesting the preponderance of additive gene action in controlling these variables while superior SCA variances were noticed with plant height, number of sympodia/plant, number of bolls/plant, boll weight, lint index, GOT, seed cotton yield and lint yield signifying the non-additive gene action (Usharani *et al*., 2016). The ratio of GCA to SCA less than unity confirmed the results and hence the selection of these traits should go through with population improvement approaches like recombinant selection in segregating generations.

The proportional contribution of lines, testers, and their L × T interaction (%) for various traits in *Gossypium hirsutum* L was presented in table 3. The

Table 2. Analysis of variance for combining effects of different characters in *Gossypium hirsutum* L.

Source of Variation	df	DFF	Plant Height (cm)	Number of Monopodia/ plant	Number of Sympodia/ plant	No of bolls/ plant	Boll weight (g)	Seed index (g)	Lint Index (g)	GOT (%)	SCY (kg/ha)	LY (kg/ha)
Replicates	1	5.352**	236.463	0.296	12.519	50.074	0.463	0.296	0.463	3.13	17424.1	10361.19
Genotypes	26	5.185**	623.92**	0.553**	45.113**	320.313**	1.385**	12.386**	3.013**	55.095**	216558**	72367.74**
Parents (P)	8	3.5**	909.5**	0.347*	25.375	212.764*	0.764**	11.00**	2.056**	9.347	86971.1	15972.72
F1 hybrids (Crosses)	17	6.087**	494.596*	0.655**	55.851**	287.177**	1.518**	4.562	2.224**	74.309**	282364**	98804.44**
Parent vs F1 hybrids (Crosses)	1	3.343*	537.787	0.454	20.454	1744.04**	4.083**	156.482**	24.083**	94.454**	134550	74104.09**
Parents (Line)	2	6.167**	1954.17**	0.167	73.167*	700.167**	1.5**	0.167	3.500**	4.167	271424*	43450.17**
Parents (Testers)	5	2.933**	522.283*	0.4*	7.283	58.933	0.533*	16.733**	1.333*	13.2	21708.3	7076.15
Line × Tester effect	10	3.194**	490.994*	0.294	50.861**	354.983**	1.694**	3.494	2.528**	53.133**	297682**	85625.48**
Error	26	0.467	200.04	0.142	14.48	70.766	0.194	2.335	0.463	5.976	49258.8	7680.57
5 ² GCA		1.537	24.517	0.104	7.273	19.427	0.188	0.331	0.211	15.976	35385	18052.74
5 ² SCA		1.384	99.16	0.075	15.688	132.142	0.722	0.277	0.956	23.014	123244	39072.21
5ß ² GCA/5 ² SCA		1.11	0.25	1.39	0.46	0.15	0.26	1.19	0.22	0.69	0.29	0.46

*Significance at 5% level **Significance at 1% level

line × tester effect was significant for all the traits except for the seed index while lines and testers exhibited the lowest contribution. Monicashree *et al.* 2017 reported similar findings in their study.

Combining ability

The GCA and SCA estimates for seed cotton yield and its attributing traits were given in Tables 4 and 5.

Days to 50% flowering: The lines exhibited a GCA range from -1.611 (SCS 1207) to 0.972 (TCH 1837), whereas among the testers the GCA ranged from -1.528 (Lam GPC 51) to 1.139 (Lam GPC 117). The negative estimates of GCA are essential for earliness. Nine out of eighteen F_1 hybrids showed desired negative SCA effects ranging from -1.889 to -0.222 for early maturity. The F_1 hybrids i.e., SCS1207 / Lam GPC 355 (-1.8999) and GISV298 / Lam GPC 235 (1.472) were found as best specific cross combinations for early maturity as these hybrids exhibited maximum negative SCA effects in the desirable direction. At the GCA level, the female line SCS 1207 and the male tester Lam GPC 51 exhibited significant negative GCA effects for days to flowering and performed significant negative SCA effects in their F_1 hybrids through contribution as high × low, low × high, and low × low general combiners.

Plant height (cm): The lowest GCA values were observed by the line SCS 1207 (-7.528) and the highest was recorded by TCS 1837 (5.472). Concerning males, the lowest value was noticed with the tester Lam GPC 274 (-12.194) and the highest with Lam GPC 117 (12.472). For the trait plant height, ten F_1 hybrids revealed positive SCA effects ranging from 0.528 to 21.944, while negative SCA effects were expressed by eight crosses ranging from -0.472 to -24.222. The F_1 hybrids *viz.*, GISV298 / Lam GPC 51 (21.944) followed by SCS1207 / Lam GPC 235 (13.361) and GISV298 / Lam GPC 274 (11.444) expressed maximum positive SCA effects with high × low, low × high and high × low GCA effects while the cross combinations GISV298 / Lam GPC 235 followed by SCS1207 / Lam GPC 51 exhibited negative SCA for this trait. The cross combinations *viz.*, GISV 298 / Lam GPC 235, GISV 298 / Lam GPC 117, SCS 1207 / Lam GPC 51, TCH 1837 / Lam GPC 274 with high × high, low × low and high × low GCA respectively exhibited negative SCA values which are useful for the development of short-statured genotype.

Number of monopodia/plant: The GCA ranged

Table 3. The proportional contribution of lines, testers, and their L × T interaction (%) for various traits in *Gossypium hirsutum* L.

Source of Variation	df	DFF	Plant height (cm)	Number of Monopodia/ plant	Number of Sympodia/ plant	No of bolls/ plant	Boll weight (g)	Seed index (g)	Lint Index (g)	GOT (%)	SCY (kg/ha)	LY (kg/ha)
Line effect	2	23.694*	545.028	0.861	136.194	441.083	3.528	5.528	4.194	259*	624410	292045
Tester effect	5	4.828	481.628	1.294*	33.694	90	0.361	6.311	0.828	42.783	114908	47866
Line × Tester effect	10	3.194**	490.994*	0.294*	50.861**	354.983**	1.694**	3.494	2.528**	53.133**	297682**	85625.5**
Error	17		292.675	0.145	19.485	90.699	0.25	2.941	0.616	7.106	51194.5	7481.07

*Significance at 5% level **Significance at 1% level

Table 4. The proportional contribution of lines, testers, and their L × T interaction (%) for various traits *Gossypium hirsutum* L.

	DFF	Plant height (cm)	Number of Monopodia/ plant	Number of Sympodia/ plant	No of bolls/ plant	Boll weight (g)	Seed index (g)	Lint Index (g)	GOT (%)	SCY (kg/ha)	LY (kg/ha)
Lines											
TCH1837	0.972**	5.472	0.194	2.028	-0.583	-0.52**8	-0.472	-0.528*	-5.333**	-261.972**	-180.11**
GISV298	0.639**	2.056	0.111	1.861	6.333*	0.556**	-0.306	0.639*	2.167*	154.694*	87.389**
SCS1207	-1.611**	-7.528	-0.306*	-3.889**	-5.75	-0.028	0.778	-0.111	3.167**	107.278	92.722**
Testers											
Lam GPC 51	-1.528**	-5.694	0.194	-0.139	0.167	-0.028	-1.056	-0.361	-2.25	66.944	-18.194
Lam GPC 274	-0.194	-12.194	-0.639**	-0.306	-2.833	-0.194	0.111	-0.028	0.083	-91.556	-29.361
Lam GPC 501	-0.194	2.806	0.194	1.194	6	0.306	-0.222	0.306	4.417**	118.111	117.139**
Lam GPC 235	0.306	6.472	0.694**	0.861	-5.333	-0.361	-0.389	-0.528	-3.25**	-222.222*	-142.36**
Lam GPC 355	0.472	-3.861	-0.139	-4.306*	1.5	0.139	-0.389	0.306	0.583	139.444	68.472
Lam GPC 117	1.139**	12.472	-0.306	2.694	0.5	0.139	1.944*	0.306	0.417	-10.722	4.306
CD 95% GCA(Line)	0.398	10.42	0.232	2.688	5.8	0.305	1.045	0.478	1.624	137.806	52.679
CD 95% GCA(Tester)	0.562	14.735	0.328	3.802	8.203	0.431	1.477	0.676	2.296	194.886	74.499

*Significance at 5% level **Significance at 1% level

from -0.306 (SCS1207) to 0.194 (TCH 1837) for females whereas the testers exhibited a range from -0.306 (SCS1207) to 0.194 (TCH 1837). The cross combinations, SCS1207 / Lam GPC 355 and TCH1837 / Lam GPC 117 showed significant negative SCA for the number of monopodia/plant with low × low and high × low GCA respectively. Most of the hybrid combinations with the line SCS 1207 exhibited zero monopodia/plant which is desirable for high-density planting systems. Eleven hybrids out of eighteen showed zero monopodia per plant which was in the desirable direction. One hybrid SCS1207 / Lam GPC 274 showed a significant positive SCA effect for this trait.

Number of sympodia/plant: The lines exhibited GCA range from -3.389 (SCS1207) to 2.028 (TCH 1837), while testers' GCA ranged from -4.306 (Lam GPC 355) to Lam GPC 117 (2.694). The SCA effects ranged from -8.528 to 6.722. Nine hybrids out of eighteen expressed positive SCA effects for this trait along with high × high, high × low, low × high, and low × low GCA effects. The cross combination, SCS1207 / Lam GPC 117 (low × high GCA) exhibited the highest significant positive SCA (6.722) for this trait.

Number of bolls/plant: For this trait, a GCA range of -5.75 (SCS 1207) to 6.333 (GISV 298) was observed for females while testers expressed a range of -5.333 (Lam GPC 235) to 6.000 (Lam GPC 501). Twelve cross combinations expressed positive SCA effects ranging from 0583 to 17.417, while leftover six F1 hybrids exhibited negative SCA effects (-28.167 to -4.083). Highly significant positive SCA effects were manifested by the F1 cross combination i.e. SCS1207 / Lam GPC 117 (17.417) followed by GISV298 / Lam GPC 235 (11.167) and TCH1837 / Lam GPC 117 (10.75) with low × high, high × low and low × high GCA effects.

Boll weight (g): For boll weight, the GCA for lines ranged from -0.528 (TCH 1837) to 0.556 (GISV 298) whereas testers exhibited a range of -0.361 (Lam GPC 235) to 0.306 (Lam GPC 501). Positive SCA effects ranging from 0.028 to 1.028 were shown by ten F_1 hybrids, whereas the rest eight F_1 crosses exhibited negative SCA values (-1.556 to -0.139). A significant positive SCA effect was possessed by the F1 hybrid TCH1837 / Lam GPC 117 (1.028) followed by TCH1837 / Lam GPC 501 (0.861). Therefore, parents with low × high GCA effects produced F_1 hybrids with desirable SCA effects for this trait.

Seed Index (g): Overall, the highest positive GCA effects of 0.078 (SCS 1207) and 1.944 (Lam GPC 117) and the least -0.472 (TCH 1837) and -1.056 (Lam GPC 51) were expressed by the females and males respectively. Eight F_1 hybrids revealed positive SCA with a range of 0.222 to 1.889, while negative SCA values (-1.528 to -0.028) were noted in ten F_1 hybrids. However, F_1 hybrids SCS1207 / Lam GPC 51 (1.889), SCS1207 / Lam GPC 117 (1.389) and GISV298 / Lam GPC 355 (1.306) were identified as best specific combiners by having maximum SCA effects. In the above F_1 hybrids, the line SCS 1207 and tester Lam GPC 117 were having high positive GCA effects while the line GISV 298 and the tester Lam GPC 51 and Lam GPC 355 exhibited low positive GCA effects.

Lint Index (g): Among the lines, the maximum GCA effects were observed by GISV 298 (0.639) and while the least was exhibited by TCH 1837 (-0.528) whereas, among the testers, Lam GPC 177 (0.306) and Lam GPC 235 (-0.528) expressed maximum GCA and minimum GCA respectively. For the lint index, eight F_1 hybrids revealed positive SCA with a range of 0.278 to 1.361, while negative SCA values (-2.306 to -0.056) were exhibited by ten F_1 hybrids. The F_1 hybrid TCH1837 / Lam GPC 117 (1.361) exhibited significant positive SCA effects (1.361) followed by SCS1207 / Lam GPC 117 (0.944), TCH1837 / Lam GPC 501 (0.861) and GISV298 / Lam GPC 51 (0.861) were found as best specific combiners by having maximum SCA effects. In the above F_1 hybrids, the lines (GISV 298) and testers Lam GPC 117 and Lam GPC 501 were having high GCA effects while the lines TCH 1837, SCS 1207 and the tester Lam GPC 51 exhibited low GCA effects.

Ginning Out Turn (GOT) (%): Maximum GCA effect was noticed with the line, SCS 1207 (3.167) while minimum with TCH 1837 (-5.333). Among the

Table 5. Specific combining ability effects of lines x testers for various traits in *Gossypium hirsutum* **L.**

Hybrid	DFF	Plant height (cm)	Number of Monopodia/ plant	Number of Sympodia/ plant	No of bolls/ plant	Boll weight (g)	Seed index (g)	Lint Index (g)	GOT (%)	SCY (kg/ha)	LY (kg/ha)
TCH1837 / Lam GPC 51	-0.472	-0.472	-0.194	-2.361	-7.417	-1.306**	-0.361	-0.472	-3.000	-370.861*	-167.722*
TCH1837 / Lam GPC 235	-0.306	10.861	0.306	-1.861	0.583	0.028	-0.028	-0.306	-2.000	76.806	-7.056
TCH1837 / Lam GPC 117	0.361	3.861	0.306	1.806	10.75	1.028**	-0.361	1.361*	8.333**	539.806**	325.778**
TCH1837 / Lam GPC 501	-0.306	0.528	-0.194	2.806	4.25	0.861*	0.806	0.861	3.833	212.472	133.444*
TCH1837 / Lam GPC 355	0.528	-2.306	0.139	2.306	0.75	-0.472	-0.528	-0.639	-3.833	-324.861	-183.389**
TCH1837 / Lam GPC 274	0.194	-12.472	-0.361	-2.694	-8.917	-0.139	0.472	-0.806	-3.333	-133.361	-101.056
GISV298 / Lam GPC 51	1.361**	21.944	-0.111	3.806	5.167	0.611	-1.528	0.861	4.000*	5.472	80.778
GISV298 / Lam GPC 235	-1.472**	-24.222	-0.111	2.806	11.167	0.444	-0.194	0.528	5.000*	176.139	149.444*
GISV298 / Lam GPC 117	-0.806	-13.222	-0.111	-8.528*	-28.17**	-1.556**	-1.028	-2.306**	-8.167**	-591.361**	-340.222**
GISV298 / Lam GPC 501	-0.472	-2.056	0.389	0.972	0.833	-0.222	0.639	-0.306	-2.667	-5.694	-54.056
GISV298 / Lam GPC 355	1.361**	6.111	0.222	-4.528	3.333	0.444	1.306	0.694	0.667	52.472	19.111
GISV298 / Lam GPC 274	0.028	11.444	-0.278	5.472	7.667	0.278	0.806	0.528	1.167	362.972*	144.944*
SCS1207 / Lam GPC 51	-0.889	-21.472	0.306	-1.444	2.25	0.694	1.889	-0.389	-1.000	365.389*	86.944
SCS1207 / Lam GPC 235	1.778**	13.361	-0.194	-0.944	-11.75	-0.472	0.222	-0.222	-3.000	-252.944	-142.389*
SCS1207 / Lam GPC 117	0.444	9.361	-0.194	6.722*	17.417*	0.528	1.389	0.944	-0.167	51.556	14.444
SCS1207 / Lam GPC 501	0.778	1.528	-0.194	-3.778	-5.083	-0.639	-1.444	-0.556	-1.167	-206.778	-79.389
SCS1207 / Lam GPC 355	-1.889**	-3.806	-0.361	2.222	-4.083	0.028	-0.778	-0.056	3.167	272.389	164.278*
SCS1207 / Lam GPC 274	-0.222	1.028	0.639*	-2.778	1.25	-0.139	-1.278	0.278	2.167	-229.611	-43.889
CD 95% SCA	0.974	25.523	0.569	6.585	14.208	0.746	2.559	1.171	3.977	337.553	129.037

*Significance at 5% level **Significance at 1% level

testers, Lam GPC 501 exhibited the highest GCA of 4.417 while the least was expressed by Lam GPC 235 (-3.250). Eight F1 hybrids exhibited positive SCA effects ranging from 0.667 to 8.333. The F1 hybrids *viz*., TCH1837 / Lam GPC 117 (8.333) followed by GISV298 / Lam GPC 235 (5.000) and GISV298 / Lam GPC 51 (4.000) expressed maximum positive SCA with low × high and high × low GCA effects. Ten cross combinations exhibited negative SCA values for this trait.

Seed Cotton Yield (SCY) (kg/ha): For this trait, among lines, GCA ranged from -261.972 (TCH 1837) to 154.694 (GISV 298) whereas, in the testers, the range was from -222.222 (Lam GPC 235) to 139.444 (Lam GPC 355). For seed cotton yield, positive SCA effects were demonstrated by ten F_1 hybrids ranging from 5.472 to 539.806, while eight F_1 hybrids exposed negative SCA effects (-591.361 to -5.694). However, the highest needed SCA effects were exhibited by the F1 hybrids i.e., TCH1837 / Lam GPC 117 (539.806), SCS1207 / Lam GPC 51 (365.379), GISV298 / Lam and GPC 274 (362.972) for seed cotton yield. Further, these results revealed that low × low, high × high, and high × low GCA parental genotypes were involved in the manifestation of desirable SCA effects in F1 hybrids for seed cotton yield.

Lint Yield (kg/ha): The line SCS 1207 (92.722) and GISV 298 (87.389) while the testers Lam GPC 501 (117.139) and Lam GPC 355 (68.472) revealed high positive GCA effects for this trait. Nine out of eighteen F_1 hybrids showed desired positive SCA effects ranging from 14.444 to 325.778 for this trait while rest nine hybrids showed negative SCA effects ranging from -340.222 to -7.056. The F_1 hybrids i.e., TCH1837 / Lam GPC 117 (325.778), SCS1207 / Lam GPC 355 (164.278), GISV298 / Lam GPC 235 (149.444), GISV298 / Lam GPC 274 (144.944) and TCH1837 / Lam GPC 501 (133.444) were identified as best specific cross combinations for lint yield as these hybrids exhibited maximum significant

Table 6. Estimates of Mid Parental Heterosis for various characters in F1hybrid generation *Gossypium hirsutum* L.

Hybrid	DFF	Plant height (cm)	Number of Monopodia/ plant	Number of Sympodia/ plant	No of bolls/ plant	Boll weight (g)	Seed index (g)	Lint Index (g)	GOT (%)	SCY (kg/ha)	LY (kg/ha)
TCH1837 / Lam GPC 51	-2.38 *	-6.31	60.00 *	-13.04	1.05	-44.44 **	-40.00 **	-10.00	-39.44 **	-34.09 **	-61.65 **
TCH1837 / Lam GPC 235	2.83 **	7.53	100.00 **	-2.27	2.54	-22.22 *	-43.33 **	-21.74	-39.44 **	-29.90 **	-55.14 **
TCH1837 / Lam GPC 117	3.17 **	14.02	60.00 *	22.73	33.00	25.00 *	-28.81 *	21.74	0.00	-3.98	-5.3
TCH1837 / Lam GPC 501	-0.40	-9.12	14.29	12.77	19.63	11.11	-32.14 **	18.18	-1.41	-10.28	-12.53
TCH1837 / Lam GPC 355	2.38 *	-15.58	14.29	-16.33	7.98	-22.22 *	-34.69 *	-4.76	-33.80 **	-33.27 **	-55.29 **
TCH1837 / Lam GPC 274	0.00	-21.75	-33.33	-14.29	-16.75	-12.50	-17.39	-5.26	-33.80 **	-33.77 **	-55.29 **
GISV298 / Lam GPC 51	1.20	30.99 *	33.33	40.54	54.29 *	46.67 **	-46.94 **	75.00 **	1.41	17.58	16.21
GISV298 / Lam GPC 235	1.64	-2.34	42.86 *	48.57 *	49.45 *	33.33 *	-42.37 **	36.84 *	1.41	7.03	15.36
GISV298 / Lam GPC 117	2.01 *	21.38	0.00	-5.71	-25.41	7.69	-31.03 **	-5.26	-25.35 **	-21.47 *	-41.55 **
GISV298 / Lam GPC 501	0.00	3.89	25.00	28.95	35.29 *	33.33 *	-30.91 *	44.44 **	1.41	14.76	13.36
GISV298 / Lam GPC 355	4.42 **	4.65	0.00	-32.50	35.35 *	46.67 **	-16.67	76.47 **	0.00	14.99	13.82
GISV298 / Lam GPC 274	0.40	12.34	-42.86 *	50.68 *	38.14 *	53.85 **	-11.11	86.67 **	0.00	21.01 *	23.09 *
SCS1207 / Lam GPC 51	-4.49 **	-12.73	33.33	-13.04	76.47 *	33.33 *	-10.20	33.33	-3.03	26.73 *	17.35
SCS1207 / Lam GPC 235	5.00 **	25.44	14.29	1.54	4.76	-6.67	-32.20 **	11.11	-12.12	-19.88 *	-26.85 *
SCS1207 / Lam GPC 117	2.04 *	38.10 *	-33.33	60.00 *	110.85 **	53.85 **	-6.90	55.56 **	7.58	1.67	5.29
SCS1207 / Lam GPC 501	0.00	2.2	-25.00	-21.13	37.84	6.67	-38.18 **	29.41	16.67	-2.07	10.26
SCS1207 / Lam GPC 355	-2.86 **	-7.78	-50.00 **	-22.67	33.8	20.00	-25.00	50.00 **	18.18 *	17.41	33.05 **
SCS1207 / Lam GPC 274	-2.02 *	-1.54	-14.29	-20.59	40.58	23.08	-20.00	71.43 **	13.64	-13.71	-2.46

*Significance at 5% level **Significance at 1% level

positive SCA effects in the desirable direction. At the GCA level, the female lines SCS 1207 and GISV 298 and the testers Lam GPC 117 and Lam GPC 501 showed high positive GCA effects while the female TCH 1837 and the males' Lam GPC 355, Lam GPC 235, and Lam GPC 274 exhibited low GCA effects and contributed their best F_1 hybrids through contribution as low × high, high × high, high × low and low × high general combiners. The hybrids, TCH1837 / Lam GPC 117 followed by SCS1207 / Lam GPC 51 and GISV298 / Lam GPC 274 manifested high specific combining ability for seed cotton yield and lint yield.

Among the lines, GISV 298 followed by SCS 1207, and among the testers, Lam GPC 355 followed by Lam GPC 501 showed significant positive GCA effects for ginning out turn percent, seed cotton yield, and lint yield and were identified as the best general combiners/pollinators for these traits. The line SCS 1207 and the tester Lam GPC 501 were also identified for earliness, hence, these can be used for breeding programs with the objective of earliness and high yield. Among the parents, the lines *viz*., GISV 298, SCS 1207 followed by TCH 1837; the testers *viz*., Lam GPC 501, Lam GPC 235, and Lam GPC 355 yielded high seed cotton yield as well as lint yield. Concerning GOT (%), the line SCS 1207 and the testers, Lam GPC 235 and Lam GPC 117 exhibited high GOT percent.

In the current investigation, the specific F_1hybrid combinations with high × high and high × low general combiners accomplished well for seed cotton yield/ha, lint yield/ha, and GOT (%). Karademir *et al.*, 2016 and Chinchane *et al.*, 2018, in their investigation, reported that having at least one good GCA parent in the hybrid combinations produced best-performed hybrids for seed cotton yield as well as for other traits in cotton. Hence, the traits like seed cotton yield/ha, lint yield/ha, and ginning out turn percent could be further improved by using the high general combiners.

Table 7. Estimates of Better ParentalHeterosis (Heterobeltiosis) for various characters in F_1 hybrid generation*Gossypium hirsutum* L.

Hybrid	DFF	Plant height (cm)	Number of Monopodia/ plant	Number of Sympodia/ plant	No of bolls/ plant	Boll weight (g)	Seed index (g)	Lint Index (g)	GOT (%)	SCY (kg/ha)	LY (kg/ha)
TCH1837 / Lam GPC 51	-3.91 **	-23.08 *	33.33	-27.27	-18.64	-50.00 **	-46.43 **	-30.77 *	-42.67 **	-42.63 **	-66.10 **
TCH1837 / Lam GPC 235	-0.78	-9.17	100.00 **	-21.82	-14.41	-30.00 **	-46.88 **	-30.77 *	-29.51 **	-36.76 **	-62.33 **
TCH1837 / Lam GPC 117	1.56	-9.76	33.33	-1.82	12.71	0.00	-32.26 **	7.69	-1.39	-11.77	-12.76
TCH1837 / Lam GPC 501	-1.56	-17.46	0.00	-3.64	11.02	0.00	-32.14 *	0.00	-4.11	-19.12 *	-20.98 *
TCH1837 / Lam GPC 355	0.78	-23.08 *	0.00	-25.45	-2.54	-30.00 **	-42.86 **	-23.08	-34.72 **	-38.24 **	-58.76 **
TCH1837 / Lam GPC 274	-0.78	-34.02 **	-33.33	-29.09	-26.27	-30.00 **	-32.14 *	-30.77 *	-29.85 **	-39.71 **	-60.36 **
GISV298 / Lam GPC 51	0.80	25.21	0.00	40.54	31.07	37.50 **	-51.85 **	55.56 **	-4.00	17.11	13.59
GISV298 / Lam GPC 235	-0.80	-3.36	25.00	40.54	32.04	25.00	-46.88 **	30	18.03	2.42	11.13
GISV298 / Lam GPC 117	1.60	10.92	-25.00	-10.81	-33.01	0.00	-35.48 **	-10	-26.39 **	-26.29 *	-45.34 **
GISV298 / Lam GPC 501	0.00	-3.26	25.00	25.64	33.98	25.00	-32.14 *	44.44 *	-1.37	9.9	8.2
GISV298 / Lam GPC 355	4.00 **	-2.88	0.00	-37.21	30.10	37.50 **	-25.93	66.67 **	-1.39	7.14	6.3
GISV298 / Lam GPC 274	0.00	10.92	-50.00 *	48.65	30.10	42.86 **	-25.93	55.56 **	5.97	14.67	19.92
SCS1207 / Lam GPC 51	-5.65 **	-13.9	0.00	-18.92	45.83	25.00	-18.52	25.00	-14.67	21.25	15.14
SCS1207 / Lam GPC 235	4.13 **	22.75	0.00	0.00	-16.46	-12.5	-37.50 **	0.00	-4.92	-20.22	-29.79 *
SCS1207 / Lam GPC 117	0.81	30.04	-50.00 *	57.58 *	65.85 *	42.86 **	-12.90	40.00 *	-1.39	0.04	-1.17
SCS1207 / Lam GPC 501	-1.60	-7.61	-25.00	-28.21	0.99	0.00	-39.29 **	22.22	5.48	-2.56	5.64
SCS1207 / Lam GPC 355	-4.03 **	-16.91	-50.00 *	-32.56	0.00	12.50	-33.33 *	50.00 *	8.33	14.65	24.71 *
SCS1207 / Lam GPC 274	-3.97 **	-3.45	-25.00	-25.00	6.59	14.29	-33.33 *	50.00 *	11.94	-14.22	-4.61

*Significance at 5% level **Significance at 1% level

Among all eighteen F_1 hybrids, TCH1837 / Lam GPC 117 was the topmost cross combination with desirable SCA effects for all the traits except for the seed index involving high × high as well as high × low and low x high combinations. The 2nd best scoring F1 hybrids were TCH1837 / Lam GPC 117 (325.778), SCS1207 / Lam GPC 355 (164.278), GISV298 / Lam GPC 235 (149.444), GISV298 / Lam GPC 274 (144.944) and TCH1837 / Lam GPC 501 (133.444) which showed desirable SCA effects for boll weight, ginning out turn, seed cotton yield/ha and lint yield/ha. It was observed that the best F_1 cross combinations were derived from at least one of the parents with high/average GCA for a given character in cotton. The females/ lines and males/ testers with needed GCA effects accomplished well and exhibited extreme genetic variability in their F_1 hybrid combinations. It was also noticed that for the development of good hybrid combinations the parents don't need to always have high GCA. It was evident that the parents with low GCA also contributed to yielding promising hybrids in the current study. These findings are in agreement with Reddy *et al.* 2017. These results indicated the non-additive gene action for seed cotton yield, lint yield, and ginning out turn hence, selection can be done in F_4-F_5 generations for these traits.

Heterosis Estimates

Heterosis estimates are used to determine the degree of phenotypic variance due to genetic variance. Positive heterosis is generally considered desirable for all studied traits, except days to 50% flowering and the number of monopodia/plant. The estimates of mid-parental and better-parental heterosis were mentioned in Tables 6 and 7. In the current study the results revealed that out of eighteen F_1 crosses, seven crosses were promising and exhibited positive heterotic values relative to the better parent for seed cotton yield and lint cotton yield. The F_1 hybrid SCS1207 / GP355 exhibited positive better parental heterosis for the number of bolls/plant, boll weight, lint index, ginning out turn, seed cotton yield/ha, and lint yield/ha and exhibited negative heterosis for days to 50% flowering, plant height and the number of monopodia in the desirable direction. The F_1 hybrid, GISV298 / GP274 exhibited significant positive heterosis for the number of sympodia/ plant, the number of bolls/plant, boll weight, lint index, seed cotton yield/ha, and lint yield/ha. The crosses GISV298/GP51, GISV298/GP235, GISV298 / GP274, SCS1207/GP51, SCS1207 / GP355 and GISV298 / Lam GPC 274 were identified as promising crosses with positive mid/better parental heterosis for number of bolls/plant, boll weight, lint index, seed cotton yield/ha and lint yield/ha. Similar results were reported by Bankar *et al.* (2018), Khokhar *et al.* (2018), Patel and Patel (2018), and Gnanasekaran *et al.,* 2019.

Conclusion

The current study showed that non-additive gene effects were important for attaining extreme improvement in quantitative traits.

The female lines GISV 298 and SCS 1207 and the testers Lam GPC 501 and Lam GPC 355 were identified as the best general combiners, and their involvement in F_1 hybrids SCS1207 / Lam GPC 355, GISV298 / Lam GPC 235, GISV298 / Lam GPC 274 showed the best performance for boll weight, ginning out turn, seed cotton yield and lint yield traits with positive better parental heterosis.

Therefore, these promising hybrids may be preferred for future heterosis breeding of cotton crop improvement programs.

From the current study, the F_1 hybrid, SCS1207 / Lam GPC 355 was considered the best hybrid for ginning out turn, seed cotton yield/ha, and lint yield/ha with high GCA and high SCA coupled with positive better parental heterosis. Hence, this hybrid can be further tested in multi-location testing at the station and the All India Coordinated Crop Improvement program for commercial scale.

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