Published September, 1967

Heterosis and Combining Ability in Intraspecific and Interspecific Crosses of Cotton[1]

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ABSTRACT

Trials were conducted in 1961 and 1962 on seven and eight varieties, respectively, of *G. hirsutum* L. and *G. barbadense* L. and all possible reciprocal crosses between them. The average magnitude of heterosis for lint yield was 24.5% and 21.6% in the intraspecific crosses of *G. hirsutum* L. and *G. barbadense* L., respectively, and 72.8% in the interspecific crosses. Heterosis for lint yield was associated in all cases with heterosis for yield of seed-cotton and in many cases also for the number of bolls per m^2. Heterosis for boll-weight was found only in *G. hirsutum* L. intraspecific crosses where it was associated with heterosis for seed-index, lint-index, and number of seeds per boll. The interspecific crosses had a low lint-percent because heterosis for seed-index was much more pronounced than heterosis for lint-index in these crosses.

Effects of general combining ability in the interspecific crosses, which were more pronounced than effects of specific combining ability, corresponded to the performance of the parental varieties themselves. If heterosis in interspecific crosses is to be used to breed F$_1$ hybrids, the selection of parental varieties should be made on the basis of their own performance for those traits that have shown consistent and significant effects of general combining ability.

MANIFESTATIONS of heterosis in hybrids of cotton were studied by many authors. The practical utilization of this heterosis may be feasible if a usable male-sterility were to be found. The cytoplasmic-genic male-sterility found by Meyer and Meyer (11) is an important step towards this goal, but there are many difficulties in its utilization for commercial production of F$_1$ seeds.

It was found (9) that heterosis for lint yield averaged 20% in intraspecific crosses of *G.hirsutum* L., 26% in intraspecific crosses of *G.barbadense* L., and 82% in interspecific crosses of these species. Heterosis for lint yield in intraspecific crosses of *G.hirsutum* L. was studied by several authors. Its magnitude was reported to be 35% by Jones and Loden (6), 27% by Miller and Marani (13), and 18% by Miller and Lee (12). Hawkins et al. (5) reported an average heterosis of 24%, and several of their hybrids gave significantly higher yields than the better parent. A smaller degree of heterosis was reported by White and Richmond (16), Turner (15), Kime and Tilley (7), and Christidis (2). No data are available for heterosis in intraspecific crosses of *G.barbadense* L. Heterosis in interspecific crosses of these species was reviewed by Stroman (14) and by Loden and Richmond (8). Barnes and Staten (1) reported that the lint yield of the interspecific cross 'Pima 32' $\times$ 'Acala 1517C' exceeded that of the better parent by 45%. Fryxell et al. (4) reported that the same cross exceeded the yield of the better parent by 21%.

MATERIALS AND METHODS

Two trials, in 1961 and 1962, were conducted at the Bet Dagan Experimental Farm, on an alluvial clay-type soil. The following parental varieties were used: *(1)* 'Acala 4-42'; *(2)* 'Acala 1517C'; *(3)* 'Empire W'; *(4)* 'Coker 100A'; *(5)* 'Karnak'; *(6)* 'Malaki'; *(7)* 'Giza 7'; and *(8)* 'Pima 32'. The first four varieties are upland cotton, *G. hirsutum* L.; the others are *G. barbadense* L. (5, 6, 7 are Egyptian varieties and 8 an American-Egyptian variety). The parental varieties were selfed for two or three generations before making the crosses.

The 1961 trial included reciprocal F$_1$ hybrids and selfed progeny of seven varieties ('Coker 100A' was not included) in all possible combinations. The design was a 7 $\times$ 7 lattice square with eight replicates. The 1962 trial included reciprocal F$_1$ hybrids in all combinations and selfed progeny of all eight varieties; the design an 8 $\times$ 8 lattice square with nine replicates.

Normal cultural practices for irrigated cotton were followed in both trials. Each plot consisted of one row 3 m long, with a space of 1 m between rows. Planting dates were April 26-27 in 1961, and April 27-29 in 1962. Sowing was done by hand in hills spaced 20 cm apart, with subsequent thinning to one or two plants per hill.

Harvesting was done by hand at frequent intervals, seven times in 1961 and six in 1962. In 1961, a sample of 20 bolls was taken and weighed separately from each plot at each harvest; in 1962, all bolls were counted at each harvest, to obtain information on the mean boll weight. Random samples of approximately 300 g of seed-cotton were taken from early, medium, and late harvests of each plot and ginned by a 20-cm (8-inch) roller-gin. Lint percent (weighted mean) and lint yield were calculated from these determinations. Seed-index was tested by weighing four lots of 100 seeds from each sample. Lint-index was calculated from seed index and lint percent data. The number of seeds per boll was calculated from boll weight, seed index and lint index data. The number of bolls per m^2 was calculated from yield and boll weight data. The mean date of maturity was calculated by the method described by Christidis and Harrison (3) as the mean of maturity dates of all harvests, weighted by the yield of seed-cotton of each harvest. Height of plants was measured at the end of the season on three random plants in each plot.

RESULTS

Results for mean performance of parent varieties and F$_1$ crosses, and the effects of heterosis in each group of crosses are presented in Table 1. Heterosis was calculated as the percentage increase of F$_1$ performance above the mean performance of the parent varieties.

Heterosis for yields of seed-cotton and of lint in the intraspecific hybrids of *G.hirsutum* L. was more pronounced in 1961 than in 1962. Heterosis for yield was associated in these hybrids with a significant heterosis for boll weight. In 1961 it was also associated with a large, though not statistically significant heterosis for the number of bolls produced. Heterotic effects for the number of seeds per boll, seed index and lint index, which contributed to the increase in boll weight, were significant in both years. The lint percent of the F$_1$ hybrids was significantly higher than the parental mean in 1961 but not in 1962. F$_1$ plants were somewhat taller and in 1961 matured earlier than the parental varieties.

Heterosis for yield of seed-cotton and of lint in the intraspecific hybrids of *G.barbadense* L. was significant and of nearly the same magnitude in 1961 and 1962. It was associated with a significant heterosis for

[1] Contribution from The Hebrew University of Jerusalem, Faculty of Agriculture, Rehovot, Israel. This research was financed in part by grant FG-Is-114 (project A10-CR-2) from the U. S. Department of Agriculture, under P.L. 480. Received May 20, 1967.

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Table 1. Mean performance of varieties and crosses and the degree of heterosis.

	Variety or cross†	Yield of seed-cotton, g/m²	Yield of lint, g/m²	No. bolls, /m²	Boll weight, g	Lint index, g	Seed index, g	Lint %	No. seeds /boll	Plant height, cm	Mean date of maturity‡
					1961						
Mean performance of parent varieties	h	241	88	35	7.1	7.4	13.1	36.3	34.9	131	24
	b	253	82	74	3.5	6.0	12.5	32.3	18.7	174	40
	Avg	247	85	55	5.3	6.7	12.8	34.3	26.8	153	32
Mean performance of crosses	h × h	324	121	41	8.0	8.2	13.7	37.5	36.7	137	22
	b × b	301	100	85	3.6	6.2	12.7	32.6	18.9	175	36
	h × b	493	155	100	5.0	7.2	15.6	31.7	21.9	181	30
Percentage increase of cross performance over mid-parents	h × h	34.4**	38.2**	19.6	12.7**	10.9**	4.6**	3.3**	5.1**	4.6**	- 8.3*
	b × b	19.0**	21.6*	15.1**	2.9	3.5**	2.3**	0.8	1.2	0.6	-10.0**
	h × b	99.6**	82.3**	83.2**	-5.7	8.2**	22.3**	-7.8**	-18.3**	18.7**	- 6.3**
					1962						
Mean performance of parent varieties	h	249	96	41	6.0	7.6	12.0	38.7	30.7	119	16
	b	258	86	87	3.0	6.1	12.2	33.5	16.3	150	32
	Avg	254	91	64	4.5	6.9	12.1	36.1	23.5	135	24
Mean performance of crosses	h × h	266	103	42	6.5	7.9	12.5	38.8	31.7	122	16
	b × b	311	105	100	3.1	6.3	12.2	33.9	16.9	156	31
	h × b	464	149	113	4.1	6.8	14.3	32.4	19.7	167	26
Percentage increase of cross performance over mid-parents	h × h	6.9	7.6	2.7	7.6**	4.8**	4.3**	0.1	3.4*	2.6*	- 1.4
	b × b	20.4**	22.0**	15.5**	4.7	2.5*	0.3	1.4**	3.5	4.0**	- 0.1
	h × b	83.3**	63.9**	75.6**	-7.9**	-0.4	18.0**	-10.3**	-16.2**	24.0**	9.8**
					Average of 1961 and 1962						
Percentage increase of cross performance over mid-parents	h × h	22.5	24.5	11.3	11.9**	8.8	5.0**	1.8	5.3**	3.1*	- 4.9
	b × b	19.6**	21.6**	15.3**	4.5**	3.0**	1.3**	1.1**	2.3	2.3**	- 5.1
	h × b	91.2	72.8**	79.6**	-6.9*	3.9	20.6	-9.3	-17.7	20.8	1.8
F ratio for variance of interaction heterosis × years	h × h	3.91*	4.20*	0.45	3.04	8.57**	0.15	17.63**	0.04	1.54	5.66*
	b × b	0.05	0.03	0.14	0.03	0.49	3.31	0.90	0.40	2.55	22.74**
	h × b	4.51*	3.61	0.34	2.66	83.49**	32.03**	49.84**	4.42*	5.76*	45.67**

*, ** Significant, 5% and 1% levels, respectively. † h = G. hirsutum L. varieties; b = G. barbadense L. varieties. ‡ Days after August 31.

Table 2. Components of variance in the interspecific crosses.

	Yield of seed-cotton, g/m²	Yield of lint, g/m²	No. bolls /m²	Boll weight, g	Lint index, g	Seed index, g	Lint %	No. seeds /boll	Plant height, cm	Mean date of maturity‡
G. hirsutum L.										
σ^2 g.c.a.†	0	0	55.28	0.0984**	0.029**	0.832*	2.692*	5.19**	423.96*	16.43**
σ^2 g.c.a. × years	842**	100*	30.39*	0.0055	0	0.027**	0.051*	0	3.03	0
G. barbadense L.										
σ^2 g.c.a	0	0	0	0.0059	0.051	0.807*	0.856	1.67**	8.57	13.66**
σ^2 g.c.a. × years	0	0	0	0	0.014**	0.056**	0.162**	0	4.12	0.33
σ^2 s.c.a†	0	61	0	0.0060	0.028	0.102	0	0.11	0	0
σ^2 s.c.a. × years	14.7*	44	81.72*	0	0.002	0.072**	0.160**	0	0	0.66
Error variance	825	120	55.30	0.0192	0.010	0.026	0.065	0.45	12.31	0.86

*, ** Significant, 5% and 1% level, respectively. † σ^2 g.c.a. = general combining ability variance. σ^2 s.c.a. = specific combining ability variance
‡ Days after August 31.

the number of bolls produced, but heterosis for boll weight was small and not significant. There were small but significant effects of heterosis for lint index, and in 1961 also for seed index, but not for the number of seeds per boll. Lint percent of the F_1 hybrids was somewhat higher than that of the parent varieties. The F_1 plants were somewhat taller than those of the parent varieties in 1962, and matured earlier in 1961.

Heterosis for yield of seed cotton and yield of lint in the interspecific crosses was of a very large magnitude. It was associated with a pronounced heterosis for the number of bolls produced, whereas the boll weight and the number of seeds per boll of these crosses were lower than the mean of the parental varieties. Heterosis for lint index was found in 1961 but not in 1962. Heterosis for seed index was of a very large magnitude in these crosses, resulting in a low lint percent. Plants of the interspecific crosses were taller than those of either parent. The mean date of their maturity was somewhat earlier than the parental mean in 1961 and somewhat later in 1962. In both years the hybrids matured later than the *G.hirsutum* L parents and earlier than the *G.barbadense* L. parents.

Components of variance for general and specific combining ability effects in the interspecific crosses are given in Table 2. The performance of individual parental varieties and of their interspecific crosses is presented in Table 3.

Significant general combining ability (g.c.a.) effects of *G.hirsutum* L. parents in the interspecific crosses were found for boll weight, lint index, seed index, lint percent, number of seeds per boll, plant height and mean date of maturity. Their g.c.a. effects for yield of seed-cotton or lint yield were not consistent from year to year. In many cases the g.c.a. corresponded to the performance of the parental varieties themselves. For example, Coker 100A and Empire W had g.c.a. for larger bolls, a higher lint percent and a lower seed index than did Acala 4-42 or Acala 1517C, and Acala 1517C exhibited g.c.a. for taller plants.

The g.c.a. effects of *G. barbadense* L. parents in the interspecific crosses were significant only for seed index, number of seeds per boll and mean date of maturity. These g.c.a. effects also corresponded in many cases to the relative performance of the parental varieties.

Variance for specific combining ability effects was not significant for any of the traits examined, but a significant interaction of specific combining ability with years was found for yield of seed-cotton and some other traits. This indicated that a good performance of any particular crossing combination was not consistent from year to year.

Table 3. Performance of parental varieties and their interspecific crosses.

		Yield of seed cotton, g/m²	Yield of lint, g/m²	No. bolls, /m²	Boll weight, g	Lint index, g	Seed index, g	Lint %	No. seeds /boll	Plant height, cm	Mean date of maturity†
		G. hirsutum L. varieties and crosses - 1961									
Parent varieties	Acala 4-42	240	84	34	7.2	7.3 b	13.5 a	35.4 b	35	129 b	23
	Acala 1517C	254	93	36	7.2	7.7 a	13.4 a	36.4 a	34	147 a	26
	Empire W	230	87	33	6.9	7.2 b	12.3 b	37.1 a	35	117 c	22
Interspecific crosses with all G. barbadense L. varieties	Acala 4-42	493 a	150 b	102 a	4.8 b	7.1 b	16.0 a	30.8 c	21 b	179 b	31 a
	Acala 1517C	519 a	164 a	106 a	4.9 b	7.3 a	15.6 b	31.9 b	21 b	192 a	31 a
	Empire W	466 b	150 b	90 b	5.2 a	7.3 a	15.2 c	32.3 a	23 a	170 c	29 b
		G. hirsutum L. varieties and crosses - 1962									
Parent varieties	Acala 4-42	209	78	32	6.5 a	7.8 a	12.9 a	37.8 b	31 a	116 b	14
	Acala 1517C	238	93	39	5.9 b	8.1 a	12.8 a	39.0 a	27 b	135 a	16
	Coker 100A	267	104	46	5.9 b	7.2 b	11.1 b	39.1 a	33 a	112 b	17
	Empire W	279	108	48	5.8 b	7.2 b	11.3 b	39.0 a	32 a	113 b	17
Interspecific crosses with all G. barbadense L. varieties	Acala 4-42	460	143 b	113	4.1 b	6.8 b	15.0 a	31.3 c	19 b	166 b	26 a
	Acala 1517C	450	144 b	112	4.0 b	7.0 a	14.8 b	32.1 b	19 b	179 a	27 a
	Coker 100A	482	156 a	115	4.2 ab	6.6 c	13.4 d	33.0 a	21 a	162 c	25 b
	Empire W	465	153 ab	110	4.3 a	6.9 ab	14.0 c	33.1 a	21 a	161 c	25 b
		G. barbadense L. varieties and crosses - 1961									
Parent varieties	Karnak	245	85	77	3.2	5.9	11.5 c	33.9 a	19	175	40
	Malaki	250	76	71	3.5	5.9	13.2 a	31.0 c	18	173	38
	Giza 7	257	85	75	3.5	5.9	12.1 b	32.7 b	20	173	41
	Pima 32	261	83	73	3.6	6.1	13.1 a	31.7 b	19	173	41
Interspecific crosses with all G. hirsutum L. varieties	Karnak	481	155	98	4.9	7.3	15.4 c	32.2 a	22 b	179 bc	31 a
	Malaki	504	155	102	4.9	7.4 a	16.3 a	31.2 b	21 c	181 ab	31 a
	Giza 7	487	154	99	5.0	7.0 d	14.9 d	31.9 a	23 a	177 c	28 b
	Pima 32	498	155	98	5.1	7.2 c	15.8 b	31.3 b	22 b	184 a	31 a
		G. barbadense L. varieties and crosses - 1962									
Parent varieties	Karnak	298	103	97	3.0	6.2	11.7 b	34.7 a	17	158	34
	Malaki	239	77	80	3.0	6.2	12.9 a	32.3 b	16	151	32
	Giza 7	213	72	78	2.9	6.0	11.6 b	34.1 a	16	144	30
	Pima 32	283	92	92	3.1	6.1	12.6 a	32.7 b	17	148	30
Interspecific crosses with all G. hirsutum L. varieties	Karnak	474	153	114	4.2	6.9 a	14.2 b	32.8 a	20 ab	166	26 a
	Malaki	458	144	113	4.1	6.9 a	14.6 a	32.3 b	19 b	170	26 a
	Giza 7	460	151	111	4.1	6.7 b	13.8 c	32.9 a	20 a	166	25 b
	Pima 32	466	147	112	4.2	6.7 b	14.6 a	31.6 c	20 ab	166	26 a

* Results followed by the same letter within each group are not significantly different, 5% level, by Duncan's multiple range test. There were no significant differences within any group where no letters follow the results. † Days after August 31.

DISCUSSION

Magnitude of Heterotic Effects

The heterotic effects found in this study may be compared with those reported from our earlier (1959 and 1960) trials (9, 10). In four trials, average heterosis for lint yield in the *G.hirsutum* L. intraspecific crosses was between 8% and 38%, and it was significant in two out of four trials. In the *G.barbadense* L. intraspecific crosses it ranged from 12% to 41% and was significant in three out of four trials. The increase of F_1 performance above that of the best parental variety, however, was of a much smaller magnitude and it was not statistically significant in most cases. The advantage to be gained by breeding intraspecific F_1 cotton hybrids is therefore rather doubtful. In the interspecific crosses, heterosis for lint yield ranged from 64% to 93% and was significant in all four trials. These crosses performed significantly better than the best parental varieties. A considerable advantage would therefore be gained by using interspecific F_1 cotton hybrids, if suitable methods of producing F_1 seeds on a commercial scale were found.

Heterosis for lint yield was in most cases closely associated with heterosis for the number of bolls produced per unit-area, whereas boll size of the interspecific crosses was usually intermediate. A disadvantage of the interspecific crosses is their low lint percent, resulting from the heterosis for seed index, which was much higher than heterosis for lint index. Other disadvantages of the interspecific crosses are the excessive height of plants and their relatively late maturity.

Combining Ability in the Interspecific Crosses

Effects of g.c.a. were more pronounced than effects of specific combining ability, and the magnitude of the former was in most cases in accordance with the performance of the parental varieties themselves. This probably indicates that the genetic effects are largely additive, which is in agreement with previously reported results (9, 13, 16).

The effects of g.c.a. for lint yield, yield of seed cotton, and the number of bolls were not consistent from year to year. More consistent effects of g.c.a. were found for boll weight, lint index, maturity and plant height. Consistent effects of g.c.a. were also found for seed index and lint percent, but their magnitude had a significant interaction with years.

Significant effects of specific combining ability were seldom found. When such effects were found, they had a significant interaction with years. If breeding interspecific hybrid varieties of cotton is to be possible, the selection of parents for crossing should be based on traits that have shown consistent and significant effects of general combining ability. The good association between the performance of the parental varieties and their g.c.a. effects leads to the conclusion that the selection of parental varieties for crosses may be based in many cases on their own performance. The evaluation of combining ability for lint yield is much more difficult, and should be made over a wide range of environmental conditions.

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