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Heterosis of yield and its components in upland cotton (*Gossypium hirsutum* L.)

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Abstract
The present investigation was carried out to study heterosis of upland cotton (*Gossypium hirsutum* L.) at Surat, Gujarat. The magnitude of heterosis varied enormously for seed cotton yield and its attributing characters. The high magnitudes of standard heterosis was observed for lint index, bolls per plant and seed cotton yield per plant; whereas, sympodia per plant exhibited least heterotic values. The heighest possitive heterosis for seed cotton yield over better parent and standard check was observed to be 74.70 and 45.53 per cent, respectively. The cause of heterosis might be due to heterosis in its component traits, mainly bolls per plant, boll weight and seed index. The hybrids *viz*., GSHV-184 x GSHV-188, GSHV-184 x GSHV-192, GSHV-184 x G Cot 20, GSHV-192 x GN.Cot 22 and GSHV-188 x G Cot 20 displayed high per se performance, high significant and positive standard heterosis and heterobeltiosis for seed cotton yield and many yield contributing attributes, indicating that these hybrids may be utilized for further breeding programme as they likely to throw a desirable segregants.

Keywords: Heterosis, cotton, seed cotton yield, heterobeltiosis, hybrids

Introduction
Cotton is the most important cash crop in India and popularly known as “White Gold”. It plays a vital role in agricultural, industrial, social and monetary affairs of the country. Cotton is the most important renewable natural textile fibre and sixth largest source of vegetable oil in the world. Despite the advent of a multitude of other fibres, “King Cotton” rules the world of textiles. Cotton contributes to 35% of the global fabric needs and 60% of clothing in India. For decades, India is the leading country in terms of area under cotton in the world. India surpassed the United States in the year 2006 and China in the year 2015 in raw cotton production and lead raw cotton production in the world. In India, cotton is cultivated over an area of 122 lakh hectares with an annual production of 377 lakh bales with average productivity of 524 Kg/ha during 2017-18. Gujarat, Maharashtra and Telangana are the major cotton growing states contributing around 71% (86.4 lakh hectares) of the area and 65% (246 lakh bales) of cotton production in India. Gujarat is the second largest cotton growing state with acreage of 26.18 lakh hectares and largest cotton producing state of India with production of 104.00 lakh bales. The average productivity of cotton in the state is 675 kg lint ha^{-1} which is higher than national productivity Anonymous (2018) [1]. The nature and magnitude of heterosis help in identifying superior crosses for their exploitation to obtain better transgressive segregants. In the commercial explotation of hybrid vigour, excess of F_1 over standard check (hybrid) is of great significance. Hence, the present investigation was undertaken to determine the extent of heterosis over standard check GN.Cot.Hy.-14 for seed cotton yield and its component traits.

Materials and Methods
In the present study, eight genetically diverse parents of *Gossypium hirsutum L. viz.*, GSHV-184, GSHV-188, GSHV-192, GSHV-195, GISV-308, G. Cot 16, G. Cot 20 and GN Cot 22 were crossed in half diallel fashion during *Kharif* 2016-17. The complete set of twenty eight crosses and their eight parents along with standard check GN.Cot.Hy.-14 were evaluated in a randomized block design, replicated thrice at Main Cotton Research Station, Surat, Navsari Agricuctural University, Navsari (Gujarat), India during *Kharif* 2017-18. Each entry was represented by single row plot of 4.5 m length spaced at 1.20 m apart and plant to plant distance was 45 cm. One guard row was planted on both the sides of the experiments. All recommended agronomical practices and plant protection measures were followed as and

when required to raise the best crop condition. Observations were recorded on five randomly selected competitive plants from each genotype per replication. The data were recorded on eight traits *viz.*, plant height (cm), Sympodia per plant, bolls per plant, boll weight (g), ginning percentage (%), seed index (g), lint index (g) and seed cotton yield per plant (g). The heterosis as percentage deviation from the better parent (heterobeltiosis) and the standard check (standard heterosis) for each character was worked out as per the standard procedure given by Fonseca and Patterson (1968) [6].

Results and Discussion

The estimates of heterosis over better parent and standard check for various traits has been presented in Table-1. The degree and direction of heterosis varied enormously for seed cotton yield and its attributing characters. Overall, the magnitudes of heterotic effects were high for lint index, bolls per plant and seed cotton yield per plant; whereas, sympodia per plant exhibited least heterotic values. The quantum of heterobeltiosis and standard heterosis for plant height ranged from -1.05 (GSHV-188 x GISV-308) to 43.17 per cent (GSHV-195 x G Cot 16) and -19.00 (GSHV-184 x GSHV-192) to 23.56 per cent (GSHV-192 x G Cot 20), respectively. Only cross *viz*., GSHV-184 x GSHV-192 (-19.00%) showed significant negative (desirable) standard heterosis. Though sixteen out of twenty eight crosses exhibited significant heterotic effects over better parent, it was in positive direction indicating that hybrids were tall compared to their parents. These finding was in accordance with results obtained by Ghevariya *et al.* (2016) [7] and Arbad *et al.* (2017) [2].

Sympodia per plant is the major component, which is directly reflecting the seed cotton yield. Magnitude of heterobeltiosis and standard heterosis varied from -15.43 (GISV-308 x G Cot 16) to 60.12 (GSHV-192 x G Cot 20) per cent and -17.72 (GISV-308 x G Cot 16) to 11.01 per cent (GSHV-195 x G Cot 16), respectively. The hybrid GSHV-192 x G Cot 20 recorded highest magnitude of heterobeltiosis (60.12%) followed by GSHV-195 x G Cot 16 (48.87%), GSHV-195 x G Cot 20 (44.24%), GSHV-188 x G Cot 16 (44.12%) and GSHV-188 x GSHV-192 (41.66%). None of the cross showed significant and positive standard heterosis for this trait. The present findings were in close association with results reported by Muhammad *et al.* (2014) [9] and Sharma *et al.* (2016) [12].

Bolls per plant is one of the important yield contributing characters which is directly associated with seed cotton yield per plant. For this trait, fourteen crosses exhibited significant heterosis over better parent in positive direction with a range from -29.30 (GISV-308 x G Cot 20) to 76.37 per cent (GSHV-192 x G Cot 20). As regards to standard heterosis, eighteen F_1's exhibited positive and significant to highly significant heterosis with a range from -12.92 (GISV-308 x G Cot 20) to 54.17 per cent (GSHV-192 x G Cot 16). The hybrid, GSHV-192 x G Cot 16 reflected significantly highest positive standard heterosis (54.17%) followed by GSHV-188 x G Cot 20 (48.44%) and GSHV-184 x GSHV-195 (37.20%). Heterosis for this trait was also reported by earlier worker Solanki *et al.* (2014) [13], Chhavikant *et al.* (2017) [5] and Babu *et al.* (2018) [3].

The minimum and maximum heterobeltiosis and standard heterosis for boll weight was from -24.92 (GSHV-188 x GSHV-195) to 34.51 per cent (GSHV-195 x G Cot 16) and -28.26 (GISV-308 x G Cot 16) to 16.86 per cent (GSHV-184 x G Cot 16), correspondingly. Among twenty eight crosses, nine crosses for heterobeltiosis while eight crosses for standard heterosis showed significant performance in desirable direction. As regards to standard heterosis, three promising hybrids in order were GSHV-184 x G Cot 16 (16.86%), GSHV-184 x G Cot 16 (14.58%), GSHV-184 x GSHV-188 (13.93%) and GSHV-188 x GN. Cot 22 (12.95%). The same results assembled by other researchers Nakum *et al.* (2014) [10] and Arbad *et al.* (2017) [2].

Ginning percentage is important parameter from the point of mill owner because it determines the economic returns. In cotton considerable premium attaches to ginning percentage. Hence genotypes with high ginning percentage are desirable. The extent of heterobeltiosis for ginning percentage ranged from -14.06 (GSHV-188 x G Cot 20) to 5.87 per cent (G Cot 20 x GN. Cot 22). None of the cross combination registered significant and positive heterosis over better parent, whereas fifteen hybrids showed economic heterosis in positive direction. The cross combination GISV-308 x GN. Cot 22 recorded maximum economic heterosis (18.27%) followed by crosses GSHV-188 x GN. Cot 22 (17.19%), GSHV-188 x GSHV-195 (16.95%) and G Cot 20 x GN. Cot 22 (16.03%). The results are akin to the findings of Tuteja (2014) [14] and Babu *et al.* (2018) [3].

The hybrids recorded heterosis over better parent for seed index from -18.68 (GSHV-192 x GN. Cot 22) to 34.46 per cent (GSHV-188 x GISV-308). Fourteen and eighteen F_1's exhibited positive and significant heterobeltiosis and standard heterosis, respectively for the trait. The cross combination GSHV-192 x G Cot 20 depicted significantly maximum heterotic effect over standard check (25.69 per cent) which was followed by crosses GSHV-184 x GSHV-195 (24.56%), GSHV-184 x GN. Cot 22 (23.30%) and GSHV-188 x GN. Cot 22 (23.55%). Similar result was reported by Bilwal *et al.* (2018) [4].

Lint index varied from -19.21 (GSHV-192 x G Cot 16) to 42.35 per cent (G Cot 16 x G Cot 20) and 0.70 (GSHV-184 x G Cot 20) to 57.63 per cent (GSHV-188 x GN. Cot 22) for heterobeltiosis and standard heterosis, respectively. Overall, thirteen hybrids exhibited significant and positive heterotic effect over better parent while twenty one hybrids showed significant standard heterosis. Among these, top three promising hybrids for lint index were GSHV-188 x GN. Cot 22 (57.63%), G Cot 20 x GN. Cot 22 (40.71%) and GSHV-188 x GSHV-195 (40.19%). Heterosis for this trait was also reported by earlier worker Lingaraja *et al.* (2017) [8].

The results revealed that fifteen crosses demonstrated significant heterotic effects in positive direction over better parent with a range from -29.69 (GISV-308 x G Cot 16) to 74.70 per cent (GSHV-195 x G Cot 20). The top most heterotic crosses were GSHV-195 x G Cot 20 (74.70%), G Cot 16 x G Cot 20 (63.51%) and GSHV-195 x G Cot 16 (55.68%). The spectrum of variation for standard heterosis ranged from -22.33 (GISV-308 x G Cot 16) to 45.53 per cent (GSHV-184 x GSHV-188). Total ten hybrids exhibited significant positive heterosis over the standard check. The most heterotic hybrids in order were GSHV-184 x GSHV-188 (45.53%), GSHV-184 x GSHV-192 (37.40%), GSHV-184 x G Cot 20 (35.30%), GSHV-192 x GN. Cot 22 (33.20%) and GSHV-188 x G Cot 20 (27.12%). Significant heterotic variation for seed cotton yield has been also reported by22 (23.30%) and GSHV-188 x GN. Cot 22 (23.55%). Similar result was reported by Bilwal *et al.* (2018) [4] and Rathava *et al.* (2018) [11].

The *per se* performance of top five crosses which showed significant standard heterosis over standard check GN.Cot.Hy.-14 along with better parent heterosis for seed cotton yield and the yield attributing traits which registered significant and desirable standard heterosis for the particular cross is summarized in Table 3.

It was noted that the top ranking crosses based on *per se* performance coincide with standard heterosis (Table 3). Whereas ranking based on better parent heterosis and *per se* performance varied slightly. This indicated that ranking based on standard heterosis is more reliable as compared to better parent heterosis. On the basis of table 3, cross GSHV-184 x GSHV-192 observed most heterotic for more number of characters. The crosses, which showed significant and positive standard heterosis for seed cotton yield, also manifested significant standard heterosis in desired direction for one or more yield attributing characters. As regards to yield components, twenty one hybrids for lint index, eighteen hybrids each for bolls per plant and seed index, fifteen crosses for ginning percentage, while eight crosses for boll weight exhibited significant positive heterosis over standard check. It is therefore, suggested that, for getting economic heterosis for seed cotton yield from F_1 hybrids, parents which can compensate each other for main yield components especially the component traits *viz.*, bolls per plant, boll weight, seed index, lint index and ginning percentage should be involved. The hybrids *viz.*, GSHV-184 x GSHV-188, GSHV-184 x GSHV-192, GSHV-184 x G Cot 20, GSHV-192 x GN. Cot 22 and GSHV-188 x G Cot 20 exhibited high *per se* performance, higher desired directional heterobeltiosis and standard heterosis for seed cotton yield and many yield contributing attributes, indicating that these hybrids may be utilized for further breeding programme as they likely to throw a desirable segregants.

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

Sr. No.	Name of the crosses	Plant height (cm)		Sympodia per plant		Bolls per plant		Boll weight (g)	
		BP	SC	BP	SC	BP	SC	BP	SC
1	GSHV-184 x GSHV-188	19.27**	-6.09	2.69	-13.42*	23.66**	27.59**	8.28*	13.93**
2	GSHV-184 x GSHV-192	2.88	-19.00**	21.82**	2.71	26.20**	30.21**	11.68**	5.86
3	GSHV-184 x GSHV-195	30.78**	2.97	11.36	-6.11	32.98**	37.20**	-4.87	-17.26**
4	GSHV-184 x GISV-308	26.45**	-0.44	-1.07	-3.75	1.84	25.45**	-1.54	-11.48**
5	GSHV-184 x G Cot 16	22.04**	-3.91	14.63	-3.35	5.69	9.05	34.36**	16.86**
6	GSHV-184 x G Cot 20	30.19**	2.51	7.11	-9.69	20.39**	24.22**	14.69**	8.71*
7	GSHV-184 x GN. Cot 22	23.34**	-2.89	4.71	0.23	13.67*	32.26**	4.59	-9.04*
8	GSHV-188 x GSHV-192	24.03**	15.62**	41.66**	-1.90	19.22*	7.57	-7.97**	-3.18
9	GSHV-188 x GSHV-195	12.32	-2.02	29.10**	-3.73	18.97*	7.34	-24.92**	-21.01**
10	GSHV-188 x GISV-308	-1.05	-1.12	0.48	-2.24	-29.13**	-12.71	-7.66	-2.85
11	GSHV-188 x G Cot 16	13.15	-2.98	44.12**	0.30	41.46**	27.64**	-22.29**	-18.24**
12	GSHV-188 x G Cot 20	2.80	-2.99	37.92**	-4.49	64.52**	48.44**	-18.89**	-14.66**
13	GSHV-188 x GN. Cot 22	2.28	-2.56	11.84	7.06	-15.22*	-1.35	7.35	12.95**
14	GSHV-192 x GSHV-195	19.61**	4.34	26.78**	-5.46	45.27**	27.08**	6.10	0.57
15	GSHV-192 x GISV-308	25.09**	16.61**	8.75	5.81	5.20	29.58**	-19.07**	-23.29**
16	GSHV-192 x G Cot 16	17.54*	0.78	37.60**	-4.23	71.58**	54.17**	-14.26**	-18.73**
17	GSHV-192 x G Cot 20	32.55**	23.56**	60.12**	9.44	76.37**	34.17**	-12.11**	-16.69**
18	GSHV-192 x GN. Cot 22	3.91	-3.14	15.62*	10.67	1.40	17.98*	17.53**	11.40**
19	GSHV-195 x GISV-308	34.87**	17.65**	-1.78	-4.44	-10.54	10.20	8.33	-2.61
20	GSHV-195 x G Cot 16	43.17**	22.76**	48.87**	11.01	8.44	-2.56	34.51**	14.58**
21	GSHV-195 x G Cot 20	22.16**	6.57	44.24**	7.57	50.92**	32.03**	0.09	-5.13
22	GSHV-195 x GN. Cot 22	10.79	-3.35	9.28	4.60	0.61	17.06*	3.11	-10.83*
23	GISV-308 x G Cot 16	6.67	-8.54	-15.43*	-17.72**	-10.47	10.28	-20.20**	-28.26**
24	GISV-308 x G Cot 20	13.69*	7.29	0.81	-1.92	-29.30**	-12.92	6.01	0.49
25	GISV-308 x GN. Cot 22	8.18	3.05	12.15	9.12	2.61	26.39**	10.42*	-0.73
26	G Cot 16 x G Cot 20	12.05	-3.92	42.65**	-0.72	49.18**	34.05**	-7.30	-12.13
27	G Cot 16 x GN. Cot 22	25.89**	7.94	1.11	-3.22	-11.19	3.33	28.72**	11.32**
28	G Cot 20 x GN. Cot 22	0.37	-5.27	-4.64	-8.72	-0.29	16.02*	14.78**	8.79*
	S.E.(d) ±	7.249	7.249	0.932	0.932	2.193	2.193	0.169	0.169
	CD @ 5%	14.873	14.873	1.858	1.858	4.375	4.375	0.337	0.337
	CD @ 1%	19.194	19.194	2.467	2.467	5.808	5.808	0.448	0.448

*, ** Significant at 5 and 1 per cent probability levels, respectively.

Table 2: Estimates of heterosis over better parent (BP) and standard check (SC) for various characters in upland cotton

Sr. No.	Name of the crosses	Ginning percentage (%)		Seed index (g)		Lint index (g)		Seed cotton yield per plant (g)	
		BP	SC	BP	SC	BP	SC	BP	SC
1	GSHV-184 x GSHV-188	-13.18**	5.20	8.37*	20.65**	21.96**	30.25**	52.11**	45.53**
2	GSHV-184 x GSHV-192	-8.18*	-0.89	2.64	17.63**	-9.57	16.13*	54.78**	37.40**
3	GSHV-184 x GSHV-195	-9.15**	2.28	11.88**	24.56**	17.21**	28.86**	28.38*	13.96
4	GSHV-184 x GISV-308	-13.63**	0.98	2.04	13.60**	4.42	15.26*	0.54	11.07
5	GSHV-184 x G Cot 16	0.82	1.54	4.64	16.50**	18.35*	19.18**	43.02**	26.96**
6	GSHV-184 x G Cot 20	-10.09**	-5.41	-1.92	9.19*	0.00	0.70	52.41**	35.30**
7	GSHV-184 x GN. Cot 22	-4.55	4.61	10.97**	23.55**	15.09*	32.35**	21.68*	20.60*
8	GSHV-188 x GSHV-192	-12.16**	6.43	-13.19**	-0.50	-14.87**	9.33	8.91	4.20
9	GSHV-188 x GSHV-195	-3.48	16.95**	20.22**	10.08**	27.52**	40.19**	-11.74	-15.56
10	GSHV-188 x GISV-308	-7.44*	12.15**	34.46**	16.62**	26.15**	39.23**	-23.23*	-15.19
11	GSHV-188 x G Cot 16	-10.43**	8.52*	14.02**	8.56*	15.27*	23.10**	9.22	4.49

12	GSHV-188 x G Cot 20	-14.06**	4.12	12.11**	-0.88	-1.63	5.06	32.87**	27.12**
13	GSHV-188 x GN. Cot 22	-3.27	17.19**	23.46**	23.30**	37.07**	57.63**	13.06	12.06
14	GSHV-192 x GSHV-195	-3.61	8.52*	-5.16	8.69*	-3.87	23.45**	51.85**	9.58
15	GSHV-192 x GISV-308	-7.55*	8.09*	5.71	21.16**	6.25	36.44**	-9.82	-0.37
16	GSHV-192 x G Cot 16	-1.99	5.78	-16.92**	-4.79	-19.21**	3.75	48.74**	4.13
17	GSHV-192 x G Cot 20	-1.03	6.83	9.67**	25.69**	8.49	39.32**	45.21**	4.35
18	GSHV-192 x GN. Cot 22	-0.31	9.26*	-18.68**	-6.80	-17.04**	6.54	34.39**	33.20**
19	GSHV-195 x GISV-308	-5.13	10.92**	9.35*	0.13	6.56	17.61*	-2.73	7.45
20	GSHV-195 x G Cot 16	-4.78	7.20	25.53**	19.52**	20.94**	32.96**	55.68**	12.35
21	GSHV-195 x G Cot 20	-1.89	10.46**	13.20**	3.65	9.60	20.49**	74.70**	26.07*
22	GSHV-195 x GN. Cot 22	0.90	13.60**	-11.85**	-11.96**	-6.52	7.50	8.15	7.19
23	GISV-308 x G Cot 16	-10.37**	4.80	5.95	0.88	-1.82	8.37	-29.69**	-22.33*
24	GISV-308 x G Cot 20	-3.37	12.98**	25.93**	11.34**	21.56**	34.18**	-20.97*	-12.69
25	GISV-308 x GN. Cot 22	1.16	18.27**	5.55	5.42	18.95**	36.79**	14.99	27.02**
26	G Cot 16 x G Cot 20	3.63	9.01*	26.32**	20.28**	42.35**	37.14**	63.51**	17.50
27	G Cot 16 x GN. Cot 22	-0.98	8.52*	2.02	1.89	0.53	15.61*	15.48	14.46
28	G Cot 20 x GN. Cot 22	5.87	16.03**	11.98**	11.84**	22.37**	40.71**	27.30**	26.18*
	S.E.(d) ±	1.225	1.225	0.287	0.287	0.270	0.270	12.799	12.799
	CD @ 5%	2.443	2.443	0.572	0.572	0.538	0.538	25.527	25.527
	CD @ 1%	3.244	3.244	0.760	0.760	0.714	0.714	33.890	33.890

*, ** Significant at 5 and 1 per cent probability levels, respectively.

Table 3: Best heterotic crosses and their performance for seed cotton yield and related traits in upland cotton

Sr. No.	Crosses	Seed cotton yield (g/plant)	Better parent heterosis (%)	Standard heterosis (%)	Significant and desirable standard heterosis in other traits
1	GSHV-184 x GSHV-188	188.00	52.11**	45.53**	Bolls per plant. Boll weight, Seed index and Lint index
2	GSHV-184 x GSHV-192	177.50	54.78**	37.40**	Plant height, Bolls per plant, Seed index and Lint index
3	GSHV-184 x G Cot 20	174.78	52.41**	35.30**	Bolls per plant, Boll weight, Seed index
4	GSHV-192 x GN. Cot 22	172.07	34.39**	33.20**	Bolls per plant, Boll weight, Ginning percentage
5	GSHV-188 x G Cot 20	164.22	32.87**	27.12*	Bolls per plant

*, ** Significant at 5 and 1 per cent probability levels, respectively.

It was further observed that the most heterotic hybrids as well as the top performing hybrids for seed cotton yield per plant and its components essentially involved one either good or average best performing parent for the respective trait. This may be due to fact that good yielding parents have different constellations of gene showing complementary interaction when brought together in hybrids based on mean value rather than extent heterosis. Thus it could be concluded that *per se* performance could be profitably utilized as an effective primary test for evaluating potentiality of parents.

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