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RR Vaid
Department of Genetics and Plant Breeding, N. M. College of Agriculture, Navsari Agricultural University, Navsari, Gujarat, India

Dr. GO Faldu
Main Cotton Research Station, Navsari Agricultural University, Surat, Gujarat, India

NB Chaudhary
Department of Genetics and Plant Breeding, B. A. College of Agriculture, Anand Agricultural University, Anand, Gujarat, India

KB Chaudhary
Department of Genetics and Plant Breeding, N. M. College of Agriculture, Navsari Agricultural University, Navsari, Gujarat, India

Corresponding Author:
RR Vaid
Department of Genetics and Plant Breeding, N. M. College of Agriculture, Navsari Agricultural University, Navsari, Gujarat, India

Combining ability and gene action analysis for yield traits, fiber quality, and biochemical traits of cotton (*Gossypium hirsutum* L.)

RR Vaid, Dr. GO Faldu, NB Chaudhary and KB Chaudhary

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Abstract
The main objective of this study was to determine the general combining ability of the parents and specific combining ability of hybrids and gene action for yield traits, fiber quality, and biochemical traits of cotton (*Gossypium hirsutum* L.). The crossing programme was carried out during *kharif* 2019-20 at Main Cotton Research Station, Navsari Agricultural University, Surat. The experimental material consisted of thirteen parents (4 females and 9 males) and their thirty-six resultant crosses with a check GN. Cot. Hy-14 was evaluated in a randomized block design with three replications by using line × tester analysis. The crosses GISV-171 × GJHV-523, H-1452 × TCH-1705, GSHV-172 × TCH-1828, PBH-116 × SCS-1061, and PBH-116 × TCH-1705 were promising hybrids having high SCA effects for seed cotton yield per plant. Out of them H-1452 × TCH-1705 for days to 50% flowering, all five crosses for bolls per plant, four crosses for boll weight *viz.*, GISV-171 × GJHV-523, GSHV-172 × TCH-1828, PBH-116 × SCS-1061, PBH-116 × TCH-1705, one cross PBH-116 × TCH-1705 for seed index and oil content, one cross H-1452 × TCH-1705 for gossypol content and one cross PBH-116 × SCS-1061 for protein content showed significant SCA effect in the desired direction. The ratio of σ^2gca /σ^2sca revealed that the majority of the characters manifested less than unity except for ginning outturn which clearly indicated the preponderance of additive type of genetic variance in the inheritance of these characters.

Keywords: Replication, additive varience, general combining ability, specific combining ability, gene action

Introduction
Cotton is a major fibre crop of global importance value. Cotton is known as the king of fibre and it is one of the momentous and an important cash crops exercising profound influence on economics and social affairs of the world. Cotton is the world's most important commercial plant belongs to genus *Gossypium* under tribe *Gossypieae* of Malvaceae family. As per USDA estimate in India, cotton is covered about 12.60 million ha of land and it occupies second position in production with 25.80 million bales (each of 170 kg) next to China among all cotton producing countries in the world. The average productivity of India is 446 kg/ha. Gujarat is the second largest cotton growing state with 26.60 lakh ha and largest cotton producing state of India with production of 87.50 lakh bales. The average productivity of cotton in state (559.21 kg/ha) is higher than the national average (Anonymous 2018-2019) [1].
Selection of parents for a hybridization programme is an important aspect in the crop improvement. In any sound breeding programme, the proper choice of parents based on their combining ability is a pre-requisite. Such studies not only provide necessary information regarding the choice of parents but, also illustrate the nature and magnitude of gene action involved in the inheritance of the characters of economic interest. The combining ability analysis was carried out to obtain useful information for selection of better parents and crosses for their further use in breeding programme. The information regarding the nature and magnitude of gene action could also be obtained, which is useful in deciding breeding methodology aiming at exploitation of fixable (additive) and none fixable (non-additive) genetic variances. Line × Tester analysis is the simple method for identification of parents and hybrids by gca and sca, respectively.

Materials and Methods
The present investigation was carried out to exploit information about combining ability of parents and hybrids at Main Cotton Research Station, Navsari Agricultural University, Surat

during year 2019-20. The experimental materials comprised of thirteen diverse genotypes of cotton including four female parents *viz.*, PBH-116, GSHV-172, H-1452 and GISV-171 as well as nine male parents *viz*., TCH-1828, GJHV-523, SHJ-23, GSHV-199, 8401, SCS-1061, TCH-1705, TCH-1761 and GISV-267 of *Gossypium hirsutum* L. and their 36 crosses (line × tester) along with GN. Cot. Hy-14 as standard check.

The present investigation was carried out with a view to study of Combining ability and gene action analysis for yield traits, fiber quality and biochemical traits of cotton *viz*., days to 50% flowering, bolls per plant, boll weight (g), seed cotton yield per plant (g), ginning outturn (%), seed index (g), fiber length (mm), fiber strength (g/tex), fiber fineness (mv), oil content (%), gossypol content (mg/100g) and protein content (mg /g). The observations were recorded from randomly selected 5 plants from each genotype in each replication.

The mean performance of parents as well as hybrids was subjected to statistical analysis. Analysis of variance was carried out to test the significance for each character as per methodology suggested by Panse and Sukhatme (1985) [7]. The variation among the hybrids was partitioned further into sources attributable to general and specific combining ability components in accordance with the procedure suggested by Kempthorne (1957) [3].

Results and Discussion

The analysis of variance showed highly significant differences among the genotypes for all the traits revealed that the considerable amount of variability was observed among experimental material. Analysis of variance depicting mean sum of squares for twelve quantitative traits is presented in Table 1. The genotypic variance was further partitioned into parents, hybrids and parents vs hybrids. The differences among parents highly significant for all characters under investigation except days to 50% flowering, boll weight (g) and oil content (%). Hybrids were also found highly significant for all character. Differences due to parents vs hybrids were also found significant for all the traits under study.

The estimates of σ^2gca were significant for all the traits except bolls per plant and protein content. The significant values for gca variances were also noted by Sawarkar *et al.* (2015) [10] for days to 50% flowering, boll weight, fiber strength, fiber fineness and oil content; Roy *et al.* (2018) [9] for bolls per plant, boll weight, seed cotton yield, ginning outturn and seed index. The estimates of σ^2sca were significant for all the character except ginning outturn and oil content. The ratio of σ^2gca /σ^2sca revealed that all the characters manifested values less than unity except ginning outturn. The variance due to GCA were higher in magnitude than their respective SCA variances for ginning outturn indicating preponderance of additive gene effects for these characters. Almost similar results have been reported by Makhdoom *et al.* (2019) [5]. For other characters except ginning outturn having higher SCA variance than their respective GCA variance. Similar results have been reported by Sawarkar *et al.* (2015) [10], Usharani *et al.* (2016) [11] and Monicashree *et al.* (2017) [6].

Among four lines and eight testers, none of the parents were good general combiner for all the traits under study. Among parents, line PBH-116 was found good general combiner for seven characters *viz*., days to 50% flowering, bolls per plant, boll weight, seed cotton yield per plant, seed index, fiber strength and gossypol content. Whereas, tester TCH-1761 was exhibited good general combiner for four characters *viz*., bolls per plant, boll weight, seed cotton yield per plant and seed index. SHJ-23 registered good general combining ability for seed index, fiber length, fiber strength and fiber fineness. GISV-267 was observed good general combiner for boll weight, seed index, fiber strength, gossypol content and protein content. Similar results have been reported by Sawarkar *et al.* (2015) [10], Kumbhalkar *et al.* (2018) [4] and Bandhavi *et al.* (2019) [2]. The crosses *viz*., GISV-171 × GJHV-523, H-1452 × TCH-1705, GSHV-172 × TCH-1828, PBH-116 × SCS-1061 and PBH-116 × TCH-1705 were promising hybrids having high SCA effects for seed cotton yield per plant. Out of them, H-1452 × TCH-1705 for days to 50% flowering, all five crosses for bolls per plant, four crosses for boll weight *viz*., GISV-171 × GJHV-523, GSHV-172 × TCH-1828, PBH-116 × SCS-1061, PBH-116 × TCH-1705, one cross PBH-116 × TCH-1705 for seed index and oil content, one cross H-1452 × TCH-1705 for gossypol content and one cross PBH-116 × SCS-1061 for protein content showed significant SCA effect in desired direction. Similar results have been reported by Patel *et al.* (2012) [8], Kumbhalkar *et al.* (2018) [4] and Makhdoom *et al.* (2019) [5].

Table 1: Analysis of variance (mean sum of square) for experimental design for different traits in *G. hirsutum* L

Source of variation	Df	Days to 50% flowering	Bolls per plant	Boll weight (g)	Seed cotton yield per plant (g)	Ginning outturn (%)	Seed index (g)	Fiber length (mm)	Fiber Strength (g/tex)	Fiber fineness (mv)	Oil content (%)	Gossypol content (mg/100g)	Protein content (mg/g)
Replications	2	7.61	9.50	0.10	62.46	7.31	0.16	1.47	1.56	0.04	0.01	18.73	31.63
Treatments	48	15.97**	176.60**	0.54**	2777.50**	11.57**	2.19**	4.07**	13.60**	0.45**	1.19**	18269.18**	1823.60**
Parents	12	10.33	78.37**	0.18	1997.19**	15.98**	2.30**	5.82**	17.80**	0.27**	0.45	24018.71**	2981.19**
Parents *vs* Crosses	1	39.00*	951.57**	3.26**	18168.59**	31.02**	6.44**	15.17**	26.48**	2.68**	17.16**	65724.01**	1399.46**
Crosses	35	17.25**	188.14**	0.59**	2605.29**	9.50**	2.03**	3.16**	11.79**	0.45**	0.98**	14942.06**	1438.83**
Error	96	6.81	12.58	0.10	255.80	2.69	0.06	0.61	0.86	0.03	0.52	137.83	45.76

* and ** indicates significance at 5% and 1% levels of probability, respectively

Table 2: Analysis of variance (mean sum of square) for combining ability and variance components for different characters in *G. hirsutum* L.

Source of variation	Df	Days to 50% flowering	Bolls per plant	Boll weight (g)	Seed cotton yield per plant (g)	Ginning outturn (%)	Seed index (g)	Fiber length (mm)	Fiber Strength (g/tex)	Fiber fineness (mv)	Oil content (%)	Gossypol content (mg/100g)	Protein content (mg/g)
Replications	2	10.36	5.08	0.21	385.67	4.29	0.05	1.49	1.48	0.06	0.03	68.49	1.58
Crosses	35	17.25**	188.14**	0.59**	2605.29**	9.50**	2.03**	3.16**	11.80**	0.45**	0.98*	14942.06**	1438.83**
Error	70	7.38	13.59	0.11	274.02	3.23	0.07	0.48	0.87	0.03	0.52	127.70	45.15

Variance components													
σ^2_{gca}		1.62**	7.88	0.05**	154.65*	0.63**	0.22**	0.20**	1.17**	0.04**	0.08**	1655.87**	44.80
σ^2_{sca}		1.65*	61.42**	0.10**	723.44**	0.59	0.37**	0.44**	1.96**	0.08**	0.08	2241.09**	548.59**
$\sigma^2_{gca}/\sigma^2_{sca}$		0.98	0.13	0.49	0.21	1.06	0.59	0.45	0.59	0.53	0.99	0.74	0.08

* and ** indicates significance at 5% and 1% levels of probability, respectively

Table 3: General combining ability effect of parents for different characters in *G. hirsutum* L.

Sr. No.	Parents	Days to 50% flowering	Bolls per plant	Boll weight (g)	Seed cotton yield per plant (g)	Ginning outturn (%)	Seed index (g)	Fiber length (mm)	Fiber strength (g/tex)	Fiber fineness (mv)	Oil content (%)	Gossypol content (mg/100g)	Protein content (mg/g)
Lines													
1	PBH-116	-1.13*	1.64*	0.30**	13.71**	-0.25	0.48**	0.27	0.98**	0.12**	-0.29*	-8.10**	-4.87**
2	GSHV-172	1.80**	2.42**	-0.13*	2.38	0.14	0.04	-0.16	-0.45*	-0.20**	-0.28*	-43.44**	-0.97
3	H-1452	0.61	-2.73**	-0.19**	-15.38**	0.37	-0.59**	-0.19	-1.14**	-0.07*	0.48**	37.73**	8.76**
4	GISV-171	-1.28*	-1.32	0.01	-0.71	-0.26	0.07	0.08	0.61**	0.15**	0.08	13.81**	-2.92*
	SE (g_i)	0.50	0.68	0.06	3.08	0.32	0.05	0.15	0.18	0.03	0.14	2.26	1.30
Testers													
1	TCH-1828	-1.17	1.50	0.27**	10.31*	-0.72	0.39**	0.97**	-0.22	-0.09	-0.17	24.01**	11.47**
2	GJHV-523	-0.25	7.42**	-0.02	20.66**	0.02	-0.57**	0.46*	0.51	0.06	-0.21	-37.53**	-6.57**
3	SHJ-23	-1.08	-2.92**	-0.20*	-7.75	-0.73	0.80**	0.47*	2.10**	-0.29**	0.29	32.17**	-2.33
4	GSHV-199	2.25**	-2.83**	0.01	-10.87*	-0.17	-0.41**	0.22	-0.03	-0.46**	-0.23	-68.97**	-7.20**
5	8401	0.50	-0.33	-0.18	-9.25*	0.18	0.10	0.03	-0.73**	-0.04	0.10	-27.00**	-2.61
6	SCS-1061	-1.00	0.83	-0.05	-3.16	3.47**	-0.73**	-1.44**	-2.86**	0.49**	-0.26	44.65**	-3.53
7	TCH-1705	0.83	-4.00**	-0.47**	-23.61**	-2.06**	-0.36**	0.55*	0.36	0.05	0.20	55.28**	5.05*
8	TCH-1761	-1.17	3.67**	0.27**	19.99**	-0.63	0.27**	-1.09**	-0.13	0.27**	0.32	52.02**	-8.81**
9	GISV-267	1.08	-3.33**	0.36**	3.67	0.63	0.50**	-0.17	0.99**	0.03	-0.04	-74.64**	14.55**
	SE (g_j)	0.75	1.02	0.09	4.62	0.47	0.07	0.23	0.27	0.05	0.21	3.39	1.95

* and ** indicates significance at 5% and 1% levels of probability, respectively

Table 4: Specific combining ability effect of crosses for different characters in *G. hirsutum* L.

Sr. No.	Crosses	Days to 50% flowering	Bolls per plant	Boll weight (g)	Seed cotton yield per plant (g)	Ginning outturn (%)	Seed index (g)
1	PBH-116 × TCH-1828	0.13	6.94**	0.15	24.36*	0.64	0.75**
2	PBH-116 × GJHV-523	-1.12	-2.97	-0.37*	-19.36*	0.01	-0.09
3	PBH-116 × SHJ-23	-0.95	-0.97	-0.02	-6.56	-0.03	-0.30*
4	PBH-116 × GSHV-199	-1.62	-12.72**	0.46*	-49.86**	-1.44	0.03
5	PBH-116 × 8401	2.80	-7.89**	-0.22	-8.28	-1.17	-0.93**
6	PBH-116 × SCS-1061	1.63	6.94**	0.51**	29.56**	0.87	-0.07
7	PBH-116 × TCH-1705	0.46	6.78**	-0.43*	27.05**	0.02	0.53**
8	PBH-116 × TCH-1761	1.13	3.78	0.03	4.32	0.51	-0.08
9	PBH-116 × GISV-267	-2.45	0.11	-0.10	-1.23	0.60	0.14
10	GSHV-172 × TCH-1828	-0.80	6.17**	0.56**	30.02**	-0.17	0.27
11	GSHV-172 × GJHV-523	0.29	-6.08**	-0.25	-21.26*	0.69	0.19
12	GSHV-172 × SHJ-23	-0.21	-1.08	-0.08	-1.44	-0.71	-0.17
13	GSHV-172 × GSHV-199	2.12	9.50**	-0.33	16.00	1.68	-0.51**
14	GSHV-172 × 8401	-3.13*	15.00**	-0.08	20.99*	0.57	-0.49**
15	GSHV-172 × SCS-1061	0.37	-3.83	-0.08	0.36	-0.68	-0.16
16	GSHV-172 × TCH-1705	2.20	-9.00**	-0.01	-31.00**	-1.06	-0.06
17	GSHV-172 × TCH-1761	-2.80	-8.00**	-0.17	-25.77**	-0.61	0.35*
18	GSHV-172 × GISV-267	1.95	-2.67	0.45*	12.09	0.30	0.59**
19	H-1452 × TCH-1828	0.39	-14.35**	-0.51**	-53.39**	1.61	0.32*
20	H-1452 × GJHV-523	1.47	3.73	-0.11	3.79	-0.53	0.26

Table 4: Continue…….

Sr. No.	Crosses	Days to 50% flowering	Bolls per plant	Boll weight (g)	Seed cotton yield per plant (g)	Ginning outturn (%)	Seed index (g)
21	H-1452 × SHJ-23	0.97	-0.60	0.13	-5.56	1.06	-0.27
22	H-1452 × GSHV-199	-0.03	4.65*	0.13	13.90	-0.34	-0.41**
23	H-1452 × 8401	-0.94	-0.85	0.01	1.28	-2.37*	0.43**
24	H-1452 × SCS-1061	-2.11	2.31	-0.21	15.72	-0.01	0.40**
25	H-1452 × TCH-1705	-3.61*	10.48**	0.20	35.38**	0.54	-0.37*
26	H-1452 × TCH-1761	1.06	-3.19	0.12	5.64	0.11	-0.55**
27	H-1452 × GISV-267	2.81	-2.19	0.24	-16.76	-0.07	0.19
28	GISV-171 × TCH-1828	0.28	1.24	-0.20	-0.98	-2.07*	-1.34**
29	GISV-171 × GJHV-523	-0.64	5.32*	0.74**	36.83**	-0.17	-0.36*

30	GISV-171 × SHJ-23	0.19	2.66	-0.03	13.56	-0.32	0.73**
31	GISV-171 × GSHV-199	-0.47	-1.43	-0.26	19.96*	0.11	0.89**
32	GISV-171 × 8401	1.28	-6.26**	0.30	-13.99	2.97**	0.99**
33	GISV-171 × SCS-1061	0.11	-5.43**	-0.22	-45.65**	-0.19	-0.18
34	GISV-171 × TCH-1705	0.94	-8.26**	0.25	-31.44**	0.51	-0.10
35	GISV-171 × TCH-1761	0.61	7.41**	0.02	15.80	-0.01	0.28
36	GISV-171 × GISV-267	-2.31	4.74*	-0.59**	5.89	-0.83	-0.92**
	$SE(S_{ij})$	1.51	2.05	0.19	9.23	0.95	0.15

* and ** indicates significance at 5% and 1% levels of probability, respectively

Table 4: Continue…….

Sr. No.	Crosses	Fiber length (mm)	Fiber strength (g/tex)	Fiber fineness (mv)	Oil content (%)	Gossypol content (mg/100g)	Protein content (mg/g)
1	PBH-116 × TCH-1828	0.52	1.60**	0.41**	-0.28	5.27	-23.41**
2	PBH-116 × GJHV-523	0.34	1.01	-0.23*	0.17	-82.12**	14.55**
3	PBH-116 × SHJ-23	-0.60	-1.35*	-0.28**	-0.03	10.25	0.16
4	PBH-116 × GSHV-199	0.88	1.94**	-0.12	-0.66	4.15	28.60**
5	PBH-116 × 8401	0.10	-0.33	-0.03	-0.21	53.54**	3.18
6	PBH-116 × SCS-1061	-0.82	-2.46**	0.12	0.24	16.82*	15.54**
7	PBH-116 × TCH-1705	0.30	0.52	0.17	1.06*	6.55	4.48
8	PBH-116 × TCH-1761	1.12*	0.21	-0.14	0.04	2.23	5.69
9	PBH-116 × GISV-267	-1.84**	-1.14*	0.10	-0.32	-16.68*	-48.79**
10	GSHV-172 × TCH-1828	-0.16	-0.11	0.27*	0.35	63.45**	3.56
11	GSHV-172 × GJHV-523	0.40	1.14*	-0.11	-0.64	-33.35**	-22.52**
12	GSHV-172 × SHJ-23	0.25	1.44**	0.37**	0.15	25.79**	9.25*
13	GSHV-172 × GSHV-199	-0.73	-1.70**	-0.16	-0.54	17.34*	-10.94**
14	GSHV-172 × 8401	-0.74	-2.37**	-0.18	0.53	-107.93**	18.53**
15	GSHV-172 × SCS-1061	0.66	0.17	0.06	0.34	47.35**	-19.49**
16	GSHV-172 × TCH-1705	-0.24	0.71	-0.11	-0.34	36.34**	14.83**
17	GSHV-172 × TCH-1761	-0.68	-0.17	-0.25*	-0.21	-13.19	0.62
18	GSHV-172 × GISV-267	1.24**	0.89	0.13	0.36	-35.81**	6.15
19	H-1452 × TCH-1828	-0.90*	-1.82**	0.13	0.00	-8.39	-7.38
20	H-1452 × GJHV-523	-0.16	-1.35*	-0.04	0.69	47.87**	19.64**

Table 4: Continue…….

Sr. No.	Crosses	Fiber length (mm)	Fiber strength (g/tex)	Fiber fineness (mv)	Oil content (%)	Gossypol content (mg/100g)	Protein content (mg/g)
21	H-1452 × SHJ-23	-0.49	-0.40	-0.29**	0.15	-38.35**	3.50
22	H-1452 × GSHV-199	-0.22	-1.28*	0.02	0.83*	-29.98**	-22.64**
23	H-1452 × 8401	0.84	1.49**	0.36**	0.06	43.99**	1.85
24	H-1452 × SCS-1061	0.41	2.29**	-0.22*	-0.54	-39.52**	-21.34**
25	H-1452 × TCH-1705	0.25	-0.41	-0.12	-0.65	-42.09**	-27.94**
26	H-1452 × TCH-1761	-0.54	-0.25	0.26*	-0.35	27.83**	0.91
27	H-1452 × GISV-267	0.83	1.74**	-0.10	-0.19	38.65**	53.40**
28	GISV-171 × TCH-1828	0.55	0.33	-0.81**	-0.07	-60.33**	27.23**
29	GISV-171 × GJHV-523	-0.58	-0.80	0.38**	-0.22	67.60**	-11.67**
30	GISV-171 × SHJ-23	0.85	0.31	0.20	-0.27	2.31	-12.91**
31	GISV-171 × GSHV-199	0.07	1.04	0.26*	0.37	8.49	4.97
32	GISV-171 × 8401	-0.20	1.21*	-0.15	-0.38	10.40	-23.57**
33	GISV-171 × SCS-1061	-0.25	0.00	0.05	-0.04	-24.65**	25.29**
34	GISV-171 × TCH-1705	-0.31	-0.82	0.05	-0.07	-0.80	8.64*
35	GISV-171 × TCH-1761	0.10	0.21	0.14	0.53	-16.87*	-7.22
36	GISV-171 × GISV-267	-0.23	-1.48**	-0.12	0.15	13.84*	-10.76**
	$SE(S_{ij})$	0.45	0.54	0.10	0.42	6.78	3.91

* and ** indicates significance at 5% and 1% levels of probability, respectively

Table 5: Top five per se performance with SCA effects of crosses and GCA effects of parents involved for seed cotton yield per plant in *G. hirsutum* L.

Best crosses ($P_1 \times P_2$)	Mean yield per plant (g)	SCA effects	GCA effects	
			P_1	P_2
GISV-171 × GJHV-523	194.10	36.83**	-0.71	20.66**
PBH-116 × TCH-1828	185.70	24.36*	13.71**	10.31*
GSHV-172 × TCH-1828	180.03	30.02**	2.38	10.31*
PBH-116 × SCS-1061	177.43	29.56**	13.71**	-3.16
PBH-116 × TCH-1761	175.34	4.32	13.71**	19.99**

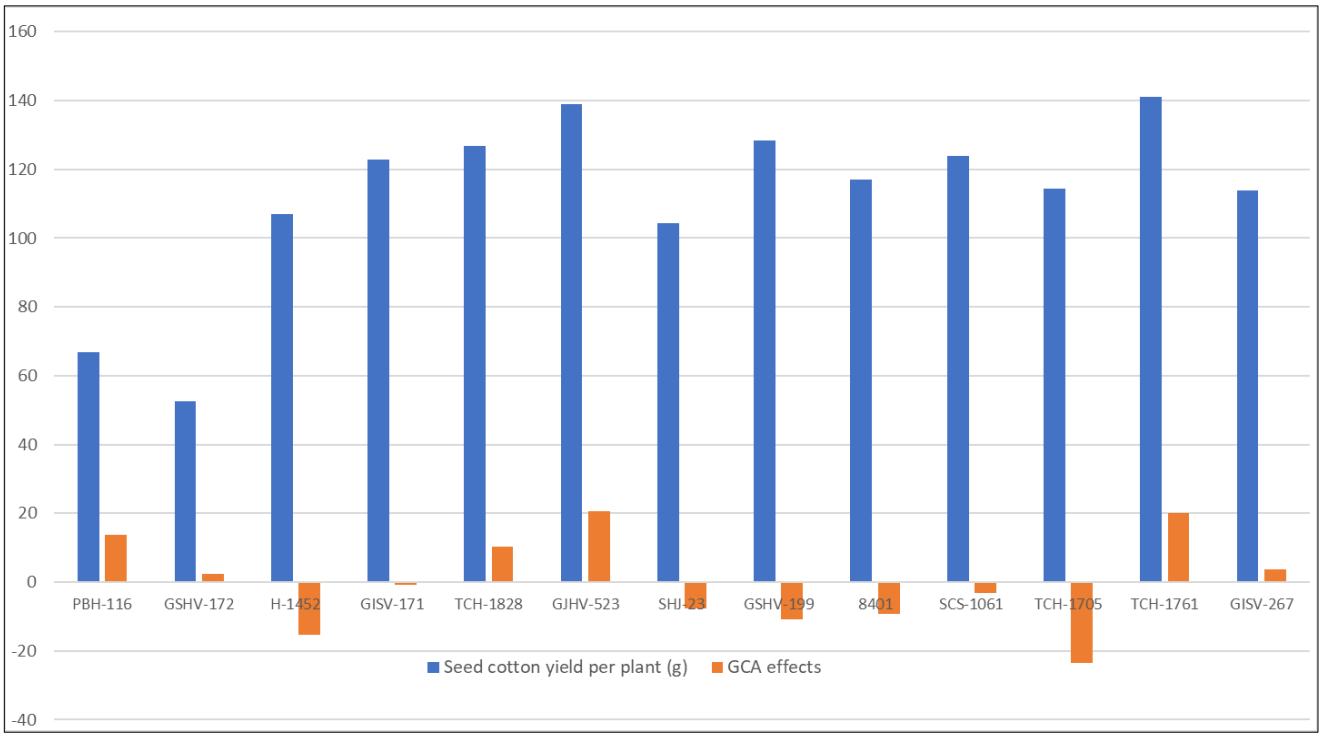

Fig 1: Mean values and gca effects of parents for seed cotton yield in *G. hirsutum* L.

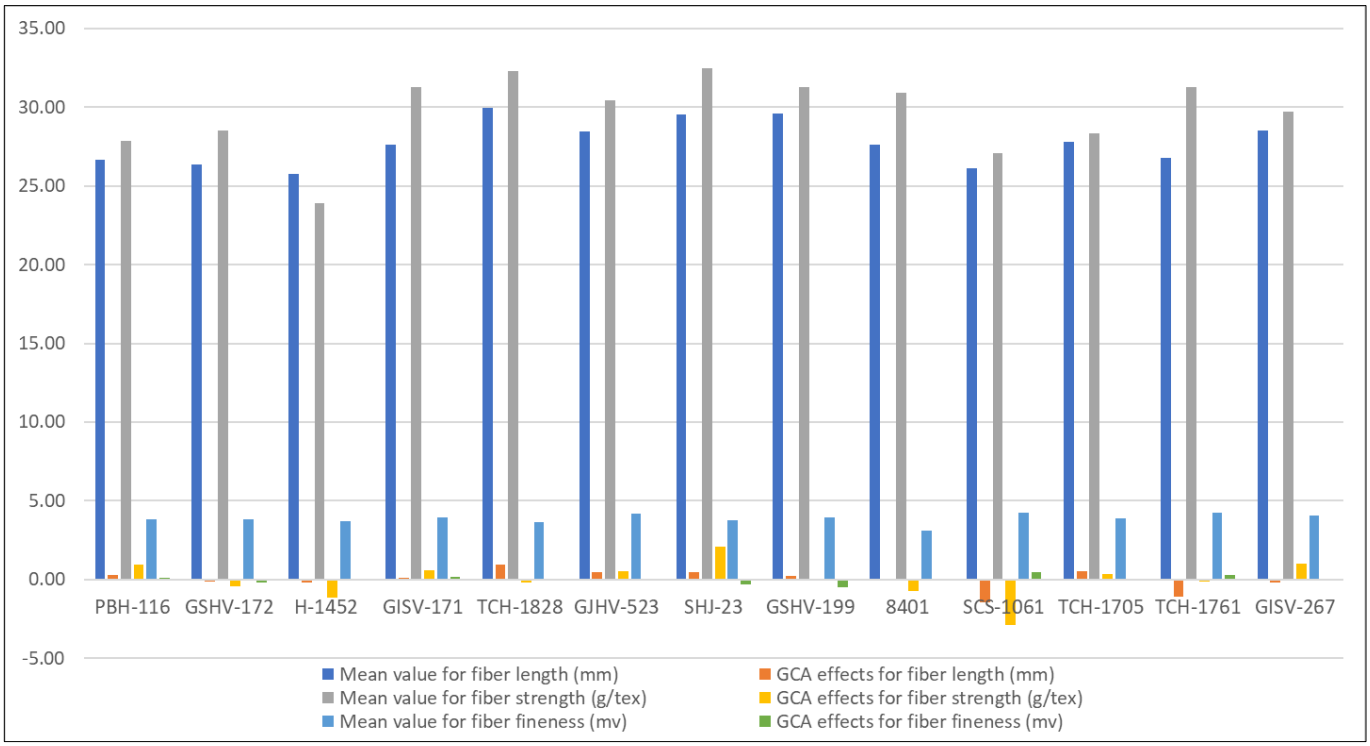

Fig 2: Mean values and GCA effects of parents for fiber length, fiber strength and fiber fineness in *G. hirsutum* L.

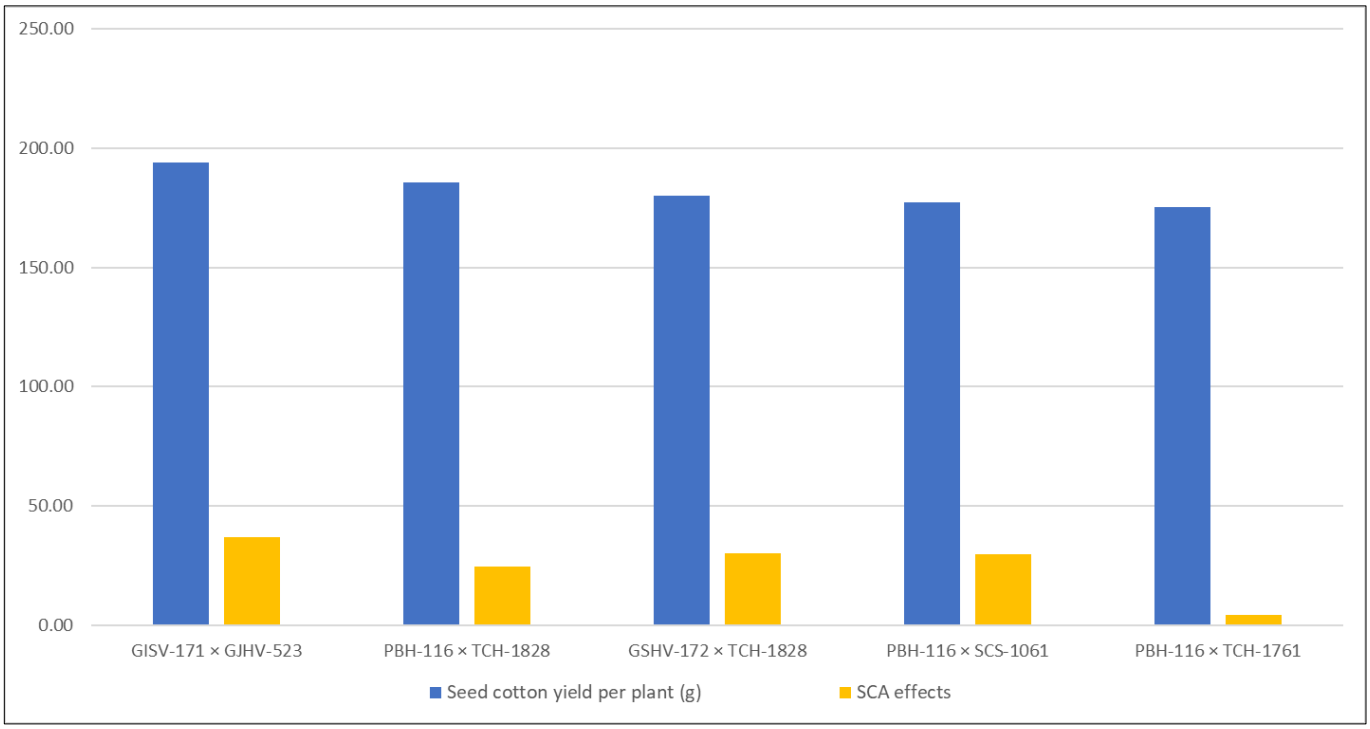

Fig 3: The top five crosses in terms of *per se* performance along with SCA effects for seed cotton yield in *G. hirsutum* L.

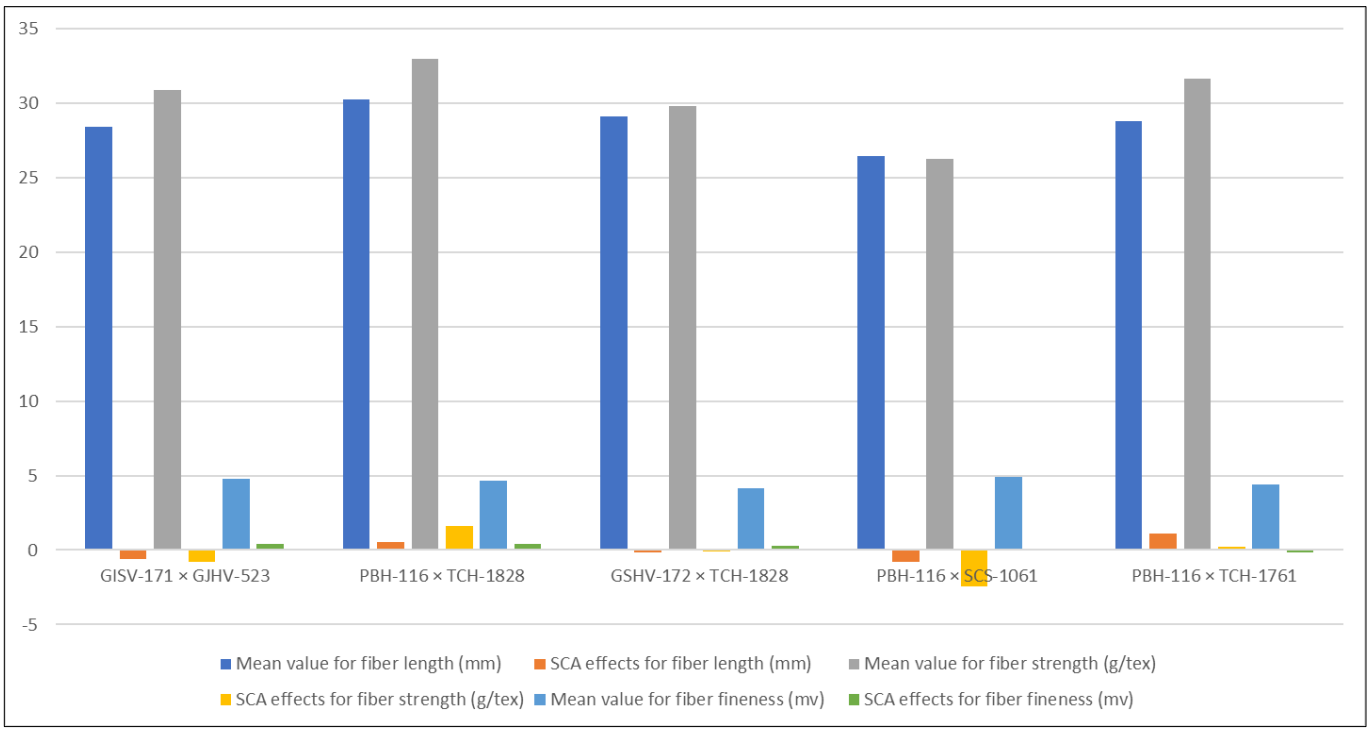

Fig 4: Mean values and SCA effects for fiber length, fiber strength and fiber fineness in top five crosses in terms of seed cotton yield

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