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Heterosis and combining ability for seed cotton yield and quality parameters in cotton (*Gossypium hirsutum* L.)

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Abstract
The present investigation was carried out at Main Cotton Research Station, Surat to study heterosis and combining ability for seed cotton yield and its component traits in cotton using 12 parents and resultant 35 hybrids along with one standard check GN.Cot.Hy.-14 in a line x tester mating design. A complete set of forty eight genotypes was planted in randomized block design in tree replicates at the Main Cotton Research Station, NAU, Surat during *kharif* 2016. Significant heterobeltiosis and standard heterosis observed for seed cotton yield as well as fibre quality parameters. The crosses *viz.*, TCH 1777 X G Cot 20, HS 294 X G Cot 20, BGDS 1063 X G Cot 20, P- 5430 X 76-IH-20 and CCH- 14- 1 X G Cot 20 manifested significant heterobeltiosis and positive standard heterosis over check GN.Cot.Hy-14 for seed cotton yield. The ratio of GCA variance to SCA variance was less than unity except 2.5 % span length and fibre strength which indicated preponderance of non-additive genetic variance for inheritance of these traits. Among parents, G Cot 20 and CCH-14-1 were found good general combiners for seed cotton yield and its contributing traits, while parent LRA- 5166 exhibited good general combining ability for fibre quality traits. Best specific combinations were TCH 1777 X G Cot 20, HS 294 X G Cot 20, BGDS 1063 X G Cot 20, P- 5430 X 76-IH-20 and CCH- 14- 1 X G Cot 20 were recorded as the most promising based on *per se* performance and SCA effects so such crosses would be used commercially for future.

Keywords: Combining ability, cotton, GCA, heterobeltiosis, heterosis, hybrids, line x tester analysis, SCA, seed cotton yield

Introduction
Cotton is one of the most important fibre crops in the world. It is grown as commercial crop and popularly known as the "White Gold". Cotton is the precious gift and most important cash crop of nature to the mankind. It is also known as the 'King of Apparel Fibre' enjoys a pre-eminent status among all cash crops in the country. *Gossypium* includes 50 species, four of which are cultivated, 44 are wild diploids and two are wild tetraploids (Percival and Kohel, 1990). Out of the four cultivated species, *Gossypium hirsutum* L. and *Gossypium barbadense* L. commonly known as new world cottons are tetraploids (2n=4x=52), whereas, *Gossypium herbaceum* L. and *Gossypium arboreum* L. are diploids (2n=2x=26) and are commonly known as old world cottons. India is the pioneer in the world for commercial exploitation of heterosis in cotton. Hybrids had played significant role to attain self-sufficiency in cotton production in India, having largest cotton growing area. Hybrids had played significant role to attain self-sufficiency in cotton production in India, having largest cotton growing area, one of the largest producers of long and short staple cotton. The nature and magnitude of heterosis help in identifying superior crosses for their exploitation to obtain better transgressive segregants. Knowledge of combining ability is useful for the selection of desirable parents for exploitation of hybrid vigour. Selection based on phenotypic performance alone is not a sound procedure particularly where metric traits are under the influence of epistatic genes. It is therefore, necessary to choose parents on their intrinsic genetic value. Therefore, the present investigation was under taken using Line x Tester mating design involving seven genotypes as female and five genotypes as male for breeding improved varieties/hybrids with higher yield during cropping season of *kharif* 16.

Materials and Methods
Complete set of 48 entries comprising of seven female lines, *viz.*, TCH 1777, SCS 1062, BGDS 1063, P- 5430, CCH- 14- 1, HS 294, F- 2501 and five testers, *viz.*, 76-IH-20, Surat

Dwarf, LRA- 5166, G Cot 10, G Cot 20 and their 35 F_1s and one check GN. Cot. Hy.-14 were sown at the Main Cotton research Station, NAU, Surat during *kharif* 2016. The trial was conducted in a randomized block design replicated thrice. Each entry was planted in a single row. Row to row and plant to plant distances was 120 cm and 45 cm, respectively. All the recommended packages of practices were adopted for raising a healthy crop. Observations were recorded on five randomly selected plants, excluding the border lines. The data were recorded on characters *viz.*, seed cotton yield per plant (g), 2.5% span length (mm), fibre strength (g/tex), fibre fineness (mv) and oil percentage (%).

Result and Discussion

The aim of heterosis study in the present investigation was to search out the superior combinations of parents with high degree of economic heterosis as well as its exploitation to get better transgressive segregants. The heterosis over better parent (heterobeltiosis) and the standard check (standard heterosis) for each character was estimated as per the standard procedure given by Fonseca and Patterson (1968) [3]. Combining ability is useful for the selection of desirable parents for exploitation of hybrid vigour. It is therefore, necessary to choose parents on their intrinsic genetic value. Combining ability described by Sprague and Tatum (1942) [17] elucidates the nature and magnitude of gene action involved in the inheritance of yield and its component traits. Seed cotton yield is the most important economic character in cotton. In present investigation, 24 and 16 crosses exhibited significant and positive heterobeltiosis and standard heterosis over standard check GN.Cot.Hy.-14 and ranged from -6.10 to 60.18 per cent and -14.24 to 57.38 per cent, respectively, for seed cotton yield in pooled analysis. Top five crosses *viz.*, TCH 1777 X G Cot 20 (60.18, 57.38 %), HS 294 X G Cot 20 (41.94, 39.45 %), BGDS 1063 X G Cot 20 (41.56, 39.09 %), P- 5430 X 76-IH-20 (34.66, 32.49 %) and CCH- 14- 1 X G Cot 20 (34.43, 32.08) manifested significant positive better parent and standard heterosis correspondingly in pooled analysis. The hybrids with high heterosis for seed cotton yield had also registered high SCA effects for the characters.

It was also noticed that the hybrids involving average x good, poor x good and good x good parents had showed maximum standard heterosis. Heterotic crosses involved either good or average combiner as one of the parents. Good yielding parents may have different constellations of gene showing complementary interaction when brought together in hybrids based on mean value rather than extent heterosis Kalpande *et al.* (2008) [5] and Preetha and Raveendaran (2008) [12].

Table 1: Estimates of heterosis over better parent (BP) and standard check (SC) for various characters in cotton

Crosses	Seed cotton yield per plant (g)		2.5% span length (mm)		Fibre strength (g/tex)		Fibre fineness (mv)		Oil percentage (%)	
	BP	SC	BP	SC	BP	SC	BP	SC	BP	SC
TCH 1777 X 76-IH-20	1.78	-0.94	1.40	-1.58	-1.62	1.10	-8.40 **	-18.19 **	3.80	7.66 **
TCH 1777 X Surat Dwarf	6.63	3.78	-2.53	-5.39 **	-5.34 *	-16.01 **	8.96 **	-8.82 **	1.84	4.63
TCH 1777 X LRA- 5166	1.63	-1.08	7.10 **	3.96	-3.02	-5.69 **	3.15	-7.88 **	1.44	4.23
TCH 1777 X G Cot 10	13.24 *	10.21	-0.42	-3.34	0.01	-8.23 **	5.25	-6.00 *	-0.26	2.74
TCH 1777 X G Cot 20	60.18 **	57.38 **	-7.82 **	-10.52 **	-5.86 **	-7.53 **	2.10	-8.82 **	8.09 **	11.06 **
SCS 1062 X 76-IH-20	3.90	-0.93	-2.55	-3.15	-7.84 **	-5.30 **	-0.51	-8.11 **	-0.44	3.27
SCS 1062 X Surat Dwarf	20.34 **	3.31	-8.15 **	-8.72	-10.82 **	-10.88 **	9.24 **	-8.58 **	6.10 *	7.52 **
SCS 1062 X LRA- 5166	16.20 *	-0.25	0.07	-0.55	-1.31	-1.38	4.32	-3.66	3.22	4.30
SCS 1062 X G Cot 10	15.12 *	-1.17	-3.03	-3.63	-1.87	-1.94	-3.05	-10.46 **	6.80 **	10.01 **
SCS 1062 X G Cot 20	17.10 **	15.06 *	-5.20 *	-5.79 **	-0.78	-0.85	10.91 **	2.44	5.07 *	4.75
BGDS 1063 X 76-IH-20	5.08	0.20	-4.06 *	-2.20	-6.16 **	-3.57	1.97	-2.96	8.98 **	13.03 **
BGDS 1063 X Surat Dwarf	-6.10	-14.24 *	-6.76 **	-4.95 *	-12.55 **	-13.57 **	17.37 **	-1.78	0.67	2.03
BGDS 1063 X LRA- 5166	3.82	-5.19	-1.26	0.66	-5.90 **	-7.00 **	6.09 *	-2.02	-1.41	-0.38
BGDS 1063 X G Cot 10	26.15 **	15.20 *	-3.96 *	-2.09	-5.22 **	-6.33 **	10.20 **	3.84	9.36 **	12.64 **
BGDS 1063 X G Cot 20	41.56 **	39.09 **	-4.42 *	-2.57	-2.32	-3.46	-7.64 **	-3.66	11.36 **	10.45 **
P- 5430 X 76-IH-20	34.66 **	32.49 **	-1.33	-7.66 **	-5.54 **	-1.27	-1.78	-9.28 **	6.21 *	10.16 **
P- 5430 X Surat Dwarf	23.98 **	21.96 **	-0.50	-4.47 *	-13.66 **	-9.75 **	1.12	-15.38 **	6.73 **	8.76 **
P- 5430 X LRA- 5166	33.47 **	31.29 **	0.15	-4.03 *	-3.99 *	0.35	0.00	-7.64 **	3.49	5.46 *
P- 5430 X G Cot 10	3.50	1.81	3.91	-3.52	-15.04 **	-11.20 **	-0.76	-8.35 **	5.79 *	8.96 **
P- 5430 X G Cot 20	34.14 **	31.95 **	-1.15	-8.21**	-9.26 **	-5.16 **	-3.05	-10.46 **	8.97	11.04 **
CCH- 14- 1 X 76-IH-20	13.10 *	10.25	-1.68	-5.32 **	-8.70 **	-6.18 **	10.60 **	-4.60	3.25	8.19 **
CCH- 14- 1 X Surat Dwarf	25.74 **	22.58 **	-5.03 *	-8.54 **	-2.84	-11.70 **	6.16	-11.16 **	2.26	7.16 **
CCH- 14- 1 X LRA- 5166	33.62 **	30.26 **	0.46	-3.26	2.04	-0.78	5.44	-9.05 **	4.24	9.24 **
CCH- 14- 1 X G Cot 10	25.61 **	22.45 **	-3.81	-7.37 **	9.24 **	0.25	9.78 **	-5.30 *	4.33	9.33 **
CCH- 14- 1 X G Cot 20	34.43 **	32.08 **	-2.32	-5.94 **	4.32 *	2.47	18.75 **	2.44	-0.33	4.45
HS 294 X 76-IH-20	-0.32	-4.96	-0.08	-6.49 **	-14.58 **	-12.23 **	-4.68	-9.28 **	2.30	6.10 *
HS 294 X Surat Dwarf	12.66	-5.78	-7.14 **	-10.85 **	-3.99	-16.68 **	9.80 **	-8.11 **	9.08 **	11.31 **
HS 294 X LRA- 5166	17.08 *	-3.45	-0.80	-4.95 *	-1.78	-4.49 *	7.36 *	-0.85	6.82 **	9.00 **
HS 294X G Cot 10	32.31 **	11.84	2.00	-6.64 **	2.46	-5.97 **	4.23	-1.78	3.06	6.16 *
HS 294 X G Cot 20	41.94 **	39.45 **	0.88	-7.66 **	-4.53 *	-6.22 **	4.90	5.48 *	8.82 **	11.04 **
F- 2501 X 76-IH-20	16.25 *	10.84	4.23	-2.46	-3.03	-0.35	-1.23	-6.00 *	4.07	7.95 **
F- 2501 X Surat Dwarf	21.25 **	13.25 *	-3.06	-6.93 **	0.01	-16.08 **	4.20	-12.80 **	8.40	11.90 **
F- 2501 X LRA- 5166	5.64	-1.33	3.02	-1.28	3.96 *	1.10	4.31	-3.66	1.87	5.15 *
F- 2501X G Cot 10	25.54 **	17.25 **	1.50	-5.90 **	9.47 **	0.46	7.21 *	1.03	4.02	7.37 **
F- 2501 X G Cot 20	30.78 **	28.49 **	5.54 *	-2.16	-0.58	-2.33	-7.42 **	-3.42	10.63 **	14.20 **
S.E.(d) ±	8.24	8.24	0.62	0.62	0.61	0.61	0.12	0.12	0.38	0.38
CD @ 5 %	16.24	16.24	1.22	1.22	1.21	1.21	0.25	0.25	0.75	0.75
CD @ 1 %	21.41	21.41	1.60	1.60	1.60	1.60	0.32	0.32	1.00	1.00

For 2.5% span length, only two crosses had depicted significant positive heterobeltiosis and none of the cross showed standard heterosis. The cross TCH 1777 X LRA-5166 which ranked first in *per se* performance for 2.5% span length, had also exhibited significant and positive value for heterobeltiosis. Similar results have been reported by Kaushik and Singh (2012) [6], Srinivas and Bhadru (2015) [18], Sharma *et al.* (2016) [15] and Lingaraja *et al*. (2017) [8].

Fibre strength is one of the important properties of cotton fibre. Only three crosses had showed significant and positive better parent heterosis and none of the crosses showed significant positive standard heterosis, respectively. The cross combination F- 2501 X G Cot 10 manifested highest magnitude of heterobeltiosis in positive direction in the present study. These results are in partial agreement with the results obtained by Sharma *et al.* (2016) [15] and Lingaraja *et al*. (2017) [8].For fineness 03 and 20 hybrids exhibited significant negative heterobeltiosis and standard heterosis respectively. The cross combination TCH 1777 X 76-IH-20 had exhibited the highest significant and negative heterosis over better parent as well as over the standard checks. Similar results have been reported by Kaushik and Singh (2012) [6] and Sharma *et al.* (2016) [15].

For oil percentage 14 and 26 hybrids exhibited significant positive heterobeltiosis and standard heterosis respectively. The cross combinations BGDS 1063 X G Cot 20 and F- 2501 X G Cot 20 exhibited the highest significant positive heterosis over better parent and over the standard check, respectively. The results are in parity with the findings of Ganapathy and Nandarajan (2008) [4] and Sawarkar *et al.* (2015) [14].

Table 2: Estimates of general combining ability (GCA) effects of parents for different characters in cotton

Parents	Seed cotton yield per plant (g)	2.5% span length (mm)	Fibre strength (g/tex)	Fibre fineness (mv)	Oil percentage (%)
TCH 1777	0.85	0.39 *	-0.52 **	-0.20**	-0.26 *
SCS 1062	-13.33 **	0.09	0.48 v	0.01	-0.27 *
BGDS 1063	-8.27 **	0.74 **	-0.37	0.21**	-0.03
P- 5430	14.17 **	-0.28	0.06	-0.21**	0.17
CCH- 14- 1	13.68 **	-0.43 *	0.76 **	0.01	-0.01
HS 294	-7.72 **	-0.80 **	-1.10 **	0.14**	0.15
F- 2501	0.62	0.28	0.68 **	0.04	0.24 *
SE gi	2.36	0.19	0.20	0.04	0.12
SE (gi-gj)	3.33	0.27	0.29	0.06	0.17
76-IH-20	-8.68 **	0.17	0.52 **	-0.12**	0.05
Surat Dwarf	-9.07 **	-0.74 **	-2.49 **	-0.18**	-0.02
LRA- 5166	-8.05 **	1.01 **	0.96 **	0.04	-0.38**
G Cot 10	-2.85	0.01	0.28	0.09**	0.07
G Cot 20	28.65 **	-0.44 **	0.73 **	0.17**	0.28**
SE gi	1.99	0.16	0.17	0.03	0.10
SE (gi-gj)	2.82	0.23	0.24	0.05	0.15

The combining ability analysis gives an indication of the variance due to GCA and SCA, which represents a relative measure of additive and non-additive gene actions, respectively. It is an established fact that dominance is a component of non-additive genetic variance. Breeders use these variance components to infer the gene action and to access the genetic potentialities of the parents in hybrid combinations.

GCA effects of parents were positively and significantly associated with their mean values for majority of characters. However, this could not be applicable for all characters; it might be due to inter-allelic interactions. Good general combining ability of CCH- 14- 1 and G Cot 20 for one or more yield attributes might have result of high combining ability of the parent for seed cotton yield. Hence, these parents may be useful in future breeding programme to improve yield.

A summarized account of the best *per se* performance of parents/hybrids and specific combiner, best general combiner, most heterotic crosses revealed, the best performing parent for *per se* may not always be a best general combiner (Dave *et al.* 2015[1] and Kumar *et al*. 2017) [7]. The best general combiner may not always produce best specific combinations (Patel *et al.* 2014 [11], Rajamani *et al.* 2014) [13].

However, in some cases, high SCA effects of F_1 coincided with high GCA effects of their parents. Parent P- 5430 and CCH- 14- 1 had high *per se* performance coupled with good GCA for seed cotton yield. Sivia *et al.* (2017) [16] reported similar kind of relationship between *per se* performance of parents with their GCA effects.

Table 3: Estimates of specific combining ability (SCA) effects of parents for different characters in cotton

Parents	Seed cotton yield per plant (g)	2.5% span length (mm)	Fibre strength (g/tex)	Fibre fineness (mv)	Oil percentage (%)
TCH 1777 X 76-IH-20	-11.01	0.38	2.12**	-0.27**	0.20
TCH 1777 X Surat Dwarf	-4.34	0.13	-0.26	0.23**	-0.20
TCH 1777 X LRA- 5166	-11.83 **	1.22 **	-0.46	0.06	0.09
TCH 1777 X G Cot 10	-2.00	0.00	-0.59	0.10	-0.57 *
TCH 1777 X G Cot 20	29.18 **	-1.73 **	-0.81	-0.11	0.48
SCS 1062 X 76-IH-20	3.18	0.20	-0.90 *	0.01	-0.46
SCS 1062 X Surat Dwarf	9.21	-0.58	0.35	0.04	0.26
SCS 1062 X LRA- 5166	3.46	0.15	-0.12	0.06	0.12
SCS 1062 X G Cot 10	-2.96	0.22	0.39	-0.32**	0.55
SCS 1062 X G Cot 20	-12.89 *	0.01	0.29	0.22	-0.47
BGDS 1063 X 76-IH-20	-0.38	-0.16	0.50	0.04	0.79**
BGDS 1063 X Surat Dwarf	-19.18 **	-0.08	0.36	0.15	-0.82**
BGDS 1063 X LRA- 5166	-8.17	-0.13	-1.03 *	-0.07	-0.84**
BGDS 1063 X G Cot 10	13.74 *	0.03	-0.14	0.15	0.71**
BGDS 1063 X G Cot 20	13.99 *	0.34	0.32	-0.28**	0.16
P- 5430 X 76-IH-20	20.06 **	-0.80	0.79	0.17	0.15
P- 5430 X Surat Dwarf	6.50	1.08 *	1.12 *	-0.07	0.00
P- 5430 X LRA- 5166	17.87 **	-0.54	0.85	0.08	-0.15
P- 5430 X G Cot 10	-26.50 **	0.62	-2.11 **	0.00	-0.05
P- 5430 X G Cot 20	-17.94 **	-0.36	-0.65	-0.18 *	0.05
CCH- 14- 1 X 76-IH-20	-8.96	0.07	-1.46 *	0.17	0.03
CCH- 14- 1 X Surat Dwarf	7.82	0.00	-0.19	-0.09	-0.06
CCH- 14- 1 X LRA- 5166	17.00 **	-0.15	-0.20	-0.21 *	0.61 *
CCH- 14- 1 X G Cot 10	1.42	-0.40	0.80	-0.08	0.19
CCH- 14- 1 X G Cot 20	-17.28 **	0.48	1.05 *	0.21 *	-0.77**
HS 294 X 76-IH-20	-7.77	0.08	-1.49 **	-0.18 *	-0.45
HS 294 X Surat Dwarf	-8.48	-0.33	0.11	-0.07	0.41
HS 294 X LRA- 5166	-6.40	-0.29	0.49	0.06	0.42
HS 294X G Cot 10	8.72	0.20	0.71	-0.04	-0.46
HS 294 X G Cot 20	13.94 *	0.34	0.18	0.23**	0.08
F- 2501 X 76-IH-20	4.88	0.22	0.46	0.07	-0.26
F- 2501 X Surat Dwarf	8.47	-0.22	-1.49 **	-0.20 *	0.41
F- 2501 X LRA- 5166	-11.93 **	-0.26	0.47	0.02	-0.26
F- 2501X G Cot 10	7.57	-0.66	0.94 *	0.19 *	-0.36
F- 2501 X G Cot 20	-8.99	0.92 *	-0.38	-0.09	0.47
SE sij	7.45	0.60	0.64	0.13	0.39
SE (Sij-Sjk)	5.27	0.42	0.45	0.09	0.27

SCA effects represent dominance and epistatic effects and can be related with heterosis [Falconer, 1960] [2]. Significant heterotic and positive SCA effects appeared in seven cross combinations for seed cotton yield. CCH- 14- 1 X G Cot 20 had both good combining parents for seed cotton yield. Heterosis in this cross might have resulted from the interaction of dominant gene. Dave *et al*. (2015) [1] and Sivia *et al.* (2017) [16] reported close relationship between GCA effects of parents and SCA effects of their resultant crosses. The crosses, HS 294 X G Cot 20, BGDS 1063 X G Cot 20 and P- 5430 X 76-IH-20 had good x poor combining parents. Positive SCA effects in crosses between good and poor combiners could be ascribed to better complementation between favourable alleles of the parents involved (Lodam *et al.* 2014) [9]. While in a cross of average x good (TCH 1777 X G Cot 20) parents, magnitude of SCA was higher which might be due to average combiner and complementary epistatic effect in the same direction.

Table 4: Best heterotic crosses and their *per se* performance with GCA effects and SCA effects for seed cotton yield in *G. hirsutum*

Sr. No.	Crosses		Seed cotton yield per plant (g)	Better parent heterosis (%)	Standard heterosis (%)	SCA effects	GCA effects	
							P_1	P_2
1	TCH 1777 X G Cot 20		209.15	60.18 **	57.38 **	29.179 **	0.847 A	28.645 ** G
	129.34	130.57						
2	HS 294 X G Cot 20		185.33	41.94 **	39.45 **	13.939 *	-7.724 ** P	28.645 ** G
	109.59	130.57						
3	BGDS 1063 X G Cot 20		184.85	41.56 **	39.09 **	13.987 *	-8.266 ** P	28.645 ** G
	121.37	130.57						
4	P- 5430 X 76-IH-20		176.04	34.66 **	32.49 **	20.056 **	14.171 ** G	-8.677 ** P
	130.73	126.72						
5	CCH- 14- 1 X G Cot 20		175.53	34.43 **	32.08 **	-17.28 **	13.679 ** G	28.645 ** G
	129.56	130.57						

A summarized account of best crosses on the basis of SCA effects with mean performance and heterosis along with best *per se* of parent and GCA effects of parents for various characters are presented in Table 4. The comparison of the crosses selected on the basis of their SCA effects with mean performance as well as heterosis revealed that, the ranking on the basis of SCA effects was not always reflected by the ranking based on *per se* performance and crosses showing high mean performance may not always shown high SCA effects (Kumar *et al*. (2017)) [7]. There was no consistent association between *per se* performance of the crosses and their SCA effects. Although, high SCA effects denote high heterotic response, this may be due to poor performance of the parents in comparison with their hybrids. The estimates of SCA effects may not always lead to a correct choice of hybrid combination. Choice of best hybrids with high *per se* performance with significant SCA and heterosis for yield and fibre quality traits have also been reported by Patel *et al.* (2014) [11], Dave *et al.* (2015) [1], Kumar *et al*. (2017) [7], Monicashree *et al*. (2017) [10].

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