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Influence of Lint Percentage, Boll Size, and Seed Size on Lint Yield of Upland Cotton with High Fiber Strength[1]

T. W. Culp and D. C. Harrell[2]

ABSTRACT

Our major objectives in breeding cotton (*Gossypium hirsutum* L.) have been to change negative genetic associations between lint yield and fiber strength, and lint yield and length. We also find an association between low lint percentage and extra-long (above 35 mm) fiber length. With the introduction of the C 6-5 breeding line into the cotton breeding program at the Pee Dee Exp. Stn. in South Carolina in 1955, the latter association was broken.

Through a program of hybridization and selection, lint percentage and lint yield of the PD lines were raised 5 and 12%, respectively. The introduction of C 6-5 germplasm was accompanied by increases in seed and boll size. The selection of the line, AC 241, caused a reduction in boll and seed size; however, this line has fruit and seeds somewhat larger than desired. We are currently pursuing a program to reduce boll and seed size through hybridization of PD lines with southeastern commercial cottons.

***Additional index words:* *Gossypium hirsutum* L., Yield components, Linkage, Breeding, Selection.**

CULP and Harrell (6, 7) recently reported 25 years of work aimed at increasing, or restoring, the yield of upland cotton (*Gossypium hirsutum* L.), while retaining a portion of the *G. arboreum* L. $\times$ *G. thurberi* Tod. fiber strength of Beasley's (1) trispecies hybrid. Some 14 breeding lines and cultivars, developed in the 40-year Pee Dee cotton-breeding program, showed a lint yield increase of 45 to 55%, with a decrease of 30 to 40% (40 to 50 units) in yarn strength relative to that of the first satisfactory selections derived from crosses with trispecies hybrids.

Although some fiber and yarn strength has been sacrificed as lint yields have advanced, recent breeding lines (10) have equaled adapted southeastern cultivars in yield, while greatly surpassing them in fiber and yarn strength. Moreover, these breeding lines have equaled, or exceeded, the fiber properties and yarn strength of the high quality check, Pee Dee 2165, which had the best combination of fiber properties and lint yield in the Pee Dee program in 1965.

The changing technology of the textile industry (12) has made new demands on cotton fibers, particularly in regard to tensile strength. Some requirements for high fiber strength have been satisfied by blending with man-made fibers (4), but we still need high fiber strength in medium staple cotton, to offset the losses that result from durable press treatments. Since we have progressed significantly in increasing yields while maintaining a desired level of fiber quality (10), we are closer to satisfying the demands of the textile industry while simultaneously meeting the wishes of the cotton producer.

In our efforts to further improve lint yields while maintaining a desired level of fiber quality, we have recently emphasized yield components, other plant characteristics, and their relationships to lint yield in high fiber strength cottons. Our objective was to investigate changes since 1945 in lint percentage, boll size, and seed size of selected breeding lines, as they and their progenies were subjected to selection pressure for yield, lint percentage, and fiber quality in the Pee Dee breeding program. Boll and seed size were allowed to vary at random, except plants with extremely large or small bolls and seeds were eliminated from the program. A knowledge of changes in these yield components and in the plant characteristics that influence them, should be helpful in future breeding plans for improving yield and fiber strength of PD lines. This information also should be helpful to many breeders across the Cotton Belt who are using PD breeding stocks in their cotton improvement programs.

MATERIALS AND METHODS

The pedigree breeding system has been used to develop most PD lines (6). These lines can be traced to several crosses (7) between TH 108 (K)[3], TH 171 (K), 'Earlistaple', 'Sealand,' and AHA 6-1-4. By 1952, five extra-long staple, high fiber strength lines (A, F, J, N, and T) had been developed and yield-tested. These lines are considered as cycle 1 selections for this study. Cycle 1 selections were intercrossed, and the following lines (cycle 2 selections) were among those selected and yield-tested by 1955: AE, AF, AN, AT, FJ, and FT. Some of these were further intercrossed, and FJA and FTA (cycle 3 selections) were added to the group by 1958. During this period, the California breeding line, C 6-5 (3) was introduced to improve the lint percentage of the PD stocks. This series of crosses led to the development

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[2] Research agronomists, ARS-USDA, Pee Dee Exp. Stn., Florence, SC 29501.

[3] Letters represent the breeding stocks as follows:

A	= KSE (Hybrid 313)	M	= Coker 100 A
C	= C 6-5	N	= KPE (Hybrid 482)
D	= Dixie King	O	= Atlas
E	= Earlistaple	P	= AHA 6-1-4
F	= KPSE (Hybrid 330)	Ro	= Carolina Queen
G	= Auburn 56	R	= Coker 201
Ho	= Coker 413	S	= Sealand
H	= Coker 421	T	= KPE (Hybrid 304)
J	= KPE (Hybrid 363)	V	= Coker 310
K	= Triple Hybrid	W	= Empire WR

of AC and CE by 1960. Further intercrossing produced cycle 4 selections AC.FJA, AC.NA, and AC.FTA. The first two of these lines were released as noncommercial breeding stocks in 1966 (17). Line AC also was crossed on 'Dixie King' and 'Auburn 56' in 1961, and these lines (cycle 5 selections), in turn with other PD lines, were crossed on 'Coker 421' and 'TH 149' in 1965. Recent outstanding selections (cycle 6 selections) (10) from these crosses were tested in 1970, 1971, and 1972.

The testing program used to evaluate PD breeding lines and strains was outlined recently (7). Lint yields and yarn strength of these breeding lines were reported elsewhere (6, 7, 10). Lint percentage, boll size, and seed index were determined in one or more trials for three or more years on the Pee Dee Exp. Stn., Florence, S.C., from 1956 to 1972. A randomized block design with four to eight replications was used for each test. The yearly mean value for lint percentage, boll size, and seed index for each breeding line consisted of the average value of all selections within a line in all tests grown in that year.

The bolls of breeding line C 6-5 were extremely large and did not open properly at Florence. Estimates of lint percentage, boll size, and seed index were obtained from 1954 F_4 progeny rows grown at the U.S. Cotton Field Stn., Shafter, Calif. (3).

'Coker 100 A' from 1956 to 1964 and 'Coker 201' from 1962 to 1972 (tested as 'Carolina Queen' from 1962 to 1966) were grown as checks in all tests during the respective periods. Variation in characters was studied by comparison of breeding lines as a percentage of the check, Coker 201. The mean value, obtained by an average of strains, tests, and years, was considered the most reliable estimate of lint percentage, boll size, and seed index for each breeding line.

For boll sample data, a 25-boll sample consisting of unweathered bolls from the middle of the fruiting zone of the plants was hand-picked from four to six replications of each test. Boll samples from two replications (1 and 2, 3 and 4, or 5 and 6) were combined at ginning to make two or three 50-boll samples. Seed cotton/plot was obtained with a spindle-type picker.

Boll sample data consisted of: i) lint-percentage, weight of lint ginned from a sample of seed cotton, expressed as a percentage of the weight of seed cotton; ii) boll size, weight/boll (g); and iii) seed index, weight of 100 seeds (g). Because seed index was not measured for breeding lines in yield tests before 1964, an estimate for those years was obtained by averaging the seed index of individual F_2, F_3, and F_4 plants.

Possibly, estimates of lint percentage, boll size, and seed index are overestimates, because our data are from sound, well-developed open bolls, whereas seed cotton/plot contains all types of bolls. However, no adjustments were considered necessary because we are primarily interested in the relative differences among breeding lines and check cultivars.

RESULTS AND DISCUSSION

Lint Percentage

The lint percentage of check cultivars and major breeding lines developed in the Pee Dee cotton improvement program at Florence, S.C. are given in Fig. 1. Minor improvements in lint percentage were made during cycle 1 selection of breeding lines A, F, J, N, and T. This improvement would not account for the major increases in yield, however. Eliminating rank growth, late maturity, and inefficient boll retention typical of triple hybrid breeding lines resulted in more harvestable bolls/area of production.

Breeding lines selected from crosses with line A (cycle 2 selections AE, AF, and AN) generally showed a slight improvement in lint percentage and lint yield over parental lines. Selections from the combinations of lines FJA and FTA (cycle 3 selections) also had similar increases in lint percentage and yield. These selections, although consistently higher in yield, seldom had lint percentages much higher than those of the extra-long staple stocks, which averaged 2 to 5% below medium staple southeastern cultivars.

The adverse relationship between extra-long staple and low lint percentage has been a persistent problem in cotton improvement programs. Jenkins and Bailey (11) succeeded in breaking this deleterious association in Sea Island cotton (*G. barbadense* L.) in the early 1950's, but this high lint percentage was never transferred to commercial cotton cultivars. They selected stable extra-long staple breeding lines with 40 to 45% lint from a complex intraspecific cross with 'Puerto Rican Sea Island,' 'Earlipima,' Egyptian lines, 'Tanguis,' Guatamala lines, and 'Pima 32.' Culp and Harrell (6) used one of these breeding lines with high lint percentage in the complex backcrossing and composite-crossing program from which breeding line Q_1 (6) or Pee Dee 4461 (20) was selected.

In recent years, other researchers and commercial breeders have successfully increased fiber length while improving lint percentage two to three units. A major improvement in lint percentage of PD lines came with the introduction of breeding line C 6-5 into the Pee Dee program in 1955. Although a very poor agronomic type for the Southeast, C 6-5 had excellent fiber strength and high lint percentage, 39.5 (3). From the AC crosses, breeding lines with 39% lint and yield increases of 12% above the previous highest yielding high fiber strength lines were selected. (In 1960, we considered the development of high strength lines that yielded 85% of the check, Coker 100 A, a major breeding accomplishment. This yield, however, was considerably short of our goal of 100%).

The AC lines combined well with cycle 3 selections FJA, FTA, NA, G, and D. There were minor reductions in lint percentages, but lint yields were increased substantially. Breeding lines from cycle 4 selections, Pee Dee 2165 (AC.FJA), Pee Dee 0259 (AC.NA), and Pee Dee 4381 (AC.G), released in 1966 (17) and 1968 (18), respectively, produced 85 to 95% as much lint as the present day check, Coker 201. Coker 201 produced about 5% more lint than Coker 100 A in tests at Florence in 1962, 1963, and 1964, indicating that breeders are striving for ever-increasing yields in developmental breeding.

During this cycle 4 selection period, high fiber strength 'Atlas' from the Ga. Coastal Plain Exp. Stn.

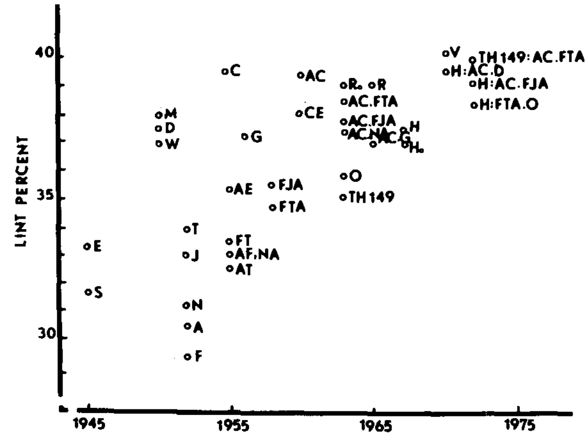

Fig. 1. Lint percentage of breeding stocks grown at Florence, S. C. from 1945 to 1972.[3]

(8) and 'TH 149' from the N.C. Exp. Stn. (15) were released. Although these cultivars produced yields equivalent to those of Pee Dee 2165 at Florence, both were significantly lower in lint percentage. Atlas and TH 149 have lint percentages within the range of PD lines before the introduction of C 6-5 germplasm. These data indicate the difficulty experienced by breeders in raising lint percentage of breeding lines with *G. arboreum* × *G. thurberi* fiber strength, although crosses were made to parents with high lint percentage, and selection pressure was exerted to increase this characteristic.

Increases in lint percentage of PD breeding lines did not parallel the yield increases of 45 to 55% obtained since 1945 (7). If lint yield and lint percentage are calculated as a percentage of Coker 201 and plotted as a mean for each selection cycle (Fig. 2), lint yields conform to a straight line increase. Lint percentages during the first four selection cycles paralleled lint yield increases with a correlation between lint yield and lint percentage of 0.750. During selection cycles 5 and 6, lint percentages remained at a constant high level, while lint yields continued to increase significantly; hence the lower correlation of 0.417 between lint percentage and lint yield. Thus, it is important to maintain high lint percentages to insure high yields; however, some other factor must be responsible for increased lint yields during selection cycles 5 and 6.

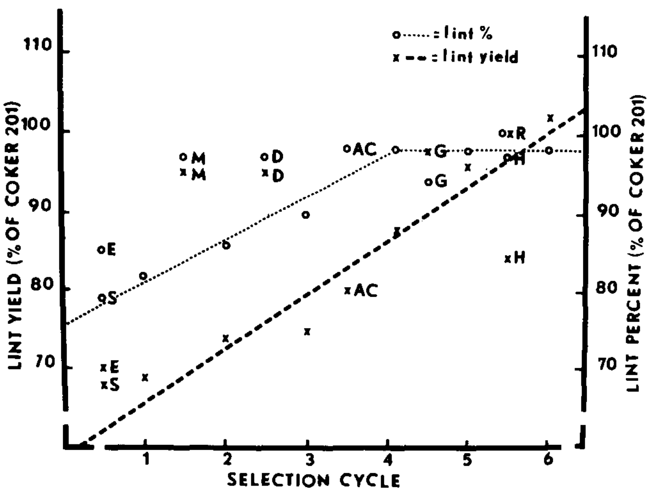

Fig. 2. Lint yield and lint percentage of breeding stocks.

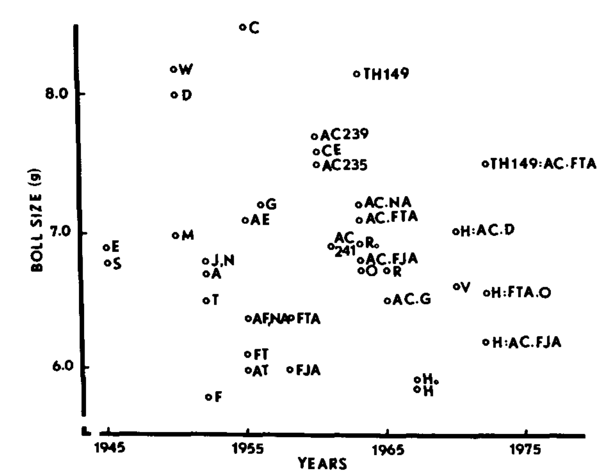

Fig. 3. Boll size of breeding stocks.

Boll Size

A survey of the check cultivars tested at Florence (Fig. 3) suggests that both medium-to-small and extra-large boll cultivars persist in the Southeast. Coker cultivars have medium to small bolls, and the more recent releases have the smallest bolls. G and O have medium bolls, but D, 'Empire WR,' and TH 149 (crossed once to 'Rowden' and twice to Empire 10) have very large ones.

The extra-long staple cultivars (S and E), high fiber strength lines (cycle 1 selections A, F, J, N, and T), and their derivatives (cycle 2 selections AE, AF, AN, AT, FJ, and FT, and cycle 3 selections FJA and FTA) have medium to small bolls. The introduction of the extra-large boll type, C, resulted in promising AC and CE lines that had intermediate to large bolls, but were larger than we desired.

From this large group of cross combinations, AC 241 with significantly smaller bolls was selected by visual observation in the field. This rare find among hundreds of segregates first suggested the possibility of a mutation. However, it can be explained as a recombination of genes, because line A had slightly smaller bolls. AC 241 was crossed to most high fiber strength PD lines, and selections from these combinations had medium bolls.

When lint yield and boll size are calculated as a percentage of Coker 201 and plotted as a mean for each selection cycle (Fig. 4), boll size per se is essentially independent of lint yield. During selection cycles 1, 2, and 3, boll size remained constant while lint yields advanced significantly. The correlation between lint yield and boll size was 0.196 during this period. With

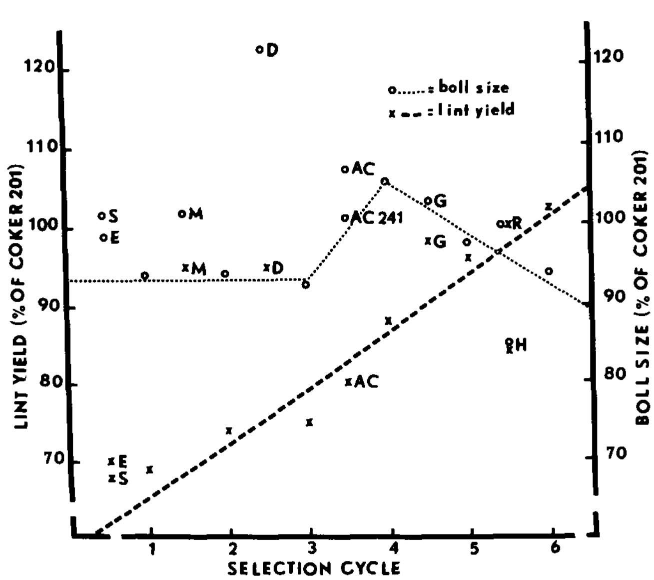

Fig. 4. Lint yield and boll size of breeding stocks.

the introduction of C in cycle 4 selections, lint yield and boll size advanced simultaneously. However, the correlation between lint yield and boll size was only 0.309. Boll size decreased as lint yields increased during selection cycles 5 and 6; however, the correlation coefficient equaled —0.012.

Since the advent of the mechanical cotton picker, boll size has been de-emphasized in breeding. Bridge et al. (2) found a general change to smaller bolls, smaller seed, and higher lint percentage in successful Delta cultivars. Our data indicate a similar trend for southeastern cultivars in our tests, probably the result of selection for ecological optima for yield.

Although evidence is limited and some excellent big boll cultivars have been developed, we suspect cultivars that produce a larger number of medium to small bolls will recover more rapidly from environmental stress and will produce greater yields over a period of years. Harrell (9) has shown that PD lines before 1968 (selection cycles 1 through 4) produced the highest yields in tests at Florence but lacked "breadth of adaptability" when tested at other locations. Ramey and Worley (16) suggested that boll size was minor, but important, in determining lint yield in their study. Therefore, boll size and associated characteristics might make the greatest contribution to lint yield by increasing varietal adaptability.

Seed Size

Seed indexes of cultivars and breeding lines were not determined in yield tests before 1964. We used the average seed index of individual F_2, F_3, and F_4 plants and other advanced generations for our best estimate. Culp and Harrell (5) reported only minor differences in seed index between F_4 and yield test entry. Therefore, these estimates should be highly reliable because they involved several to many selections for three or more years at Florence.

The Coker cultivars (M, Ro, R, V, Ho, and H) are noted for their small seed, seed indexes of < 12.0 (Fig. 5). Other southeastern cultivars (W, D, and TH 149) have extra-large seed and indexes above 14.5. The extra-long staple cultivars of the late 1940's and early 1950's (S and E) have seed indexes of about 13.5. Early PD breeding lines (cycle 1 selections A, F, J, N, and T) and their derivatives (cycle 2 selections AE, AF, AN, AT, FJ, and FT, and cycle 3 selections FJA and FTA) have equal or smaller seed than S and E. Seed of PD lines were much larger than those of the Coker cultivars, although they had similar size bolls.

The introduction of C (3), which had extra-large seed (seed index = 16.4), slightly increased the seed size of PD lines. The selection of AC 241 with medium-large seed (seed index = 13.0) was a significant find and furnished germplasm that was used to reduce seed size of high fiber strength PD lines. AC 241, used in cross combinations with PD lines, D, G, and H, has produced improved PD lines with smaller seed. However all PD lines, except a few recently derived from crosses with the above cultivars, have larger seed in relation to boll size. Unfortunately, PD lines thus have fewer seeds/boll than most southeastern commercial cultivars.

Comparison of lint yield and seed size as a percentage of Coker 201 (Fig. 6), suggest that seed size is essentially independent of lint yield. Seed size was about constant while lint yields advanced during selection cycles 1 thru 4. Lint yields continued to advance, while seed size decreased during selection cycles 5 and 6. The correlation between lint yield and seed size was —0.325 during this period.

Boll and Seed Size

We expected a strong positive correlation (r = 0.843) between seed size and boll size because of their relationship in the development of the cotton plant.

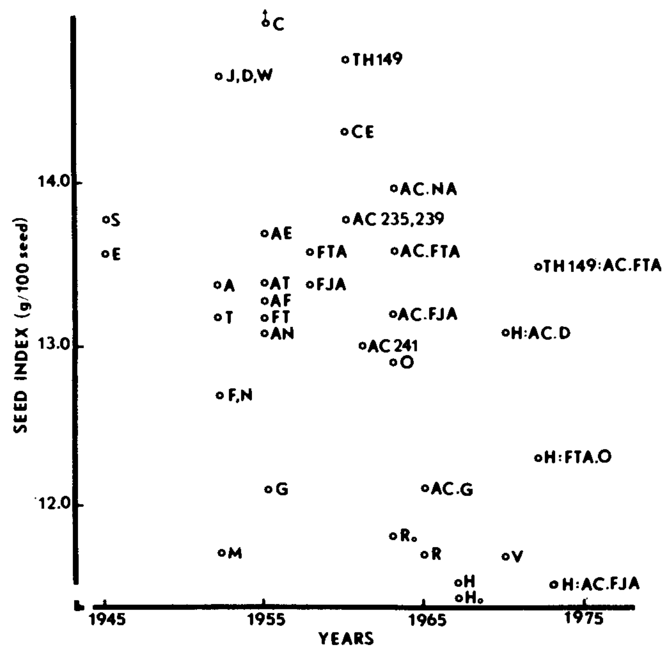

Fig. 5. Seed index of breeding stocks.

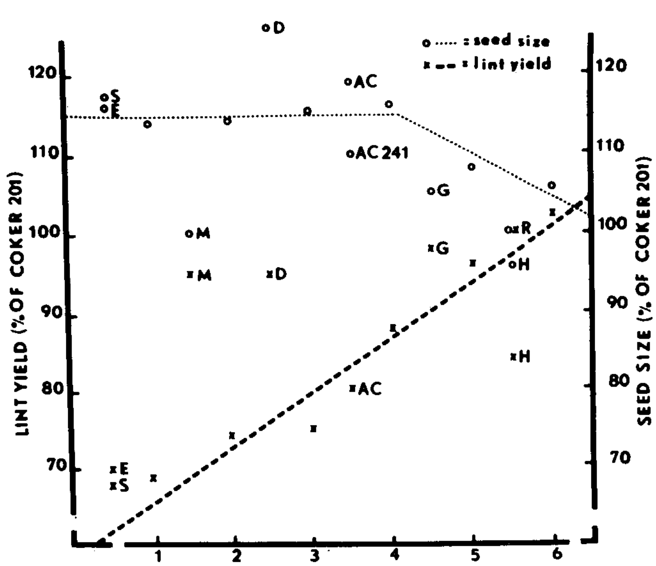

Fig. 6. Lint yield and seed index of breeding stocks.

Seed size and boll size of PD lines are parallel during all selection cycles, except 4 (Fig. 7). During selection cycle 4, boll size advanced, while seed size remained in the medium-large range. The difference in relationship between boll and seed size must be attributed to selection AC 241.

In the 1930's and early 1940's, Sturkie (19) showed that boll and seed size were significantly influenced by moisture, fertilizer, and other environmental conditions, whereas lint percentage was affected less. Miller et al. (14) showed a substantial cultivar × location × year interaction for lint yield and relatively small interactions for lint percentage and weight/boll. They suggested that the interactions for traits other than lint may be considered as relatively unimportant. We found correlations of small magnitude between lint percentage and boll or seed size.

Breeding Implications

Miller and Rawlings (13) found that as yield was increased by selection, lint percentage, seeds/boll, earliness, fiber elongation, and fiber coarseness increased; boll size, seed size, fiber length, and fiber strength decreased. Except for the major yield increase from the introduction of C during selection cycle 4, lint yields of PD lines have increased significantly, with only minor increases in lint percentage. Bridge et al. (2) suggested a close association between lint yield and lint percentage. Thus, improved lint percentage may have been important in increasing lint yield. Ramey and Worley (16) found a high correlation between lint percentage and lint yield ($r = 0.93$) of 16 cotton cultivars that were developed between 1920 and 1960 and were tested in Mississippi in 1967 and 1968 (2). However, using yield models and increasing the lint percentage of cultivars with low lint percentage within the ranges of those with high lint percentage did not appreciably alter lint yields. Except for the increase in yield obtained with the introduction of C which possessed high lint percentage, our data agree with the findings of Ramey and Worley (16), particularly during selection cycles 5 and 6. Thus, some factor or factors other than lint percentage must be responsible for the major yield improvements in PD lines during recent years.

Our data during selection cycles 5 and 6, also agree with the findings of Miller and Rawlings (13) and Bridge et al. (2) that increases in lint yield accompanied decreases in boll and seed size. Ramey and Worley (16) found that boll size was only minor, though important, in determining lint yield. We suggest that over a wide ecological area with varying seasonal effects, cultivars with medium to small bolls and seed might adjust more rapidly to adverse conditions and produce higher yields than big boll cultivars.

We (6, 7) agree with Miller and Rawlings (13) that fiber length and strength generally decrease as lint yields increase. Nevertheless, we have succeeded in increasing lint yields while maintaining a high level of fiber strength and length in PD breeding lines (10).

Selection for high lint percentage is a major consideration of most cotton breeders, because of the ease in measuring this yield component and its high correlation with lint yield. Our data suggest that unless

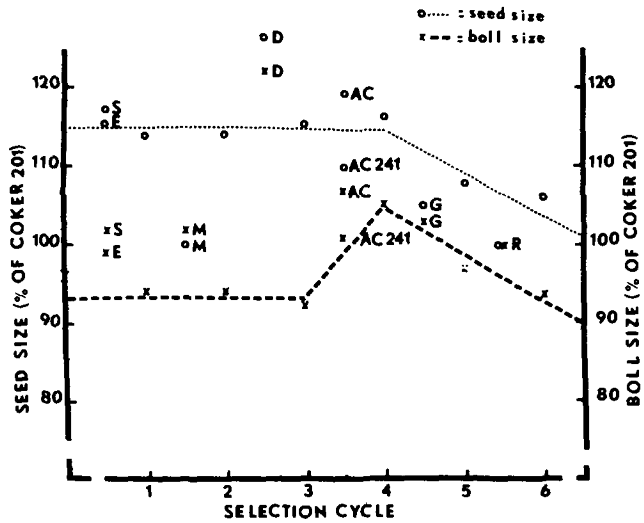

Fig. 7. Boll and seed size of breeding stocks.

a source of high lint percentage is introduced into the germplasm, it is impossible to raise the lint percentage of promising cultivars significantly. Selection for high lint yields is probably sufficient to maintain high lint percentage in breeding lines and cultivars.

Breeders generally apply only limited selection pressure for boll and seed size. Lint yield and lint percentage are given the most attention in the selection process, and boll and seed size follow in what is likely a nonrandom process. Our data suggest that breeders might make progress by selecting for medium to small boll cultivars that contain the greatest possible number of small seed/boll.

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