https://doi.org/10.29321/MAJ.10.A03095

Madras agric. J. 65 (7) : 421—429, July, 1978.

Studies on Heterosis in Upland in Cotton (*Gossypium hirsutum* L.)

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High heterosis was recorded for yield and number of bolls and medium for boll weight. Very little but significant heterotic effects were recorded in case of halo length and ginning percentage, while for seed index only negative heterosis was observed. It was revealed that genetic diversity between parents was essential to obtain high heterotic effects. Parents of interspecific origin and that originating from different eco-geographical regions seem to have a great promise. Various hybrids exhibited differential response in different locations.

Commercial exploitation of F_1 hybrids in cotton has achieved spectacular success in India as evidenced by large scale spread of 'Hybrid-4' (Patel, 1971) and Varalaxmi hybrids (Katarki, 1971) in Central and Southern states of India. Both these hybrids are late in maturity and highly unadapted to North Indian conditions. However, such results support the idea of developing a suitable hybrid for Northern India as well, for quicker and larger benefits. Accordingly, studies on heterosis with respect to various economic characters would be of considerable interest. Several workers in cotton have reported sufficient heterosis over mid or better parent for yield and few other characters in cotton. (Turner, 1953; White and Richmond, 1963; Marani, 1963, 1968; Singh and Murty, 1971; Kumar *et al.*, 1974).

MATERIALS AND METHODS

The material consisted of four diverse male parents, twelve female parents and their forty eight F_1 crosses. The experiment was laid out in a randomised block design with three replications. Ajmer, Padampur and Sriganganagar in Rajasthan 1973. The individual plot size consisted of one row 4.5 metre long, with inter-row and interplant spacings of 75 cm. and 30 cm. respectively, Observations were recorded on seed cotton yield per plant, number of boll weight, halo length, ginning percentage and seed index, Heterosis as percentage increase over the better parent was calculated for the various characters under study.

RESULTS AND DISCUSSION

The pooled analysis of variance for parents and hybrids is given in

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Part of the Ph.D. Thesis submitted by the author to the Rajasthan University, Jaipur.

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TABLE I. Pooled analysis of variance for parents and hybrids

	DF	Yield/ plant	No. of bolls	Boll weight	Halo length	G.P.	Seed index
Locations	2	380616.91*	5957.31*	160.954*	261.46*	43.89*	218.57*
Treatments	63	3650.50*	358.62*	0.710*	7.48*	5.56*	2.11*
Hybrids (H)	47	1702.82*	181.41*	0.680*	5.21*	4.98*	1.46*
Parents (P)	15	2727.06*	282.29*	0.405	13.85*	6.84*	4.27*
H vs. P	1	111763.89*	9827.90*	7.259*	18.85*	13.85*	0.11
Tr. x Loc.	126	1351.65*	107.45*	0.510*	1.50*	1.03*	0.99*
Hyb. x Loc.	94	1541.85*	115.44*	0.480*	1.42*	0.91*	0.92*
Par. x Loc.	30	891.89*	76.59*	0.675*	1.75*	1.49*	1.11*
H vs. P x Loc.	2	741.41*	224.51*	0.017	2.309	0.63	2.40*
Pooled Error	378	126.28	17.33	0.162	1.19	0.45	0.77

* Significant at 5 per cent level　　Loc. = Location

G.P. = Ginning percentage.

Table I. Significant differences were obtained for locations, treatments, hybrids and parents for all characters except for boll weight in case of parents. The interactions with locations were also significant in every case indicating differential respons of the various genotypes in different environments. A comparison of parents *vs.* hybrids revealed highly significant differences between parents and hybrids for all characters except seed index and number of sympodial branches. This indicate the presence of high degree of heterosis and its instability in case of yield. boll number and seed index as indicated by significant interaction with locations,

In order that studies on heterosis be of practical value, the heterotic effects were calculated as percentage over the better parent for all characters studied and are tabulated in Table III. Maximum heterosis was obtained in case of yield per plant and number of bolls followed by boll weight. As many as thirty nine crosses for yield and thirty four crosses for boll number manifested significant heterosis ranging from 13.6 to 108.8 per cent and 20.0 to 80.0 per cent respectively, while only nine crosses exhibited hecterotic effects for boll weight ranging from 12.1 to 68.6 per cent. Very little but significant heterosis to an extent of 6.2 to 6.7 per cent in case of two crosses for halo length and 2.4 to 4.4 per cent for four crosses for ginning percentage was observed. In case of seed index, three crosses exhibited significant negative heterosis to an extent of 13.6 to 18.0 per cent, while none of the crosses gave significant positive heterosis which is a favourable situation. The first three crosses giving the highest heterotic effects for yield were: P10 x TH46 (108.8%), H297 x TH46 (73.4%) and RS105 x TH46 (61.8%); for boll number they were: PS10 x TH46 (80.0%), RS67 x TH46 (57.6%) and H297 x TH46 (56.3 %) while for boll weight Nectariless x RS 76 (68.6%), CP1998F x RS 76 (48.6%) and CP1998F x RS455 (23.1 %) were the important crosses. Heterosis for halo length was observed for two crosses: RS9 x RS76 (6.7%) and CP1998F x RS76 (6.2%) and for ginning percentage, CP1998F x TH46 (4.4%), H297 x RS555 (4.2%) and PS10 x TH46(2.7%)were the first three crosses in order exhibiting significant heterosis. Three crosses, CP1998F x SH369 (−18.0%) Nectariless x SH369 (−150%) and CPI 998F x TH46 (−13.6%) were exhibited significant negative heterosis for seed index, while none of the crosses manifested significant positive heterosis for this trait.

The crosses giving the highest yield along with percentage increase over the superiormost parent at each location are tabulated in Table II. H297 x TH46, RS67 x RS455 and PS10 x RS455 were the first three highest yielding crosses in pooled data; while CP1998F x SH369, PS10 x RS76, PS 10 x RS455 at Ajmer; H297 x TH46, RS67 x RS455, H297 x RS455, at Padampur and 5143C x RS455, CP1998F x RS76 and RS105 x ES455 at Sriganganagar were the first three crosses in order. These hybrids gave 47 to 64 per cent, 24 to 35 per cent, 67 to 98 per cent and 60 to 75 per cent higher yield over the superior most parent in pooled data and at other locations: Ajmer, Padampur and Sriganaganagar respectively.

An essential factor in the breeding for heterosis is the identification of the hybrids that are more productive. The extent of heterosis depends primarily on the magnitude of non-additive gene effects expressed often when parents represent wide genetic diversity. The parents used in the present study were highly diverse. Three male parents RS 455, TH46 and SH369 are

TABLE II. First five highest yielding crosses at each location alongwith yield in gms. per plant and percentage heterosis over superior-most parent

Ajmer	Padampur	Sriganganagar	Pooled
CP 1998F x SH 369 (217.36, 35%)	H 297 x TH 46 (1369.16, 98%)	5143C x RS 455 (100.53, 75%)	H 297 x TH 46 (133.03, 64%)
PS 10 x RS 76 (200.79, 25%)	RS 67 x RS 455 (126.53, 80%)	CP 1998F x RS 76 (97.36, 69%)	RS 67 x RS 455 (120.86, 49%)
PS 10 x RS 455 (200.43, 24%)	H 297 x RS 455 (117.20, 67%)	RS 105 x RS 455 (93.23, 60%)	PS 10 x RS 455 (119.50, 47%)
PS 10 x TH 46 (189.74, 17%)	RS 277 x RS 455 (115.10, 64%)	RS 295 x TH 46 (89.23, 53%)	RS 277 x RS 455 (118.76, 46%)
H 297 x TH 46 (189.40, 17%)	Nectariless x RS 455 (104.00, 49%)	RS 67 x RS 455 (88.73, 52%)	5143C x RS 455 (117.06, 44%)

TABLE III. Pooled mean performance of parents, hybrids and heterosis in percentage over the better parent for different characters

Pedigree	Yield/plant		No. of bolls		Boll weight		Halo length		G.P.		Seed Index	
	Mean	%Het.	Mean	%Het.	Mean	%Het.	Mean	%Het.	Mean	%Het.	Mean	%Het.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Males												
SH 369	68.90		24.0		2.76		26.77		31.98		9.15	
RS 455	81.13		27.9		2.76		23.99		31.22		8.95	
TH 46	51.37		17.4		2.80		23.99		32 31		9.05	
RS 76	61.86		23.3		2.45		25.13		31.03		8.71	
Females												
RS 295	70.53		25.3		2.69		24.51		32.07		8.15	
RS 105	59.51		21.2		2.69		25.33		32.10		8.95	
RS 273	75.73		22.1		3.26		25.22		31.56		9.20	
RS 277	68.27		23.8		2.82		24.43		32.46		8.35	
H 297	76.68		24.8		2.73		25.96		31.52		9.06	
5143C	76.62		26.0		2.71		23.15		33.09		7.93	
RS 67	61.31		19.9		2.82		25.28		32.23		8.90	
PS 10	36.64		12.7		2.74		23.59		32.99		7.99	
Nectariless	27.93		9.9		2.34		21.56		34.07		7.52	
D 33	64.93		19.4		3.05		23.52		33.12		8.58	
RS 9	81.04		27.5		2.89		25.03		30 96		9.14	
CP1998F	35.71		11.9		2.10		25.25		32.95		6.80	
Hybrids												
RS295 x SH 369	99.53	41.1**	31.8	25.6**	3.17	14.8*	25.87	−3.4	32.35	0.8	8.25	−9.2
RS105 x SH 369	98.43	42.8**	31.4	30.7**	3.06	10.8	24.74	−7.6	32.09	−0.1	8.17	−10.8
RS273 x SH 369	95.23	26.0**	31.7	32.1**	2.96	−9.3	26.02	−3.7	31.63	−1.1	9.53	3.6
RS277 x SH 369	92.93	34.8**	34.6	44.2**	2.59	−8.2	25.30	−5.5	32.15	−1.0	8.79	−4.0
RS297 x SH 369	95.83	24.9**	33.7	40.4**	2.86	3.6	25.82	−3.6	32.16	0.5	8.47	−7.4

[Contd.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
5143C x SH 369	85.70	11.8	31.6	21.5**	2.62	−5.1	24.07	−10.1**	32.73	−1.1	8.59	−6.2
RS 67 x SH 369	92.03	33.5**	28.8	20.0**	3.19	13.1	24.78	−7.4**	32.45	0.9	8.16	−9.9
PS 10 x SH 369	94.16	36.6**	30.9	29.8**	3.03	9.8	24.30	−9.3**	33.55	1.6	8.33	−9.0
Nect. x SH 369	83.96	21.8**	31.1	29.7**	2.58	−6.6	24.46	8.7**	33.78	−0.9	7.78	−15.0*
D 33 x SH 369	97.20	41.0**	28.9	20.4*	3.34	9.5	25.69	−4.0	33.63	−2.4*	8.48	−7.4
RS 9 x SH 369	83.33	3.4	27.9	1.5	2.99	3.5	24.88	−7.1**	31.23	−2.4*	8.33	−9.0
CP1998F x SH 369	103.80	50.6**	31.2	30.0**	3.07	11.2	25.39	−5.2	33.75	2.4**	7.51	−18.0*
RS 295 x RS 455	80.96	−8.3	28.5	1.9	2.54	−8.0	24.86	−1.2	32.40	1.0	8.21	−8.3
RS 105 x RS 455	107.56**	32.5**	37.6	34.6**	2.96	7.2	24.39	−0.9	32.21	0.3	8.83	−1.4
RS 273 x RS 455	101.90**	25.6**	33.2	19.1**	2.64	−19.1**	25.19	−0.2	31.98	1.3	9.37	1.8
RS 277 x RS 455	118.76	46.3**	35.1	25.7**	3.29	16.6*	24.23	−0.9	32.74	0.8	9.15	2.2
H 297 x RS 455	104.96	28.6**	36.0	25.7**	2.98	8.0	25.02	−4.0	32.88	4.2**	8.71	−3.9
5143C x RS 455	117.06	44.2**	40.1	43.5**	2.88	4.3	24.33	1.8	33.12	0.1	8.51	−5.0
RS 67 x RS 455	120.86	48.9**	35.6	27.6**	3.36	19.1**	24.57	−2.9	32.29	0.4	8.97	0.2
PS 10 x RS 455	119.50	47.2**	34.5	23.5**	3.16	14.5*	23.96	−0.1	33.04	0.1	9.01	0.6
Nect. x RS 455	112.80	39.0**	34.0	21.8**	3.19	15.5*	23.61	−1.6	33.46	−1.8	8.67	−3.2
D 33 x RS 455	94.36	16.3**	28.8	3.1	3.17	3.9	24.23	1.0	32.30	−2.6*	8.78	−1.9
RS 9 x RS 455	92.20	13.6*	31.6	13.3	2.95	2.0	25.35	1.2	31.73	1.6	8.91	−2.6
CP1998F x RS 455	72.96	−10.1	19.8	−30.0**	3.40	23.1	25.68	1.7	32.88	−0.3	9.08	1.4
RS 295 x TH 46	100.20	44.6**	32.3	27.5**	3.01	7.5	24.71	0.8	32.95	0.7	8.15	−10.0
RS 105 x TH 46	96.33	61.8**	32.2	51.7**	3.07	9.6	24.77	−0.5	33.39	2.0*	8.28	−8.6
RS 273 x TH 46	92.73	22 4**	28.5	28.9**	3.32	1.8	24.12	−4.4	32.91	0.6	8.91	−3.2
RS 277 x TH 46	105.53	54.3**	34.8	45.9**	2.98	5.6	25.27	3.3	33.11	1.1	9.13	0.9
H 297 x TH 46	133.03	73.4**	38.9	56.3**	3.22	15.0*	25.32	−2.5	32.15	−1.8	8.62	−4.9
5144C x TH 46	102.93	34.3**	35.6	36.8**	2.72	−2.9	23.52	−2.0	32.64	−1.4	8.65	−4.5
RS 67 x TH 46	92.50	50.8**	31.4	57.6**	2.73	3.9	24.74	−2.1	32.52	−0.7	8.54	−5.7
PS 10 x TH 46	107.16	108.8**	31.3	80.0**	3.14	12.1*	24.35	1.5	33.89	2.7**	8.45	−6.7
Nect. x TH 46	80.13	55.9**	26.2	50.8	3.07	9.6	23.84	−0.7	33.71	−1.0	8.44	−6.8
D 33 x TH 46	85.90	32.2**	27.8	43.4**	3.00	−1.7	24.13	3.1	32.48	−2.0*	8.60	−4.8
RS 9 x TH 46	86.80	7.1	29.6	7.3	2.88	−0.4	25.64	2.4	32.01	−2.2*	8.49	−7.2
CP1988F x TH 46	81.83	59.2**	22.6	30.3**	3.09	10.3	25.39	0.6	32.42	4.4**	7.82	−13.6*
RS 295 x RS 76	106.43	50.9**	36.5	44.2**	2.86	6.3	25.53	1.6	32.41	1.0	8.22	−5.7

[Contd.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
RS 105 x RS 76	75.63	22.2**	29.5	26.7**	2.56	—4.9	25.59	1.8	31.65	—1.5	8.59	—4.1
RS 273 x RS 76	89.03	17.5*	27.6	18.6**	3.13	—4.0	25.35	0.5	31.31	—0.8	8.39	—3.9
RS 277 x RS 76	93.56	37.0**	28.0	17.6*	3.17	12.4	25.43	1.1	31.91	—1.8	8.44	—3.1
H 297 x RS 76	82.03	6.9	28.0	13.0	2.89	5.8	24.99	—3.8	31.91	1.2	8.38	—7.6
5143C x RS 76	79.76	4.0	26.6	2.2	2.84	4.8	24.13	—4.0	31.87	—3.7**	8.38	—3.8
RS 67 x RS 76	82.83	33.8**	29.8	28.0**	2.61	—7.5	25.24	—0.1	32.21	0.1	8.39	—5.8
PS 10 x RS 76	94.93	53.4**	26.4	13.3	3.09	—12.8	24.83	—1.2	33.22	0.6	8.36	—4.1
Nect. x RS 76	91.60	48.0**	21.6	—7.4	4.13	68.6**	23.99	—4.6	33.56	—1.5	8.28	—5.0
D 33 x RS 76	67.40	3.8	26.4	13.3	2.66	12.8	25.03	—0.5	82.65	—1.5	8.35	—4.2
RS 9 x RS 76	78.60	—3.1	25.5	—7.5	3.09	6.9	26.84	6.7**	31.28	0.8	9.05	—1.0
CPI 998F x RS 76	74.63	20.6*	20.3	—13.0	3.64	48.6**	26.80	6.2**	32.38	—1.8	8.54	—2.0
S.E. ±	3.55		1.36		0.13		0.35		0.22		0.29	
C.D. 5%	10.06		3.84		0.37		1.00		0.62		0.81	
C.D. 1%	13.18		5.04		0.48		1.32		0.81		1.06	

derivative of interspecific crosses, involving *G. hirsutum* parent on one hand and *G. tomentosum*, *G.thurberi* and *G. barbadense* respectively as the other parents. These parents, thus, have a wider genetic base. The fourth parent RS76, a variety of intra-specific origin developed in Rajasthan can be said to be related to few female varieties of Indian origin, particularly from North India. Thus, all the male parents were widely diverse and unrelated among themseleves in relation to their genetic as well as geographical origin and of the twelve females, four varieties had American origin, one originated from Russia, one from Ceylon and the rest from India.

It was observed that as many as thirty nine hybrids for yield, and thirty four hybrids for number of bolls showed significant heterosis ranging from 13.6 to 108.8 per cent and 20 to 80 per cent respectively, while for boll weight only nine crosses exhibited significant heterosis. Thus, number of bolls was more important as compared to boll weight in expression of high heterosis. These results are in conformity with the earlier reports (Turner, 1953; White and Richmond, 1963; Marani, 1968; Singh and Murty, 1971; Kumar et al. 1974.) For halo length, ginning percentage and seed index very little but significant heterosis of the order of 1.0 to 6.7 per cent was exhibited. Little or no heterosis for lint length and lint percentage was also observed by several workers (Jones and Loden, 1951; Miller and Marani, 1963; Miller and Lee, 1964; Singh, *et al.* 1964.). A low heterotic response for these characters does not justify a hybrid programme specifically for these characters. While high heterotic effects obtained for certain characters especially for yield is very encouraging, but the crosses showing high heterotic response are not the ones giving the top most yields. This is due to the fact that in such cases the parental variety with which the comparison is made has not been high yielding. Miller and Lee (1964) also noted that the percentage increase in heterosis tends to be higher at low yield level. In practice, however, the selection of a productive hybrid may not be weighed by the expression of heterosis above the better parent alone, but in relation to other hybrids or the best parental lines or the check variety. If the highest heterotic percentage for yield in the experiment is compared with the best performing parent, the highest heterosis percentage above the better parent of 108.8 per cent is reduced to 64.0 per cent, while for number of balls and boll weight, the value is reduced from 80.0 to 44.0 per cent and 68.6 to 35.0 per cent respectively. The percentage heterosis over the superior most parental veriety for first five crossess at each location varies from 17 to 35 per cent at Ajmer, 49 to 98 per cent at Padampur, 52 to 75 per cent at Sriganganagar and 39 to 64 per cent in pooled data.

An examination of the Table I reveals that different hybrids occupied the first six positions for yield of seed cotton at each location and no hybrid was common to all locations which as per expectations due to larger hybrid x locations interactions. This signifies that for estimation of heterosis due consideration must be given to the environment in which the estimates are made. It further reveals that majority of the high yielding crosses and crosses exhibiting higher heterosis over better parent involved one male parent of interspecific origin crossed either to American or Ceylonese or Indian parents of interspecific origin. One of the most outstanding hybrids in India viz. 'Hybrid-4' also involved one American parent and other parent of interspecific origin. In some cases American or Russian x Indian crosses also exhibited high yield performance. More or less, similar situation existed in case of boll weight in which heterosis was more pronounced.

It, thus, appears that parents of interspecific origin and that originating from different geographical regions have a great promise. Utilization of diverse American and short branched Russian types for hybridization programme in cotton has also been suggested by Singh, *et al.*, (1971) and Russian short branced type by Singh, *et al.*, (1971). The role of diverse germplasm as an important factor for contributing to high heterotic response, as revealed in the present study has also been emphasized in cotton by few workers (Joshi *et al.* 1960; Miller and Marani, 1963; Hawkins *et al.* 1965; Singh and Murty, 1971; Kumar *et al.* 1974.). The lack of substantial heterotic response from crosses of Indian x Indian parents of hirsutum origin may be due to their closer genetic relationship. The suggests that heterosis is probably no-due to any single genetic cause and genetic diversity seems to be as important as combining ability of the parental varieties. It signifies the importance of a various plant introduction programme in a breeding project to explore the new sources of germplasm of diverse origin. The present study further indicates that the top most hybrids at each location have potentialities for commercial exploitation. In absence of readily available high yielding variety in Northern India, it may be desirable to proceed with hybrid programme in a 'take-off' stage followed by sternest efforts for obtaining high yielding pure line populations. A low value of heterosis for fibre and ginning characters do not permit such a programme for these characters alone. However, it may probably be much easier to incorporate halo length and ginning percentage in hybrids alongwith yield as compared to variety. Two hybrids, CPI998F x SH369 at Padampur and H297 x TH 46 at Ajmer combined high yield, good fibre quality and high ginning percentage. Parental variety RS455, followed by TH46, both of interspecific origin which have entered into maximum number of high yielding crosses in combination with other lines deserve particular attention for use in further breeding programmes. These varieties had shown good general combining ability as well. Use of parents of different interspecific origin in crosses among themselves which somehow could not be included in the present investigation, is also recommended for further studies as they may also provide fruitful results.

The author is thankful to Dr. Ranbir Singh, Director of Agriculture, and Dr. R. L. Mathur, Jt. Director of Agriculture (Research) for providing necessary facilities and to Dr. D. Gupta, Retd. Vice-Principal, Govt. College, Kota for guidance.

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