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Research Article

Combining ability and heterosis studies in cotton (*Gossypium hirsutum* L.) for yield and fibre quality traits

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Abstract
Cotton is India's most important cash crop and it is used for agricultural and industrial purposes for all over the world. The greatest way for identifying superior hybrids and best combiners of parents is by L×T design. For analyzing the combining ability and heterosis for various yield attributing variables as well as quality traits, the parents *viz.,* four lines and four testers were crossed to produce sixteen hybrids. MCU5 × KC3 cross contributed to positive, highly significant heterosis for the traits *viz.,* the number of sympodial branches, lint index and the number of bolls per plant, along with highly significant values of *sca* for the traits *viz*., the number of sympodial branches, seed cotton yield per plant and micronaire. CO14 × NDLH1938 had a highly significant *sca* effect for the trait of upper half mean length along with significant heterosis for the traits, *viz.,* boll weight and seed cotton yield per plant. Therefore, MCU5 had the best *gca* value for the upper half mean length among the four lines. The KC3 tester had a high *gca* value, indicating that it contributes to additive genes among the four testers. For some traits, not all good combiners have good *sca* effects. In the majority of the qualities investigated, non-additive or dominant gene action was seen. Heterosis breeding can be used to exploit the amount of available vigour.

Keywords: Combining ability, *G. hirsutum*. L., intraspecific hybrids, heterosis, Cotton.

INTRODUCTION

Cotton is one of India's most important cash crops, with a yield of 462 kg/ha in 2021, which is a significant increase from the previous year (Annual yield of cotton in India FY 2014-2021-Statista Research Development). It is one of the major contributory sectors of Indian exports. The GDP was boosted in India to a great extent by the world market for textiles and clothing. Among the four species of cotton, upland cotton (*Gossypium hirsutum*) occupies about 95% of the production. Heterosis is the phenomenon that illustrates the general combining ability (*gca*) and specific combining ability (*sca*) of the parental lines. According to Shull (1952), the F_1 generation shows vigour and productivity by making crosses between the inbred lines. A systematic approach to combining ability studies was reported by Kempthorne (1957) through the Line × Tester method of analysis. L×T is the most effective biometrical technique for analyzing the genetic profiles of characters in general. For hybrid improvement, the study of heterosis provides information about usefulness of the parents in breeding programs. Various traits involved in this study were investigated for the selection of parents, the magnitude and nature of gene action through the combining ability studies. By identifying suitable high yielding hybrids exhibiting high economic heterosis in cotton productivity as reported by Patil (2018). For significant improvement of cotton yield and fibre quality parameters, heterosis breeding is the best method. The main objective of this study is to find the best combiners for yield and quality parameters and explore the best combinations of hybrids for the same.

MATERIALS AND METHODS

The present research on heterosis and combining ability was undertaken in the Department of Cotton, Centre for Plant Breeding and Genetics, Tamil Nadu Agricultural University, during February and August 2021. Four *Gossypium hirsutum* genotypes, MCU5, MCU7, CO14 and CO17, were utilized as lines (high yield) and four *Gossypium hirsutum* genotypes, KC2, KC3, NDLH1755 and NDLH1938, were used as testers (donor parent for jassid resistance and good quality for lint). Using Doak's method, each of the four lines was crossed with four testers individually utilizing manual emasculation and pollination (Doak, 1934). Thus, 16 F_1 hybrid seeds were produced and were evaluated along with their eight parents and a commercial check (MCU 5). The experiment was conducted in a Randomized Block Design with two replications (RBD). Each hybrid was raised in ten rows, with the line and testers raised in four rows. The spacing for each neighboring plant was 90 x 45 cm. To get a superior crop all the agronomic practices were used under well-fertilized and irrigated conditions.

Five plants were randomly selected from the genotypes in each replication for biometrical observations, *viz*., plant height (cm), the number of sympodial branches, the number of bolls per plant, boll weight (g), lint index (g), single cotton yield per plant (g), ginning outturn (%), upper half mean length (mm), elongation percentage, and micronaire value (µg / inch) were recorded. Lint samples were ginned for testing the fibre quality characteristics, *viz*., upper half mean length, elongation percentage, and micronaire, which were analyzed using 10 g of lint sample through the High Volume Instrument (HVI) 900 classic. Then mean data collected from hybrids along with their parents and checks was statistically analyzed by using the TNAUSTAT for calculating the heterosis. The estimation of heterosis was done by calculating the superiority of the F_1 over standard check (MCU 5) and combining ability was estimated through line × tester method of analysis Kempthorne (1957). The total variance was portioned into replication and treatment for ten characters. The mean data were tabulated for yield contributing traits and analysis of variance (ANOVA), standard error, and co-efficient of variation were reported in the tables through the TNAUSTAT software tool were used.

RESULTS AND DISCUSSION

Per se performance on plant height indicate that CO17 × NDLH1755 (119.88 cm) was the tallest, followed by CO14 × NDLH1938 (115.86 cm) and MCU5 × NDLH1938 (71.04 cm) was found to be dwarf, followed by MCU7 × NDLH1755 (71.29 cm) (Table 1). The range of number

Table 1. ***Per se*** **performance of 16 F_1 hybrids for seed cotton yield and their associated traits in *Gossypium hirsutum***

Crosses	PH	SB	NBPP	BW	LI	GOT	SCYPP	UHML	EL	MIC
MCU5 × KC2	88.01	21.47	24.49	4.34	4.13	31.81	106.28	31.73	5.24	3.64
MCU5 × KC3	99.72	32.01	37.35	3.87	4.75	36.54	144.56	31.53	6.27	4.89
MCU5 × NDLH1755	108.63	28.52	34.72	3.57	4.79	39.92	124.10	31.60	6.63	3.57
MCU5 × NDLH1938	71.04	24.75	28.61	3.73	4.20	38.14	106.58	26.06	6.77	3.62
MCU7 × KC2	83.82	23.23	33.55	3.73	4.87	40.58	124.96	28.64	5.46	4.58
MCU7 × KC3	114.56	25.70	28.71	4.48	4.26	35.50	128.60	26.97	6.43	4.33
MCU7 × NDLH1755	71.29	29.28	23.19	3.57	4.25	38.68	82.78	29.68	6.83	3.52
MCU7 × NDLH1938	99.10	28.81	32.35	3.41	4.39	36.58	110.51	29.17	5.21	4.39
CO14 × KC2	99.90	25.33	30.29	4.52	4.27	38.82	136.90	28.25	5.39	3.14
CO14 × KC3	73.90	28.74	31.35	4.50	4.76	36.61	141.09	30.84	6.73	4.72
CO14 × NDLH1755	81.11	22.47	34.32	4.46	4.87	37.43	152.90	26.07	6.18	4.59
CO14 × NDLH1938	115.86	29.34	36.12	4.30	4.27	38.82	155.32	31.53	5.20	4.17
CO17 × KC2	110.59	24.60	31.19	4.31	5.06	38.93	134.28	29.70	5.49	4.59
CO17 × KC3	71.36	27.58	30.53	3.18	4.11	35.77	97.14	27.07	6.77	3.22
CO17 × NDLH1755	81.27	31.27	36.84	3.56	4.31	35.92	131.34	31.59	5.49	4.13
CO17 × NDLH1938	119.88	26.14	27.86	3.32	4.30	39.09	92.44	29.65	6.38	4.59
Mean	93.13	26.83	31.34	3.93	4.47	37.45	123.11	29.38	6.03	4.11
SEd	2.40	0.40	0.67	0.08	0.11	1.34	3.19	0.66	0.13	0.14
CD (0.05)	4.97	0.83	1.38	0.17	0.23	2.77	6.60	1.37	0.27	0.30

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of sympodial branches was from 21.47 to 32.01. The maximum value for the number of sympodial branches was recorded in MCU5 × KC3 (32.01), followed by CO17 × NDLH1755 (31.27). MCU5×KC3 (37.35) had the most number of bolls per plant followed by CO17 × NDLH1755 (36.84) and MCU7 × NDLH1755 (23.19) had the least number of bolls. Boll weight was the highest in CO14 × KC2 (4.52 g) followed by CO14 × KC3 (4.50 g) and it ranged from 3.18 to 4.52 g. The lint index was the highest in CO17 × KC2 (5.06 g) followed by MCU7 × KC2 (4.87 g) and CO14 × NDLH1755 (4.87 g). Ginning outturn was maximum in MCU7 × KC2 (40.58 %) followed by MCU5 × NDLH1755 (39.92 %) and minimum values were recorded in MCU5 × KC2 (31.18 %) followed by MCU7×KC3 (35.50 %). The seed cotton yield per plant was high in CO14 × NDLH1938 (155.32 g) followed by CO14 × NDLH1755 (152.90 g) and low in MCU7 × NDLH1755 (82.78 g) followed by CO17 × NDLH1938 (92.44 g). The longest upper half mean length was recorded in MCU5 × KC2 (31.73 mm) followed by MCU5 × NDLH1755 (31.60 mm) and the shortest was recorded in MCU5 × NDLH1938 (26.06 mm) followed by CO14 × NDLH1755 (26.07 mm). The elongation percentage was the highest in MCU7 × NDLH1755 (6.83 %) followed by MCU5 × NDLH1938 (6.77 %) and CO17 × KC3 (6.77 %) and was the lowest in CO14 × NDLH1938 (5.20 %) followed by MCU7 × NDLH1938 (5.21 %). The micronaire values were the highest in MCU5 × KC3 (4.89 µg per inch) followed by CO14 × KC3 (4.72 µg/inch) and CO14 × KC2 (3.14 µg/inch), whereas it was lowest in CO17 × KC3 (3.22 µg / inch). MCU 5 exhibited high mean performance for the traits *viz.,* seed cotton yield per plant (117.68 g), upper half mean length (29.10 mm) and elongation per cent (6.56%) (**Table 2**). High *per se* performance for the trait, the number of sympodial branches per plant and the number of bolls per plant were identified in the line CO 14 (29.51, 31.30), respectively. Boll weight was found to be highest in CO 17(4.24 g) among the lines. The tester NDLH 1755 had the highest mean performance for the trait, the number of sympodial branches per plant (29.43). The tester NDLH 1938 had the highest mean performance for the traits namely, the number of bolls per plant (30.60) and upper half mean length (28.52 mm). The single plant yield trait in the tester KC3 was found to have high *per se* performance (108.97 g) and the same trait was found to be highest among the lines in MCU 5 (117.68 g). The tester KC2 was found to have the highest *per se* performance for the trait elongation per cent (6.18%) and the lowest mean value for the trait micronaire value (3.37 µg/inch).

The heterosis estimate among the parents involved in the cross combination is a measure of genetic variability. A breeder would be able to make a decision based on the heterosis research for the exploitation of the potential hybrid and the extent to which it could be used as a breeding material. The heterosis estimates which are superior to those of better parents (Heterobeltiosis) and conventional parents (standard heterosis) were considered as the best hybrids as reported by Naik *et al.* (2020). The cross MCU 5 × NDLH1938 exhibited the lowest significant mid parent heterosis (-32.01 %), better parent heterosis (-37.86 %) and standard heterosis (-37.86%) for the trait plant height (**Table 3**). MCU 5 × KC3 contributed the highest significant value for the traits *viz.,* the number of sympodial branches

Table 2. Mean performance of parents for different characters in *Gossypium hirsutum*

	PH	SB	NBPP	BW	LI	SCYPP	GOT	UHML	EL	MIC
LINES										
MCU 5	114.33	28.46	29.42	4.00	4.10	117.68	34.40	29.10	6.56	4.68
MCU 7	73.80	23.29	23.53	4.21	4.39	98.95	36.54	28.72	5.82	3.22
CO 14	81.90	29.51	31.30	3.36	5.45	105.03	38.89	28.13	5.58	3.68
CO 17	88.13	21.38	22.81	4.24	4.89	96.60	39.11	27.20	5.28	4.74
SE	1.00	0.28	0.27	0.03	0.05	1.44	0.54	0.31	0.04	0.07
CD (P=05)	2.13	0.59	0.59	0.05	0.10	3.08	1.14	0.66	0.09	0.16
TESTERS										
KC 2	114.65	22.55	24.50	3.67	4.23	89.82	32.49	26.00	6.18	3.37
KC 3	104.03	22.94	25.77	4.23	4.35	108.97	36.21	28.24	5.60	4.35
NDLH 1755	102.44	29.43	29.98	3.55	4.58	106.38	35.23	26.24	5.69	4.89
NDLH 1938	94.67	28.48	30.60	3.40	4.26	103.90	35.50	28.52	5.65	3.41
SE	1.00	0.28	0.27	0.03	0.05	1.44	0.54	0.31	0.04	0.07
CD (P=05)	2.13	0.59	0.59	0.05	0.10	3.08	1.14	0.66	0.09	0.16

PH: Plant height (cm)
SB: Number of sympodial branches
NBPP: Number of bolls per plant
BW: Boll Weight (g)
LI: Lint Index (g)
GOT: Ginning outturn (%)
SCYPP: Seed Cotton yield per plant (g)
UHML: Upper Half Mean Length (mm)
EL: Elongation percentage (%)
MIC: Micronaire value (µg/inch)

Table 3. Heterotic effects of 16 F_1 hybrids for yield and quality traits in upland cotton

Crosses	PH			SB			NBPP			BW		
	di	dii	diii	di	dii	diii	di	dii	diii	di	dii	diii
MCU5 × KC2	-23.13 **	-23.24 **	-23.02 **	-15.83 **	-24.58 **	-24.58 **	-9.15 **	-16.76 **	-16.76 **	13.17 **	8.50 **	8.50 **
MCU5 × KC3	-8.67 **	-12.78 **	-12.78 **	24.58 **	12.49 **	12.49 **	35.37 **	26.97 **	26.97 **	-5.95 **	-8.51 **	-3.25 *
MCU5 × NDLH1755	0.23	-4.98 *	-4.98 *	-1.46	-3.08 *	0.21	16.89 **	15.79 **	18.00 **	-5.30 *	-10.63 **	-10.63 **
MCU5 × NDLH1938	-32.01 **	-37.86 **	-37.86 **	-13.07 **	-13.10 **	-13.04 **	-4.67 *	-6.50 **	-2.75	0.74	-6.87 **	-6.88 **
MCU7 × KC2	-11.04 **	-26.89 **	-26.68 **	1.40	-0.21	-18.36 **	39.70 **	36.95 **	14.02 **	-5.40 **	-11.41 **	-6.88 **
MCU7 × KC3	28.84 **	10.12 **	0.20	11.19 **	10.35 **	-9.72 **	16.47 **	11.41 **	-2.41	6.22 **	5.91 **	12.00 **
MCU7 × NDLH1755	-19.09 **	-30.40 **	-37.64 **	11.10 **	-0.49	2.88	-13.34**	-22.67 **	-21.19 **	-7.93 **	-15.10 **	-10.75 **
MCU7 × NDLH1938	17.65 **	4.68	-13.31 **	11.29 **	1.14	1.21	19.51 **	5.70 *	9.94 **	-10.13 **	-18.79 **	-14.63 **
CO14 × KC2	1.66	-12.86 **	-12.62 **	-2.67	-14.15 **	-11.00 **	8.56 **	-3.24	2.94	28.68 **	23.16 **	13.00 **
CO14 × KC3	-20.50 **	-28.96 **	-35.36 **	9.59 **	-2.61	0.97	9.87 **	0.16	6.56 **	18.66 **	6.38 **	12.50 **
CO14 × NDLH1755	-11.99 **	-20.81 **	-29.05 **	-23.76 **	-23.86 **	-21.06 **	12.01 **	9.65 **	16.66 **	29.04 **	25.49 **	11.38 **
CO14 × NDLH1938	31.23 **	22.38 **	1.34	1.20	-0.56	3.09 *	16.70 **	15.40 **	22.77 **	27.41 **	26.66 **	7.50 **
CO17 × KC2	9.08 **	-3.54	-3.27	12.04 **	9.14 **	-13.55 **	31.87 **	27.33 **	6.02 *	8.92 **	1.65	7.62 **
CO17 × KC3	-25.73 **	-31.40 **	-37.58 **	24.49 **	20.25 **	-3.09 *	25.71 **	18.49 **	3.79	-24.87 **	-24.91 **	-20.50 **
CO17 × NDLH1755	-14.71 **	-20.66 **	-28.91 **	23.13 **	6.29 **	9.89 **	39.57 **	22.88 **	25.22 **	-8.41 **	-15.82 **	-10.88 **
CO17 × NDLH1938	31.16 **	26.63 **	4.86 *	4.86 **	-8.22 **	-8.15 **	4.33	-8.95 **	-5.30 *	-12.98 **	-21.61 **	-17.00 **
SE	2.0805	2.4024	1.459	0.3457	0.3992	0.2841	0.5779	0.6673	0.4638	0.0728	0.0841	0.0377

Table 3. Continued

Crosses	LI			GOT			SCYPP			UHML		
	di	dii	diii	di	dii	diii	di	dii	diii	di	dii	diii
MCU5 × KC2	-0.66	-2.13	0.85	-4.88	-7.53	-7.53	2.44	-9.69 **	-9.69 **	15.15 **	9.02 **	9.02 **
MCU5 × KC3	12.49 **	9.32 **	15.85 **	3.50	0.91	6.22	27.56 **	22.83 **	22.83 **	9.98 **	8.35 **	8.35 **
MCU5 × NDLH1755	10.37 **	4.59	16.83 **	14.65 **	13.30 **	16.03 **	10.77 **	5.45	5.45	14.23 **	8.61 **	8.61 **
MCU5 × NDLH1938	0.36	-1.53	2.32	9.13 *	7.44	10.87 *	-3.80	-9.43 **	-9.43 **	-9.52 **	-10.43 **	-10.43 **
MCU7 × KC2	13.12 **	11.06 **	18.78 **	17.59 **	11.05 **	17.98 **	32.40 **	26.29 **	6.18 *	4.68 *	-0.28	-1.58
MCU7 × KC3	-2.41	-2.85	3.90	-2.41	-2.86	3.20	23.70 **	18.01 **	9.27 **	-5.30 *	-6.09 *	-7.32 **
MCU7 × NDLH1755	-5.08 *	-7.10 **	3.78	7.80 *	5.86	12.46 **	-19.37 **	-22.19 **	-29.66 **	8.00 **	3.33	1.98
MCU7 × NDLH1938	1.56	0.11	7.07 **	1.56	0.11	6.35	8.96 **	6.36 *	-6.10 *	1.93	1.57	0.24
CO14 × KC2	-11.69 **	-21.58 **	4.15	8.78 *	-0.18	12.85 **	40.51 **	30.34 **	16.33 **	4.39	0.44	-2.92
CO14 × KC3	-2.76	-12.58 **	16.10 **	-2.49	-5.85	6.44	31.86 **	29.48 **	19.89 **	9.43 **	9.21 **	5.98 *
CO14 × NDLH1755	-2.94	-10.65 **	18.66 **	0.98	-3.77	8.79	44.64 **	43.72 **	29.92 **	-4.07	-7.29 **	-10.40 **
CO14 × NDLH1938	-12.00 **	-21.58 **	4.15	4.37	-0.18	12.85 **	48.67 **	47.87 **	31.98 **	11.35 **	10.59 **	8.37 **
CO17 × KC2	11.09 **	3.58	23.41 **	8.74 *	-0.46	13.15 **	44.06 **	39.01 **	14.10 **	11.65 **	9.19 **	2.06
CO17 × KC3	-11.05 **	-15.97 **	0.12	-5.03	-8.54 *	3.97	-5.49	-10.86 **	-17.46 **	-2.33	-4.13	-6.96 **
CO17 × NDLH1755	-8.93 **	-11.77 **	5.12 *	-3.37	-8.16 *	4.40	29.40 **	23.45 **	11.60 **	18.22 **	16.12 **	8.54 **
CO17 × NDLH1938	-5.96 **	-11.98 **	4.88 *	4.79	-0.04	13.63 **	-7.79 **	-11.03 **	-21.45 **	6.43 **	3.98	1.89
SE	0.0956	0.1104	0.0654	1.1588	1.3381	1.0141	2.7144	3.1343	2.1706	0.5739	0.6627	0.4312

** Significant at 1 per cent level, * Significant at 5 per cent level
PH: Plant height , LI: Lint Index, UHML: Upper Half Mean Length, SB: Number of sympodial branches GOT: Ginning outturn, EL: Elongation percentage, NBPP: Number of bolls per plant, SCYPP: Seed Cotton yield per plant, MIC: Micronaire value, BW: Boll weight

Table 3. Continued

Crosses	EL			MIC		
	di	dii	diii	di	dii	diii
MCU5 × KC2	-17.79 **	-20.14 **	-20.14 **	-9.51 **	-22.22 **	-22.22 **
MCU5 × KC3	3.21	-4.35 *	-4.35 *	8.42 **	4.59	4.59
MCU5 × NDLH1755	8.33 **	1.14	1.14	-25.46 **	-27.02 **	-23.82 **
MCU5 × NDLH1938	10.98 **	3.28	3.28 *	-10.51 **	-22.65 **	-22.65 **
MCU7 × KC2	-9.05 **	-11.73 **	-16.78 **	39.10 **	36.11 **	-2.14
MCU7 × KC3	12.71 **	10.58 **	-1.91	14.40 **	-0.46	-7.48 *
MCU7 × NDLH1755	18.70 **	17.37 **	4.12 *	-13.14 **	-27.94 **	-24.79 **
MCU7 × NDLH1938	-8.99 **	-10.32 **	-20.44 **	32.58 **	28.89 **	-6.09
CO14 × KC2	-8.25 **	-12.70 **	-17.70 **	-10.72 **	-14.54 **	-32.80 **
CO14 × KC3	20.54 **	20.38 **	2.75	17.43 **	8.39 *	0.75
CO14 × NDLH1755	9.81 **	8.80 **	-5.64 **	7.18 *	-6.04	-1.92
CO14 × NDLH1938	-7.35 **	-7.88 **	-20.67 **	17.77 **	13.45 **	-10.79 **
CO17 × KC2	-4.15 *	-11.17 **	-16.25 **	13.14 **	-3.27	-2.03
CO17 × KC3	24.56 **	21.00 **	3.28 *	-29.15 **	-32.07 **	-31.20 **
CO17 × NDLH1755	0.18	-3.43	-16.25 **	-14.29 **	-15.56 **	-11.86 **
CO17 × NDLH1938	16.85 **	13.02 **	-2.67	12.64 **	-3.16	-1.92
SE	0.1109	0.1281	0.0701	0.1246	0.1438	0.1012

** Significant at 1 per cent level, * Significant at 5 per cent level
PH: Plant height , LI: Lint Index, UHML: Upper Half Mean Length, SB: Number of sympodial branches GOT: Ginning outturn, EL: Elongation percentage, NBPP: Number of bolls per plant, SCYPP: Seed Cotton yield per plant, MIC: Micronaire value, BW: Boll weight

and lint index, with a mid-parent heterosis of 24.58 and 12.49 per cent, respectively. The same cross had the highest significant standard heterosis for the traits *viz.,* the number of sympodial branches (12.49 %) and the number of bolls per plant (26.97%). The cross MCU 5 × NDLH1755 revealed the highest significant better parent heterosis for the trait ginning outturn with a value of 13.30 per cent. The cross MCU 7 × KC2 was found to have the highest significant mid parent (39.70 %) and better parent heterosis (36.95 %) for the trait number of bolls per plant; the highest significant better parent heterosis for the trait lint index (11.06 %); the highest significant mid parent (17.59 %) and standard heterosis (17.98 %) for the trait ginning outturn. MCU 7 × NDLH1755 cross had a highly significant standard heterosis for the trait elongation percentage (4.12 %). The highest significant standard heterosis value for the traits *viz.,* boll weight (13.00 %) and micronaire (-32.80 %) was recorded in the cross CO 14 × KC2. The cross CO 14 × NDLH1755 had a highly significant mid parent value for the trait boll weight. CO 14 × NDLH1938 had highly significant better parent heterosis for the trait boll weight (26.66 %). The same cross was contributing the trait of single plant yield. It had significant mid parent (48.67 %), better parent (47.87 %) and standard heterosis (31.98 %) values. Similar results were reported for high standard heterosis in cotton by Akbar *et al.* (2020). These results are in agreement with the findings of Naik *et al*. (2020) who reported significant positive heterosis for seed cotton yield per plant. The highest standard heterosis values for the trait lint index (23.41 %) were found in the cross CO 17 × KC2. The cross CO 17×KC3 showed the highest significant better parent value for the traits number of sympodial branches (20.25 %) and elongation per cent (21.00 %). The same cross had highly significant mid parent heterosis for the trait elongation per cent with the value of 24.56 per cent. Similar findings were reported by Tuteja and Agrawal (2013) in cotton. The cross CO 17 × KC3 revealed a highly significant negative value for the trait micronaire with the mid parent value (29.15 %) and better parent value (-32.07 %). The upper half mean length was identified to be highly significant in the cross CO 17 × NDLH1755 with the mid parent and better parent values of 18.22 and 16.12 per cent, respectively.

The analysis of variance for combining ability for ten biometrical traits was given in **Table 4.** The mean sum of squares of all the genotypic values was extremely significant to all the traits. The variance of *gca* was found to be lower than variance of *sca* in all the biometrical traits studied. The combining ability analysis exhibits the dominance of non-additive gene action in all yield and fibre quality contributing traits. The general combining ability effects (*gca*) of parents provide important information about the choice of parents in terms of their hybrid performance (**Table 5**). Singh and Singh (1985)

Table 4. ANOVA for seed cotton yield and its components in *Gossypium hirsutum*

SOURCE	DF	PH	SB	NBPP	BW	LI	GOT	SCYPP	UHML	EL	MIC
REPLICATION	1	0.6793	0.2041	1.6502	0.0158	0.0021	0.1587	64.5889	0.0554	0.0391	0.0001
GENOTYPES	23	537.1467**	20.5161**	37.3919**	0.3858**	0.2494**	9.9252**	838.9123**	7.4044**	0.6671**	0.7164**
CROSS	15	608.9671	19.1926	34.2816	0.4497	0.1975	9.2808	944.2269	8.2499	0.8334	0.6470
LINES	3	25.8758	1.2864	17.2737	1.0617	0.0171	2.9147	2062.8511	3.6501	0.1701	0.1177
TESTERS	3	381.7922	37.7692	9.1335	0.4491	0.1412	6.9460	203.6321	0.8466	2.0254	0.2137
L x T	9	879.0558	18.9692	48.3336	0.2460	0.2764	12.1812	818.2170	12.2509	0.6572	0.9679
PARENT	7	440.0813	24.5188	23.7480	0.2893	0.3919	9.7359	142.1202	2.6821	0.3192	0.9612
Cross vs Parents	1	139.2981	12.3482	179.5528	0.1021	0.0312	20.9160	4136.7377	27.7780	0.6064	0.0442
ERROR	23	5.7714	0.1593	0.4453	0.0071	0.0122	1.7905	10.1525	0.4392	0.0164	0.0207

**** Significant at 1 per cent level**

Table 5. General combining ability effects for various traits in *Gossypium hirsutum*

Parents	PH	SB	NBPP	BW	LI	GOT	SCYPP	UHML	EL	MIC
LINES										
MCU5	-1.28	-1.60 **	-1.60 **	-0.05 *	-0.01	-0.84 *	-0.36	0.85 **	0.20 **	-0.18 **
MCU7	-0.93	1.62 **	1.62 **	-0.13 **	-0.03	0.39	-12.35 **	-0.77 **	-0.05	0.10
CO14	-0.43	-0.78 **	-0.78 **	0.52 **	0.07	0.47	11.54 **	-0.21	-0.15 **	0.05
CO17	2.65 **	0.76 **	0.76 **	-0.34 **	-0.03	-0.02	1.18	0.12	0.00	0.02
SE	0.7087	0.1373	0.2392	0.0194	0.0337	0.3784	1.1195	0.2196	0.0315	0.0518
TESTERS										
KC2	2.45 **	2.72 **	2.72 **	0.29 **	0.11 **	0.09	23.40 **	0.20	-0.64 **	-0.12 *
KC3	-3.24 **	-0.99 **	-0.99 **	0.08 **	-0.01	-1.34 **	7.97 **	-0.28	0.52 **	0.18 **
NDLH1755	-7.55 **	-3.39 **	-3.39 **	-0.14 **	0.08 *	0.54	-25.64 **	0.35	0.25 **	-0.16 **
NDLH1938	8.34 **	1.67 **	1.67 **	-0.24 **	-0.19 **	0.71	-5.73 **	-0.28	-0.14 **	0.09
SE	0.7087	0.1373	0.2392	0.0194	0.0337	0.3784	1.1195	0.2196	0.0315	0.0518

** Significant at 1 per cent level, * Significant at 5 per cent level

proposed that parents which has high *gca* would result in transgressive segregants in the further population. Hence, *gca* impacts that were significant were taken into consideration for heterosis studies as suggested by Gnanasekaran *et al*. (2019). The parent MCU 5 had exhibited a high *gca* value for the traits *viz.,* upper half mean length (0.85) and elongation per cent (0.20). High *gca* for the traits namely, number of bolls (1.68), boll weight (0.52) and single plant yield (23.44) were identified in the line CO 14. The line CO 17 was found to have the highest significant *gca* value for the trait number of sympodial branches. The tester KC2 was found to have a highly significant *gca* value for the trait boll weight (0.29) and lint index (0.11). The tester KC3 had the lowest significant gca plant height value of -7.55 and the highest significant values for the traits number of sympodial branches (1.68), single plant yield (4.74), and elongation per cent (0.52). The tester NDLH1755 had the lowest significant *gca* value for the trait micronaire (-0.16) and the highest significant value for the trait number of bolls per plant (0.92). Positive and negative values of *gca* were observed for most of the traits between lines and testers in cotton, as reported by Yehia *et al.* (2019).

The specific combining ability of 16 hybrids revealed that the cross MCU5 × KC3 recorded positive highly significant for the number of sympodial branches, seed cotton yield per plant and micronaire value (**Table 6**). Among the characters, the ginning outturn shows positive highly significant *sca* values in the cross MCU5 × NDLH1755. The cross MCU5 × NDLH1938 had a negative highly significant *sca* effect along with a positive highly significant elongation percentage. The cross MCU7×KC3 had a highly significant *sca* effect for boll weight. The *sca* effect was found to be positive highly significant for the trait upper half mean length in the cross CO14 × NDLH1938. The cross CO17 × KC2 showed a highly significant *sca* effect for lint index. Among the selected genotypes, were useful for further hybridization programmes. According to Yehia *et al.*(2019) most heterotic hybrids with good *sca* effects had at least one good general combining parent. Good combiners need not always

Table 6. Specific combining ability effects for various traits in *Gossypium hirsutum*

Crosses	PH	SB	NBPP	BW	LI	GOT	SCYPP	UHML	EL	MIC
MCU5 × KC2	-6.29 **	-2.05 **	-5.34 **	0.17 **	-0.44 **	-4.88 **	-16.59 **	1.30 *	-0.36 **	-0.17
MCU5 × KC3	11.11 **	3.65 **	5.42 **	-0.09 *	0.29 **	1.28	19.44 **	1.58 **	-0.48 **	0.78 **
MCU5 × NDLH1755	24.33 **	0.77 *	2.50 **	-0.17 **	0.24 **	2.77 **	4.05	1.02 *	0.15 *	-0.21
MCU5 × NDLH1938	-29.15 **	-2.37 **	-2.58 **	0.09 *	-0.09	0.83	-6.90 **	-3.89 **	0.68 **	-0.40 **
MCU7 × KC2	-10.82 **	-0.35	5.56 **	-0.37 **	0.32 **	2.66 **	10.75 **	-0.17	0.11	0.49 **
MCU7 × KC3	25.61 **	-2.74 **	-1.38 *	0.60 **	-0.18 *	-1.00	12.15 **	-1.37 **	-0.07	-0.06
MCU7 × NDLH1755	-13.35 **	1.47 **	-7.19 **	-0.09 *	-0.27 **	0.31	-28.60 **	0.71	0.59 **	-0.53 **
MCU7 × NDLH1938	-1.43	1.62 **	3.01 **	-0.14 **	0.13	-1.97 *	5.70 *	0.83	-0.63 **	0.10
CO14 × KC2	4.75 **	2.03 **	-1.27 *	-0.22 **	-0.38 **	0.81	-12.15 **	-1.12 *	0.15 *	-0.89 **
CO14 × KC3	-15.55 **	0.59 *	-2.32 **	-0.02	0.22 **	0.04	-10.19 **	1.94 **	0.33 **	0.37 **
CO14 × NDLH1755	-4.03 *	-5.06 **	0.38	0.15 **	0.24 **	-1.03	6.68 **	-3.45 **	0.05	0.59 **
CO14 × NDLH1938	14.82 **	2.44 **	3.21 **	0.09 *	-0.09	0.19	15.66 **	2.64 **	-0.54 **	-0.07
CO17 × KC2	12.36 **	0.37	1.05 *	0.42 **	0.51 **	1.41	17.99 **	-0.00	0.09	0.57 **
CO17 × KC3	-21.17 **	-1.50 **	-1.72 **	-0.49 **	-0.33 **	-0.32	-21.40 **	-2.15 **	0.22 **	-1.09 **
CO17 × NDLH1755	-6.95 **	2.82 **	4.31 **	0.11 *	-0.21 **	-2.05 *	17.87 **	1.73 **	-0.80 **	0.15
CO17 × NDLH1938	15.76 **	-1.69 **	-3.64 **	-0.03	0.04	0.95	-14.46 **	0.42	0.49 **	0.37 **
SE	1.4175	0.2745	0.4785	0.0389	0.0675	0.7569	2.0424	0.4392	0.0629	0.1035

** Significant at 1 per cent level, * Significant at 5 per cent level
PH: Plant height , LI: Lint Index, UHML: Upper Half Mean Length, SB: Number of sympodial branches GOT: Ginning outturn, EL: Elongation percentage, NBPP: Number of bolls per plant, SCYPP: Seed Cotton yield per plant, MIC: Micronaire value, BW: Boll weight

have good *sca* effects. This matched the findings of Bilwal *et al.* (2018). All qualities studied showed dominance, or non-additive gene activity. The majority of results of the present study matched with those of Nirania *et al.* (2010), Patel *et al.* (2014) and Jaiwar *et al.* (2012).

Cotton yield and lint will be in great demand in the future. In such conditions, selected hybrids can improve the quality and production of cotton. The hybrid MCU5 × KC3 showed high mean performance for sympodial branch number and boll number. Also, the cross CO14 × NDLH1938 exhibited substantial *sca* values for upper half mean length, boll weight, and seed cotton yield per plant. High yield and fibre quality were obtained by crossing MCU5 × KC3 and CO14 × NDLH1938 with the relevant traits. Among the four lines utilized in the study, the trait upper half mean length had significantly significant *gca* values. KC3 had the highest significant *gca* values for the number of sympodial branches, seed cotton output per plant and elongation per cent among the four testers.

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