Published September, 1961

Comparative Effectiveness of Three Breeding Methods in Modifying Coarseness of Cotton Fiber[1]

J. D. Bilbro, Jr.[2]

THE present-day cotton breeder has several breeding methods from which to choose. Each of these methods has certain advantages and disadvantages, and no one method seems to be superior in attaining all breeding objectives. It seems logical, therefore, that breeders should in some cases evaluate two or more methods as to their relative effectiveness in resolving certain types of breeding problems.

The relative effectiveness of a breeding method can be evaluated in terms of progress effected and also in terms of time and labor required to make this progress.

The primary objective of this study was to evaluate the relative effectiveness of three breeding methods in modifying fiber coarseness. The breeding methods were recurrent selection, selection-while-inbreeding, and mass selection.

REVIEW OF LITERATURE

Recurrent, pedigree, and mass selection methods have been used extensively by breeders. (The pedigree method when used with self-pollination might be more properly termed "selection-while-inbreeding.") However, in most cases no attempt was made to compare the effectiveness of two or more breeding methods concurrently.

Sprague and Brimhall (4) in 1950 and Sprague et al. (5) in 1952 published results of studies of the relative effectiveness of selection within selfed lines and recurrent selection for increasing oil content of the corn kernel. They concluded that recurrent selection was superior.

Fetooh[3] compared recurrent selection with pedigree selection in a study of breeding for high and low fiber strength in populations derived from a three-species cotton hybrid. In view of the results obtained, Fetooh stated: ". . . pedigree selection is recommended when the main object is to produce strains with exceptionally high levels of a certain character. Recurrent selection, on the other

---

[1] Journal Paper No. 552, Oklahoma State University, Agricultural Experiment Station, Stillwater, Oklahoma. Contribution from the Department of Agronomy. Part of a thesis submitted by the author in partial fulfillment for the Ph.D. degree. Received for publication Jan. 16, 1961.

[2] Research Agronomist, Crops Research Division, ARS, USDA, Lubbock, Texas, (formerly, Graduate Assistant, Oklahoma State University). The author is indebted to John M. Green, formerly Professor, Oklahoma State University, and Research Agronomist, Crops Research Division, for his assistance in conducting this experiment.

[3] Fetooh, A. A. The relative effectiveness of two systems of breeding for high and low fiber strength in cotton. Unpubl. Ph.D. Thesis, Texas A. & M. College, College Station, Texas. 1955.

hand, is more effective for selection on a broad-base, especially in material derived from interspecific hybrids."

Johnson and Goforth (3) compared the results from a cycle of recurrent selection with those from the fourth generation of controlled mass selection in sweetclover. With reference to combining ability, they stated: "From these results it may be inferred that four generations of visual selection for desirable plants in the second year was not as effective as a single cycle of recurrent selection based upon progeny performance."

MATERIALS AND METHODS

Gene action, heritability, and inheritance of fiber coarseness—To evaluate critically the respective breeding methods it was deemed necessary to have information about the inheritance, heritability, and type of gene action governing fiber coarseness. Since very little pertinent information was found in the literature, a test was conducted to obtain this information.

The parental strains, CR–2 and 4–24 (breeding strains from Acala 5 and Stormmaster, respectively), were cross-pollinated in the summer of 1954 and the crossed seed harvested. These seeds and seeds of the parents were planted in the Cotton Winter Breeding Facility, Iguala, Mexico, in the fall of 1954. The F_1 plants were self-pollinated and also crossed to each parent. The parents were also recrossed to produce additional F_1 seeds. The following entries were grown in 1955 and 1956: the parents, the F_1, the F_2, and both backcrosses. The experimental design was a randomized complete block with 10 replications. Warner's method (6) was used to estimate the heritability of fiber coarseness; the type of gene action was tested by the method of Charles and Smith (1), and the means and frequency distributions of micronaire units were studied to determine the type of inheritance.

Recurrent selection vs. selection-while-inbreeding—The study of recurrent selection vs. selection-while-inbreeding was begun in 1953 by selecting on the basis of desirable agronomic type 101 plants from an F_2 population of CR–2×4–24, grown at the Oklahoma Cotton Research Station at Chickasha. Of the 101 plants, 83 had both self- and open-pollinated bolls, whereas the remaining 18 had only open-pollinated bolls. The plants were harvested individually and the seed cotton samples from the open-pollinated and those from self-pollinated bolls were ginned separately on a small, 8-saw gin. The lint samples from the open- and self-pollinated bolls from the same plant were combined to have sufficient lint for a micronaire analysis. (The micronaire is an instrument now widely used in the cotton trade to determine fiber coarseness.) One sample too small for analysis was discarded. Micronaire values were determined on the remaining 100 plants. The 10 plants that had produced the coarsest lint were transplanted from the field to the greenhouse at Chickasha. During the winter of 1953–54 the surviving 9 plants were crossed in 28 of the 36 possible combinations. Self-pollinated seeds from each of the 9 plants were saved.

The following summer the seeds of the 28 crosses were planted in duplicate, 50-foot rows and the resulting plants irrigated as needed. In the fall 100 plants were selected on the basis of desirable agronomic type with one or more plants being taken from each of the 28 crosses. Again the 10 plants that had produced the coarsest line were transplanted to the greenhouse. The 8 surviving plants were intercrossed in all 28 of the possible combinations. Self-pollinated seeds from each of the 8 plants were saved.

Self-pollinated seeds were available from only 7 of the 10 field-grown F_2 plants selected to begin the recurrent selection program. To initiate the selection-while-inbreeding program the self-pollinated seeds from each of these seven plants were planted in individual F_3 progeny rows at Iguala, Mexico, in the winter of 1953–54. Self-pollinated seeds from the 19 plants (representing 5 of the original 7 F_2 plants) that produced the coarsest lint were planted at Chickasha. At time of harvest 98 plants were selected, from 18 of the 19 F_4 lines, on the basis of agronomic type. Self-pollinated seeds from the 11 plants (representing 4 F_2 plants and 8 F_4 lines) that had produced the coarsest lint were planted at Iguala, Mexico, in the winter of 1954–55. Self-pollinated seeds were saved from the 10 plants (representing 2 of the F_2 plants and 3 of the F_5 lines) that had produced the coarsest lint.

To compare the relative effectiveness of the two breeding methods a randomized block experiment with 8 replications was conducted under irrigation at Chickasha in 1955 and repeated in 1956, with a different randomization, at the Agronomy Farm near Perkins. (This test was rain-grown except for two irrigations in late August.) Plot size was 2 rows, 40 inches apart and 20 feet long. The plants were spaced approximately two feet apart within the rows. Entries in the test were the parents of the original cross, the F_4 (bulk of 19 F_3 plants) and F_6 (bulk of 3 F_5 lines) generations, recurrent selection cycles I and II, and a composite sample of self-pollinated seeds from the intercross parents of each recurrent selection cycle. The plants were harvested individually and the micronaire values determined. As the number of plants per row was not constant, row means were used for the analysis of variance. A combined analysis was made on entry totals from the two tests. Duncan's (2) multiple range test was applied to the means. The coefficient of inbreeding for the second cycle of recurrent selection was calculated from a formula given by Sprague et al. (5).

Recurrent selection vs. mass selection—Beginning in 1953 with an F_4 population of Oklahoma Special×Lankart 57 two cycles of recurrent selection were made in the manner given in the previous section. However, in this case all 10 plants selected as intercross parents of the respective cycles lived. For the first cycle, 30 of the 45 possible intercross combinations were made and, for the second, 42 of the 45 possible ones.

The mass selection program was begun by bulking 19 grams of the open-pollinated seeds from each of the 10 plants used to initiate the recurrent selection program. In 1954 these seeds, designated as "mass selection I" seeds, were planted at a low rate in a small, isolated block on the Agronomy Farm near Perkins. The amount of naturally effected cross-pollination for this area is approximately 30%. Selection procedures were the same as those used in the recurrent selection program. Subsequently, mass selection cycles II and III were made in 1955 and 1956, respectively. Field-testing procedures were the same as those described under "Recurrent selection vs. Selection-while-inbreeding." Entries in the 1955 test were the parents of the original cross, the two cycles of recurrent selection, a composite sample of self-pollinated seeds from the intercross parents of each recurrent selection cycle, and mass selection cycles I and II. The 1956 test included these same entries and also mass selection III. The data were analyzed as in the previous section. In the combined analysis of the 1955–56 data, mass selection III was omitted.

RESULTS

Gene action, heritability, and inheritance of fiber coarseness—The analysis of variance of micronaire values showed that there were highly significant differences among entries in both the 1955 and 1956 tests and also in the combined data. The entries×years interaction was not significant. The entry means and multiple range results for the 1955, 1956, and combined data are given in Table 1. The observed and calculated micronaire units are given in Table 2.

Frequency distributions were unimodal for the parents and derived populations.

Heritability estimates were 30.4%, 73.6%, and 60.7% for 1955, 1956, and the combined data, respectively.

Recurrent selection vs. selection-while-inbreeding—The mean micronaire units for entries in the 1955 and 1956 tests and for the combined data are given in Table 3. The F_6 generation produced the coarsest lint in both years and the F_4 generation ranked second (with CR-2) in 1955 and third in 1956. The recurrent selection II populations had higher micronaire units than the recurrent selection I populations in both years. The entry×years mean square of the combined data was highly significant; and CR-2 showed the greatest genotype-environment interaction by ranking second (with the F_4 generation) in 1955 but ranking seventh in 1956. 4–24 was seventh and eighth in rank in 1955 and 1956, respectively.

The combined data analysis showed that the F_6 generation produced the coarsest lint. The F_4 generation had a significantly higher mean than 4–24. There were no significant differences among the remaining means.

The coefficient of inbreeding in recurrent selection II was 4.72%. The F_4 generation traced back to 5 F_2 plants and the F_6 traced back to 2. Thus, the F_6 generation was highly inbred.

Table 1—Mean micronaire values for CR–2, 4–24, and 4 populations derived from a cross between them.

1955		1956		Combined	
Entry	Mean*	Entry	Mean	Entry	Mean
CR-2	4.16 a†	CR-2	5.13 a†	CR-2	4.65 a†
F_1 × CR-2	4.11 a	F_1	5.13 a	F_1 × CR-2	4.60 ab
F_1	3.91 b	F_1 × CR-2	5.08 ab	F_1	4.52 bc
F_2	3.89 b	F_2	4.95 ab	F_2	4.42 cd
F_1 × 4-24	3.88 b	F_1 × 4-24	4.89 bc	F_1 × 4-24	4.36 de
4-24	3.84 b	4-24	4.71 c	4-24	4.27 c

* Calculated on a per-row basis. † Any two means followed by the same letter are not significantly different at odds of 19:1.

Table 2—Mean micronaire values for CR–2, 4–24, and 4 populations derived from a cross between them compared with calculated values assuming arithmetic and geometric gene action.

Year and type of population	Observed mean*	Calculated mean	
		Arithmetic	Geometric
1955:			
4-24	3.83 ± .02994	-	-
F_1	3.90 ± .03450	3.99	3.99
F_2	3.94 ± .04232	3.95	-
F_1 × 4-24	3.86 ± .03219	3.87	3.89
F_1 × CR-2	4.10 ± .04003	4.03	4.05
CR-2	4.15 ± .04052	-	-
1956:			
4-24	4.72 ± .03263	-	-
F_1	5.10 ± .03317	4.92	4.92
F_2	4.93 ± .05090	5.01	-
F_1 × 4-24	4.87 ± .03786	4.91	4.82
F_1 × CR-2	5.07 ± .04097	5.11	5.02
CR-2	5.12 ± .04429	-	-
1955 and 1956 combined:			
4-24	4.28 ± .02205	-	-
F_1	4.50 ± .02392	4.46	4.45
F_2	4.44 ± .03379	4.48	-
F_1 × 4-24	4.37 ± .02480	4.39	4.36
F_1 × CR-2	4.58 ± .02878	4.57	4.54
CR-2	4.64 ± .03028	-	-

* Calculated on an individual plant basis.

Table 3—Mean micronaire values for entries grown to determine the relative effectiveness of recurrent selection and selection-while-inbreeding in modifying fiber coarseness.

1955		1956		Combined	
Entry	Mean	Entry	Mean	Entry	Mean
F_6	4.68 a†	F_6	6.12 a†	F_6	5.40 a†
F_4	4.32 b	R.S. II	5.52 b	F_4	4.90 b
CR-2	4.32 b	F_4	5.48 b	R.S. II	4.84 bc
R.S. II P.*	4.19 bc	R.S. II P.	5.40 bc	R.S. II P.	4.79 bc
R.S. II	4.16 bc	R.S. I P.	5.33 bc	R.S. I P.	4.72 bc
R.S. I P.	4.12 c	R.S. 1	5.27 cd	CR-2	4.71 bc
4-24	4.05 c	CR-2	5.11 d	R.S. 1	4.65 bc
R.S. I	4.04 c	4-24	4.76 e	4-24	4.41 c

* P. denotes intercross parents. † Any two means followed by the same letter are not significantly different at odds of 19:1.

Recurrent selection vs. mass selection—Mean micronaire values for entries in the 1955 and 1956 tests and for the combined data are given in Table 4.

The differences among the micronaire units of the entries in the 1955 test were rather small and most of them were not statistically significant.

In the 1956 test mass selection III had the highest micronaire value. The ranking of the other entries was essentially the same as in the 1955 test except for mass selection II which was seventh in rank rather than third as in 1955. The entries × years mean square of the combined data was highly significant, indicating a genotype-environment interaction. This interaction was probably due largely to the change in rank of the mass selection II populations.

In the combined data (mass selection III excluded) Lankart 57 was significantly lower in micronaire value than the other entries. The differences among the remaining entries were not significant.

The coefficient of inbreeding for recurrent selection II was 4.8%. The amount of inbreeding for the mass selection populations could not be estimated.

DISCUSSION

The results of the study of the type of gene action controlling fiber coarseness were inconclusive. The parents used in the study were similar in micronaire values; hence, the calculated arithmetic and geometric values did not differ sufficiently to make a reliable test for type of gene action.

There was no clear indication of dominance as indicated by the relations of the observed means of F_1 and segregating generations to the calculated values. The unimodal frequency distributions of micronaire units in all populations indicated fiber coarseness was quantitatively inherited. Stith[5] and Nakornthap[6] reported similar findings.

Heritability estimates from the data obtained from the respective years differed greatly. The estimate from 1956 data was more than twice as large as that from the 1955 data. This difference was the result of a greater increase in 1956 of within-row variance of the F_2 than in the two backcross populations. The estimate made from the combined data, 60.7%, probably had the widest application since it represents the "average" of data from two completely different environments. This figure for heritability is comparable to those obtained by Stith[5] but somewhat higher than those reported by Manning[7] and Nakornthap.[6]

The character under selection in these breeding studies, as pointed out previously, was quantitative in inheritance and had a high heritability; therefore, selection on an individual plant basis (without progeny testing) should have been effective in increasing the frequency of genes for this character regardless of the breeding procedure employed. The results of the breeding method studies indicate this to be a correct assumption.

In four generations of selection and inbreeding the mean fiber coarseness was raised significantly above the mean of

[5] Stith, L. S. Heritability and interrelationships of some quantitative characters in a cross between two varieties of *Gossypium hirsutum*. Unpub. Ph.D. Thesis, Iowa State College, Ames, Iowa, 1955.

[6] Nakornthap, Arth. Inheritance of certain economic characters in a cross between a cultivated upland variety of cotton, *Gossypium hirsutum*, and a strain derived from a three-species hybrid of *Gossypium hirsutum*, *G. thurberi* and *G. hirsutum*. Unpub. Ph.D. Thesis, Texas A. & M. College, College Station, Texas, 1954.

[7] Manning, C. W. Selection techniques in cotton breeding. Unpub. Ph.D. Thesis, Iowa State College, Ames, Iowa, 1954.

Table 1—Mean micronaire values for entries grown to determine the relative effectiveness of recurrent selection and mass selection in modifying fiber coarseness.

1955		1956		1956*		Combined*	
Entry	Mean	Entry	Mean	Entry	Mean	Entry	Mean
R.S. II P †	4.00 a‡	M.S. III	5.25 a‡	Okla. Special	5.15 a‡	Okla. Special	4.56 a‡
Okla. Special	3.96 a	Okla. Special	5.15 ab	R.S. II	5.09 ab	R.S. II P.	4.53 a
M.S. II	3.94 ab	R.S. II	5.09 abc	R.S. II P.	5.07 ab	R.S. II	4.51 a
R.S. II	3.93 ab	R.S. II P.	5.07 bc	M.S. I	4.96 bc	M.S. I	4.41 a
R.S. I P.	3.92 ab	M.S. I	4.96 cd	R.S. I	4.96 bc	M.S. II	4.40 a
M.S. I	3.86 ab	R.S. I	4.96 cd	M.S. II	4.85 c	R.C. I P.	4.37 a
R.S. I	3.76 bc	M.S. II	4.85 d	R.S. I P.	4.83 c	R.S. I	4.36 a
Lankart 57	3.63 c	R.S. I P.	4.83 d	Lankart 57	4.39 d	Lankart 57	4.01 b
		Lankart 57	4.39 e				

* Omitting M.S. III † P. denotes intercross parents. ‡ Any two means followed by the same letter are not significantly different at odds of 19:1.

the high parent. The limit of improvement was probably not reached but was theoretically being approached as the F_6 generation traced back to only two F_2 plants and, therefore, was highly inbred.

The total change in gene frequency effected by the recurrent selection procedure was not so great as that effected by the selection-while-inbreeding procedure. The mean of recurrent selection II exceeded the mid-parent and mean of the high parent only in 1956. However, the best indication of the relative progress made by the respective breeding methods can be obtained by comparing the means of the F_4 generation with those of recurrent selection II. In this case each breeding procedure will have been through an equal number of cycles. If this comparison is made neither method seems superior, although both have been effective in increasing the frequency of genes for lint coarseness.

It should be pointed out that two cycles of recurrent selection with a slight amount of inbreeding were as effective as two generations of selection-while-inbreeding in which the degree of inbreeding was rather high. This indicates that the frequency of genes for fiber coarseness can be increased without excessive inbreeding. The findings in this respect are not directly comparable to those of other workers, particularly Fetooh[3] and Sprague et al. (5).

Results of the recurrent selection vs. mass selection study failed to indicate a definite superiority, from the standpoint of progress, for either method. None of the mass selection or recurrent selection populations was significantly different from the mid-parent value in 1955 or in the combined data. However, in 1955, recurrent selection II and mass selection II were much nearer to the high parent value than to the mid-parent value. This indicates the breeding methods had increased the frequency of genes for lint coarseness. In 1956, the means of recurrent selection II and mass selection III were significantly higher than the mid-parent but the mean of mass selection II was not.

There are no published reports of studies comparing recurrent selection and mass selection directly comparable with this study. However, the results of Johnson and Goforth's work (3) with sweetclover may be mentioned. These authors inferred, with reference to combining ability, that one cycle of recurrent selection based upon progeny performance was superior to four generation of visual (mass) selection for desirable plants.

Although the parental material used in the two studies (i.e., recurrent selection vs. selection-while-inbreeding and recurrent selection vs. mass selection) were not the same, progress in increasing frequency of genes for fiber coarseness was made in both. However, the length of time and amount of labor necessary for the production of a cycle, or generation, were not the same for the respective breeding methods. One "growing season" and approximately 20 man-hours of labor were required for a cycle of mass selection; one growing season and approximately 60 man-hours of labor were required for one generation of selection-while-inbreeding; and two growing seasons and approximately 300 man-hours of labor were required for one cycle of recurrent selection.

Thus from the standpoint of progress made and time and labor required, mass selection was the most efficient of the three methods used in these studies and selection-while-inbreeding and recurrent selection followed in that order. However, to determine which breeding method could have increased the frequency of genes for fiber coarseness to the highest level (ultimate maximum gain) additional generations and cycles of the respective methods would have been necessary.

SUMMARY AND CONCLUSIONS

A study was made to determine the relative effectiveness of recurrent selection, selection-while-inbreeding, and mass selection for increasing the frequency of genes for fiber coarseness. For the study of recurrent selection vs. selection-while-inbreeding, two cycles of recurrent selection and four generations of selection-while-inbreeding were completed, beginning with an F_2 population of CR–2×4–24. For the study of recurrent selection vs. mass selection, 2 cycles of recurrent selection and 3 cycles of mass selection were completed, beginning with an F_4 population of Oklahoma Special×Lankart 57.

The inheritance of fiber coarseness was studied using the parental, F_1, F_2, and backcross populations of the cross CR–2×4–24.

The relative progress made by the respective breeding methods was determined by conducting replicated tests at a different location in each of two years. Also the breeding methods were compared as to time and labor requirements.

The conclusions drawn from these studies may be summarized as follows:

(a) Fiber coarseness is quantitatively inherited and has a relatively high degree of heritability.

(b) All three breeding methods were effective in increasing the frequency of genes for fiber coarseness.

(c) From the standpoint of time and labor required, mass selection was the most efficient method and selection-while-inbreeding and recurrent selection followed in that order.

(d) With respect to actual breeding progress, the selection-while-inbreeding method was superior to the recurrent selection method; recurrent selection and mass selection did not appear to differ significantly in progress effected.

(e) A genotype-environment interaction was indicated by the changes in rank among the entries from environment to environment.

(f) Additional cycles, or generations, would have been necessary to determine which breeding method could have effected the maximum increase in frequency of genes for fiber coarseness.

LITERATURE CITED

1. Charles, D. R., and Smith, H. H. Distinguishing between two types of gene action in quantitative inheritance. Genetics. 24:34–48. 1939.
2. Duncan, D. B. Multiple range and multiple F tests. Biometrics. 11:1–42. 1955.
3. Johnson, I. J., and Goforth, Foy. Comparison of controlled mass selection and recurrent selection in sweetclover, *Melilotus officinalis*. Agron. J. 45:535–539. 1953.
4. Sprague, G. F., and Brimhall, B. Relative effectiveness of two systems of selection for oil content of the corn kernel. Agron. J. 42:83–88. 1950.
5. ————, Miller, P. A., and Brimhall, B. Additional studies of the relative effectiveness of two systems of selection for oil content of the corn kernel. Agron. J. 44:329–331. 1952.
6. Warner, J. N. A method for estimating heritability. Agron. J. 44:427–430. 1952.