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Heterosis for seed cotton yield and yield contributing traits cotton (*Gossypium hirsutum* L.)

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Abstract
Estimation of heterosis is very important to spot out the promising hybrid combinations for commercial exploitation of heterosis and to identify the best segregants to develop varieties. The objective of this study was to estimate the heterosis of all types i.e. mid parantal heterosis, heterobeltoisis and standard heterosis for yield contributing parameters. Nine genotypes and 20 F_1 hybrids developed by crossing the parental genotypes in L x T design were sown in a randomized complete block design along with RCH 659 as standard check. It was observed that the line × tester interactions made greater contribution to the total variance for yield and its attributes. Proportional contribution of lines to total variance was very low for all the traits, while testers also followed similar pattern and contributed a minimum to the total variance. However, maximum variance was extended by line x tester interaction for all the yield contributing traits studied. Out of 20 hybrids, the cross combinations namely, TCH1716 × L 765, TCH1716 × L 766, GSHV179 × L 765 and F 2453 × L 766 were accompanied by significant and positive heterosis for number of bolls per plant, boll weight, number of sympodia per plant and lint index besides seed cotton yield per plant. It indicated larger scope for heterosis breeding for commercial exploitation of heterosis. The crosses that shown desirable heterosis over standard check can be advanced for isolation of improved lines for different yield contributing traits.

Keywords: Cotton, heterosis, heterobeltiosis, standard heterosis, yield contributing traits

Introduction
Cotton is an important commercial cash crop in the country, being the principal raw material for textile industry and popularly known as the "White Gold". Cotton grown in more than 100 countries in the world in which India occupies the foremost position in cotton acreage and production as well. Cotton plays a key role in the national economy in terms of generation of direct and indirect employment of about more than 60 million people in the agricultural and industrial sectors of cotton production and processing, textile and related exports which accounts for nearly 16 per cent of India’s export earnings. It is grown in nearly 11.5 million hectares which is almost 34.6 per cent of the world cotton acreage with a total production and productivity of 35.1 million bales and 568 kg/ha (AICCIP Annual Report, 2018-19).
Cotton is one of the few often cross pollinated crop which is accessible to development of homozygous genotypes as varieties and at the same time amenable for commercial exploitation of heterosis by exploitation of additive as well as non-additive genetic variance. Hybrids have occupied nearly 90% area of cotton cultivated in India. There is a continuous need to develop more potential hybrids and adopt novel approaches for improving hybrid performance.
Estimation of heterosis guides the breeder to identify the superior crosses that are likely to throw transgressive segregants (Singh *et al*., 1982) [19]. The directions and magnitude of heterosis and type of gene action determines the further scope of exploitation. The measures of heterosis over better parent (heterobeltiosis) and over standard check (standard heterosis) are better rational parameters for assessing its practical utility. It is not possible to manipulate and enhance the degree of dominance and at best we may choose such population, which are differing for the allelic status of such yield influencing loci. If such populations are identified, which are diverse from each other, it means the plants belonging to the diverse populations in general differ for the allelic status of yield influencing loci (Falconer, 1981) [2].
The degree of economic heterosis should be considered superior, if any of the F_1 hybrids performs better than the best commercial variety released for cultivation. Hence, the present

investigation was taken up to identify promising hybrid combination with superior seed cotton yield for commercial exploitation as a hybrid.

Material and Methods

The present study of estimation of heterosis of *G. hirsutum* L. genotypes and F_1 hybrids of cotton was carried out at RARS, Lam, Guntur, ANGRAU during 2017-18 and 2018-19. Out of nine genotypes chosen for the study, four were designated as lines (Females) and five as testers (Males). During *kharif*, 2017-18, the parents (four lines and five testers) were sown in a crossing block at a spacing of 105 x 60 cm. Hybridization was effected in a line x tester (4 x 5) design to produce 20 hybrid combinations. Hybridization was carried out following hand emasculation and pollination method. Crossing was taken up one week after flower initiation. Flower buds, likely to open the next day were chosen for emasculation and anthers of selected buds were removed gently with the help of nail and covered with red colored straw tube to prevent natural out crossing. Emasculation was carried out between 3 and 6 P.M.

The emasculated buds were pollinated on next day with pollen of male parent between 9 and 11 A.M. Four to five flower buds of female parent were pollinated by one flower of male parent. After pollination, the staminal column was covered with white colored straw tube for prevention of cross pollination with undesirable pollen. A label with details of the cross was also tied on the pedicel for identification at harvest. The white colored straw tubes were removed after completion of fertilization *i.e*., four days after pollination. Sufficient care was taken to ensure nicking of parents and all recommended practices were adopted to obtain sufficient number of crossed bolls for each cross combination.

During 2018-19, the nine parents and 20 hybrids were sown in four rows measuring six meters in a RCB design with two replications along with parents and standard hybrid check RCH 659. The row and plant spacings adopted were 105 and 60 cm, respectively. Recommended cultural practices were carried out and the crop was grown under uniform field condition to minimize environmental variations to the maximum possible extent. The data were recorded from 10 plants /entry / replication for the traits *viz.,* Seed cotton yield (kg/ha) (SCY), lint yield (kg/ha), number of bolls per plant, boll weight (g), ginning out turn (%) (GOT), seed index (g), lint index (g), plant height (cm) (PH), number of monopodia per plant, number of sympodia per plant, days to 50 per cent flowering (DFF). Forty well developed open bolls were randomly hand harvested from each row of parents and F_1's. The bulked bolls from each genotype were ginned. The L x T analysis of heterosis was performed as suggested by Kempthrone (1957) [9]. Heterosis was calculated in terms of percent increase (+) or decrease (-) of the F_1 hybrids against its mid parent, better parent and standard parent value as suggested by Fehr (1987) [3].

Results and discussion

Estimation of heterotic effects is necessary to identify the new cross combinations that are suitable for direct exploitation. Presence of sizeable magnitude of heterosis is very crucial for its exploitation in crop improvement programmes. Amount of heterosis in F_1 is an indication of genetic diversity among the parents involved in crosses. Heterosis breeding has led to considerable yield improvements in a most of the cross as well as self-pollinated crops.

Significant differences were detected among parents and F_1 hybrids for all the yield contributing traits studied indicating the presence of sufficient genetic variability among them (Table 1). The proportional contributions of lines and testers and their interactions (Line × Tester) to the total variance were varied among the investigated characters. Results revealed that line × tester interactions made greater contribution to the total variance for all the yield contributing traits studied. Proportional contribution of lines to total variance was very low for all the traits, while testers also followed similar pattern and contributed a minimum to the total variance. However, maximum variance was extended by line x tester interaction for all the traits studied.

Mean performance is an important selection criterion as it reveals their real value of the parents or hybrids. Shimna and Ravikesavan (2008) [18] suggested that the *per se* performance of hybrids appeared to be an useful index in judging them and Gilbert (1958) [5] reported that parents with good *per se* performance would result in good hybrids. Parents and hybrids showing high mean performance with positive significance were considered for all the traits except days to first flowering, plant height and number of monopodial branches per plant for which negatively significant mean values were taken into consideration. The mean performance and heterosis among 20 hybrids are presented in Table 2 and 3.

Earliness and dwarf stature of the crop are most preferred in cotton also as desired in most of the crops. Therefore, earlier flowering and short plants were taken into consideration. Among the 20 hybrids, BGDS 1033× HYPS 152 was the earliest to flower with a mean of 56.5 days followed by BGDS 1033 × L 766 (57.0) and F 2453 × GISV 164(57.5) and the hybrid GSHV179 × HYPS 152 found to be very late (64.0). The same hybrid BGDS 1033 × GISV 164 showed lowest negative heterosis, while the highest standard heterosis was observed by F 2453× HYPS 152 (13.91%). The hybrid combination F 2453 × L 765 (95.3cm) was the shortest among the tested hybrids followed by TCH1716 × GISV 164 with a mean plant height of 95.8cm. However, the hybrid TCH1716 × L 765 was the tallest (172.6cm).The hybrids TCH1716 × GISV 164 and F 2453 × L 765were found to express all the three types of heterosis in the desired direction

Monopodial branches are the vegetative branches and large number of monopodia makes the plant look bushy, occupies more space and usually results in a slow rate of boll formation when compared to sympodial branches or fruiting branches. Hence, plants having lesser monopodial branches were taken into consideration while exercising selections. The hybrids GSHV179 × L 765 (0.7) and F 2453 × L 766 (0.8) showed lower number of monopods, while the highest number of 2.3 monopodia were recorded by the hybrid combinations TCH1716 × L 766, F 2453 × L 765 and F 2453 × GJHV 516. The hybrids GSHV179 × L 765, GSHV179 × GISV 164 and BGDS 1033 × GISV 164expressed significant relative heterosis, heterobeltoisis and standard hererosis in the desired negative direction. The cross combination GSHV179 × L 765 exhibited a highest mean of 20.2 sympodial branches while the lowest number was recorded by TCH1716 × GJHV 516 (11.8). Significant positive heterosis of all the types was expressed by the hybrids *viz.*, TCH1716 × L 765, TCH1716 × L 766 and GSHV179 × L 765. High heterosis for sympodia per plant was also reported by Nirania *et al*. (2005) [12] and Tuteja *et al*. (2013) [22].

In cotton, the number of bolls per plant and boll weight are the important yield attributing traits which are positively associated with single plant yield. Yield in cotton is one of the most important economic characters and is the final product of multiplicative interaction of its contributing traits. Number of bolls per plant was highest in TCH1716 × L 766 (76.5) followed by GSHV179 × L 765 (71.2), while the lowest number of bolls were recorded by GSHV179 × HYPS 152 (35.9). Estimate of heterosis for number of bolls per plant over standard check varied between -35.8 (GSHV179 × HYPS 152) and 37.23 (TCH1716 × L 766) per cent. Out of 20 hybrids tested, only one hybrid TCH1716 × L 766 was found to express positive and significant standard heterosis for boll number. This indicated that increase in boll number also contributes for increase in seed cotton yield. Improvement in above yield attributes/characters by exploitation of heterosis in cotton showed considerable scope for increasing yield. The result assemble with the worker Tuteja *et al*. (2011) [20], Tuteja *et al*. (2013) [22] and Tuteja (2014) [21].

Seed cotton yield is also directly proportional to boll weight hence these trait important for contribution. Among the tested hybrids bigger bolls were observed in TCH1716 × L 766 (5.40 g) followed by TCH1716 × L 765 (5.05g). However, the lowest boll weight was recorded by the hybrid BGDS 1033 × GJHV 516 (3.80g). The heterosis for boll weight was found in positive direction in 8 out of 36 cross-combinations. The highest estimate of significant and positive standard heterosis for boll weight was exhibited by hybrid TCH1716 × L 766 (36.71%) followed by TCH1716 × L 765, GSHV179 × L 765 (27.85%) 2 (22.78) and BGDS 1033× HYPS 152 (21.52%). However the lowest standard heterosis was expressed by BGDS 1033 × GJHV 516 (-3.8%). Jain (1996) [6] and Kumar *et al*. (2003) [10] have reported similar findings for this traits in *G. hirsutum* L.

The extent of lint index was the highest in hybrid GSHV179 × L 765 (6.70)followed by TCH1716 × L 766 (6.65) and F 2453 × GJHV 516 (6.25), while the lowest lint index was shown by GSHV179 × HYPS 152 (4.05). The hybrid combination TCH1716× HYPS 152 showed significant relative heterosis and standard heterosis in the desired direction but could not express heterobeltoisis. Similarly, the seed index stretched between 7.6 (GSHV179 × HYPS 152) and 11.0 (TCH1716× HYPS 152). Out of 20 hybrids, F 2453 × L 765 and GSHV179 × GJHV 516 expressed highest GOT of 38.8%, while the least GOT was recorded by TCH1716× HYPS 152(31.8%). The hybrids *viz*., TCH1716 × L 766, GSHV179 × L 765 and F 2453 × GJHV 516 showed significant standard heterosis in the desired direction. F 2453 × L 766. Pole *et al*. (2008) [15] and Jyotiba *et al*. (2010) [7] also reported high heterosis for seed index.

Significant positive relative heterosis for ginning out turn was shown by TCH1716 × L 766, GSHV179 × GJHV 516, BGDS 1033 × L 766 and F 2453 × L 766. However, none of the hybrids could express sigficant heterobeltoisis and standard heterosis. Preetha and Raveendaran (2008) [16], Patel *et al*. (2009) [13] and Geddam *et al*. (2011) [4] also reported varying magnitude of heterosis for this character.

The highest seed cotton yield and lint yield was noticed in TCH1716× HYPS 152as 3078 kg/ha and 1173 kg/ha, respectively, while the lowest seed cotton yield was recorded by F 2453 × L 765 (1905 kg/ha). Out of 20 hybrids, five hybrids expressed significant positive heterosis over mid parent. The range of heterobeltosis was from –21.44 (F 2453 × GJHV 516) to 41.0 (TCH1716 × L 766) per cent, However, standard heterosis ranged between –27.84 (GSHV179 × L 766) to 16.8 (TCH1716 × L 766) per cent with a mean of -4.80 per cent. Only four cross combinations expressed positive non significant standard heterosis and 16 hybrids revealed negative heterosis over commercial check. Presence of heterosis over mid parent and commercial check was reported by Similar results were also reported by Amalabalu *et al*. (2012) [1], Kumar *et al*. (2013) [11], Patel *et al*. (2012), Tuteja *et al*. (2013) [22] and Tuteja (2014) [21].

It was revealed that positive heterosis for seed cotton yield per plant in four crosses were not accompanied by single unique trait. High significant and positive heterosis for seed cotton yield per plant in crosses TCH1716 × L 765, TCH1716 × L 766, GSHV179 × L 765 and F 2453 × L 766 were accompanied by significant and positive heterosis for number of bolls per plant, boll weight, number of sympodia per plant and lint index. This indicated that in different crosses, the pathway for realizing heterotic effect varied from cross to cross. This results revealed that number of sympodia per plant, number of bolls per plant, boll weight and lint yield per plant were the main contributors toward increased in heterotic effects for seed cotton yield per plant. While ginning percentage, seed index and lint yield per plant were secondary contributors toward increased heterotic effects for seed cotton yield per plant in specific cross combinations only. Similar findings have been reported by Jyotiba *et al*. (2010) [7], Kaushik and Shastry (2011) [8] and Patil *et al*. (2011) [14].

Based on data of standard heterosis, it can be concluded that, three cross combinations namely TCH1716 × L 765 and TCH1716 × L 766 appeared to be the most heterotic crosses for seed cotton yield per plant to exploit heterosis in cotton. The present study revealed of considerable amount of heterosis for seed cotton yield per plant in cotton. It indicates larger scope for heterosis breeding for commercial exploitation of heterosis. The crosses showing desirable heterosis over standard check can be advanced for isolation of improved lines for different yield contributing traits.

Table 1: Analysis of variance (mean squares) for combining ability for yield, yield components and quality parameters in cotton

Source of variation	DF	DFF	PH (cm)	No. of monopods	No. of Sympodia	No. of Bolls/Plant	Boll wt (g)	Lint Index (g)	Seed index(g)	GOT (%)	SCY (Kg/ha)	Lint yield (Kg/ha)	UHML (mm)	ML (mm)	UI (%)	Mic (ug/inch)	Bundle strength (g tex)	E (%)
Replications	1	0.27	177.25	0.12	2.16	0.01	0.62*	0.3	0.58	8.55	4027.3	7473.2	10.09	20.52**	11963.6**	0.00017	18.77*	7.96**
Treatments	2.8	9.59**	779.66**	0.51**	7.04**	135.73**	0.36**	0.87**	1.43	10.22*	226740.9**	40968.2**	8.83**	8.91**	912.95	0.206**	7.2*	0.32
Parents	8	7.37**	153.68	0.59**	0.66	54.05	0.23*	0.92**	0.41	12.33*	150653.2*	33041.9*	12.99**	13.5**	2.12	0.278**	6.17	0.13
Parents *vs* Crosses	1	13.04*	2568.37**	0.06	6.02	188.73*	1.98**	1.02	1.12	37.56**	1100797**	254300.1**	11.88*	20.22**	25511.72**	0.42**	3.93*	0.98
Crosses	19	10.34**	949.09**	0.5**	9.78**	167.34**	0.32**	0.84**	1.87	7.89	212774.9**	33077.6**	6.92**	6.39**	1.78	0.16**	7.8	0.36
Lines	3	27.75*	1044.9	0.44	14.13	213.77	0.57	0.19	3.64	12.37	455755.3	28916.4	11.46	9.99	1.73	0.21	11.42	0.53
Testers	4	8.27	1017.64	0.488	13.3	275.3	0.37	0.73	0.57	13.22	132348.5	3769.57	8.42	7.7	1.75	0.28	14.56	0.43
Lines x	12	6.67*	902.27*	0.527**	7.51**	119.74**	0.24**	1.04**	1.86**	5	178838.	32580*	5.29	5.05*	1.81	0.11**	4.65	0.3

Testers		*	*								6*			*				
Error	28	1.88	251.4	0.056	1.75	35.21	0.1	0.27	0.82	4.16	63765.36	10931.2	2.57	1.16	944.56	0.03	3.66	0.83
Total	57	5.64	509.6	0.28	4.36	83.97	0.24	0.56	1.11	7.22	142775.5	25625.6	5.78	5.31	1122.35	0.119	5.67	0.71
σ2 GCA		1.79	86.65	0.045	1.329	23.25	0.041	0.057	0.143	0.959	25587.3	2485.8	0.8188	0.853	-104.75	0.0239	1.036	-0.038
σ2 SCA		2.39	325.4	0.235	2.881	42.26	0.070	0.021	0.520	0.419	57536.6	10824.3	1.359	1.942	-471.4	0.037	0.492	-0.264
σ2 GCA/σ2 SCA		0.749	0.266	0.1914	0.4619	0.552	0.5871	0.275	0.295	2.289	0.448	0.0079	0.6025	0.439	-0.2222	0.6128	0.0210	-0.1445

Table 2: Estimates of Mean performance and heterosis for 20 F_1 hybrids for yield and its contributing parameters in cotton (*Gossypium hirsutum* L.)

S. No	Cross combination	DFF	PH (cm)	No. of monopods	No. of Sympodia	No. of Bolls/Plant	Boll wt (g)	Lint Index (g)	Seed index (g)	GOT (%)	SCY (Kg/ha)	Lint yield (Kg/ha)
1	TCH1716 × L 765	60.5	172.6	1.1	19.1	65.7	5.05	5	8.35	37.7	2918.3	1096.3
2	TCH1716 × GJHV 516	58.0	121.0	1.8	11.8	53.85	4.4	5.25	9.5	35.8	2460.3	879.3
3	TCH1716 × GISV 164	58.5	95.8	1.6	15.0	52.6	4.65	5.15	10.85	32.25	2654	855.1
4	TCH1716 × L 766	58.5	171.6	2.3	18.0	76.85	5.4	6.65	10.8	38.15	3078	1173
5	TCH1716× HYPS 152	58.0	141.0	1.3	16.2	49.5	4.65	5.95	11	31.85	2563	814.9
6	GSHV179 × L 765	59.5	168.8	0.7	20.2	71.25	5.05	6.7	8.55	37.5	3028	1136.2
7	GSHV179 × GJHV 516	61.5	127.5	1.7	13.8	51.1	4.05	5.6	8.95	38.55	2132	824.4
8	GSHV179 × GISV 164	59.5	115.1	1.1	14.1	47.5	4.6	5.8	9.2	38.75	2633	1019.6
9	GSHV179 × L 766	60.5	111.9	1.4	13.6	48.5	4.2	5.65	9.4	37.65	1899	713.7
10	GSHV179 × HYPS 152	64.0	122.0	1.1	12.5	35.95	4	4.05	7.6	34.8	2292	735
11	BGDS 1033 × L 765	58.0	121.0	1.5	13.5	53.6	4.8	5.4	9.3	36.8	2495	919.5
12	BGDS 1033 × GJHV 516	58.0	116.5	1.4	13.1	48.1	3.8	4.5	8.55	34.7	2275	791.7
13	BGDS 1033 × GISV 164	58.0	109.4	1.0	13.2	46.6	4.1	5.5	9.35	37.4	2317	871.3
14	BGDS 1033 × L 766	57.0	123.2	2.2	12.7	52.35	4.2	5.95	8.3	38.3	2571	989.3
15	BGDS 1033× HYPS 152	56.5	119.6	1.3	13.5	49.6	4.5	5.1	9.1	35.9	2499	787.1
16	F 2453 × L 765	61.0	95.3	2.3	13.4	49.8	4.4	5.6	8.85	38.8	1905	738.9
17	F 2453 × GJHV 516	60.5	128.4	2.3	13.4	44.3	4.85	6.25	10.55	37.25	2199	787.1
18	F 2453 × GISV 164	57.5	119.5	1.5	14.4	54	4.2	4.85	7.85	37.9	2206	835.8
19	F 2453 × L 766	59.0	129.4	0.8	14.4	53.7	4.6	5.4	8.95	37.6	2547	958.1
20	F 2453× HYPS 152	65.5	128.0	1.2	14.5	50.8	4.5	5.5	9.75	32.6	2325	840.3

Table 3: Superior crosses with per se performance and heterosis for seed cotton and its contributing traits in cotton

Character	Superior cross	Per se Performance	MP (%)	BP (%)	SC (%)
Seed cotton yield (kg/ha)	TCH1716 × L 765	2918.3	31.44**	20.36	10.84
	TCH1716 × L 766	3078.0	46.60**	41.00**	16.88
	GSHV179 × L 765	3028.0	34.94**	24.89*	15.01
	F 2453 × L 766	2549.0	29.91*	16.88	-3.28
Lint yield (kg/ha)	TCH1716 × L 765	1096.3	39.47**	23.67	16.32
	TCH1716 × GJHV 516	879.3	39.16*	28.24	-6.71
	TCH1716 × L 766	1173.0	70.15**	69.17**	24.50*
	F 2453 × L 766	958.1	49.56**	38.12*	1.65
	GSHV179 × L 765	1136.2	36.07**	28.17*	20.55
GOT (%)	TCH1716 × L 766	38.1	16.05**	12.21	6.42
	GSHV179 × GJHV 516	38.5	11.18*	1.58	7.53
	BGDS 1033 × L 766	38.3	11.10*	2.96	6.83
	F 2453 × L 766	37.6	12.81*	7.57	5.02
Seed index (g)	TCH1716× HYPS 152	11.0	17.96*	10.0	20.88*
Lint Index (g)	TCH1716 × L 766	6.65	39.27**	29.13**	31.68**
	GSHV179 × L 765	6.70	9.84	9.84	32.67**
	F 2453 × GJHV 516	6.25	28.87**	21.36*	23.76*
Boll wt (g)	TCH1716 × L 765	5.05	19.53**	6.32	27.85**
	TCH1716 × L 766	5.40	41.18**	36.71**	36.71**
	GSHV179 × L 765	5.05	16.76*	6.32	27.85**
	F 2453 × L 765	4.40	-1.12	-7.37	22.78*
No.of boll/plant	TCH1716 × L 765	65.7	34.98**	25.86*	17.32
	TCH1716 × L 766	76.85	42.45**	37.97**	37.23**
	GSHV179 × L 765	71.25	63.14**	57.81***	27.23*
No. of Sympodia/Plant	TCH1716 × L 765	19.1	37.16**	36.43**	37.41**
	TCH1716 × L 766	18.0	29.03**	29.50**	29.50**
	GSHV179 × L 765	20.2	46.38**	45.85**	45.32**
No.of Monopods/plant	GSHV179 × GISV 164	1.1	-38.03**	-46.34**	-38.89
	BGDS 1033 × GISV 164	1.0	-35.48*	-37.5*	-44.44
	BGDS 1033× HYPS 152	1.3	88.33**	-44.44**	-27.78*
	GSHV179 × HYPS 152	1.1	-22.81	-46.34**	-38.89**

Plant Height(cm)	TCH1716 × GISV 164	95.8	-15.45	-16.62	-22.55
	GSHV179 × L 765	168.8	66.6**	46.95**	36.50*
	TCH1716 × L 765	172.6	54.08**	50.26**	39.57**
DFF	BGDS 1033 × L 766	57.0	-3.8	-1.61	0.87
	GSHV179 × GJHV 516	61.5	2.07	0	6.96**
	F 2453 × L 765	61.0	0.83	-7.26**	6.09*
	F 2453× HYPS 152	65.5	3.97*	2.34	13.49**

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