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Heterotic effects and combining ability analysis for seed oil and fibre quality traits in American cotton (*Gossypium hirsutum* L)

Jay R Kanasagra, Dr. MG Valu, Dr. Lata J Raval and Foram A Thesiya

Abstract
The present investigation was taken up to study the heterotic responses, combining ability and gene action for fibre quality characters of 45 hybrid combinations. These hybrids along with one standard check are evaluated in a Randomized Block Design (RBD) with three replications during *Kharif* 2020. The results of heterotic responses revealed that the cross combination GBHV-185 × G.Cot-10 showed the highest and most desirable significant standard heterosis for oil content (%), GJHV-589 × G.Cot-10 for ginning percentage, whereas the cross GSHV-173 × G.Cot-10 for 2.5% span length. For fibre strength and fibre fineness, none of the crosses showed a desirable significant standard heterotic response. The result of combining ability showed that lines such as GSHV-173, GBHV-185 and GJHV-589, and testers such as GJ.Cot-101 and G.Cot-10 were proved as good general combiners for oil content and lint quality parameters. For ginning percentage, a cross GJHV-574 × G.Cot-10 exhibited the highest positive and significant sca effect. The cross GJHV-577 × G.Cot-38 had a good combining ability effect for oil content. For 2.5% span length, only one cross showed a positive and significant sca effect i.e. GJHV-581 × G.Cot-10. None of the cross combinations witnessed a significant and desirable sca effect in the case of fibre strength. For fibre fineness, only one cross GSHV-172 × G.Cot-38 (-0.36) showed a desirable, negative and significant sca effect.

Keywords: Heterotic responses, combining ability, 2.5% span length, fibre strength, fibre fineness, ginning percentage

Introduction
Cotton, known as the "King of Apparel Fibre," is the most important cash crop, serving as the primary raw material for the country's thriving textile sector. Cotton maintains a unique position in natural and international trade as a vital industrial commodity with applications in textile and non-textile sectors. Cotton, also known as "the silver fibre," is still nature's miraculous fibre, supplying a wide range of useful items. No other fibre can match the extraordinary properties that cotton possesses, allowing people all over the world to be clothed.

Only four of the 50 species of *Gossypium* are used as a source of fibre. *G. herbaceum* is grown in dry areas of Asia and Africa, while *G. arboretum* is grown primarily in India. The species *G. Barba dense* is known for its long staple, which is called after its location in Barbados (South America). It accounts for 9% of overall cotton production. In the United States, it is known as Egyptian or Sea Island cotton, as well as Pima cotton. The species *G. hirsutum* accounts for more than 90% of all cotton production. Because of its hairiness, the species was given the name *hirsutum*. Cotton cultivation began on higher ground in the United States, earning it the nickname "upland cotton" (Endrizzi *et al.*, 1985) [4].

Cotton is primarily grown for the purpose of producing fibre. Cotton price is influenced by the progress of quality parameters in the textile industry. Cotton improvement programmes have a strong emphasis on hybrid development, which has helped cultivars improve. The most effective strategy for enhancing fibre quality is hybridization. The first and most important step in a heterosis breeding programme is to choose parents or inbreeds based on their physical diversity and combining ability to produce superior hybrids. The analysis of combining ability helps to identify superior parents and their hybrids. One of the most effective approaches for evaluating a large number of parents or inbreeds is to use a line × tester.

Oil crop breeding is generally more difficult than cereal or legume breeding because most oil crops are dual- or multi-purpose crops that require simultaneous modification of multiple quality traits. Cotton fibre productivity and quality are the most important crop characteristics;

however, cotton seed oil is a by-product, hence oil content is not a primary breeding goal. Cottonseed kernels have a protein content of 27.83–45.6 percent and an oil content of 28.24–44.05 percent (Sun *et al*., 1987) [28]. Cottonseed oil offers high nutritious benefits in addition to flavour stability; it has a 3: 1 ratio of unsaturated to saturated fatty acids, which meets the recommendations of many health professionals. Cotton seed oil outperforms other oils since it has a longer shelf life and can survive higher temperatures for food due to its strong antioxidant content (Sekhar & Rao, 2011) [25]. Various breeding strategies have been used with varying degrees of success to improve the quantity and quality of cottonseed oil content, and heterosis breeding is one of them.
Heterosis breeding is used to achieve a quick advantage in improving a certain trait. As a result, the current research was carried out in order to improve the quality of oil and fibre by developing prospective hybrids.

Materials and Methods

Plant material

There were 60 test entries in total, with 45 hybrids developed from nine female lines and five male parents, 14 parents, and one standard check (GN.Cot.Hy-14). Through line × tester mating design, the crosses were made during *Kharif* 2019 at Cotton Research Station, Junagadh Agricultural University, Junagadh.

Field trial

The complete set of 60 genotypes comprising 45 hybrids, 14 parents and one standard check (GN.Cot.Hy-14) were evaluated in a Randomized Block Design with three replications at Cotton Research Station, Junagadh Agricultural University, Junagadh during *Kharif* 2020. Each entry was accommodated in a single row plot of 6.3 metres length with row to row and plant to plant distances of 120 cm and 45 cm, respectively. All the recommended agronomical practices and plant protection measures were followed for raising a good crop. The observations were recorded on five randomly selected plants from each genotype in each replication for oil content (%), ginning percentage (%), 2.5% span length (mm), fibre strength (g/tex) and fibre fineness (mv).

Statistical analysis

Based on the fixed-effect statistical model, analysis of variance was used to examine the significance of differences between genotypes for all traits as suggested by Panse and Sukhatme (1985) [15]. Different heterosis estimates were calculated as suggested by Fonseca and Patterson (1968) [5]. Analysis of variance for combining ability was performed according to the model given by Kempthorne (1957) [11], which is related to North-Carolina design-II (Comstock and Robinson, 1952) [3] in terms of covariance of half-sibs (H.S.) and full-sibs (F.S.).

Results and Discussion

The purpose of this study was to use line × tester analysis to elucidate information on the magnitude of heterosis, combining ability and gene action for oil content and fibre quality parameters. Nine female and five male parents were involved in the study. The current investigation's findings are discussed below.

Analysis of variance for experimental design

For all of the traits, the analysis of variance revealed extremely significant differences between genotypes, indicating that there was a great level of variability among the experimental material. This confirmed that the material was suitable for the research. Parents, hybrids, and parent’s vs hybrids were used to divide the genotypic variance. The differences between the parents and hybrids were also found to be significant for all traits, implying that the parents and hybrids themselves have considerable diversity. For ginning percentage and oil content, the mean squares due to parents *vs* hybrids were also found to be significant, indicating that heterosis may be used for the majority of the characters under consideration. Analysis of variance depicting the mean sum of squares for oil content and three fibre quality parameters are presented in Table 1.

Table 1: Analysis of variance (mean square) for line × tester design for oil content and fibre quality parameters in cotton

Sources	DF	Mean square for				
		Oil content (%)	Ginning percentage (%)	2.5% span length (mm)	Fibre strength (g/tex)	Fibre fineness (mv)
Replications	2	0.00453	0.77	0.01395	0.40701	0.00107
Genotypes	58	0.11397**	7.49**	6.38569**	9.68090**	0.36045**
a) Parents	13	0.14195**	12.10**	9.54390**	16.17641**	0.55795**
b) Hybrids	44	0.10740**	5.79**	5.59580**	7.90827**	0.30767**
c) Parents vs. Hybrids	1	0.03975*	22.28**	0.08386	3.23487	0.11532
Error	116	0.00984	0.89	1.02625	1.07155	0.09280

Mean performance of parents and hybrids

The first and most important stage in a successful breeding programme is to choose superior parents because superior parents' genes are passed down to their progenies. Tables 2 and 3 show the average performance of parents and hybrids in terms of oil content and fibre quality metrics.
Oil content in parents ranged from 18.55% (GN.Cot-22) to 19.32% (G.Cot-10), with a parental mean of 18.90%, whereas it fluctuated from 18.53% (GTHV-15/220 GN.Cot-22) to 19.24% (GBHV-185 G.Cot-10) in crosses, with a hybrid mean of 18.86%.
Hybrids had a slightly higher ginning percentage (34.22%) than parents (33.39%), according to the mean performance statistics for the ginning percentage. The cross GJHV-589 × G.Cot-10 had the highest ginning percentage (37.33%) among the hybrids, whereas the cross GJHV-583 × GJ.Cot-101 had the lowest (29.60%). GSHV-173 had the highest ginning percentage (36.47%) and GJHV-574 had the lowest ginning percentage (29.50%) among the lines. G.Cot-20 had the highest ginning percentage (35.50%) among the testers. GN.Cot-22, on the other hand, had the lowest ginning percentage (32.60%). The average percentages for parents and hybrids were 33.39% and 34.22%, respectively.
GJHV-581 had a minimum (24.47 mm) 2.5% span length and

GSHV-173 had a maximum (30.70mm) 2.5% span length in the case of lines. G.Cot-20 had the shortest 2.5% span length (25.17mm) and G.Cot-10 had the longest (30.40mm) among the testers. GJHV-581 × G.Cot-20 had the shortest% span length (24.87mm) and GSHV-173 × G.Cot-10 had the longest (30.43 mm) among the hybrids.

Minimum fiber strength was registered by the parent GJHV-583 (25.50g/tex) while, maximum fiber strength was registered by the parent GSHV-173 (34.37g/tex). In the case of hybrids, the lowest value for fiber strength was recorded by the cross GJHV-583 × G.Cot-10 (25.40g/tex) and the highest was recorded by the cross GSHV-173 × GJ.Cot-101 (32.93g/tex).

The minimum micronaire is desirable for fibre quality. The micronaire value among the parents fluctuated between 4.60 (G.Cot-10) to 6.10 mv (GJHV-589). Among hybrids, it ranged from 4.70 (GSHV-172 × G.Cot-38) to 5.97 mv (GJHV-589 × GN.Cot-22).

Table 2: Mean performance of parents and their hybrids for oil content and fibre quality parameters

Sr. No.	Genotypes	Oil content (%)	Ginning percentage (%)	2.5% Span length (mm)	Fibre strength (g/tex)	Fibre fineness (mv)
Hybrid						
1	GJHV-574 × GJ.Cot-101	19.15	33.27	28.33	28.60	5.20
2	GJHV-574 × G.Cot-38	18.84	34.37	26.30	27.77	5.37
3	GJHV-574 × GN.Cot-22	18.74	34.00	27.03	28.37	5.50
4	GJHV-574 × G.Cot-20	18.89	31.37	25.67	27.47	5.37
5	GJHV-574 × G.Cot-10	19.08	36.77	29.03	26.37	4.80
6	GJHV-577 × GJ.Cot-101	19.13	32.77	29.07	29.70	5.10
7	GJHV-577 × G.Cot-38	18.70	32.80	26.50	28.10	5.47
8	GJHV-577 × GN.Cot-22	18.68	34.60	27.30	28.83	5.33
9	GJHV-577 × G.Cot-20	19.18	34.13	25.47	28.63	5.37
10	GJHV-577 × G.Cot-10	19.21	34.67	28.90	27.53	4.73
11	GJHV-581 × GJ.Cot-101	18.77	33.03	25.27	29.13	4.80
12	GJHV-581 × G.Cot-38	18.71	34.67	25.47	27.00	5.03
13	GJHV-581 × GN.Cot-22	18.62	33.60	26.33	28.00	5.33
14	GJHV-581 × G.Cot-20	18.77	35.70	24.87	26.77	5.30
15	GJHV-581 × G.Cot-10	19.10	33.40	29.23	26.20	4.77
16	GJHV-583 × GJ.Cot-101	18.95	29.60	27.73	26.50	5.30
17	GJHV-583 × G.Cot-38	18.77	34.10	25.47	27.20	5.50
18	GJHV-583 × GN.Cot-22	18.62	33.73	26.53	25.80	5.80
19	GJHV-583 × G.Cot-20	18.84	33.70	25.13	26.10	5.60
20	GJHV-583 × G.Cot-10	18.96	34.60	27.37	25.40	4.90
21	GJHV-589 × GJ.Cot-101	19.07	34.77	27.83	28.47	5.20
22	GJHV-589 × G.Cot-38	18.85	34.17	26.70	27.83	5.40
23	GJHV-589 × GN.Cot-22	18.75	35.50	27.27	28.23	5.97
24	GJHV-589 × G.Cot-20	19.01	33.77	26.23	27.03	5.83
25	GJHV-589 × G.Cot-10	19.15	37.33	28.67	26.33	5.00
26	GBHV-185 × GJ.Cot-101	18.92	35.33	27.27	30.10	4.77
27	GBHV-185 × G.Cot-38	18.76	34.43	26.60	29.10	5.07
28	GBHV-185 × GN.Cot-22	18.56	35.23	27.50	29.27	5.40
29	GBHV-185 × G.Cot-20	18.87	34.70	25.80	28.57	4.90
30	GBHV-185 × G.Cot-10	19.24	33.50	28.40	29.13	4.87
31	GSHV-172 × GJ.Cot-101	18.75	33.40	28.03	30.30	5.00
32	GSHV-172 × G.Cot-38	18.74	34.57	26.77	27.77	4.70
33	GSHV-172 × GN.Cot-22	18.58	33.57	27.47	29.17	5.50
34	GSHV-172 × G.Cot-20	18.74	35.03	26.60	27.37	5.10
35	GSHV-172 × G.Cot-10	18.70	33.53	28.50	27.77	4.83
36	GSHV-173 × GJ.Cot-101	18.92	37.27	29.50	32.93	4.77
37	GSHV-173 × G.Cot-38	18.79	34.10	28.10	32.03	5.10
38	GSHV-173 × GN.Cot-22	18.63	36.43	29.20	30.77	5.37
39	GSHV-173 × G.Cot-20	18.85	34.60	26.10	29.53	4.90
40	GSHV-173 × G.Cot-10	19.17	35.33	30.43	31.57	4.77
41	GTHV-15/220 × GJ.Cot-101	18.87	34.27	28.43	29.60	5.13
42	GTHV-15/220 × G.Cot-38	18.77	34.40	26.93	28.30	5.23
43	GTHV-15/220 × GN.Cot-22	18.53	33.33	27.50	28.87	5.17
44	GTHV-15/220 × G.Cot-20	18.90	34.50	25.57	27.47	5.47
45	GTHV-15/220 × G.Cot-10	18.92	32.17	28.87	27.23	4.80
Hybrid mean		18.86	34.22	34.22	28.32	5.17
Female						
46	GJHV-574	19.05	29.50	26.80	28.20	5.40
47	GJHV-577	19.22	31.53	27.10	29.43	5.43
48	GJHV-581	18.69	35.43	24.47	27.10	5.00
49	GJHV-583	18.82	35.63	25.27	25.50	5.87
50	GJHV-589	19.09	33.50	27.13	28.33	6.10

51	GBHV-185	18.80	33.70	27.13	30.23	4.63
52	GSHV-172	18.67	31.30	27.50	30.73	5.23
53	GSHV-173	18.81	36.47	30.70	34.37	4.80
54	GTHV-15/220	18.88	31.20	27.23	29.73	5.47
55	GJ.Cot-101	19.02	33.43	28.60	29.47	4.90
56	G.Cot-38	18.75	34.30	26.10	27.30	5.23
57	GN.Cot-22	18.55	32.60	27.50	28.33	5.40
58	G.Cot-20	18.88	35.50	25.17	26.40	5.20
59	G.Cot-10	19.32	33.37	30.40	25.73	4.60
Standard check						
60	GN.Cot.Hy-14	18.66	34.10	28.07	32.37	4.5
61	Parental mean	18.90	33.39	27.22	28.63	5.23
62	Overall mean	18.87	34.03	27.26	28.45	5.19
63	SEm	0.06	0.55	0.58	0.60	0.18
64	CD at 5%	0.16	1.53	1.64	1.67	0.49
65	CD at 1%	0.21	2.02	2.16	2.21	0.65
65	GJ.Cot-101	19.02	33.43	28.60	29.47	4.90
66	CV (%)	0.53	2.78	3.71	3.63	5.88

Table 3: Promising parents and F_1 for *per se* performance in cotton

Characters	Rank	Best performing parent	Per se performance of hybrid
Oil content (%)	I	G.Cot-10	GBHV-185 × G.Cot-10
	II	GJHV-577	GJHV-577 × G.Cot-10
	III	GJHV-589	GJHV-577 × G.Cot-20
Ginning percentage (%)	I	GSHV-173	GJHV-589 × G.Cot-10
	II	GJHV-583	GSHV-173 × GJ.Cot-101
	III	GJHV-589, G.Cot-20	GJHV-574 × G.Cot-10
2.5% span length	I	GSHV-173	GSHV-173 × G.Cot-10
	II	G.Cot-10	GSHV-173 × GJ.Cot-101
	III	GJ.Cot-101	GJHV-581 × G.Cot-10
Fibre strength	I	GSHV-173	GSHV-173 × GJ.Cot-101
	II	GSHV-172	GSHV-173 × G.Cot-38
	III	GBHV-185	GSHV-173 × G.Cot-10
Fibre fineness	I	G.Cot-10	GSHV-172 × G.Cot-38
	II	GSHV-173	GJHV-577 × G.Cot-10
	III	GJ.Cot-101	GSHV-173 × G.Cot-10, GSHV-173 × GJ.Cot-101, GBHV-185 × GJ.Cot-101, GJHV-581 × G.Cot-10

Magnitude of heterosis

The goal of this study's heterosis estimation was to find the optimal combination of parents that produced a high degree of relevant heterosis for oil content and fibre quality metrics for future use in cotton breeding and hybrid development. Table 4 shows the results of heterotic responses.

In the case of oil content, one cross showed significant and positive heterosis over mid-parent, while 24 crosses showed significant and positive heterosis over standard check, out of 45 hybrids. Cross GBHV-185 × G.Cot-10 had the highest, significant, and positive relative heterosis and standard heterosis. The findings are consistent with Kaliyperumal and Ravikesavan (2013).

Over mid-parent, better parent, and standard check, respectively, 18, 5 and 5 cross combinations showed significant and favourable heterosis in ginning percentage. Cross GJHV-589 × G.Cot-10 had the highest, significant, and positive heterobeltiosis and standard heterosis. Cross GJHV-574 × G.Cot-10 was found to have the greatest relative heterosis estimation. Shekhar Babu *et al.* (2011), Geddam *et al.* (2011), Pushpum *et al.* (2015), Chhavikant *et al.* (2017), Lingaraja *et al.* (2017), Arbad *et al.* (2017), Mangi *et al.* (2019), Pavitra *et al.* (2019) [6, 2, 13, 1, 14, 18] have previously reported significant heterosis for ginning percentage. 2.5% span length is an important quality criterion for cotton lint. Cross GJHV-581 × G.Cot-10 and GSHV-173 × G.Cot-10 had the highest, significant, and positive relative heterosis and standard heterosis, respectively. Patil *et al.* (2010), Kaliyaperumal *et al.* (2013), Sharma *et al.* (2016), and Lingaraja *et al.* (2017) [17, 9, 13, 26] all came up with identical results.

For fibre strength, only one cross GSHV-173 × G.Cot-10 showed significant and positive relative heterosis. While none of the cross combinations was significant for heterobeltiosis and standard heterosis. Significant heterosis for fibre strength was been reported earlier by Patil *et al.* (2010), Sawarkar *et al.* (2015), Lingaraja *et al.* (2017), Pavitra *et al.* (2019) and Shinde *et al.* (2020) [17, 23, 13, 18, 27].

The negative value for all type of heterosis is desirable for fibre fineness. The highest desirable (negative) and significant mid-parent heterosis and heterobeltiosis were shown by the crosses GSHV-172 × G.Cot-38 and GJHV-589 × G.Cot-10, respectively. Kaliyaperumal *et al.* (2013), Gnanasekaran *et al.* (2019) and I song *et al.* (2019) [10, 7, 8] also observed similar results for fibre fineness.

Table 4: Range of heterosis as well as the number of crosses with response to heterotic effects for various characters in cotton

Sr. No.	Characters	Range of heterosis (%)			No. of crosses with significant heterosis					
		H_1	H_2	H_3	H_1		H_2		H_3	
					+Ve	-Ve	+Ve	-Ve	+Ve	-Ve
1	Oil content (%)	-1.54 to 0.96	-3.18 to 0.52	-0.68 to 3.13	01	05	00	19	24	00
2	Ginning percentage (%)	-14.29 to 16.97	-16.93 to 11.44	-13.20 to 9.48	18	04	05	12	05	03
3	2.5% span length (mm)	-6.56 to 6.56	-14.98 to 1.63	-11.40 to 8.43	01	01	00	09	01	13
4	Fibre strength (g/tex)	-4.31 to 5.05	-14.06 to 0.79	-21.52 to 1.75	01	00	00	14	00	41
5	Fibre fineness (mv)	-10.19 to 7.64	-18.03 to 5.04	5.22 to 33.58	00	01	00	09	31	00

H1 = Relative heterosis, H2 = Heterobeltiosis, H3 = Standard heterosis

Analysis of variance for combining ability

Partitioning of variances (Table 5) due to the crosses showed that the mean squares due to lines and testers were significant for all characters. In case of line × tester interaction, the mean squares were significant for oil content and ginning percentage.

When compared to mean square due to line *vs* tester interaction, the mean squares due to lines and tester interaction were also shown to be significant for oil content,% span length, fibre strength, and fibre fineness.

The estimates of σ^2gca were higher than the corresponding σ^2sca for oil content, 2.5% span length, fibre strength and fibre fineness. It indicated the preponderance of additive gene action. Similar results have been also reported by Rauf *et al.* (2005) and Preetha and Raveendran (2008) [21, 19].

For remaining character like ginning percentage, σ^2sca was higher than σ^2gca indicated the preponderance of non-additive gene action. Similar results were obtained by Preetha and Raveendran (2008), Saravanan *et al*. (2010), Patel *et al*. (2012), Sawarkar *et al*. (2015), Usharani *et al*. (2016) and Khokhar *et al*. (2018) [23, 29, 21].

Table 5: Analysis of variance for combining ability for oil content and fibre quality parameters in cotton

Sources	DF	Mean squares				
		GP	OC	2.5% SL	FS	FF
Lines (L)	8	8.30**	0.12**++	7.20**++	30.78**++	0.50**++
Testers (T)	4	2.82*	0.72**++	39.29**++	17.04**++	1.74**++
Line × Tester (L× T)	32	5.53**	0.03**	0.98	1.05	0.08
Error	88	0.82	0.01	1.07	1.07	0.07
Estimates of genetic components of variance						
σ^2l		0.50	0.01	0.41	1.98	0.03
σ^2t		0.07	0.03	1.42	0.59	0.06
σ^2lt (σ^2sca)		1.57	0.005	0.006	-0.03	-0.01
σ^2gca		0.22	0.02	0.02	1.06	1.09
σ^2gca/σ^2sca		0.14	4.00	3.46	-35.33	-109

* And ** significant at 5% and 1% levels when tested against error mean squares, respectively

+, ++ Significant at 5% and 1% levels when tested against line × tester interactions mean squares, respectively

GP: Ginning percentage (%), OC: Oil content (%) 2.5% SL: 2.5% Span length, FS: Fibre strength, FF: Fibre fineness

General combining ability effects

It was observed that none of the parents was found to be good general combiner simultaneously for all the traits (Table 6).

Among the lines, line GSHV-173 was a good general combiner for ginning percentage, 2.5% span length, fibre strength and fibre fineness. While, the line GBHV-185 showed desired GCA effect for characters *viz*., fibre strength and fibre fineness. Also, a line GJHV-589 estimated a desirable GCA effect for ginning percentage and oil content. Line GSHV-172 was found to be a good general combiner for fibre fineness. These were some promising lines for the production of good hybrids.

Among the testers, two testers were good combiners. GJ.Cot-101 had given desired gca effects for different characters *viz.*, oil content, 2.5% span length, fibre strength and fibre fineness. Tester G.Cot-10 had given desired GCA effects for ginning percentage, oil content, 2.5% span length and fibre fineness. While the G.Cot-20 were a good combiner for oil content.

Parents who have been recognized as good general combiners for a larger number of characters can be considered potential parents and should be preferred in the breeding programmer to combine a larger number of characters with fewer parents in the crossing programmer. For isolating suitable recombinants, it is proposed that a population including their parents in a multiple crossing programmer be formed. Furthermore, varieties or lines with good general combining ability for a specific component may be used in the component breeding programmer for successful improvement in specific components, eventually aiming for yield improvement.

Table 6: Classification of parents with respect to general combining ability (GCA) effects for various characters in cotton

Sr. No.	Sources	OC	GP	2.5% SL	FS	FF
Lines						
1	GJHV-574	G	A	A	A	A
2	GJHV-577	G	A	A	A	A
3	GJHV-581	P	A	P	P	A
4	GJHV-583	A	P	P	P	P
5	GJHV-589	G	G	A	A	P
6	GBHV-185	A	A	A	G	G
7	GSHV-172	P	A	A	A	G
8	GSHV-173	A	G	G	G	G
9	GTHV-15/220	P	P	A	A	A
Testers						
1	GJ.Cot-101	G	P	G	G	G
2	G.Cot-38	P	A	P	A	A
3	GN.Cot-22	P	A	A	A	P
4	G.Cot-20	G	A	P	P	P
5	G.Cot-10	G	G	G	P	G

G = Good general combiner having significant, GCA effect in desirable direction

A = Average general combiner having either positive or negative but non-significant GCA effect

P = Poor general combiner having significant GCA effect in undesirable direction

OC: Oil content (%), GP: Ginning percentage (%) 2.5%, SL: 2.5% span length (mm), FS: Fibre strength (g/tex), FF: Fibre fineness (mv)

Specific combining ability effects

The data on sca effects are depicted in Table 7. For ginning percentage, seven crosses exhibited positive and significant sca effect *viz.*, GJHV-574 × G.Cot-10 (2.45), GJHV-581 × G.Cot-20 (1.68), GJHV-583 × G.Cot-10 (1.09), GJHV-589 × G.Cot-10 (1.86), GBHV-185 × GJ.Cot-101 (1.17), GSHV-172 × G.Cot-20 (1.07) and GSHV-173 × GJ.Cot-101 (2.20). Besides, seven crosses recorded a significant but negative sca effect.

For oil content, the highest value of the sca effect was depicted by GJHV-577 × G.Cot-38 (0.19) and the lowest value by the cross GSHV-172 × G.Cot-10 (-0.20). Out of 45 crosses, five crosses manifested positive and significant sca effects and only one cross showed negative significant sca effects. The highest positive sca effect was observed in hybrid GJHV-577 × G.Cot-38 (0.19) followed by GBHV-185 × G.Cot-10 (0.18) and GJHV-577 × G.Cot-20 (0.17). Hence, these crosses were identified as good specific combinations.

For 2.5% span length, only one cross showed a positive and significant sca effect i.e. GJHV-581 × G.Cot-10 (1.45) and was identified as a good specific combiner. On the other hand, only one cross registered negative and significant sca effect e.g., GJHV-581 × GJ.Cot-101 (-1.63).

In the case of fibre strength, none of the cross pairings saw a significant sca effect in either the positive or negative direction.

A negative sca effect is desirable for fibre fineness. Only one cross, GSHV-172 G.Cot-38 (-0.36), was found to have a negative and significant sca effect and to be a good specific combination. While no positive and significant sca effect was observed in any of the crosses.

Table 7: Specific combining ability (sca) effect of hybrids for ginning percentage (%), oil content (%), 2.5% span length (mm). fibre strength (g/tex) and fibre fineness (mv) in cotton

Sr. No.	Crosses	Oil content (%)	Ginning percentage (%)	2.5% span length (mm)	Fibre strength (g/tex)	Fibre fineness (mv)
1	GJHV-574 × GJ.Cot-101	0.12*	-0.21	0.39	-0.28	0.10
2	GJHV-574 × G.Cot-38	-0.01	0.46	-0.24	0.02	0.09
3	GJHV-574 × GN.Cot-22	0.3	-0.17	-0.32	0.38	-0.06
4	GJHV-574 × G.Cot-20	-0.9	-2.53**	-0.05	0.41	-0.02
5	GJHV-574 × G.Cot-10	-0.6	2.45**	0.21	-0.54	-0.10
6	GJHV-577 × GJ.Cot-101	0.06	-0.55	0.95	-0.03	0.04
7	GJHV-577 × G.Cot-38	0.19**	-0.95	-0.21	-0.49	0.23
8	GJHV-577 × GN.Cot-22	-0.07	0.59	-0.22	0.00	-0.18
9	GJHV-577 × G.Cot-20	0.17**	0.40	-0.42	0.73	0.02
10	GJHV-577 × G.Cot-10	0.03	0.51	-0.10	-0.22	-0.12
11	GJHV-581 × GJ.Cot-101	-0.11	-0.57	-1.63**	0.55	-0.10
12	GJHV-581 × G.Cot-38	0.00	0.63	-0.03	-0.45	-0.05
13	GJHV-581 × GN.Cot-22	0.05	-0.70	0.02	0.31	-0.02
14	GJHV-581 × G.Cot-20	-0.05	1.68**	0.19	0.01	0.11
15	GJHV-581 × G.Cot-10	0.11	-1.04*	1.45*	-0.41	0.06
16	GJHV-583 × GJ.Cot-101	0.03	-3.07**	0.62	-0.87	0.02
17	GJHV-583 × G.Cot-38	0.04	1.00	-0.24	0.97	0.05
18	GJHV-583 × GN.Cot-22	0.02	0.37	0.01	-0.67	0.07
19	GJHV-583 × G.Cot-20	-0.02	0.61	0.24	0.56	0.04
20	GJHV-583 × G.Cot-10	-0.07	1.09*	-0.63	0.01	-0.18
21	GJHV-589 × GJ.Cot-101	0.02	0.14	-0.17	-0.28	-0.14
22	GJHV-589 × G.Cot-38	-0.03	-0.89	0.10	0.22	-0.11
23	GJHV-589 × GN.Cot-22	0.01	0.17	-0.15	0.38	0.18
24	GJHV-589 × G.Cot-20	0.01	-1.28*	0.45	0.11	0.21
25	GJHV-589 × G.Cot-10	-0.02	1.86**	-0.22	-0.43	-0.14
26	GBHV-185 × GJ.Cot-101	-0.04	1.17*	-0.51	-0.30	-0.09
27	GBHV-185 × G.Cot-38	-0.02	-0.16	0.22	-0.16	0.03
28	GBHV-185 × GN.Cot-22	-0.09	0.37	0.31	-0.24	0..09
29	GBHV-185 × G.Cot-20	-0.04	0.12	0.24	-0.01	-0.24
30	GBHV-185 × G.Cot-10	0.18**	-1.50**	-0.26	0.71	0.21
31	GSHV-172 × GJ.Cot-101	-0.04	-0.14	-0.11	0.66	0.12
32	GSHV-172 × G.Cot-38	0.13*	0.59	0.03	-0.74	-0.36*
33	GSHV-172 × GN.Cot-22	0.10	-0.67	-0.08	0.42	0.16
34	GSHV-172 × G.Cot-20	0.01	1.07*	0.68	-0.45	-0.07
35	GSHV-172 × G.Cot-10	-0.20**	-0.85	-0.52	0.10	0.15
36	GSHV-173 × GJ.Cot-101	-0.04	2.20**	0.17	0.40	-0.07
37	GSHV-173 × G.Cot-38	0.01	-1.40**	0.17	0.64	0.09
38	GSHV-173 × GN.Cot-22	-0.02	0.67	0.46	-0.87	0.07
39	GSHV-173 × G.Cot-20	-0.05	-0.89	-1.01	-1.18	-0.22
40	GSHV-173 × G.Cot-10	0.10	-0.58	0.22	1.01	0.13
41	GTHV-15/220 × GJ.Cot-101	-0.02	1.01	0.30	0.14	0.12
42	GTHV-15/220 × G.Cot-38	0.06	0.71	0.21	-0.02	0.04
43	GTHV-15/220 × GN.Cot-22	-0.04	-0.62	-0.04	0.30	-0.31
44	GTHV-15/220 × G.Cot-20	0.07	0.82	-0.34	-0.17	0.17
45	GTHV-15/220 × G.Cot-10	-0.07	-1.93**	-0.14	-0.25	-0.02
SE (SIJ)		0.05	0.52	0.60	0.60	0.15
SE (SIJ – SKL)		0.08	0.74	0.84	0.84	0.22

SE (SIJ – SIK)	0.11	1.05	1.19	1.19	0.31
No. of desired cross	3	7	0	0	1

* And ** significant at 5% and 1% levels of probability, respectively.

Conclusion

To summarize, additive gene action was observed in the cases of oil content, 2.5% span length, fibre strength, and fibre fineness. Non-additive gene action, on the other hand, was specified for ginning percentage. Given the importance of both forms of gene actions, it is proposed that biparental mating combined with reciprocal recurrent selection can be used to exploit additive and non-additive gene actions simultaneously for population improvement. However, given the significant heterosis for all traits and the predominance of non-additive gene action, it is argued that heterosis breeding could be utilized to profitably exploit hybrid vigour in cotton on a commercial scale. The cross combinations GSHV-173 × GJ.Cot-101, GJHV-589 × G.Cot-10, GBHV-185 × G.Cot-10, and GSHV-173 × G.Cot-10 may be considered as the most promising.

References

1. Arbad SK, Deosarkar DB, Patil HV. Identification of heterotic hybrid for yield and its components over environments in inter and intra specific crosses of rain fed cotton (*Gossypium spp*.). J. Cotton Res. Dev. 2017;31(1):12-18.
2. Chhavikant KS, Kumar A, Pundir SR. Heterosis studies for seed cotton yield and other traits in upland cotton (*Gossypium hirsutum* L.). Journal of Pharmacognosy and Phytochemistry. 2017;6(6):583-586.
3. Comstock RE, Robinson HP. Genetic parameters, their estimation and significance. Proc. 6th Inst. Grassland Cong. 1952;1:284-291.
4. Endrizzi JE, Turcotte EL, Kohel RJ. Genetics, cytology, and evolution of Gossypium. Advances in genetics. 1985;23:271-375.
5. Fonseca S, Patterson FL. Hybrid vigour in seven parental diallel cross in common winter wheat (*Triticum aestivum* L.). Crop Sci. 1968;8:85-88.
6. Geddam SB, Khadi BM, Mogali S, Patil RS, Katageri IS. Nadaf HL, et al. Study of heterosis in genetic male sterility based diploid cotton hybrids for yield, yield component and fibre quality characters. Karnataka J. of Agric. Sci. 2011;24(2):118-124.
7. Gnanasekaran M, Thiyagu K, Gunasekaran M. Combining ability and heterosis studies for seed cotton yield and fibre quality traits in hirsutum cotton. Electronic Journal of Plant Breeding. 2019;10(4):1519-1531.
8. Isong A, Balu A, Isong C, Bamishaiye E. Estimation of heterosis and combining ability in interspecific cotton hybrids. Electronic Journal of Plant Breeding. 2019;10(2):827-837.
9. Kaliyaperumal A, Ravikesavan R. Genetic variation and heterotic effects for seed oil, seed protein and yield attributing traits in upland cotton (*Gossypium hirsutum* L). African Journal of Biotechnology. 2013;12(33):5183-5191.
10. Kaliyaperumal A, Karuppanasamy SK, Ravikesavan R. Heterosis studies for fibre quality of upland cotton in line x tester design. African Journal of Agricultural Research. 2013;8(48):6359-6365.
11. Kempthorne O. An introduction to Genetic Statistics. John Willey and Sons. New York, 1957.
12. Khokhar ES, Shakeel A, Maqbool MA, Abuzar MK, Zareen S, Syeda SA, et al. Studying combining ability and heterosis in different cotton (*Gossypium hirsutum* L.) genotypes for yield and yield contributing traits. Pakistan Journal of Agricultural Research. 2018;31(1):55-68.
13. Lingaraja L, Sangwan RS, Nimbal S, Sangwan O, Singh S. Heterosis studies for economic and fibre quality traits in line x tester crosses of upland cotton (*Gossypium hirsutum* L.). Int. J. Pure App. Biosci. 2017;5(2):240-248.
14. Mangi N, Khanzada S, Lashari A, Sanwal SA, Jagirani Z, Baloch M, et al. Evaluation of line × tester crosses for heterosis, heterobeltiosis and economic heterosis in cotton (*Gossypium hirsutum* L.). Bio Cell, 2019, 43(5).
15. Panse VG, Sukhatme PV. Statistical Methods for Agricultural Workers (Second edition), ICAR, New Delhi, 1985.
16. Patel NA, Patel BN, Bhatt JP, Patel JA. Heterosis and combining ability for seed cotton yield and component traits in inter specific cotton hybrids (*G. hirsutum* × *G. barbadense* L.). Madras Agric. J., 2012;99(10-12):649-656.
17. Patil SA, Naik MR, Pathak VD, Kumar V. Heterosis for yield and fibre properties in upland cotton *G. hirsutum* L. National conference on "Paradigm shift in cotton research and cotton cultivation, 2010.
18. Pavitra MJ, Kajjidoni ST, Venkatesh. Heterosis for productivity and fibre quality traits among hybrids derived from diverse lines of *Gossypium hirsutum* L. Int. J. Curr. Microbiol. App. Sci., 2019;8(2):1379-1384.
19. Preetha S, Raveendran TS. Combining ability and heterosis for yield and fibre quality traits in line x tester crosses of upland cotton (*G. hirsutum* L). International Journal of Plant Breeding and Genetics. 2008;2(2):64-74.
20. Pushpam R, Thangara K, Raveendran TS. Heterosis and combining ability studies in upland cotton for yield characters. Ele. J. Pl. Br. 2015;6(2):459-463.
21. Rauf S, Shah KN, Afzal I. A genetic study of some earliness related characters in cotton (*Gossypium hirsutum* L.). Caderno de Pesquisa Ser. Bio., Santa Cruzdo Sul. 2005;17(1):81-93.
22. Saravanan NA, Ravikesavan R, Raveendran TS. Combining ability analysis for yield and fibre quality parameters in intraspecific hybrids of *G. hirsutum* L. Electronic Journal of Plant Breeding. 2010;1(4):856-863.
23. Sawarkar M, Solanke A, Mhasal GS, Deshmukh SB. Combining ability and heterosis for seed cotton yield, its components and quality traits in *Gossypium hirsutum* L. Indian Journal of Agricultural Research. 2015;49(2):154-159.
24. Sekhar Babu G, Khadi BM, Mogali S, Patil RS, Katageri IS, Nadaf HL, et al. Study of heterosis in genetic male sterility based diploid cotton hybrids for yield, yield component and fibre quality characters. Karnataka J. Agric. Sci. 2011;24(2):118-124.
25. Sekhar S, Rao BC. Cottonseed oil as health oil. Pertanika J. Trop. Agric. Sci. 2011;34(1):17-24.
26. Sharma R, Gill BS, Dharmendra P. Heterobeltiosis for

yield, its component traits and fibre properties in upland cotton (*Gossypium hirsutum* L.). J. Cotton Res. Dev. 2016;30(1):11-15.
27. Shinde AV, Deosarkar DB, Chinchane VN. Heterosis and combining ability studies for fibre quality traits in desi cotton (*Gossypium arboreum* L.). Journal of Pharmacognosy and Phytochemistry. 2020;9(6):1087-1092.
28. Sun SK, Chen JH, Xian SK, Wei SJ. Study on the nutritional quality of cotton seeds. Scientia Agricultura Sinica. 1987;5:12-16.
29. Usharani CV, Manjula SM, Patil SS. Estimating combining ability through line × tester analysis in upland cotton. Res. Environ. Life Sci. 2016;9(5):628-633.