Journal of Pharmacognosy and Phytochemistry

Available online at www.phytojournal.com

E-ISSN: 2278-4136
P-ISSN: 2349-8234
JPP 2019; 8(2): 2049-2053
Received: 26-01-2019
Accepted: 27-02-2019

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Heterosis studies for seed cotton yield and its components over environments in cotton

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Abstract
An investigation was carried out using ten lines and five testers in a line x tester mating design to estimate the nature and magnitude of heterosis for seed cotton yield and its components in cotton. The resulting 65 genotypes including parents along with a check hybrid (G-Cot.Hy-12) were evaluated in a Randomized Block Design with three replications under three dates of sowing (environments) i.e. E_1 = Onset of monsoon, E_2 = 20 days after 1st sowing and E_3 =20 days after 2nd sowing. The pooled analysis of variance for the experimental design revealed significant differences among the genotypes, parents, hybrids and parents vs hybrids for all the characters. Remarkable levels of heterosis and heterobeltiosis were observed for seed cotton yield per plant and most of the characters studied. The heterobeltiosis and standard heterosis ranged from -37.93 to 44.44% and -44.99 to 81.98% in pooled analysis. The crosses GJHV 500 x GTHV 7/70, G. Cot 18 x GSHV 173, G. Cot 12 x GSHV 173 and GJHV 536 x GTHV 7/70 which manifested significant and desirable heterobeltiosis and standard heterosis for seed cotton yield per plant also recorded significant and positive heterosis for plant height, number of sympodia per plant, number of bolls per plant and boll weight.

Keywords: cotton, heterosis, seed cotton yield per plant, ginning percentage

Introduction
Cotton (*Gossypium* spp.), popularly known as "White Gold" is one of the most important commercial cash-cum-fibre crops and plays a key role in economic, political and social affairs of the world, cultivated in tropical and sub-tropical regions of about 80 countries. Apart from world's leading natural fibre, cotton is world's second most important oilseed (Kohel, 1989) [6]. It is prime raw material (85%) of textile industry which provides employment to millions of people in the world over for various activities such as cultivation, seed production, marketing, industrial utilization and research. Exploitation of hybrid vigour is considered to be one of the outstanding achievements in this crop. In heterosis breeding programme, it is essential to study and evaluate available useful promising diverse potential parental genotypes in their hybrid combinations for yield and yield components. Identification of a potential hybrid combination through the magnitude and direction of heterotic effects is of paramount importance. Therefore, the present investigation was attempted to analyze extent of heterosis over environments through line x tester analysis involving ten female and five male lines of cotton.

Materials and Methods
The experimental material comprised of 10 lines *viz*., GJG 101, Deviraj, G-Cot 12, G-Cot 18, G-Cot 10, GJHV 500, GJHV 511, GJHV 517, GJHV 521 and GJHV 536 and five testers namely Suraj, G-Cot 20, GSHV 173, GTHV 7/70 and GBHV 170 and their 50 hybrids derived from line x tester mating design. The resulting 50 hybrids along with their parents and standard check hybrid G-Cot.Hy-12 were evaluated in a randomized block design with three replications at Cotton Research Station, J.A.U. Junagadh over three environments (sowing dates) during *kharif* 2015-16. Environments were created through different dates of sowing during *kharif* 2015-16 *i.e.* E_1 = onset of monsoon, E_2 = 20 days after 1st sowing and E_3 =20 days after 2nd sowing. Each entry was accommodated in single row of 6.3 m. length spaced at 120 cm apart with plant-to-plant spacing of 45 cm. Recommended practices and plant protection measures were adopted timely to raise the healthy crop. Observations were recorded on 12 different traits *viz*., days to 50 % flowering, days to 50 % boll bursting, plant height (cm), number of monopodia per plant, number of sympodia per plant, number of bolls per plant, boll weight (g), seed cotton yield per plant (g), ginning percentage (%), seed index (g), lint index (g) and oil content (%).

Results and Discussion

The pooled analysis of variance over environments (Table 1) showed significant differences among the environments (sowing dates) for all the characters indicating wide variation in environmental conditions or differential expression of traits under different sowing dates. The mean squares due to parents and hybrids were also found significant for all the characters in pooled analysis over environments indicating the presence of sufficient diversity among the parents and hybrids for all the characters. The mean square due to parents vs. hybrids also revealed significant differences for all the characters in pooled analysis over environments which indicated variation among parents as a group and among hybrids as a group revealing the presence of mean heterosis for all the traits.

While considering the performance of hybrids over the environments in respect of seed cotton yield per plant, 28 hybrids over better parent and 16 hybrids over standard check hybrid exhibited significant and positive heterosis. The range of heterosis over better parent was from -37.93 to 44.44%, while heterosis over standard check hybrid ranged from -44.99 to 81.98%. High heterosis for seed cotton yield per plant has been reported by Solanki *et al*. (2014) [9], Baloch *et al*. (2015) [2], Monicashree *et al*. (2017) [8], Divya Bandhavi *et al*. (2018). Wide range of heterosis was reported for various traits usually indicates the amount of variability for the heterosis. Most of the characters expressed either wide or moderate range of heterosis over the environments (Table 2).

A comparative performance of the top five heterobeltiotic crosses for seed cotton yield per plant and its components in each environment is presented in Table 3. The crosses exhibiting the highest, significant and positive heterobeltiosis for seed cotton yield per plant were GJHV 500 x GTHV 7/70, G-Cot 18 x GSHV 173, GJHV 500 x GBHV 170, GJHV 500 x G-Cot 20 and GJHV 517 x GBHV 170 in E_1; GJHV 500 x G-Cot 20, GJHV 500 x GTHV 7/70, GJHV 517 x GSHV 173, GJHV 500 x Suraj and GJHV 517 x G-Cot 20 in E_2 and GJHV 500 x GTHV 7/70, GJHV 500 x G-Cot 20, GJHV 517 x GTHV 7/70, G-Cot 18 x G-Cot 20 and G-Cot 18 x GSHV 173 in E_3 environment. In pooled analysis, the crosses *viz*., GJHV 500 x GTHV 7/70, GJHV 500 x G-Cot 20, GJHV 517 x GTHV 7/70, GJHV 500 x Suraj and G-Cot 18 x GSHV 173 exhibited the highest significant and positive heterobeltiosis for seed cotton yield per plant. The results indicated that the degree and magnitude of heterosis varied from cross to cross for various characters under individual environments and over pooled analysis.

It is of profound interest to know the cause of heterosis for seed cotton yield. Whitehouse *et al.* (1958) [12] and Grafius (1959) [4] have suggested that there may not be any gene system for yield *per se*, as yield is an end product of the multiplicative interaction between the yield components. This would indicate that the heterosis for seed yield should be through heterosis for the individual yield components or alternatively due to the multiplicative effect of partial dominance of component characters. Williams and Gilbert (1960) [13] have reported that even simple dominance in respect of yield components may lead to expression of heterosis for yield. Hagberg (1952) [5] observed similar effects and termed it "combinational heterosis". In order to see whether similar situation exist in cotton or not, a comparison of ten most heterotic crosses for seed cotton yield was made with other yield related characters along with mean seed cotton yield per plant over environments (Table 4). The crosses *viz*., GJHV 500 x GTHV 7/70, G-Cot 18 x GSHV 173, G-Cot 12 x GSHV 173 and GJHV 536 x GTHV 7/70 which manifested significant and desirable heterobeltiosis and standard heterosis for seed cotton yield per plant also recorded significant and positive heterosis for plant height, number of sympodia per plant, number of bolls per plant and boll weight. Therefore, heterotic effects for seed cotton yield per plant could be a result of combinational heterosis. Hence, to obtain maximum heterotic effects for seed cotton yield per plant, desired level of heterosis of each component character should be worked-out to identify superior hybrids.

Highly significant and positive heterobeltiosis was also exhibited for plant height by GJHV 521 x GTHV 7/70, GJHV 511 x GSHV 173, GJHV 521 x G-Cot 20 and GJHV 511 x Suraj; for number of monopodia per plant by GJHV 536 x Suraj, GJHV 521 x Suraj, GJHV 521 x GBHV 170 and GJHV 536 x G-Cot 20; for number of sympodia per plant by G-Cot 10 x GSHV 173, G-Cot 12 x GTHV 7/70, G-Cot 12 x GSHV 173 and GJHV 521 x G-Cot 20; for number of bolls per plant by GJHV 517 x GTHV 7/70, GJHV 500 x GTHV 7/70, GJHV 517 x G-Cot 20 and G-Cot 10 x GTHV 7/70; for boll weight by GJHV 500 x GSHV 173, G-Cot 12 x GTHV 7/70, G-Cot 12 x GBHV 170 and GJHV 500 x G-Cot 20; for ginning percentage by GJHV 536 x GTHV 7/70, G-Cot 10 x Suraj and GJHV 517 x GTHV 7/70; for seed index by GJHV 517 x GSHV 173, GJHV 511 x GTHV 7/70 and GJHV 517 x GTHV 7/70; for lint index by GJHV 517 x GTHV 7/70, G-Cot 10 x GSHV 173 and G-Cot 18 x GSHV 173; for oil content by G-Cot 18 x GSHV 173, GJHV 517 x GSHV 173, GJHV 517 x GTHV 7/70 and G-Cot 18 x Suraj. Heterosis for various traits in cotton was also reported by Tuteja *et al*. (2006) [10, 11], Verma *et al.* (2006) [11] and Yanal *et al.* (2013) [14]. The results indicated that in different crosses, pathway for releasing heterotic effects varied from cross to cross. It also revealed that plant height, number of sympodia per plant, number of bolls per plant, boll weight, seed index and lint index were the main contributors towards increased seed cotton yield. High association of heterosis between these characters and seed cotton yield per plant in cotton has also been earlier reported by Amala *et al.* (2012) [1], Manish kumar *et al*. (2013a) [7], Solanki *et al*. (2014) [9], Monicashree *et al*. (2017) [8].

Overall, the crosses GJHV 500 x GTHV 7/70, GJHV 500 x G-Cot 20, GJHV 517 x GTHV 7/70, GJHV 500 x Suraj and G-Cot 18 x GSHV 173 exhibited significant and positive heterobeltiosis for seed yield per plant and its components in pooled analysis and could be exploited further for yield advancement in cotton through multilocational testing over different environments.

Table 1: Analysis of variance for the experimental design over environments for different characters in cotton

Source	DF	Days to 50 % flowering	Days to 50 % boll bursting	Plant height (cm)	Number of monopodia per plant	Number of sympodia per plant	Number of bolls per plant
Replications in E	6	6.33	16.19	29.03*	0.08*	3.71*	24.23*
Environments (E)	2	144.60*	745.11*	1002.97*	0.20*	6.14*	94.43*
Parents (P)	14	242.44*+	722.01*+	4959.08*+	3.88*+	52.23*+	649.94*+
Hybrids (H)	49	356.38*+	799.05*+	6880.42*+	3.90*+	61.36*+	906.83*+
P vs H	1	464.12*+	1242.14*	5361.03*+	10.23*+	416.82*+	4119.33*+

P x E	28	10.75*	24.62*	20.55*	0.02	1.46	10.75*
H x E	98	9.60*	26.81*	14.55*	0.02	1.04	3.02
(P vs H) x E	2	6.57	91.22*	0.90	0.01	0.71	2.74
Pooled error	384	5.27	16.28	8.32	0.02	1.73	7.07

Source	DF	Boll weight (g)	Seed cotton yield per plant (g)	Ginning percentage (%)	Seed index (g)	Lint index (g)	Oil content (%)
Replications in E	6	0.17*	305.00*	1.11	0.17*	0.14	0.03
Environments (E)	2	0.80*	7103.32*	53.23*	6.85*	8.96*	3.96*
Parents (P)	14	1.39*+	7126.57*+	36.71*+	7.38*+	6.37*+	2.53*+
Hybrids (H)	49	2.15*+	10408.79*+	30.83*+	8.20*+	6.60*+	3.04*+
P vs H	1	10.65*+	71474.25*+	105.53*+	39.79*+	30.17*+	22.42*+
P x E	28	0.02	90.16	0.75	0.09*	0.07	0.15*
H x E	98	0.04	132.69*	0.82	0.07	0.05	0.07*
(P vs H) x E	2	0.01	113.41	0.38	0.03	0.02	0.08
Pooled error	384	0.04	103.22	1.42	0.06	0.08	0.05

* Significant at P= 0.05 when tested against error mean square

\+ Significant at P= 0.05 when tested against interaction mean square

Table 2: Magnitude of heterobeltiosis (H_1) and standard heterosis (H_2) over environments for different characters in cotton

Sr. No	Characters	Range of heterosis (%)		Number of crosses with significant heterosis			
		H_1	H_2	H_1		H_2	
				+ve	-ve	+ve	-ve
1	Days to 50 % flowering	-9.66 to 17.66	-20.03 to 8.32	20	17	6	31
2	Days to 50 % boll bursting	-8.45 to 15.09	-18.39 to 9.15	13	11	8	36
3	Plant height (cm)	-33.68 to 12.88	-44.60 to 32.01	17	13	19	24
4	Number of monopodia per plant	-54.05 to 28.77	-61.42 to 32.28	20	11	10	38
5	Number of sympodia per plant	-20.81 to 21.47	-16.26 to 55.54	27	4	26	6
6	Number of bolls per plant	-43.43 to 28.04	-43.12 to 59.91	31	8	16	22
7	Boll weight (g)	-21.28 to 16.65	-19.41 to 24.79	22	11	24	15
8	Seed cotton yield per plant (g)	-37.93 to 44.44	-44.99 to 81.98	28	8	16	25
9	Ginning percentage (%)	-7.45 to 5.37	-8.34 to 9.40	7	10	16	18
10	Seed index (g)	-7.86 to 11.80	-15.97 to 20.17	28	6	30	19
11	Lint index (g)	-13.78 to 14.33	-24.40 to 35.38	23	5	21	20
12	Oil content (%)	-7.21 to 6.05	-8.17 to 4.43	29	6	30	13

Table 3: Comparative study of five most heterobeltiotic (H_1) crosses along with standard heterosis (H_2) for seed cotton yield and its components in individual environments and pooled over environments in cotton

Sr. No	Crosses	Mean seed yield per plant (g)	Seed cotton yield per plant (g)		Plant height (cm)		Number of sympodia per plant		Number of bolls per plant		Boll weight (g)	
			H_1	H_2	H_1	H_2	H_1	H_2	H_1	H_2	H_1	H_2
E_1	GJHV 500 x GTHV 7/70	147.60	43.25**	21.22**	1.20	5.82*	5.56	3.40	20.96**	-0.76	9.63*	16.40**
	G-Cot 18 x GSHV 173	218.81	38.36**	79.70**	7.17**	29.48**	16.09**	37.41**	11.67**	48.55**	14.26**	27.16**
	GJHV 500 x GBHV 170	132.68	34.62**	8.97	1.47	6.10*	-11.11	-12.93*	5.02	-7.61	6.48	13.05**
	GJHV 500 x G-Cot 20	139.94	33.33**	14.93**	-0.98	3.53	6.02	3.85	2.32	-12.63**	9.97*	16.75**
	GJHV 517 x GBHV 170	129.84	31.74**	6.64	3.63	0.91	12.17*	17.01**	25.26**	10.20*	5.74	0.71
E_2	GJHV 500 x G-Cot 20	123.80	38.26**	10.93	7.69**	8.57**	9.39	5.91	21.54**	-4.47	15.75**	22.91**
	GJHV 500 x GTHV 7/70	134.34	38.07**	20.37**	5.67*	6.53*	9.86	6.36	21.12**	3.51	12.16**	19.09**
	GJHV 517 x GSHV 173	165.25	33.23**	48.07**	14.20**	11.60**	2.70	3.64	13.90**	15.18**	12.31**	21.09**
	GJHV 500 x Suraj	103.90	32.51**	-6.91	6.94*	7.81**	6.57	3.18	4.55	-19.33**	5.14	11.64**
	GJHV 517 x G-Cot 20	117.82	30.74**	5.57	3.31	0.06	-13.96*	-13.18*	21.64**	4.15	-0.54	1.09
E_3	GJHV 500 x GTHV 7/70	126.40	53.44**	13.53	-0.62	6.65*	15.21	27.55*	27.10**	2.02	14.29**	13.09**
	GJHV 500 x G-Cot 20	132.82	45.40**	19.29**	0.85	8.22*	13.61	10.71	12.74	-1.52	19.58**	18.32**
	GJHV 517 x GTHV 7/70	118.23	43.52**	6.19	-4.49	2.96	-1.19	27.55*	36.40**	12.48*	1.67	-4.19
	G-Cot 18 x G-Cot 20	206.31	41.35**	85.30**	2.77	30.11**	-1.08	39.80**	6.09	61.55**	6.61	12.57**

	G-Cot 18 x GSHV 173	205.87	41.05**	84.91**	5.92*	34.10**	50.00**	17.62**	8.19*	64.76**	16.36**	22.86**
Pooled	GJHV 500 x GTHV 7/70	136.11	44.44**	18.46**	2.04	6.32**	14.10**	11.86**	22.90**	1.55	11.98**	16.15**
	GJHV 500 x G-Cot 20	132.19	38.73**	15.04**	2.44	6.73**	9.52*	6.68	11.78**	-6.40*	15.00**	19.29**
	GJHV 517 x GTHV 7/70	126.45	34.18**	10.05*	2.52	3.10	9.22*	20.97**	28.04**	8.32**	1.73	1.07
	GJHV 500 x Suraj	102.31	32.22**	-10.96*	5.08**	9.49**	9.35*	6.52	5.37	-19.40**	3.65	7.51**
	G-Cot 18 x GSHV 173	209.10	31.72**	81.98**	6.72**	31.49**	12.36**	39.98**	14.59**	59.91**	13.08**	24.79**

*,** Significant at 5 %and 1 % levels of probability, respectively

Table 4: Comparative study of ten most heterobeltiotic (H_1) crosses along with standard heterosis (H_2) and *per se* performance for seed cotton yield and its component characters over environments in cotton

Sr. No.	Crosses	Mean seed cotton yield per plant (g)	Seed cotton yield per plant (g)		Days to 50 % flowering		Days to 50 % boll bursting		Plant height (cm)		Number of monopodia per plant		Number of sympodia per plant	
			H_1	H_2	H_1	H_2	H_1	H_2	H_1	H_2	H_1	H_2	H_1	H_2
1.	GJHV 500 x GTHV 7/70	136.11	44.44**	18.46**	-0.82	-5.85**	-1.56	-9.32**	2.04	6.32**	8.93**	-3.94	14.10**	11.86**
2.	GJHV 500 x G-Cot 20	132.19	38.73**	15.04**	0.71	-7.28**	-4.32**	-11.86**	2.44	6.73**	-5.36*	-16.54**	9.52*	6.68
3.	GJHV 517 x GTHV 7/70	126.45	34.18**	10.05*	-7.64**	-11.96**	-0.61	-2.97*	2.52	3.10	4.55	-9.45**	9.22*	20.97**
4.	GJHV 500 x Suraj	102.31	32.22**	-10.96*	0.43	-9.49**	-5.83**	-13.81**	5.08**	9.49**	-9.82**	-20.47**	9.35*	6.52
5.	G-Cot 18 x GSHV 173	209.10	31.72**	81.98**	-4.70**	-15.60**	-4.10**	-4.83**	6.72**	31.49**	6.85**	22.83**	12.36**	39.98**
6.	G-Cot 18 x GTHV 7/70	205.42	29.40**	78.77**	-9.69**	-20.03**	-8.45**	-9.15**	2.27	26.00**	0.00	14.96**	9.08**	35.90**
7.	G-Cot 12 x GSHV 173	163.80	27.71**	42.56**	0.66	-1.17	9.19**	8.73**	5.29**	31.29**	8.39**	32.28**	16.53**	53.97**
8.	G-Cot 10 x Suraj	98.12	26.80**	-14.60**	-5.44**	-18.60**	-4.15*	-15.76**	-3.98*	-20.03**	6.25	-33.07**	15.11**	28.04**
9.	GJHV 536 x GTHV 7/70	115.68	22.75**	0.67	-2.11	-3.25**	3.98*	-2.54	5.43*	-23.81**	5.45*	-8.66**	10.10*	7.93
10.	GJHV 517 x G-Cot 20	116.51	22.28**	1.40	4.52**	-3.77**	-5.90**	-8.14**	-1.24	-0.68	13.79**	-22.05**	-18.30**	-9.51*

Sr. No	Crosses	Number of bolls per plant		Boll weight (g)		Ginning percentage (%)		Seed index (g)		Lint index (g)		Oil content (%)	
		H_1	H_2	H_1	H_2	H_1	H_2	H_1	H_2	H_1	H_2	H_1	H_2
1.	GJHV 500 x GTHV 7/70	22.90**	1.55	11.98**	16.15**	1.99	-5.33**	2.58*	3.47**	7.46*	-4.60	1.78**	3.72**
2.	GJHV 500 x G-Cot 20	11.78**	-6.40*	15.00**	19.29**	-6.24**	-6.68**	5.52**	6.44**	2.16	-4.15	1.52**	3.46**
3.	GJHV 517 x GTHV 7/70	28.04**	8.32**	1.73	1.07	4.34**	-1.25	7.08**	-4.58**	14.33**	-6.35*	5.05**	2.71**
4.	GJHV 500 x Suraj	5.37	-19.40**	3.65	7.51**	1.57	-6.68**	3.19*	4.08**	5.66	-6.20*	1.46*	3.39**
5.	G-Cot 18 x GSHV 173	14.59**	59.91**	13.08**	24.79**	3.08*	8.06**	6.13**	13.61**	11.41**	28.46**	6.05**	2.58**
6.	G-Cot 18 x GTHV 7/70	4.62*	46.00**	9.92**	21.30**	-0.12	4.70**	0.00	7.05**	-0.20	15.07**	1.10	-1.71**
7.	G-Cot 12 x GSHV 173	16.92**	37.42**	8.80**	14.08**	2.02	9.40**	1.75	15.35**	5.01*	33.10**	0.11	-2.40**
8.	G-Cot 10 x Suraj	9.83**	-3.52	1.04	-7.69**	5.00**	5.33**	1.54	14.48**	9.58**	24.22**	-4.51**	-8.17**
9.	GJHV 536 x GTHV 7/70	19.87**	-0.96	12.75**	12.01**	5.37**	-2.19	0.14	-11.01**	8.49*	-13.88**	2.75**	3.65**
10.	GJHV 517 x G-Cot 20	22.12**	3.30	-0.66	-1.36	-2.61	-3.07*	1.18	-4.46**	-2.81	-8.81**	4.24**	1.92**

*, ** Significant at 5 % and 1 % levels of probability, respectively

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