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Inheritance of Lint Quality Characteristics in Interspecific Crosses of Cotton[1]

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ABSTRACT

In interspecific crosses between varieties of upland (*Gossypium hirsutum* L.) and Egyptian (*G. barbadense* L.) cotton, tested in Israel from 1959 through 1965, F_1 performance for upper-half-mean and mean lint length exceeded that of either parent by 10 to 16% and 6 to 13%, respectively. The uniformity ratio of F_1 plants was slightly lower than the parental mean. F_2 performance for lint length was slightly above parental mean, but a significant F_2 deviation was detected for this trait. There were indications that additive, dominance, and additive $\times$ additive epistatic effects were operating in the inheritance of lint length.

The tensile strength (1/8-in. gauge, *i.e.* T_1, of the F_1's lint was almost as high as that of the stronger *G. barbadense* parental varieties. The magnitude of heterosis was 9 to 15% for this trait, with no F_2 or backcross deviations. This indicated that only additive and dominance effects were operating in the inheritance of lint strength.

Micronaire measurement of lint fineness was much lower in F_1 hybrids than in either parent (a negative heterosis of 12 to 19%). Only the dominance effects were detected as operating significantly in the inheritance of this trait, but there were considerable deviations from the model with no epistasis.

Significant effects of general combining ability were found for lint length and tensile strength. Additive gene-action was predominant for these traits. Dominance effects were the main cause of heterosis for all the traits of lint quality examined.

Additional index words: **lint length, lint uniformity ratio, lint strength, lint fineness, heterosis, *Gossypium*.**

INTERSPECIFIC crosses have been used to improve lint quality of *G. hirsutum* L. varieties, by crossing them with *G. barbadense* L. or other species and following this with repeated backcrossing to *G. hirsutum* and subsequent selection. Recently, the finding of strong heterosis for lint yield in interspecific F_1 hybrids (6, 7, 8) has made it desirable to investigate the fiber quality characteristics of these hybrids.

Balls (2) reported that the interspecific cross of 'Charara' (*G. barbadense*) $\times$ 'King' (*G. hirsutum*) showed dominance of lint length in the F_1. Fryxell et al. (4) investigated some interspecific hybrids in New Mexico and reported that their lint was longer and finer than that of the *G. barbadense* parents, whereas T_1 lint strength of most of the hybrids was within the range of their respective parents. Barnes and Staten (3) reported similar results for an F_1 hybrid of 'Pima 32' (*G. barbadense*) $\times$ 'Acala 1517C' (*G. hirsutum*). Stroman (10) reported on further tests, made in new Mexico, where he found that F_1 hybrids between *G. hirsutum* and *G. barbadense* had longer and finer lint than their parents, but their lint strength was slightly lower than that of the *G. barbadense* parental varieties.

Ali and Lewis (1) investigated a cross between selfed lines of 'Deltapine 14' (*G. hirsutum*) and 'Pima 32' and reported a heterosis of 17 and 30% for upper-half-mean (U.H.M.) length and T_1 strength of lint, respectively. F_1 performance for these traits was above that of the better parental variety, and backcross performance was close to the mean of F_1 and the recur-

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rent parent. Ramey and Miller (9) reported additive variance for U.H.M. length, T_1 strength, and fineness and dominance variance for U.H.M. in a cross of 'Empire 10' (*G. hirsutum*) and 'TH 131-5' (of *G. thurberi* × *G. arboreum* × *G. hirsutum* origin).

MATERIALS AND METHODS

Fiber quality measurements were made on samples taken from plots of seven field experiments that were carried out in the coastal region of Israel. The 1965 experiments were conducted at two locations, 1965N at Naan and 1965G at Givat-Brenner. All experiments were grown under irrigation and recommended cultural practices were followed. In each experiment, several varieties of upland cotton, *G. hirsutum*, and several varieties of Egyptian cotton *G. barbadense*, and the progeny of all interspecific crosses between them were included. The parental varieties that were used in each experiment are given in Table 1.

The F_1 generation of the interspecific crosses was included in all trials, F_2 was included in the 1964 and 1965 trials, and in both 1965 trials backcrosses to both parents were included.

The details of experimental procedures and results for yield and other data were reported previously (6, 7, 8). In 1959 there were five replications in a Youden-square design. In 1960, 1961, and 1962 the trials were designed as lattice-squares with six, eight, and nine replications, respectively. In 1964 a split-plot randomized-block design was used where each crossing-combination was assigned to a main-plot that was subdivided into four subplots which included the two parental varieties, F_1 and F_2. A similar design was used in both 1965 trials, but each main plot was subdivided into six subplots which also included backcrosses to both parental varieties. There were seven replications in 1964 and six in 1965N and 1965G.

Representative samples were taken from each plot and ginned on a miniature roller-gin. Fiber length was measured in 1959-1962 on a "Servo-Fibrograph" and expressed as U.H.M. (upper-half-mean) — mean length of the half of the fibers that contain the longer fibers; and M (mean) — average length of all fibers longer than 1/4 inch. In 1964 and 1965, fiber length was measured by a Digital Fibrograph. The 2.5% span length value was taken as roughly equivalent to U.H.M., and the Secant mean, calculated as 3 × (66.7% span length — 0.10), was taken as roughly equivalent to M. The uniformity ratio was calculated as percentage of M from U.H.M. Length in 1959-62, and as percentage of Secant mean from 2.5% span length in 1964-65.

Fiber strength was measured on a Pressley-tester with the two jaws holding the fiber bundle separated by a 3.2-mm (1/8-inch) spacer. Pressley-index (lb per mg) was multiplied by 0.68 to express strength in grams force per grex units (T_1 units). Fiber fineness was measured on a "Sheffield" Micronaire and expressed in standard (culvilinear scale) Micronaire units. All tests were made under controlled temperature (20 ± 1 C) and humidity (60 ± 5% R.H.) conditions.

Heterosis was expressed as percent deviation of the F_1 hybrids from the average of the parents, $(F_1\text{-MP})/\text{MP}$ (where MP, the mid-parent, is the average performance of P_h and P_b, the *G. hirsutum* and *G. barbadense* parental varieties, respectively). The deviation of F_2 performance from the mean of F_1 and parent average was expressed as percentage of that mean,

Table 1. Parental varieties used in each experiment.

Varieties	1959	1960	1961	1962	1964	1965N	1965G
G. hirsutum L.							
Acala 4-42	X	X	X	X	X	X	X
Coker 100W	X	X					
Empire W	X	X	X	X	X	X	X
Acala 1517C			X	X			
Coker 100A				X	X	X	X
G. barbadense L.							
Pima 32	X	X	X	X			
Pima S-1	X						
Ashmuni	X	X					
Karnak			X	X	X	X	X
Malaki			X	X	X	X	X
Giza 7			X	X	X	X	X

Table 2. Mean performance of parental varieties and the F_1 hybrids used in the 1959, 1960, 1961, and 1962 trials.

Trial	Generation*	UHM length, in.	Mean length, in.	Uniformity ratio, %	Fiber strength, T1 (g/grex)	Fineness, Micronaire units
1959	P_h	1.07	.81	75	2.39	4.03
	P_b	1.21	.87	73	3.13	3.98
	F_1	1.32	.93	71	3.16	3.31
1960	P_h	1.13	.88	78	2.29	4.51
	P_b	1.22	.91	75	3.04	4.95
	F_1	1.36	.97	72	3.05	3.67
1961	P_h	1.17	.93	80	2.39	4.01
	P_b	1.39	1.03	74	3.46	3.72
	F_1	1.44	1.04	72	3.29	3.31
1962	P_h	1.11	.83	75	2.31	4.43
	P_b	1.35	.95	71	3.28	3.86
	F_1	1.38	.96	70	3.14	3.36

* P_h = G. hirsutum parental varieties. P_b = G. barbadense parental varieties. F_1 = F_1 generation of all interspecific crosses.

Table 3. Mean performance of parental varieties and the F_1, F_2, and backcross generations used in the 1964 and 1965 trials.

Trial	Generation*	2.5% span length, in.	Secant mean length, in.	Uniformity ratio, %	Fiber strength, T_1 (g/grex)	Fineness, Micronaire units
1964	P_h	1 11	.88	79	2.32	3 69
	P_b	1.34	1.05	78	3.18	4.01
	F_1	1.37	1.07	78	3.03	3.28
	F_2	1.26	.97	77	2.88	3.54
1965 N	P_h	1.10	.80	73	2.03	3.93
	P_b	1 32	.98	74	2.60	4.04
	F_1	1.36	1.01	74	2.53	3.51
	F_2	1.24	.93	75	2.39	3.81
	Bc_h	1.20	.91	76	2.30	3.74
	Bc_b	1.32	.98	74	2.54	3.64
1965 G	P_h	1.13	.91	81	2.32	3.24
	P_b	1.31	1.03	79	3.07	3.53
	F_1	1.34	1.06	79	3.04	2.94
	F_2	1.24	.98	79	2.87	3.25
	Bc_h	1.20	.96	80	2.67	3.24
	Bc_b	1.32	1.03	78	3.09	3.18

* P_h, P_b, F_1 - see footnote to Table 2. F_2 = F_2 generation of all interspecific crosses. Bc_h = Backcrosses to G. hirsutum parental varieties. Bc_b = Backcrosses to G. barbadense parental varieties.

Table 4. Average heterosis, F_2 and backcross deviations in interspecific crosses of cotton.

Experiment	UHM length, in.†	Mean length, in.‡	Uniformity ratio	Lint strength, T_1 (g/grex)	Fineness, Micronaire units
Heterosis, %					
1959	15.7**	10.9**	-3.8*	14.5**	-17.3**
1960	15.3**	9.2**	-6.1**	14.4**	-22.4**
1961	12.0**	6.5**	-5.7	12.3**	-14.5**
1962	12.1**	8.0**	-4.4	12.2**	-18.8**
1964	11.5**	11.3**	-0.2	10.3**	-14.8**
1965 N	12.3**	13.4**	1.0	9.2**	-11.9**
1965 G	10.4**	9.9**	-0.7	12.7**	-13.0**
F_2 Deviation, %					
1964	2.5**	4.0**	1.3*	0.2	0.7
1965 N	3.4**	2.0**	-1.6**	1.3	-1.7
1965 G	3.2**	3.6**	0.4	-0.2	-2.8
Bc_h Deviation, %					
1965 N	2.0**	-0.6	-2.8**	-0.9	-0.7
1965 G	3.1**	2.8**	-0.2	0.3	-4.7*
Bc_b Deviation, %					
1965 N	1.8**	1.6*	0.2	1.2	3.7*
1965 G	0.7	1.2	0.5	-1.1	1.7

*, ** Significant, 0.05 and 0.01 levels, respectively. † 2.5% span length in 1964 and 1965 experiments. ‡ Secant mean length in 1964 and 1965 experiments.

$[\frac{1}{2}(F_1+MP)-F_2]/\frac{1}{2}(F_1+MP)$. Bc (backcross) deviation was calculated as the percentage decrease of Bc performance from the average of F_1 and the recurrent parent, $[\frac{1}{2}(F_1+P_h)-Bc_h]/\frac{1}{2}(F_1+P_h)$ and $[\frac{1}{2}(F_1+P_b)-Bc_b]/\frac{1}{2}(F_1+P_b)$ for *G. hirsutum* and *G. barbadense* backcrosses, respectively. F-tests were calculated, to test the significance of these effects, based on error terms from analysis of variance.

Genetic parameters, with or without epistatic effects, were calculated in the two 1965 experiments by the method suggested by Hayman (5). Effects of general and specific combining ability in the F_1, F_2, Bc_h and Bc_b generations were calculated as in a factorial arrangement.

RESULTS AND DISCUSSION

Mean performance of parental varieties, their F_1, F_2 and backcrosses is presented in Tables 2 and 3. Data of heterosis, F_2-deviation and backcross-deviation are given in Table 4. The performance of the parental varieties and of the generations after crossing, means for groups of experiments, is presented in Fig. 1; some particular crossing combinations are described in Fig. 2.

Cases of significant general or specific combining ability are given in Table 5. The performance of some parental varieties for U.H.M. and T_1 is compared to the average performance of their progeny in Fig. 3. Results for genetic parameters, calculated by the method of Hayman (5) are given in Table 6.

U.H.M. Length

U.H.M. length of F_1 fibers exceeded that of the *G. barbadense* parents in all the trials. F_1 performance was 10 to 16% above parental mean. In 1959 and 1960 the *G. barbadense* variety 'Ashmuni' was in-

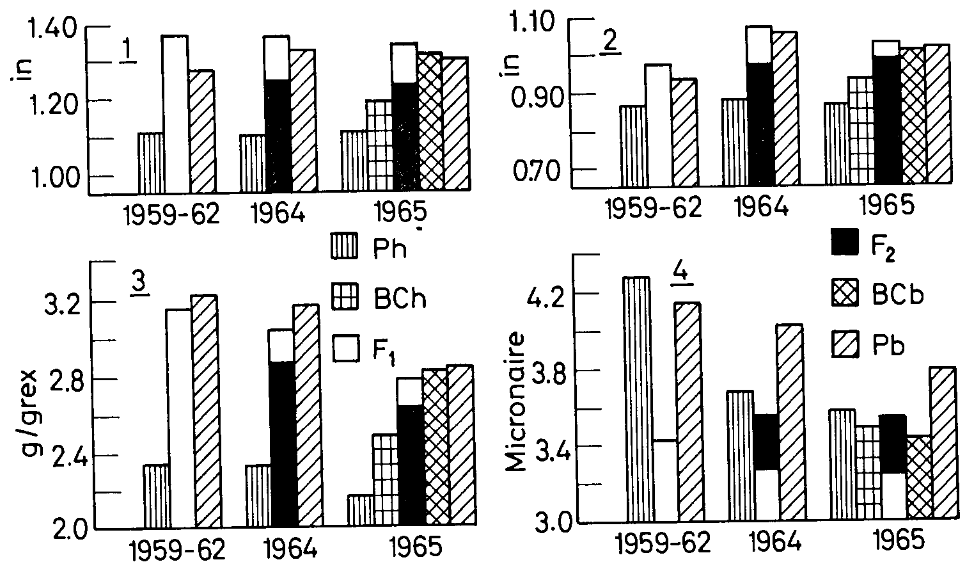

Fig. 1. Average performance of all interspecific crosses. 1. Upper-half-mean length. 2. Mean length. 3. Tensine strength, T_1. 4. Fineness.
Ph, Pb — *G. hirsutum* and *G. barbadense* parental varieties. BCh, BCb — backcrosses to these parental varieties.

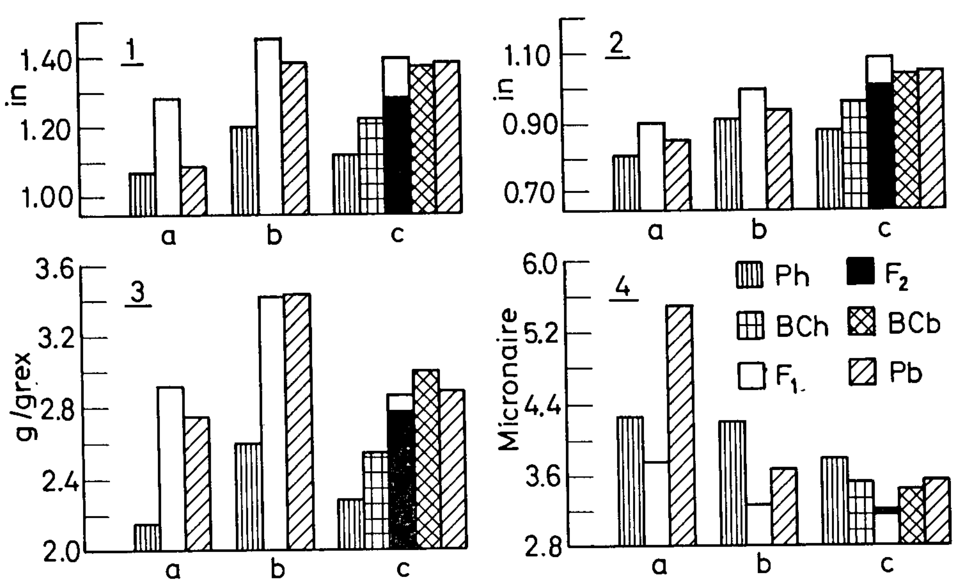

Fig. 2. Performance of some interspecific crosses. 1. Upper half-mean length. 2. Mean length. 3. Tensile strength, T_1. 4. Fineness. a — Empire W × Ashmuni, average of 1959-60. b — Acala 1517C × Pima 32, average of 1961-62. c — Acala 4-42 × Malaki, average of 1965. Ph, Pb, BCh, BCb as in Fig. 1.

Table 5. The generations and experiments in which significant (0.05 level) effects of general or specific combining ability were found.

Character	General combining ability effects of: *G. hirsutum* L. parental varieties	General combining ability effects of: *G. barbadense* L. parental varieties	Specific combining ability effects
UHM length†	F_1 (59,60,61,62,64), F_2 (65N,65G)	F_1 (59,60,61,62,65G) F_2 (64), Bc_h (65N) Bc_b (65N,65G)	F_1 (65N,65G) Bc_h (65G)
Mean length‡	F_1 (60,61,62,64) F_2 (65N,65G)	F_1 (59,60,61,62,64, 65N,65G) Bc_b (65N,65G)	F_1 (64,65G)
Uniformity ratio	F_1 (60,62)	F_1 (61,62,65G)	F_1 (65G)
Tensile strength, T_1	F_1 (60,61,62) F_2 (65G)	F_1 (59,60,61,62) F_2 (64)	F_1 (64)
Fineness, Micronaire	F_2 (65N,65G)	F_1 (59,60,61,62)	-

* Bc_h or Bc_b are backcrosses to G. hirsutum and G. barbadense varieties, respectively. Numbers in parentheses designate the experiment in which a significant effect was found. † 2.5% span length in 1964 and 1965 experiments. ‡ Secant mean length in 1964 and 1965 exiperiments.

Table 6. Estimates of genetic parameters for lint quality in 1965 N and 1965 G experiments.

		$\hat{d}$	$\hat{h}$	$\hat{i}$	$\hat{j}$	$\hat{l}$
Estimates with epistasis						
2.5% span length, in.	N	-.114*	.225*	.076*	-.001	.023
	G	-.119*	.201*	.074*	-.029*	.019
Secant mean length, in.	N	-.067*	.172*	.054*	.022	-.033
	G	-.074*	.160*	.064	-.016	.017
Uniformity ratio, %	N	1.4*	.8	.0	1.8*	-4.4
	G	1.8*	-.1	.4	0.7	0.2
Fiber strength, T_1	N	-.234*	.322	.108	.050	-.088
	G	-.414*	.370*	.028	-.042	-.079
Fineness, Micronaire	N	.100	-.955*	-.480	.155	.710
	G	.060	-.605*	-.160	.205*	-.030
Estimates with no epistasis						
Fiber strength, T_1	N	-.274*	.209*			
	G	-.380*	.345*			
Fineness, Micronaire	N	-.024	-.481*			
	G	-.104*	-.424*			

* Significantly different from zero, 0.05 level.

cluded. Its lint was relatively short (U.H.M. of 1.08 in), whereas its hybrids had long lint (U.H.M. of 1.26 and 1.32 inches in 1959 and 1960, respectively). This may explain the larger average heterosis for U.H.M found in these trials. The U.H.M. length of F_2 was slightly above the parental mean, and the deviation of F_2 from the average of F_1 and parental mean was 2 to 3% and significant. The performance of the backcrosses to *G. hirsutum* varieties was slightly above that of these varieties, whereas U.H.M. of backcrosses to *G. barbadense* was similar to that of *G. barbadense* varieties. The backcross-deviation was 2 to 3% and significant when *G. hirsutum* varieties were the recurrent parents, but when *G. barbadense* varieties were the recurrent parents backcross-deviations were smaller, and significant in only one trial.

Effects of general combining ability (g.c.a.) for U.H.M. length were significant in many cases. Progeny of Acala 4-42 and Acala 1517C had longer lint than of other varieties of *G. hirsutum* and progeny of Malaki and Pima 32 longer than of other *G. barbadense* varieties.

Examination of the genetic parameters in 1965 reveals significant values of $\hat{d}$, $\hat{h}$ and $\hat{i}$ in both trials. Additive genetic effects ($\hat{d}$) are important in the inheritance of U.H.M. length, and this may also be concluded from the clear effects of g.c.a. found. Heterosis for this trait in these F_1 hybrids is probably due to the difference between dominance and additive

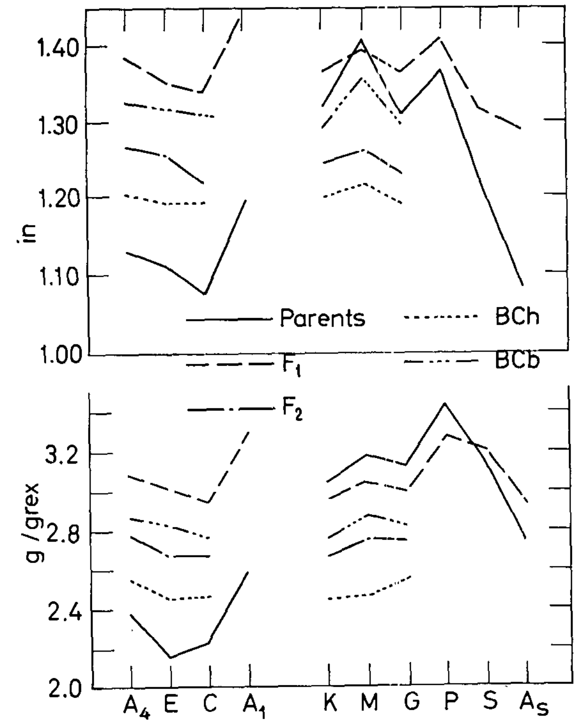

Fig. 3. Performance of parental varieties and the average performance of their progeny in the F_1, F_2, BCh and BCb generations. *G. hirsutum* varieties: A_4 = Acala 4-42, E = Empire W, C = Coker 100A, A_1 = Acala 1517C. *G. barbadense* varieties: K = Karnak, M = Malaki, G = Giza 7, P = Pima 32, S = Pima S-1, A_8 = Ashmuni. (A_4, E, C — average of all trials, F_2 and Bc data of 1965 trials only; A_1 — average of 1961-62; K, M, G — average of 1961-65, F_2 and Bc data of 1965 trials only; P — average of 1959-62; S — 1959 only; A_8 — average of 1959-60). Top: Upper-half-mean length. Bottom: Tensile strength, T_1.

× additive epistatic effects, but dominance is much more important than epistasis.

Mean Length

Results for mean length were similar to those for U.H.M. length. F_1 fibers were longer than those of either parents and heterosis was 6 to 13%. F_2 performance was slightly above parental mean, and F_2 deviation was 2 to 4%. Backcross deviations were small, and in some cases not significant. The performance of backcrosses to *G. barbadense* was similar to that of the recurrent parent. Effects of g.c.a. were generally the same as for U.H.M. length.

Significant genetic parameters found for this trait were $\hat{d}$, $\hat{h}$ and $\hat{i}$. Dominance had a more important effect than epistasis on the expression of heterosis for this trait.

Uniformity Ratio

These F_1 hybrids had, in most cases, a lower uniformity ratio than either parent, but the negative heterosis for this trait was significant only in the 1959 and 1960 trials. No clear trend can be seen in the performance of the F_2 and Bc generations for this trait. The "uniformity ratio," though important from the standpoint of the utilization of cotton lint, does not exhibit clear results because it is a ratio between two length measurements. Of the genetic parameters, only $\hat{d}$ was found to be significant in both trials, and $\hat{j}$ in one trial.

T_1, Tensile Strength

Tensile strength of F_1 hybrids was higher than the average of parental varieties (heterosis of 9 to 15%) but in most cases it was not as high as that of the *G. barbadense* parental varieties. However, when Ashmuni, and in some cases also Pima S-1 were used as parental varieties, their F_1's with varieties of *G. hirsutum* had higher T_1 values than those of either parent. This may explain why the average F_1 performance in the 1959 and 1960 experiments was slightly above that of the *G. barbadense* parents. When Pima 32, Karnak, Malaki or Giza 7 were the parental varieties, F_1 lint strength was slightly lower or approximately equal to that of the *G. barbadense* parents.

F_2 performance was very near the average of mid-parent and F_1, and backcross performance was very near to the mean of F_1 and the recurrent parent. No significant F_2 or Bc deviations were found for lint strength.

Some effects of g.c.a. were significant for T_1 strength. Progeny of Acala 4-42, and in some trials also of Acala 1517C, had stronger lint than progeny of other *G. hirsutum* varieties. Progeny of Malaki, and in 1959 and 1960 also of Pima 32, had stronger lint than progeny of other *G. barbadense* varieties.

The genetic parameters for epistasis were not significant, and therefore the model with no epistasis, given by Hayman (5), may be used. This model gave a very good fit to the results of mean generation performance. The large additive and dominance effects are sufficient to explain the g.c.a. effects and the magnitude of heterosis found for lint strength.

Fineness of Lint

The interspecific F_1 hybrids had a much lower Micronaire measurement than that of either parental variety (a negative heterosis of 12 to 19%). F_2 performance was near the average of F_1 and parental mean, and had no significant F_2 deviation was found. These findings were similar whether the *G. barbadense* parental varieties had fine lint (Pima 32 or Malaki) or coarse lint (Ashmuni). The fineness of the backcrosses was in most cases intermediate between that of F_1 and the recurrent parent, and results for Bc deviations were not consistent. Significant effects of g.c.a. were found in very few cases.

Of the genetic parameters examined, $\hat{h}$ (for dominance effects) was large, significant and negative. The additive effects, represented by $\hat{d}$ parameter, were very small because both parental varieties were similar. The parameters for epistasis were quite large, but not significant statistically (except for $\hat{j}$ in one trial). The model with no epistasis, however, did not give a good fit to the observed generation means. The deviations from this model could have been caused either by epistasis or by experimental error. The effect of environmental factors on lint fineness is quite large, and deviations due to experimental error may be relatively large. Our results indicate that dominance is more important than epistasis for lint fineness in interspecific crosses; the presence of epistasis was not clearly demonstrated.

Implications on Breeding Methodology

The practical feasibility of utilizing the heterosis for lint yield in the interspecific crosses by using F_1 hybrid varieties has been discussed previously (6, 7). The results reported here indicate that these F_1 hybrids are likely to have good lint quality characters. The additive effects and the significant g.c.a. effects found for lint length and tensile strength (T_1) indicate the importance of selecting the parental varieties on the basis of their having a high level of these traits. F_1 performance for lint length would be expected to be better than the better parental variety, whereas tensile strength would be near to that of the *G. barbadense* parent in most cases. F_1 hybrids are expected to have very fine lint, outside the range of the parental varieties, but selection of parents would not affect appreciably F_1 performance for this trait (except, possibly, when 'Ashmuni' is used as one of the parents).

Some breeders are trying to improve the lint quality of upland cotton varieties by crossing them with *G. barbadense,* and following this by repeated backcrossing to the upland parent. Our findings that additive genetic effects are important for lint length and tensile strength indicate that there is a good chance of transferring these traits from *G. barbadense* to *G. hirsutum* varieties, if suitable selection procedures were adopted. The *G. barbadense* parents included in such a breeding program should be selected on the basis of a high level of expression of these traits. A possible linkage of lint quality with any factors affecting lint yield may, of course, complicate the selection procedure. Lint fineness did not show appreciable additive effects in our study. It may be concluded that there is a very small chance of transferring this trait from *G. barbadense* to *G. hirsutum* by conventional breeding methods, when the range of parental varieties included in our study is used.

LITERATURE CITED

1. Ali, M., and C. F. Lewis. 1962. Effects of reciprocal crossing on cytological and morphological features of interspecific hybrids of *Gossypium hirsutum* L. and *G. barbadense* L. Crop Sci. 2:20-22.
2. Balls, W. L. 1912. The cotton plant in Egypt. Macmillan and Co., Ltd., London.
3. Barnes, C. E., and G. Staten. 1961. The combining ability of some varieties and strains of *Gossypium hirsutum.* New Mex. Agr. Exp. Sta. Bull. 457.
4. Fryxell, P. A., G. Staten, and J. H. Porter. 1958. Performance of some wide crosses in *Gossypium.* New Mex. Agr. Exp. Sta. Bull. 419.
5. Hayman, B. I. 1958. The separation of epistatic from additive and dominance variations in generations means. Heredity 12:371-390.
6. Marani, A. 1963. Heterosis and combining ability for yield and components of yield in a diallel cross of two species of cotton. Crop Sci. 3:552-555.
7. ————. 1967. Heterosis and combining ability in intraspecific and interspecific crosses of cotton. Crop Sci. 7:519-522.
8. ————. 1968. Heterosis and inheritance of quantitative characters in interspecific crosses of cotton. Crop Sci. 8:299-303.
9. Ramey, H. H., and P. A. Miller. 1966. Partitioned genetic variances for several characters in a cotton population of interspecific origin. Crop Sci. 6:123-125.
10. Stroman, G. N. 1961. An approach to hybrid cotton as shown by intra- and interspecific crosses. Crop Sci. 1:363-366.